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Сборник содержит труды участников Международной молодежной научной школы «Методология проектирования молодежного научно-инновационного пространства для российской энергетики». Включает пленарные лекции, материалы семинара, мастер-класса, доклады студентов и молодых ученых, представленные на секциях «Ядерные физика и энергетика», «Традиционная и альтернативная энергетика», «Общие проблемы современной физики и энергетики». Сборник представляет интерес для студентов, аспирантов, молодых ученых, преподавателей в области естественных наук.

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СОДЕРЖАНИЕ

ПЛЕНАРНЫЕ ЛЕКЦИИ

СЕМИНАР

МАСТЕР-КЛАСС

СЕКЦИЯ №1 ЯДЕРНЫЕ ФИЗИКА И ЭНЕРГЕТИКА

СОДЕРЖАНИЕ

СЕКЦИЯ №2 ТРАДИЦИОННАЯ И АЛЬТЕРНАТИВНАЯ ЭНЕРГЕТИКА

СОДЕРЖАНИЕ

СЕКЦИЯ №3 ОБЩИЕ ПРОБЛЕМЫ СОВРЕМЕННОЙ ФИЗИКИ И ЭНЕРГЕТИКИ

NUCLEAR PHYSICS AND TECHNOLOGIES

Yu.V. Daneykin,
PhD, Associate Professor,
Tomsk Polytechnic University, 30, Lenin av., Tomsk, 634050, Russia
E-mail: daneykin@tpu.ru

Nuclear reactors

Over the last quarter of a century, nuclear energy has made a progressively increasing contribution to the generation of electricity. At present 31 countries make some use of nuclear energy for electricity generation. Of these 17 rely more than 25% on nuclear energy. Averaged over these countries, nuclear energy might amount to perhaps 1% of the GDP. By any standards nuclear energy must rate as a very large industry1. It will remain so for several decades at least - even if there should be a move to reduce our reliance on this energy source.

Nuclear technology has developed over half a century. We will discuss a number of possibilities for the future later.

But to understand the present scene one needs little more than a familiarity with the state of nuclear scientific and engineering knowledge in the mid-seventies. The basics have not changed, as is inevitable in an industry with large capital costs and long construction times. The rate of change in the underlying science has been relatively slow - though the engineering elements have advanced continually and have led to progressively improved performance.

The Flowers report of 1976 remains an excellent guide to the underlying principles and the various types of nuclear reactor that have been developed. The developments since then relate to very significant improvements in fuel technology, the controls, the safety features, the sophisticated electronics and software. On the figures, we provide a summary of the key elements of modern nuclear reactors. For the purposes of this lecture, we need bear only the following basic facts in mind.

- Nuclear energy is derived from the fission of uranium by an incident neutron. The summed mass of the fission components is less than that of the uranium atom - the deficit being the source of the energy - about 200 MeV per fission.
- Natural uranium consists mainly of the isotope 238U with about 0.7% 235U.
- A fission event initiated by one neutron generates more than two neutrons. This is the basis of the chain reaction on which the operation of a reactor depends.
- The chance of a 235U atom being split is greatly enhanced if the incident neutron is slow. But the neutrons produced by a fission event are fast. By slowing them down to thermal velocities their ability to induce further fission events is enhanced. This thermalisation is effected by means of a «moderator» which, by successive collisions, progressively reduces the speed of the neutrons; it must feature a low absorption of neutrons.
- Moderators used in current reactors may consist of graphite, water or ‘heavy water’, i.e. D_2O.
- In some reactors, the uranium fuel must be enriched – the percentage of 235U has to be increased above the natural level of 0.7% - in order to reach a self-sustaining reaction. This is the case for the most commonly used reactors – the light water pressurised water reactor (PWR).

Throughout the period there have been significant advances not only in the basic engineering of new nuclear plants but also in retrofitting of improvements into older plants and in operational practice, procedures and training. The advances in fuel technology are particularly important - the total output per kg of fuel has more than doubled during the course of the last 20 years.

Of the 428 reactors currently operating in the world, 80% use light water both as a moderator and as a coolant. Of these, three quarters are PWRs, in which the heat is extracted by means of a heat exchanger, the water being kept under sufficient pressure to avoid boiling. The other quarter are boiling water reactors (BWR), in which the generated steam is fed directly to the turbines.

There are two other reactor types that we must note at this stage. The first are the Canadian heavy water moderated, light water cooled reactors (CANDU). 21 of these have been built – 16 of them in Canada. Second, the Russian light water cooled, graphite moderated reactors ‘RBMK’, which, like Magnox and CANDU, work on natural uranium. The Chernobyl disaster Currently, world wide, there are 35 reactors in the process of construction. Of these 21 are of the PWR type. It should also be noted that in the US a number of reactors have been cancelled during the construction period as a result of additional costs imposed by design changes to accommodate new safety regulations.

Which of the reactor types is best? One might attempt a ‘Which’ type analysis in which each reactor type is assessed against a number of criteria, to include:

- safety;
- capital cost per kW installed capacity;
- cost per kWh delivered (to include operational costs, fuel costs and reliability);
- lifetime;
- decommissioning costs.

There is however an additional factor: the advantages, in cost and performance, derived from building a *series* of reactors of the same type. This is a powerful factor in decision making.

The problem of waste disposal

The operation of nuclear reactors produces substantial quantities of waste material. For example, a 1 GW PWR will produce about 30 tons of spent fuel per annum. Of this, 95% is 238U, 0.9% 235U, 0.9% Pu, 3.3% fission products, and 0.06% minor actinides. The spent fuel elements, as well as being highly radioactive, continue to generate heat. After ten years, the 30 tons of spent fuel will still produce a power of several hundred kW.

Spent fuel rods are classified as high level waste ‘HLW’. They require massive shielding and provision for cooling. Both the radioactivity and the resulting heat generation decay with time, but some provision for cooling has to be provided for about 50 years.

The nuclear cycle also generates materials described as intermediate level waste ‘ILW’. An example would be the cladding around the fuel. ILW materials are sufficiently radioactive to require a barrier between them and the biosphere.

However, the level of the activity is not such as to require cooling.

Finally there is low level waste - a mixed bag of items such as protective clothing, which can be safely disposed of by shallow burial.

Both HLW and ILW2 contain long half life radioisotopes - notably 239Pu with a half life of 24,000 years. The problem of waste disposal is the effective segregation of both HLW and ILW for very long periods - in excess of 100,000 years. That seems like a very long time on the surface of the earth - but not necessarily so 500 metres below the surface. The intention of the industry, in all the countries in which it is established, is eventually to dispose of HLW and most of ILW in deep repositories. That is the intention - but to date it has not been implemented.

Nuclear technology - future prospects

Nuclear energy was born just over 50 years ago. It is only 42 years since the first reactors emerged from research in the form of a fully engineered power plant. The main development phase which has led to the present generation of reactors extended perhaps over 20 years. Nearly all existing plants have been designed and built without the benefit of accumulated real feedback experience. It would therefore be extraordinary if the technology had already approached an endpoint - if the basic designs conceived several decades ago had achieved some ultimate optimum.

In this chapter we will briefly review some of the ideas currently under consideration for a next generation of nuclear technology. There has been relatively little resource for pursuing some of these ideas. There are two main reasons. The first is the current near-stagnation of the nuclear construction industry, on account partly of past over-investment in electricity generating plant, and partly of the competition from modern fossil fuel plants - notably natural gas. The second reason is that the industry has had to react to a tightening regulation environment stemming from the concerns aroused by three major accidents - Three Mile Island, Chernobyl and Fukushima. The result is that safety in reactors has certainly been enhanced; however the extent of retrofitting additional safety systems on existing reactors has increased complexity - and cost - whilst not in every case securing additional safety benefits. The developments that have taken place have been incremental but have led to a steadily improved performance - safety, reliability and generation cost.

Advanced light water reactors

The stage that has now been attained in the development of advanced light water reactors is characterised by a number of designs which have just, or are about to, come into operation:

- the ‘Advanced Boiling Water Reactor’ (ABWR) developed by General Electric with Hitachi and Toshiba. Two units came into operation in 1996 and 1997. Several more are planned for Japan and for Taiwan;
- the Framatome, ‘N4’ PWR. Four units have been built in Chooz and Civaux and will reach commercial operation in 1999 and 2000;
- the UK Sizewell B, PWR, which came into operation in 1995.

More recently a number of enterprises have embarked on evolutionary designs. The key objectives sought include an even greater degree of safety1 with the probability of a major accident reduced by a further factor of at least 5; and design simplification with the aim of achieving a measure of standardisation which would facilitate gaining approval by licensing authorities.

One example is the 1.5 GW European Pressurised Reactor (EPR), a joint effort of Framatome and Siemens, which it was hoped would obtain simultaneous licensing approval by both Germany and France. It includes various improvements, particularly on containment, emergency core cooling systems, control rod mechanisms and one remarkable feature – provision for damage limitation in the event of a core melt down. This is achieved by arranging for molten components to flow to a purpose built spreading compartment with provision for cooling both above and below the compartment. Whilst there is now no immediate prospect of the EPR being built these evolutionary features are likely to be retained. A rather different approach is that of Westinghouse with their AP600 - a 600 MW PWR. There are two reasons for considering a reactor below the 1 GW level. It allows the provision of a *passive* safety system, a design which ensures that in the event of malfunction there is no reliance on pumps to provide emergency core cooling. Convection alone suffices.

Second, the smaller design provides opportunities for simplification and - so it was hoped - the possibility for large series manufacture. There is also the suggestion that smaller power units can be located near their loads and so reduce the cost and losses of longer transmission systems. Here again there is no immediate prospect of embarking on construction.

There is little doubt that the immediate future will be based on light water reactors. The competition is on driving down the cost whilst enhancing safety. It is important to be clear that the development of innovative models does not mean that the existing ones are not satisfactory or ‘safe enough’. What is clear is that some, though modest, further investment in research and development is needed to gain licensing approval. This is in contrast with more radical possibilities to be discussed below, where the scale of the investment in R&D requirements will be very large.

High temperature reactors

High temperature reactors (HTR) are characterised by

- the use of helium both as a coolant and as the turbine fluid;
- the use of fuel in the form of individual spherical particles just under one mm in diameter. The U or Pu core is surrounded by low density graphite and by a silicon carbide coating. Operating temperature is set at 1250 oC but the encapsulation retains its integrity at temperatures up to 2000 oC;
- a high temperature turbine contained within the pressure vessel;
- a high thermal efficiency (about 45% instead of 35%).

The reactor is designed to incorporate a considerable measure of passive safety - a claim regarded as valid. The concept is not new - it was the subject of a number of programmes in the US and in Germany in the ‘60s and up to 1975. The implied technologies, particularly those that stem from the high temperature regime, and the development of turbines that work efficiently on helium notwithstanding its low density, are very demanding. But there is continuing interest in developing this breed of reactor, both for its inherent virtues and for its inherent safety features. Even though the probabilistic failure analysis of PWRs may show an equal level of safety, it is possible that the safety of the HTR might be easier to explain to lay people.

Work is currently proceeding on high temperature reactors in a joint enterprise between General Atomics of the USA, Rosatom of Russia, Framatome of France and Fuji Electric of Japan. In China and Japan experimental reactors have been built and South Africa is planning a demonstration project (110 MWth).

Fast neutron reactors

Fast neutron reactors utilise a core of uranium mixed with plutonium. There is no moderator, so that the fast neutrons from one fission reaction are the means for producing further fission events. To avoid excessive loss of neutrons the core has to be very compact, and the power density within it very high.

Adequate cooling with gas is probably not possible, as it leads to a low power density design and hence low breeding gain; one resorts to the use of liquid metals, usually sodium or lead.

The concept is not new. The world’s first fast reactor, mercury cooled, generating 25 kW was built at Los Alamos in 1949. At about the same time plans for a fast reactor programme were initiated in the UK - leading to a low power demonstration critical assembly at Harwell in 1954.

Subsequently many countries, including France, Germany, Japan and the former Soviet Union embarked on fast neutron reactor work, usually with an additional element - a surrounding annulus of 238U, which is progressively transmuted into plutonium. The reactor can be configured so that it produces more plutonium than is used in the primary reactor core – the basis of the fast breeder reactor.

The primary motivation for embarking on breeder reactors has been the prospect of obtaining much more energy from uranium than the 1 or 2% which thermal reactor technology permits. The measure of the advantage is something like a factor of 60.

However during the last 20 years the uranium supply prospects have much improved for a number of disparate reasons:

- discovery of new uranium reserves;
- improvement in the utilisation (‘burnup’) of uranium in thermal reactors;
- reduction in the projected growth of electricity generation needs;
- impact of cheap natural gas;
- concern about the safety of the nuclear option following Chernobyl.

In addition the technology of breeder reactors, particularly when scaled to the sizes needed if they were to supplement thermal reactors, was found to be far from easy. In particular the problems stemming from the use of liquid sodium as a coolant have proved to be hard to overcome. These factors were probably the main ingredients in the decision to terminate some major demonstration projects - such as the PFR at Dounreay (250 MWe) in the UK and SuperPhenix (1.2GWe) in France.

However it is important to emphasise that whilst technology has been difficult, the fact that breeders are not, for the moment, favoured should not be regarded as a technological defeat. One example of long and on the whole satisfactory experience with a breeder is the Russian BN600 reactor (1.5 GWe) at Beloyarsk. This has operated at a load factor, averaged over 15 years, of 70% and has recently reached 76% - better than the record of Russian thermal reactors. If fast neutron reactors are to be needed, they can be built.

Will they be needed? They could, if required, serve a number of different purposes.

For example, breeder reactors would greatly extend the availability of reactor fuel. At the present price of uranium the incentive is weak. The situation could change if over the next 50 years there were to be a large expansion of nuclear energy. Even then the breeder/plutonium route might have to compete with uranium from seawater.

Fast reactors could be used to do the very opposite of breeding - they could ‘burn’ plutonium. If the plutonium stockpile is regarded as a waste product requiring safe disposal, burning it in a fast (non-breeder) reactor would be an effective solution. Burn rates of the order of one ton per annum per reactor seem possible. It is however hard to imagine that one would wish to embark on a fast reactor programme solely for this purpose. The concept would be viable, if fast reactors were to form an integral part of a next generation of nuclear power. It has been suggested that in a nuclear power system made up three quarters of standard PWRs burning slightly enriched uranium fuel and one quarter of fast neutron reactors designed for maximum consumption of plutonium, there would, under normal running conditions, be no net production of the latter.

More ambitiously one might adapt the fast reactor to the fission of Pu and some of the minor actinides and long-lived fission products in spent fuel to shorter-lived isotopes – and thereby greatly reduce the magnitude of the disposal problem. If one could transform long-life into short-life components it would clearly reduce both costs and any remnant risk associated with deep geological repositories.

But before one can begin to address the transmutation technology one must first separate the long lived material from the rest - ‘partitioning’ - and this is in itself a very major undertaking. One would concentrate on the high level waste and seek to effect the partitioning at the stage within the overall reprocessing when the HLW is in liquid form.

Partitioning and Transmutation (P&T) embodies a great deal of new technology, requiring decisions on a whole series of options before one could embark on a realistic demonstrator. For example there is the option of ‘homogeneous recycling’ where the radionuclides to be transmuted are intimately mixed with the fuel, as opposed to ‘heterogeneous recycling’ where they are physically separated from the fuel. The partitioning will certainly require extensive reprocessing and possibly even isotopic separation facilities. The concept represents major technological challenges - but there are no known fundamental reasons why, given enough effort, it should not ultimately succeed.

Accelerator-driven subcritical assemblies

The accelerator produces a beam of fast neutrons. When these are directed on to a subcritical assembly, the normal chain reaction process will lead to a neutron flux much greater than that from the incident beam. However since the assembly is subcritical the chain reaction is not self-sustaining. Switching off the accelerator beam stops the chain reaction.

This is a basic concept of long standing, originally intended as a way of producing plutonium from a slightly enriched uranium core. The method was tried in the early fifties with a 25 MeV 50 mA proton accelerator. A plan to scale up this system with a 350 MeV, 500 mA machine was abandoned when it was found that (critical) reactors were a simpler and more economic way of producing the wanted material.

Producing fissile material was then the first motivation for investigating accelerator-driven systems - and failed in competition with reactors. By the ‘70s, the emphasis had changed. Production of plutonium was no longer the problem.

Instead there was a growing interest in the possibility of transmuting long-lived waste products - notably the minor actinides. Various schemes have been studied at Los Alamos and Brookhaven in the USA, at the Japan Atomic Energy Research Institute in Japan, in Russia and in France. None has so far led to a production system.

The destruction of the minor actinides will produce an energy per fission approximately equivalent to the fission of one plutonium atom. The rate of burning of the unwanted radionuclides will determine the energy output - and hence the cooling requirements. For a high rate of transmutation, the subcritical assembly will have to be engineered in much the same way as a power reactor. The high energy proton beam itself will consume a substantial amount of energy. These considerations led Charles Bowman at Los Alamos and a little later Carlo Rubbia to propose a hybrid system, which would also generate electricity, a small portion of which would be used to drive the accelerator. The Bowman proposal was based on a thermal neutron system, that of Rubbia on fast neutrons.

Very briefly, the main features of an accelerator-driven fast reactor, described by Rubbia, somewhat whimsically, as an ‘energy amplifier’ (EA), are intended to include the following:

- a proton accelerator, 1 GeV, 10-200 mA with a heavy element target5;
- thorium based fuel;
- Pb/Bi alloy coolant - relying on convection circulation;
- output power of the order of 1.5 GWth .

How do the proposers see the advantages of an accelerator-driven subcritical reactor as compared with a ‘conventional’ fast neutron reactor? Two major motivations are advanced. The first is the inherent safety of the EA. Since the assembly is subcritical, the chain reaction will cease simply by turning the accelerator off. The problem of removal of decay heat would however remain.

In a critical reactor there are constraints just because the reaction needs to be at the critical level. The second major claim is that when, as in the EA, that constraint is removed, a much more complete incineration of the long-lived radionuclides can be achieved.

These are bold claims - and have been subjected to a good deal of criticism. A very helpful analysis of the issues has been provided by Richard Wilson. A first question might address the claim of inherent safety. The assembly is subcritical - the neutron flux is only a fraction, k, of that required to sustain the chain reaction - for a critical assembly k=1. Now the fraction of the energy generated that is required to supply the accelerator will be zero for a critical assembly and increase the further one departs from criticality6. It is therefore essential to run the system very close to criticality. This then raises the question whether, under some conditions, the assembly might not become critical. If that is accepted the precautions needed to retain control become identical to those needed in a conventional fast neutron reactor. Also, as with any reactor, cooling is essential even after shutdown.

The advantage that the EA offers in incineration of long-lived radionuclides as compared with destruction in critical reactors is controversial. But strong claims are made. For example the Los Alamos group state that accelerator-driven transmutation of waste (ATW) ‘is expected to accomplish the following:

- destroy over 99.9% of the actinides;
- destroy over 99.9% of the Tc and I - two of the major longlived radiotoxic radionuclides;
- separate Sr and Cs;
- separate uranium;
- generate electricity. ... 10- 15% of this electricity will be used to power the accelerator.’

Those are impressive claims - but of course based on preliminary studies and as yet not on any integrating experiments. The implied pyrochemical separation processes have been explored only in a pilot stage; the economics of the whole process are hard to gauge. And there is one very special problem that has worried those who have sought to assess these possibilities: the protons in the accelerator are of course in a high vacuum. One must devise a window that will transmit the protons with minimal loss, whilst withstanding normal atmospheric or even higher pressure in the reactor assembly. At present the intention is to use a curved tungsten alloy window, with a thickness at the centre of about 1.5 mm. This may prove to be a major difficulty. Not all materials problems have an answer.

The thorium fuel cycle

It has been appreciated since the earliest days of the nuclear energy development that thorium was an alternative fuel to uranium. It appears to be somewhat more plentiful than uranium. India and Brazil in particular are well supplied. Thorium is found predominantly in single isotopic form - 232Th - which is only feebly radioactive, not fissile - but it is fertile. 232Th can capture neutrons to produce9 233U which is fissile. To utilise thorium in a reactor it must therefore be mixed with a fissile material to start the process - for example enriched 235U or 237Pu. If the aim is to get rid of excess plutonium this is a way to do it. Unlike the disposal route in MOX fuel, irradiation does not produce new plutonium. If one were to fuel a PWR with Th/Pu, about twice as much Pu would be destroyed as with the established U/Pu MOX fuel. In addition the fraction of fissile Pu isotopes in the spent Th/Pu fuel would be about one third less than with U/Pu.

So where is the catch? First of all the technology for producing Th fuel is somewhat more complex and hence more costly than for U. Since for the moment there is no prospect of a uranium shortage for the easily foreseeable future, there was little incentive to make a change. But, in addition, the motivation for destroying Pu was to reduce any proliferation risk. Irradiating Th leads to 233U which is fissile and could also form the basis of a nuclear weapon. It radiates gamma rays and that would make the construction of a weapon harder - but probably not very much harder.

The merits and demerits of the Th cycle are not yet by any means clear. It is interesting to note though that all the groups who are currently exploring the accelerator-driven sub-critical array machines discussed in the previous section are basing their designs on the Th fuel cycle.

Fusion

Nuclear energy can be generated by the fusion of lighter nuclei into heavier ones, for example the fusion of deuterium with tritium to form helium. It is of course the basis of solar energy. To achieve a self-sustaining fusion reaction the gases need to form a plasma at very high temperatures and need to be sustained in that state for a sufficiently long time. It has proved to be a very difficult task – the subject of a great deal of research over the last half century. The motivation is clear - a fusion reactor could in principle provide energy from resources that are practically unlimited. Moreover there is much less of an active waste problem to take into account.

The flagship of the European Fusion Programme is the Joint European Torus (JET) located in Culham, Oxfordshire. JET and other similar machines elsewhere have provided much of the data necessary for the design of the ‘next step’ machine – the International Thermonuclear Experimental Reactor (ITER). This is a partnership between the USA, Japan, Russia and the EU. It aims to demonstrate the safe operation of a device which incorporates the key technologies to be employed early in the next century. ITER is intended to be the final step before embarking on a demonstration power station. However the funding of this venture has been delayed several times, though it is still hoped to make a start early next century.

In the mean time there is great interest in a variant of the apparatus , the ‘tokamak’ used at JET and intended for ITER – the spherical tokamak. It is smaller and could turn out be a major advance, though this is not as yet established.

Will fusion energy work? There is now no serious doubt that a machine could be built which would provide net energy. The issue that is still highly controversial is whether the technological difficulties, including some very severe materials problems, can be overcome so that a machine producing energy at an economic rate could be anticipated. Since world research in this area is proceeding at a spend rate of about $1B per annum, there is reason to be confident that an answer to this question will emerge in the next decade or two. However it seems very unlikely that fusion power could make a significant contribution to the energy needs of the world before, at the earliest, the second half of next century.

Comment

In this chapter we have reviewed some potential developments that could change the nuclear energy scene over the next few decades. The ideas are not all new - many have been around in one form or another for a long time. However the progress in materials, fuel technology and control systems has transformed the prospects of some of them. The list of the topics we have touched upon is by no means exhaustive.

What characterises all of them, with the exception of search for fusion energy, is the relatively low level of current R&D investment, which seems totally out of scale with their potential future importance.

REMOTE THERMAL "FLASH TECHNIQUE" FOR THERMOPHYSICAL PROPERTIES MEASUREMENTS AND ITS APPLICATION TO PROBLEMS OF ENERGETICS

Oleg Yu. Troitsky
Professor, Dr., Institute for Non-Destructive Testing
at Tomsk Polytechnic University, 30, Lenin av., Tomsk, 634050, Russia
E-mail: tor_43@mail.ru

Abstract. The paper is a kind of survey of works performed by author during the last two decades to obtain new remote methods of thermophysical properties measurements using flash technique, which can be applied to different objects and materials.

Key words – remote sensing, flash method, thermophysical properties.

Laser flash experiments apply transient conduction heat transfer as a tool to extract thermophysical properties (TPP) of different materials. An instantaneous heat source is generated by absorption of a laser pulse on a flat, heat-conducting, non transparent sample. The diameter of the heat source should be large compared with the sample thickness to establish approximately ID heat flow. Thermal diffusivity of the sample is determined from temperature evolution with time measured on its front or rear surfaces; data are taken shortly after the end of, or even during, the radiation heat pulse.

Laser flash belongs to a series of unsteady-state measurement methods that can be grouped according to the nature of the specific disturbance into pulse, periodic heat flow, and monotonic heating regime methods. The more recently developed of these, the pulse method, has gained much popularity among thermophysicists in the last four decades because of the ease with which initial and boundary conditions of the mathematical heat conduction model can be reproduced in a physical experiment, the simple shape of the specimen, and the wide range of materials, diffusivities and temperatures to which the method is applicable. Traditionally, the very short bursts of radiant energy are emitted from a laser or from a xenon flash lamp. As a transient energy source, single particles or a pulsed beam of particles (electrons or ions) can be used as well.

Determination of the TPP of materials is the essence of the coefficient inverse problem of thermal conductivity (IPTC). As initial data for solving such a problem, one can use the results of thermometry of an object made of a material with unknown properties. Particular attention has been paid to take into account finite pulse-time effects [1], heat losses and the depth of the flash energy absorption in the object under investigation [2]. Further, much effort was spent to use the traditional method to determine the TPP also of layered objects [3,4].

But one can use quite another view point to solve this problem: let's try to obtain TPP without making the otherwise necessary corrections for any of these impacts at all.

CLASSIFICATION AND DEFINITIONS. FOREIGN CLASSIFICATION

It's not a question of methodics but rather methodological one. It's very important part of any scientific investigation because sometimes it gives (shows) right direction of investigation.

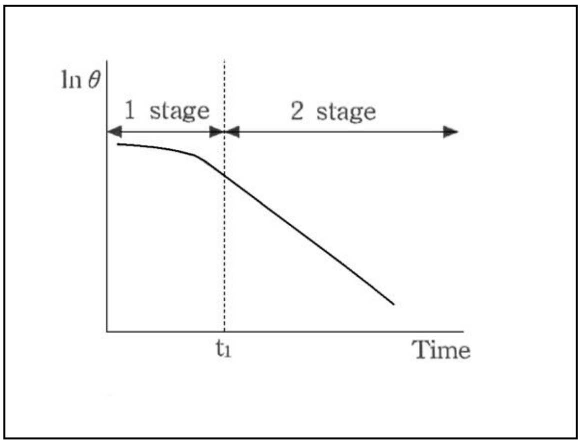
All methods for the measurements of the TPP can be divided into two groups:

1. lengthy stationary state methods;
2. faster, more productive unsteady-state methods, which are based on the analysis of the temperature response of the specimen subjected to transient thermal conditions:
   a) pulsed method;
   b) periodic heating methods;
   c) monotonic heating regime methods.

The most recently developed is the pulse method (about 80% of all the TPP results were obtained with the pulse technique).

This is the widespread foreign (with regard to RUSSIA) classification.

RUSSIAN CLASSIFICATION.



Dependence of ln θ (relative variation of the temperature) on time for cooled body.

The initial period of cooling (or heating) (1-st stage), during which the rate of temperature variation depends on the kind of initial temperature distribution, is called as the disordered stage.

At a certain moment of time $t > t_1$, the initial conditions begin to be of secondary importance and from then the process is rally determined only by the boundary conditions, the physical properties of the body, its geometry and size (2-nd stage).

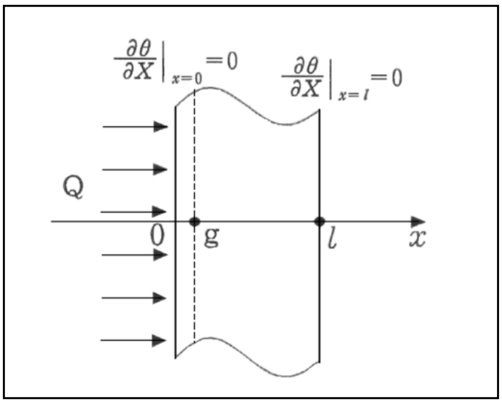
The 2-nd stage is referred to as the regular regime (there is no such definition in English-speaking countries!).

The 3-d stage is identical with the process under steady-state conditions, when the temperature of all points of the body is the same as the temperature of surroundings (i.e. there is thermal equilibrium).

It's necessary to note that the present day opinion in RUSSIA ascribes the pulsed methods to the 1-st stage (may be, due to the influence of the US, the founder of the "flash method").

It's not right! Sometimes it's possible to refer this method to the 2-nd stage with all the consequences ensuing therefrom (O.Troitsky, 12 ECTP, Vienna, Austria, Sept. 1990; 15 ECTP, Wuerzburg, FRG, Sept. 1999.)

DOUBLE-ENDED
REAR-FACE FLASH METHOD



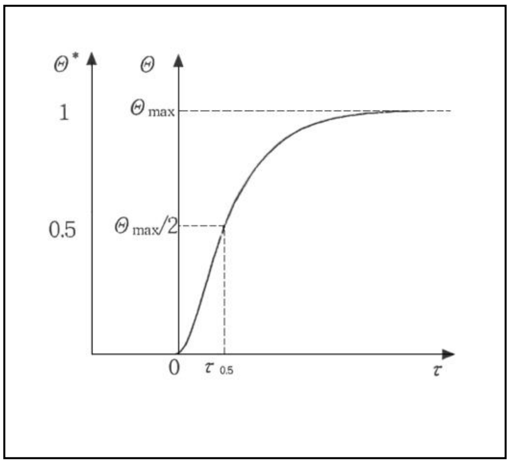
$$\theta(x,\tau)=T(x,\tau)-T_0\,,\qquad T_0=\text{ idem.}$$

$$\frac{\partial\Theta}{\partial\tau}=\alpha\frac{\partial^2\Theta}{\partial x^2}\,, \tag{1}$$

$$\frac{\partial\Theta(0,\tau)}{\partial x}=\frac{\partial\Theta(l,\tau)}{\partial x}=0\,, \tag{2}$$

$$\Theta(X,0)=\begin{cases} Q/C\rho g & 0\le X\le g; \\ 0 & g<X\le l, \end{cases} \tag{3}$$

$$\theta(x,\tau)=\frac{Q}{C\rho l}\left[1+2\sum_{n=1}^{\infty}\cos\frac{nx}{l}\sin\left(\frac{nxg}{l}\right)\frac{1}{n\pi gl}\exp\left(-\frac{n^2\pi^2}{l^2}\alpha x\right)\right]. \tag{4}$$

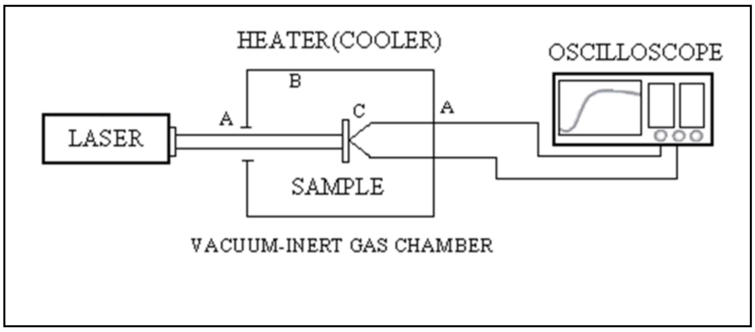


For opaque materials $g\to 0$, $\sin\left(\frac{n\pi g}{l}\right)\cong\frac{n\pi g}{l}$

$$\theta(L,\tau)=\frac{Q}{c\rho l}\left[1+2\sum_{n=1}^{\infty}(-1)^n\exp\left(-\frac{n^2\pi^2}{l^2}\alpha\tau\right)\right]. \tag{4'}$$

$$\theta_{\max}=\frac{Q}{c\rho l};\qquad \theta^*=\frac{\theta}{\theta_{\max}}.$$

$$\alpha=0.139\frac{l^2}{\tau_{0.5}}. \tag{5}$$



Windows: front- quartz glass; back- calcium fluoride.

A. Electrical resistance heater (300~3000K). High-frequency induction heater (> 2700K).

B. Thermocouple or InSb(indium antimonid), HgCdTe(mercury cadmium telluride)-detector.

$$\alpha=0.139\cdot A\frac{L^2}{(\tau_{0.5}\pm B)(1+C)}.$$

3-d All-Union Conf. on Nondestructive Testing (Khabarovsk, Sept. 1987).

ERRORS in the FLASH METHOD

A. MEASUREMENT ERRORS

1. Due to determining the effective thickness of the sample.
2. Due to measuring the time
   (1) flat and parallel surfaces(soft materials; roughened surfaces as for plasma-sprayed materials etc),
   (2) it's necessary to know maximum temperature.

B. NONMEASUREMENT ERRORS (merely deviations from an ideal situation)

1. finite pulse time effect,
2. heat losses,
3. in-depth absorption of the energy pulse,
4. nonuniform heating.
   (1) Corrections for $r_{0\cdot5}$ in Eq.5,
   (2) corrections for the constant in Eq.5,

(3) Special coatings (films, discs) e.g."glassy carbon",

(4) Focussed laser beam (USA, GB); transmission through a step-index optical fiber (Japan).

APPLICATION: TO LAYERED STRUCTURES

Effective TPP may be found, but not layer by layer.

TO DISPERSED COMPOSITES

100 < *l*/*d*, *d* – characteristic particle size.

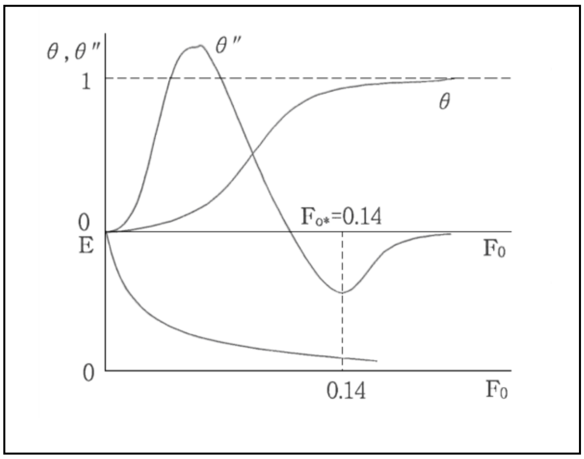
a. For $x = l$

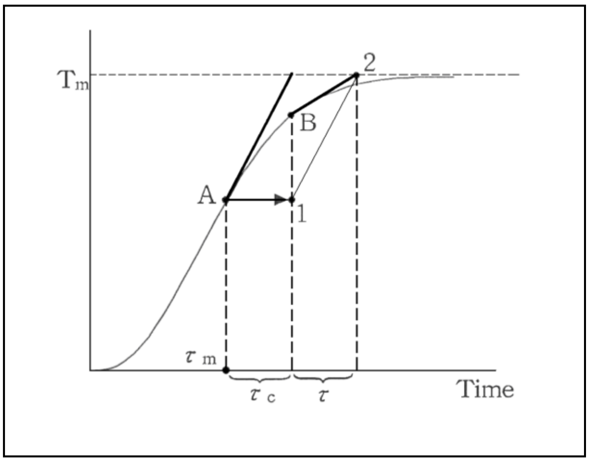
b. $$\theta = 1 + 2\sum_{n=0}^{\infty}(-1)^n A_n \exp\left(-n^2\pi^2 F_0\right); \quad \theta = \frac{T}{T_m}; \quad T_m = \frac{Q}{\rho c l}; \quad F_0 = \frac{\alpha t}{l^2}.$$

c. For $F_0 \geq F_{0*}$.

$$\theta = 1 - 2A_1 \exp\left(-\pi^2 F_0\right).$$

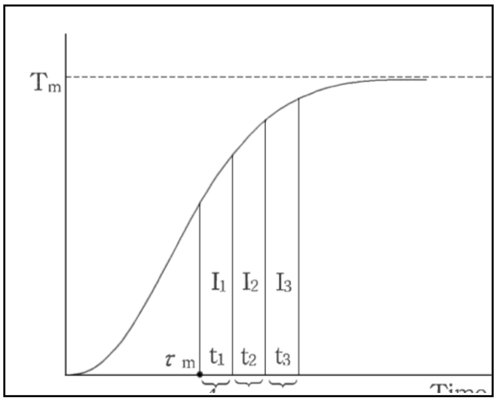
$$E = 1 - \frac{\sum_{n=0}^{\infty}(-1)^n A_n \exp\left(-n^2\pi^2 F_0\right)}{-A_1 \exp\left(-\pi^2 F_0\right)}.$$





Eq.(l) is valid for $F_0 \geq F_{0*} = 0.14$

$$0.14 \leq F_0 < 0.19$$



$$A_n = \frac{\sin(n\pi g/l)}{n\pi g/l}\,\frac{\exp\left(n^2\pi^2\alpha\tau_u/l^2\right) - 1}{n^2\pi^2\alpha\tau_u/l^2}$$

τ_c – pulse duration, *g* – depth of energy absorption.

12 ECTP(Vienna, Sept 1990) High Temp.-High Press., 1991, v.23.

MCM, 1992, N4; Int. Conf. "Nondestructive testing and evaluation of composite structures" (Riga, Oct. 1991).

$$\alpha = \frac{l^2}{\pi^2 \tau}; \quad \rho c = \frac{Q}{T_m l}; \quad \lambda = \alpha c \rho;$$

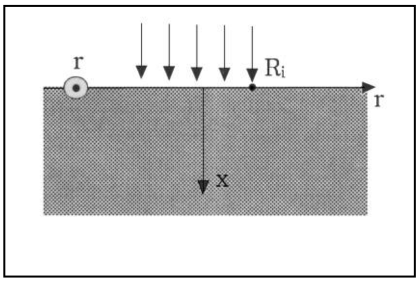
$$\tau_c = 0.1 \cdot \tau_m .$$

$$\alpha = \frac{l^2}{\pi^2 \Delta\tau} \ln\left(\frac{I_2 - I_1}{I_3 - I_2}\right); c\rho = \frac{Q\Delta\tau}{l} \frac{2I_2 - I_1 - I_3}{I_2^2 - I_1 I_3},$$

$$I_1 = \int_{\tau_m}^{t_1} T dt; \quad I_2 = \int_{t_1}^{t_2} T dt; \quad I_3 = \int_{t_2}^{t_3} T dt;$$

$$t_3 - t_2 = t_2 - t_1 = t_1 - \tau_m = \Delta\tau = 0.1 \cdot \tau_m .$$

Two-points method (1985)



$$r > 10 R_i; \quad \alpha = 6.12 \times 10^{-2} \frac{r^2}{\tau_i}; \quad c\rho = 0.05 \frac{Q}{r^3 T(\tau_i)} .$$

For a plate, if l > r,

where 1: thickness

τ_i: corresponds to the inflection point of the temperature evaluation curve.

From the moment of regutarization of the temperature regime the solution (1) can be represented by the monomial formula

$$T = A + B\exp(-C \cdot t).$$

Specifying discretely $t_k = t_{k-1} + \Delta t$, where Δt is a time step, we have

$$T_k = F \cdot T_{k-1} + D,$$

with $F = \exp(-C \cdot \Delta t)$; $D = A[1 - \exp(-C \cdot \Delta t)]$; $A = T_m = Q/(C \cdot \rho \cdot 1)$; $B = 2A_1 \cdot T_m$; $C = \pi^2 a / 1^2$.

As a criterion of the quality of identification of the TPP we choose the minimum of the root-mean-square residual

$$\min\left\{\sum_{k=1}^{n} (T_k - F T_{k-1} - D)^2\right\}.$$

Using the technique of regression analysis, we obtained (MCM, 1999, N3)

$$F = \frac{\sum_{k=1}^{n} T_k \cdot \sum_{k=1}^{n} T_{k-1} - n \cdot \sum_{k=1}^{n} T_k T_{k-1}}{\left(\sum_{k=1}^{n} T_{k-1}\right)^2 - n \cdot \sum_{k=1}^{n} (T_{k-1})^2};$$

$$D = F = \frac{\sum_{k=1}^{n} T_{k-1} \cdot \sum_{k=1}^{n} T_k T_{k-1} - \sum_{k=1}^{n} T_k \cdot \sum_{k=1}^{n} (T_{k-1})^2}{\left(\sum_{k=1}^{n} T_{k-1}\right)^2 - n \cdot \sum_{k=1}^{n} (T_{k-1})^2}$$

and

$$\alpha = -l^2 \frac{\ln F}{\Delta t \cdot \pi^2}, \quad c\rho = \frac{Q(1-F)}{l \cdot D}.$$

TIME RESTRICTION

(from the response time of the measuring system and the characteristic time of the object examined)

$$4t_d < 4.43 \cdot 10^{-3} \frac{l^2}{\alpha}.$$

For Hg Cd Te detector

$$\text{d.} \quad t_d \sim 3 \times 10^{-9} [s].$$

So, for Cu sample $1 > 30\mu$ m.

RESTRICTION from the geometrical conditions

$1 < 0.3R_i$ – for an infinite plate;

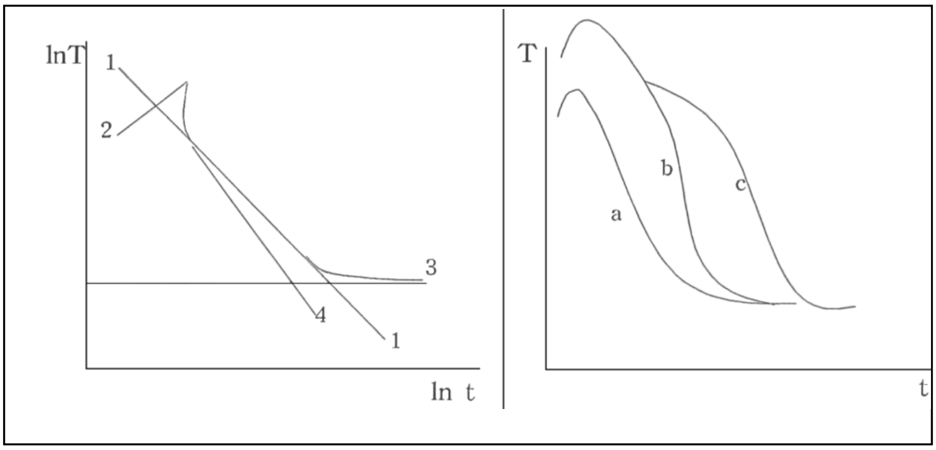
$1 < 0.3R_i$, $1 < 0.6R$ – for a disk of radius R,

with R_i – the radius of a spot of heating.

"SINGLE-ENDED"

"FRONT-FACE FLASH METHOD"

A. "Early" period following the pulsed excitation
   The IR-signal(temperature) depends on the absorption coefficients of the sample and on the thermal diffusivity of the material.
B. In the "Late"period the signal depends on the thermal diffusivity and thickness of the sample and totally insensitive to the absorption coefficients.



1. semi-infinite sample with a Dirac heat pulse;
2. finite pulse duratian effect (here a square-wave pulse);
3. finite thickness effect;
4. heat-loss effect.

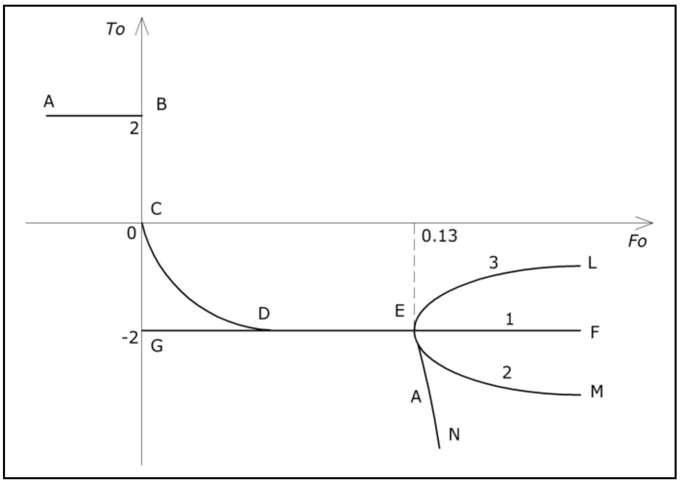
1. bare steel sample;
2. well-bonded Ni-Cr coating on steel substrate (100 μm + 3 mm);
3. delaminated coating.

CRITERION OF THERMAL HOMOGENEITY

Measurements to find TPP constitute an inverse heat transfer problem. Accordingly, questions connected with regularisation of the solution arise, i.e. it is necessary to determine the instant at which the heating regime becomes regular. If this problem is solved [5], it is possible to manage time thermograms processing in such a way that initial conditions will no longer influence the obtained TPP and very simple and convenient relationships to find TPP can be achieved. However, another problem comes up in multilayered structures: governing parameters have to be identified that clearly correlate the measured TPP with the corresponding layers. To solve this problem, we propose the use of the DCTH [5]

$$To = \frac{T}{tT'}, \qquad (1)$$

where T and T' are the temperature and its derivative with respect to time, respectively, both measured as function of time, t, at the sample surface. Behavior of the DCTH is presented in figure 1.



Behavior of the thermal homogeneity criterion, *To(t)* (schematic). The meaning of the curves is as follows: (a) straight line 1 GDEF: semi-infinite steel sample with a Dirac heat pulse; (b) curve ABCDEF: finite pulse duration effect (semi-infinite steel sample with a square-wave pulse); (c) straight line AB: direct pulse action; (d) curve CD: pulse tail effect; (e) curve 2 GDEM: the effusivity of the first layer is larger than that of the second one (Dirac heat pulse); (f) curve 3 GDEL: the effusivity of the first layer is less than that of the second one (Dirac heat pulse); (g) curve 4 GDEN: the first layer is adiabatically isolated (Dirac heat pulse).

One can see that the DCTH indeed responds to variations in the boundary and thermal transport conditions, as schematically indicated in figure 1. For putting the suggested method into practice, the deflection point E indicated in figure 1, at which the Fourier number, *Fo* ≈ 0.13, can be used as a reference for the TPP identification. It was shown previously [4] that beginning at *Fo* ≈ 0.16, the heating regime was regular, i.e. the initial conditions began to be of secondary importance, and from then the process was fully determined only by the conditions of cooling at the interface between the body and the medium, the physical properties of the body, its geometry and dimensions [6]. From the mathematical viewpoint, this means that the temperature field is described by a one-term expression:

$$T = \frac{Q}{c_1 \rho_1 L_1}\left[1 + 2A_1 \exp\left(-\pi^2 Fo\right)\right], \qquad (2)$$

which can be used to obtain the TPP. In this expression, $Fo = a_1 t/(L_1)^2$, ρ_1 denotes the density of the first layer material, and c_1 and a_1 its specific heat and thermal diffusivity, respectively. L_1 is its thickness, and Q denotes the density of pulsed energy. A_1 is a constant coefficient derived from initial conditions. Moreover, one can see from equation (2) that it is possible to process data in such a way that the coefficient A_1 will be excluded and so will not have influence on the TPP.

Thin films and film coatings, wide-used in differrent branches of modern technique and technology (from electronics up to rocket design), are too inconvenient for thermal nondestructive testing. The conventional front-face- flash methods, which are the most suitable for these purposes, have time limitation derived from relation between a response time of a measuring system (t_d) and a characteristic time of an investigated object [1]

$$4t_d < 4.43 \cdot 10^{-3}\, L^2/\alpha\,, \tag{1}$$

where L – the thickness of object, α – the thermal diffusivity.

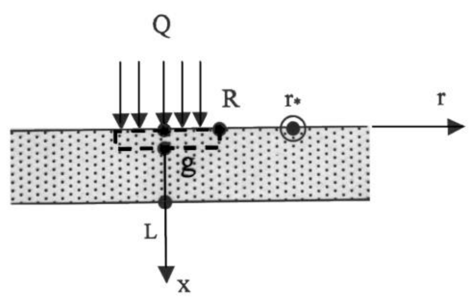


Fig. 1. Scheme of the problem

It follows from (1) that, if we refuse from a traditional temperature measuring directly at the pulsed heating region and measure the temperature at any distance “r*” from the center of the heating spot with radius “R”, we'll have as a characteristic dimension not “L” but “r*”, which can be varied, so excluding the limitation (1).

It's necessary to solve the following problem, shown in Fig. 1.

$$\frac{1}{\alpha}\frac{\partial\theta(x,r,\varphi,\tau)}{\partial\tau} = \frac{\partial^2\tau}{\partial r^2} + \frac{1}{r}\frac{\partial\theta}{\partial r} + \frac{1}{\varphi^2}\frac{\partial^2\theta}{\partial\varphi^2} + \frac{\partial^2\theta}{\partial x^2}\,; \tag{2}$$

$$\theta(x,r,\varphi,o) = \left\{\begin{matrix} \dfrac{Q}{c\rho g} & for\ \ 0 \le x \le g,\ 0 \le r \le R,\ 0 \le \varphi \le 2\pi \\ 0 & for\ \ g < x \le L,\ r > R \end{matrix}\right\}; \tag{3}$$

$$\left.\frac{\partial\theta(x,r,\varphi,\tau)}{\partial x}\right|_{\substack{x=0 \\ x=L}} = \frac{\partial\theta(x,\infty,\varphi,\tau)}{\partial r} = \theta(x,\infty,\varphi,\tau) = 0\,. \tag{4}$$

The analytical solution of (2) with (3) and (4) is

$$\theta(x,r,\tau) = \frac{Q}{c\rho L}\exp\left(-\frac{r^2*}{4\alpha\tau}\right)\left[1 + 2\sum_{n=1}^{\infty}\cos\left(\frac{n\pi x}{L}\right)\exp\left(-\frac{n^2\pi^2}{L^2}\alpha\tau\right)\right]\times$$

$$\times\left\{1 - \exp\left(-\frac{R^2}{4\alpha\tau}\right) + \sum_{p=1}^{\infty}\frac{(-1)^{p+1}}{(p!)^2}\left(\frac{r^2*}{4\alpha\tau}\right)^p\left[\left(-\frac{R^2}{4\alpha\tau}\right)^p\exp\left(-\frac{R^2}{4\alpha\tau}\right) - p\int_0^{-R^2/(4\alpha\tau)} b^{p-1}\exp b\,db\right]\right\} \tag{5}$$

Under $R > L$, r* > 10·R, r* > 2·L, $4\alpha\tau > R^2$ from (5) one can obtain the simplified expression for the temperature evolution

$$\theta = \frac{Q}{c\rho L}\cdot\exp\left(-\frac{r^2*}{4\alpha\tau}\right)\cdot\frac{r^2*}{4\alpha\tau}\cdot\frac{R^4}{16\alpha^2\tau^2}\,. \tag{6}$$

In this case, when measuring the temperature at the time moment “τ” (at the inflection point of the temperature response curve), we can obtain the simple relation to calculate the thermal diffusivity

$$\alpha = 0.042\,\frac{r^2*}{\tau}\,. \tag{7}$$

To investigate the reliability of the method, the plates of different materials, 50 mm in diameter and 100 μm thick under R =1 mm and r^* = 11 mm, were investigated.

The results of the experiments are presented in Table 1.

Table 1.

Materials	Al	Cu	Ag
$\alpha \cdot 10^6$, m^2/s – our experiments	88	114	166
$\alpha \cdot 10^6$, m^2/s – Reference data	87.2	112.9	168

With the values mentioned above, an overall error of less than ±1.2 % is estimated.

This method does not need specific instrumentation and is very easy for realization.

REFERENCES

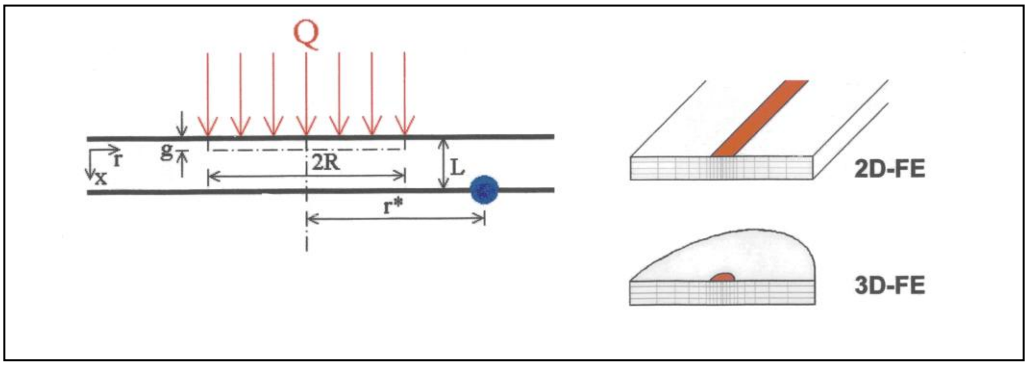
1. O.Yu. Troitsky, "A new approach to the flach technique for the remote sensing of layered materials, "Mech. Compos. Mater., 35, No. 3, 271-276 (1999).

e. Estimation of thermal diffusivity of thin film materials by a one-level, two-point "diverging" thermal wave technique.

Goal: Estimate thermal diffusivity from experimental $T(t,r^*)$ without explicit knowledge of sample thickness.

Method: Measure $T(r^*,t)$ in thin films at positions r^* outside target spot dimensions.

Realisation: Find analytical approach to 2D or 3D-Finite Element (FE) simulations.



Theory (analytical solution):

Start with
$$\frac{1}{\alpha}\frac{\partial\theta(x,r,\varphi,t)}{\partial t}=\frac{\partial^2\theta}{\partial r^2}+\frac{1}{r}\frac{\partial\theta}{\partial r}+\frac{1}{r^2}\frac{\partial^2\theta}{\partial\varphi^2}+\frac{\partial^2\theta}{\partial x^2}\,.$$

Boundary conditions:
$$\theta(x,r,\varphi,o)=\left\{\begin{matrix}\dfrac{Q}{c\rho g} & for\ 0\le x\le g,\ 0\le r\le R,\ 0\le\varphi\le 2\pi\\ 0 & for\quad g<x\le L,\ r>R\end{matrix}\right\}$$

$$\left.\frac{\partial\theta(x,r,\varphi,\tau)}{\partial x}\right|_{\substack{x=0\\x=L}}=\frac{\partial\theta(x,\infty,\varphi,t)}{\partial r}=\theta(x,\infty,\varphi,t)=0\,.$$

Solution (Grigoryev, 1974):

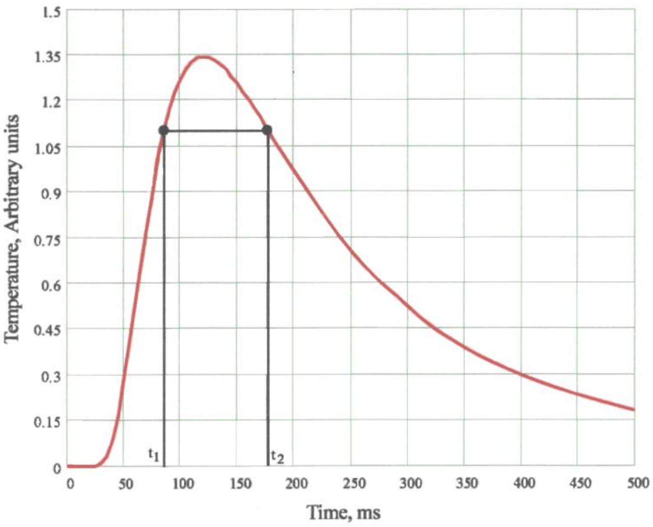
$$\theta(x,r,t)=\frac{Q}{c\rho L}\exp\left(-\frac{r^2*}{4\alpha t}\right)\left[1+2\sum_{n=1}^{\infty}\cos\left(\frac{n\pi x}{L}\right)\exp\left(-\frac{n^2\pi^2}{L^2}\alpha\tau\right)\right]\cdot$$

$$\cdot\left\{1-\exp\left(-\frac{R^2}{4\alpha\tau}\right)+\sum_{p=1}^{\infty}\frac{(-1)^{p+1}}{(p!)^2}\left(\frac{r^2*}{4\alpha t}\right)^p\left[\left(-\frac{R^2}{4\alpha\tau}\right)^p\exp\left(-\frac{R^2}{4\alpha\tau}\right)-p\int_0^{-R^2/(4\alpha t)}b^{p-1}\exp b\,db\right]\right\}$$. Eq. (5) in our paper

Approximated by:

If $x = L$, $R > L$, $4\alpha t >> R^2$, $p = 1$:

$$\theta=\frac{Q}{c\rho L}\cdot\exp\left(-\frac{r^2*}{4\alpha t}\right)\cdot\frac{r^2*}{4\alpha t}\cdot\frac{R^2}{4\alpha\tau}.$$



Approximation to Eq. (5) at $x = L$ using $4\alpha t >> R^2$, $p = 1$:

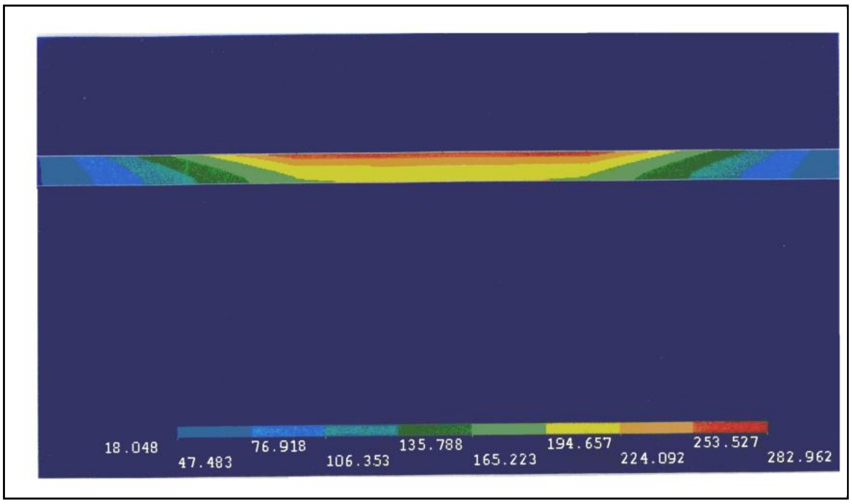
"One level, 2 points":

$$\frac{Q}{c\rho L}\cdot\exp\left(-\frac{r^2*}{4\alpha t_1}\right)\cdot\frac{r^2*}{4\alpha t_1}\cdot\frac{R^2}{4\alpha t_1}=$$

$$=\frac{Q}{c\rho L}\cdot\exp\left(-\frac{r^2*}{4\alpha t_2}\right)\cdot\frac{r^2*}{4\alpha t_2}\cdot\frac{R^2}{4\alpha t_2}$$

yields after elementary transformations:

$$\alpha = 0.125\cdot r^2*\cdot\frac{t_2-t_1}{t_1\cdot t_2\cdot\ln(t_2/t_1)}.$$



2D-Finite Element (FE) calculation: Temperature distribution (cross section) in a copper thin film (strip of 50 mm width) during irradiation.

Film thickness 100 micrometer, width of target spot 2 mm (indicated by the region with red colours). Data are given near the target point at 0.1 ms after start of irradiation (from top). Element size at the target spot 500 micrometer in length, 25 micrometers in thickness. Adiabatic case (no convection or radiation interaction with ambient). Temperatures are given in deg C.

Summary:

1) Formula for extraction of thermal diffusivity does not depend on sample thickness (interesting for thin films, quality and process control).
2) Proposed method is applicable if

$$4at >> R^2,\ r* >> R \text{ and } r* >> L,$$

$$\frac{R_0}{r*} >> 10.$$

Conclusions

Methods to obtain the TPP of different objects have been presented and tested numerically. The agreement between theory and numerical experiment is satisfactory. The present results are encouraging, because the new methods do not need corrections to radiative and convective losses, and they avoid the serious limitations imposed on standard transient measurements when applied to transparent or semitransparent materials. The methods are of great practical interest to industrial applications, because the measurements can be performed if only one side of a sample is accessible. Now we need new extraordinary, and may be even crazy, ideas to solve the thermal tomography problem, and, may be, we need new understanding of thermal wave propagation at the early stage of the process just after the instant when an excitation occurs.

1. R.E. Taylor, L.M. Clark, ”Finite pulse-time effects inflash diffusivity method”, High Temperatures – High Pressures, vol. 6, n. 1, pp. 66-72, 1974.
2. K. Beedham, I.P. Dalrymple, “The measurement of thermal diffusivity by the flash method. An investigation into errors arising from the boundary conditions”, Rev. Int. Htes Temp. et Refract., vol. 7, pp. 278-283, 1970.
3. P. Cielo, “Pulsed photothermal evaluation of layered materials”, vol.56, n. 1, pp. 230-234, 1984.
4. Troitsky, “Pulsed thermal nondestructive testing of layered materials”, SPIE Int. Symp. on Optical Engineering and Photonics in Aerospace and Remote Sensing: Thermosense XV: SPIE Proc., Orlando, Florida, USA, vol. 1933, pp. 309-312, 1993.
5. Yu. Troitsky, H. Reiss,”Remote nondestructive monitoring of coatings and materials by the flash technique”, High Temperatures – High Pressures”, vol. 32, pp. 391-395, 2000.
6. G.M. Kondratyev, Teplovye Izmereniya (Thermal Measurements.) Moscow: Mashgiz, 1957.
7. H.S. Carslaw, J.C. Jaeger, Conduction of Heat in Solids, 2-nd ed. Oxford: Clarendon, 1959.
8. Yu. Troitsky, H. Reiss, “A Numerical Simulation to Propose a Flash Method for In Situ Detection of the Thermal Diffusivity of Anisotropic Thin Film Materials”, Int. J. of Thermophysics, vol.30, n.4, pp.1283-1299, 2009.
9. H. Reiss, O.Yu. Troitsky, “Thermophysical Model to Numerically Determine the Diffusivity of Highly Excited Nuclear Matter with an Instantaneous, Internal Pulse Method”, J. of Chemical and Engineering Data, vol. 54, n. 9, pp. 2483-2497, 2009.

К ВОПРОСУ ЭНЕРГОЭФФЕКТИВНОСТИ И ЭНЕРГОСБЕРЕЖЕНИЮ В ОСВЕЩЕНИИ

Яковлев А.Н., Гончаров А.Д., Денисов И.П., Козырева И.Н., Юганнсон Ю.В., Овчарова И.С.

Томский политехнический университет

Введение

Электрическая энергия – необходимое условие жизнедеятельности человека и создания благоприятных условий его быта. В экономике России энергосбережение и энергосберегающие технологии являются приоритетными при внедрении их в производство [4].

Федеральный закон Российской Федерации от 23 ноября 2009 г. № 261-ФЗ «Об энергосбережении и о повышении энергетической эффективности и о внесении изменений в отдельные законодательные акты Российской Федерации» [1] призван обеспечить снижение потребления энергетических ресурсов при сохранении соответствующего полезного эффекта от их использования.

Этот документ не только побуждает к применению современных энергоэффективных источников света, но и к применению комплексного подхода при создании современных установок с интеллектуальными системами управления и мониторинга [5].

Согласно данным Международного энергетического агентства на освещение приходится примерно от 16 до 19 % общего мирового расхода электроэнергии.

В настоящее время почти во всем мире пытаются найти решения и средства для уменьшения потребления и более эффективного расходования природных ресурсов, и не в последнюю очередь энергии [6].

Рост тарифов на энергоносители - реальность нашего времени. Стремительный рост энергопотребления приводит к нехватке электрических мощностей. Переход к полупроводниковому освещению в России позволит снизить воздействие этих факторов на экономику.

В условиях, определяемых как экономический кризис, передовые промышленные предприятия России осуществляют мероприятия по сокращению издержек, частью которых являются затраты на электроэнергию. В этом направлении большие перспективы имеет замена традиционных источников света на светодиодные (СД) [7].

Основные отечественные производители светодиодов:

- ✓ ОАО «НИИПП»;
- ✓ ЗАО «Светлана Оптоэлектроника»;
- ✓ ЗАО «Оптоган».

Несмотря на растущий интерес к СД, в России вместо развития технологий повсеместно распространена так называемая «отверточная сборка» изделий из импортных компонентов, иными словами, копирование существующих образцов светодиодной продукции без применения инновационных подходов наращивания эффективности. Эти факторы свидетельствуют об отставании российского рынка от мировых лидеров (Китай, США, Япония).

Всего несколько компаний в мире (в России, единственная - ЗАО «Светлана Оптоэлектроника») владеют полным технологическим циклом выпуска оптоэлектронной продукции. Иными словами – комплексом современного технологического оборудования, позволяющего осуществлять изготовление продукции, начиная с роста светоизлучающих гетероструктур, сборки и монтажа светодиодов, прочих электронных элементов на печатные платы, сборку готовых светотехнических изделий [8].

За исключением очень узкого круга специалистов, мало кто ориентируется в методиках измерения светового потока, расчета тепловых характеристик, надежности и срока службы СД при различных режимах работы и т.д. К сожалению, этим пользуются многие производители осветительных приборов, указывая в документации параметры, не соответствующие реальности [9].

Государственные программы развития инновационной экономики, направленные, в том числе на внедрение ресурсоэффективных технологий, предусматривают участие вузов и научных организаций вместе с промышленными предприятиями и бизнес-структурами в организации наукоемких производств. Примером такой программы является постановления Правительства Российский Федерации от 09 апреля 2009 г. № 218 «О мерах государственной поддержки развития кооперации российских высших учебных заведений и организаций, реализующих комплексные проекты по созданию высокотехнологичного производства». Постановлением предусматривается возможность использования научно-образовательного потенциала российской науки для решения актуальных задач модернизации производственной сферы.

Полупроводниковая светотехника попала в разряд актуальных задач. В 2010 г. в условиях конкурсного отбора был поддержан проект «Разработка высокоэффективных и надежных источников света и светотехнических устройств и организация их серийного производства», который реализуется Консорциумом томских вузов (ТУСУР, ТГУ, ТПУ) и предприятием ОАО «НИИПП» Госкорпорации «Росэлектроника» в рамках постановления Правительства РФ № 218.

Переход на новые источники света и световые приборы связан с экономическими выгодами при их применении. Затраты на СД осветительный прибор окупаются при экономии в разы. Реальная экономия возможна только при проектировании «правильного света», под которым понимается светотехнический расчет с учетом всех особенностей технических характеристик СД световых приборов. В противном случае при значительных начальных затратах на оборудование и не очевидной экономии электроэнергии на выходе получается такое же количество света.

Экономия электроэнергии при проектировании и монтаже осветительных электроустановок достигается за счет правильного выбора типа ламп и светильников. ОАО «НИИПП» совместно с Томским политехническим университетом осуществляет разработку светодиодных осветительных приборов (в основном, для промышленных, предприятий ЖКХ). Проект предусматривает отказ от системы «отверточной сборки» и переход на полный цикл производства начиная с роста светоизлучающих гетероструктур и заканчивая сборкой и монтажом готовых осветительных приборов, внедрение в производство передовых научных разработок, контроль светотехнических характеристик и электромагнитной совместимости полупроводниковых приборов.

В рамках проекта ТПУ совместно с ОАО «НИИПП» создается региональный Центр по разработке высокоэффективных светодиодов и светильников на их основе для серийного выпуска и внедрения энергосберегающих систем освещения, а также дизайн-центра светотехнических устройств на основе использования современных программных средств и методов их расчета, разработанных на кафедре лазерной и световой техники ТПУ.

Модернизация осветительных установок предполагает проведение предварительного энергоаудита в области освещения. Энергоаудит представляет собой сбор информации о текущем состоянии осветительной установки, анализ информации, выработку энергосберегающих рекомендаций, реализацию предложенных рекомендаций, повторный сбор данных и анализ результатов выполненных работ по повышению энергоэффективности.

ОАО «НИИПП» совместно с ТПУ проводит энергоаудит (обследование) в области освещения и модернизацию осветительных установок на предприятиях промышленности и жилищно-коммунального хозяйства, разрабатывает дизайн-проекты реконструкций осветительных установок (3-х мерная визуализация), реализует реконструкцию и запуск осветительных установок по требованию заказчика.

В настоящей работе рассматривается пример модернизации осветительной установки с целью получения наглядного представления о преимуществах и недостатках светодиодного освещения.

Объектами исследования выбраны два помещения, а именно две лекционные аудитории учебного корпуса Национального исследовательского Томского политехнического университета, одинаковые по площади, геометрии помещения и числу встраиваемых светильников для подвесных потолков типа «Армстронг».

Осветительная установка (ОУ) аудитории № 1: 12 светильников с люминесцентными источниками света (418 ARS/R, производитель ООО «Световые технологии»).

Осветительная установка аудитории № 2: 12 светильников с источниками света на базе светодиодов (ССОН СД В-О-01-110-30-001-IP20-УХЛ4, ССОН СД В-О-01-140-35-001-IP20-УХЛ4, производитель ОАО «НИИПП»).

Целью данного исследования является сравнительный анализ светотехнических характеристик осветительных установок (по освещенности, по спектру излучения) с различными источниками света (ИС), создание дизайн-проекта новой установки, расчет энергоэффективности осветительной установки на базе светодиодов.

Характеристики освещаемого объекта

Характеристики рассматриваемых лекционных аудиторий следующие:
Габаритные размеры (Д×Ш×В): 9,92×5,7×3 м.
Стены: окрашены краской, цвет бежевый.
Пол: окрашен темно-коричневой краской.
Потолок: подвесной типа «Армстронг».

Светотехнические характеристики осветительных установок приведены в таблице 1.

Таблица 1. Характеристики сравниваемых ОУ

	ОУ аудитории № 1 (люминесцентные ИС)	ОУ аудитории № 2 (светодиодные ИС)	
Наименование светового прибора (СП)	418 ARS/R 4×18	ССОН СД В-О-01-110-30-001-IP20-УХЛ4	ССОН СД В-О-01-140-35-001-IP20-УХЛ4
Число СП в ОУ, ед.	12	6	6
Световой поток одного СП (Ф), лм	1800	2000	2500
Мощность СП ($P_{СП}$), Вт	72	30	35
Мощность ОУ ($P_{ОУ}$), Вт	864	180	210

ОУ аудитории №1 состоит из 12 люминесцентных встраиваемых светильников (418 ARS/R 4×18), которые предназначены для монтажа в подвесной потолок. Мощность каждого светильника 60 Вт, световой поток 1800 лм.

ОУ аудитории №2 состоит из 6 светодиодных светильников ССОН СД В-О-01-110-30-001-IP20-УХЛ4 (мощность 30 Вт, световой поток 2000 лм) и 6 светодиодных светильников ССОН СД В-О-01-140-35-001-IP20-УХЛ4 (мощность 35 Вт, световой поток 2500 лм). Расположение световых приборов приведено на рисунках 1 и 2. Ведомость СП представлена в таблице 2.

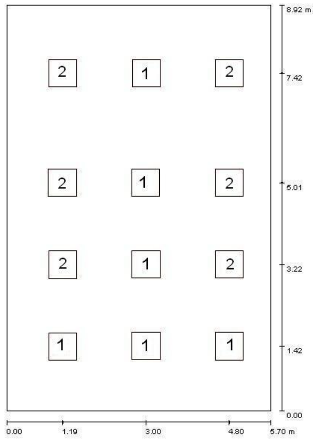


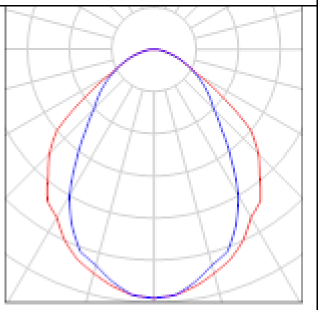
Рис.1. Расположение светильников:

1- ССОН СД В-О-01-110-30-001-IP20-УХЛ4

2- ССОН СД В-О-01-140-35-001-IP20-УХЛ4

Рис.2. Трехмерная визуализация аудитории №2 в программе DIALux

Таблица 2. Ведомость светильников

Количество, шт.	Марка светильника	Внешний вид	КСС
6	ССОН СД В-О-01-110-30-001-IP20-УХЛ4		
6	ССОН СД В-О-01-140-35-001-IP20-УХЛ4		

Сравнительный анализ освещенности, создаваемой осветительными установками с различными источниками света

Средства измерения

При проведении инструментального обследования освещенностей аудиторий в качестве средства измерения использовался Люксметр - УФ-радиометр «ТКА -01/3».

Освещенность рабочих мест

В результате проведенных измерений в аудитории №2 до и после установки светодиодных светильников составлена карта освещенностей – рис.3.

До установки светодиодных светильников освещенность варьируется от 240 лк до 570 лк на рабочей поверхности (0,8 м от пола) и от 125 лк до 260 лк в плоскости классной доски. Требованиям по уровню освещенности СНиП 23-05-95 [2] соответствует 97% рабочих мест.

После установки светодиодных светильников освещенность варьируется от 456 лк до 705 лк на рабочей поверхности (0,8 м от пола) и от 167 лк до 270 лк в плоскости классной доски. Сделано заключение о полном соответствии уровня освещенности.

Таким образом, уровень освещенности на рабочих поверхностях возрос в 1,5 раза, а в плоскости классной доски в 1,1 раз при значительном снижении энергопотребления за счет использования светодиодных источников света (ИС).

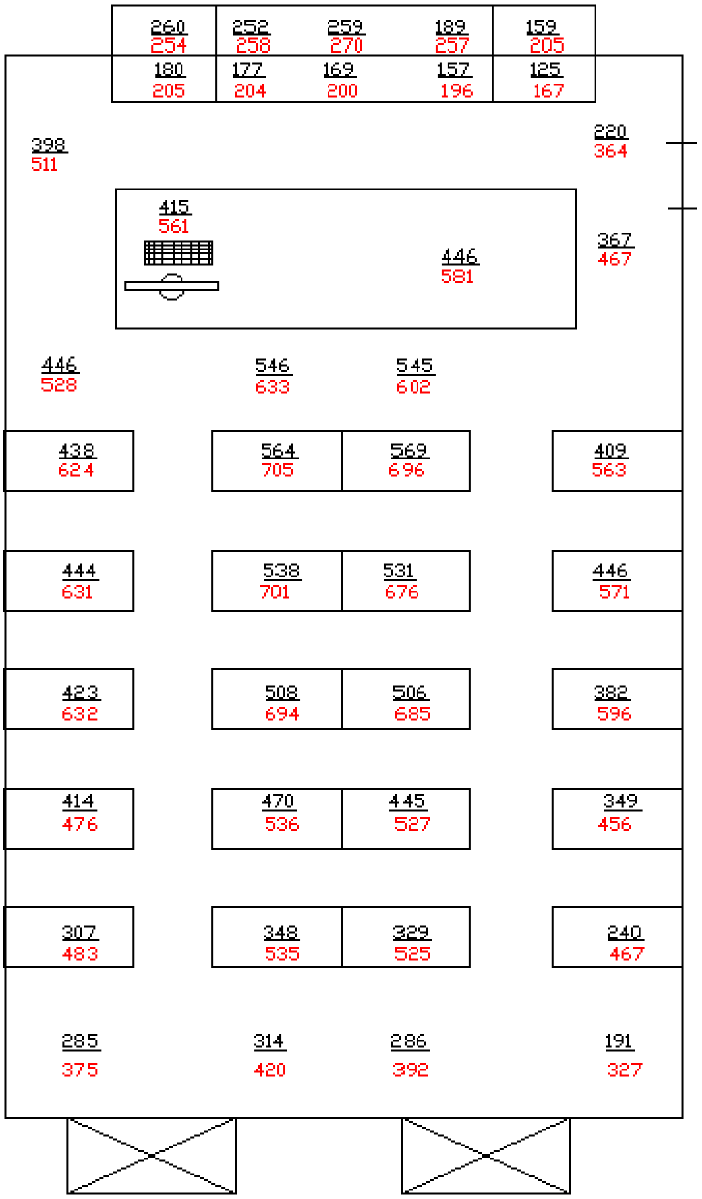


Рис.3. Карта освещенностей на рабочих местах в аудитории №2 до и после установки светодиодных светильников.

538 - освещенность до установки светодиодных светильников, лк.

701 - освещенность после установки светодиодных светильников, лк.

Сравнительный анализ спектральных характеристик осветительных установок

Средства измерения

При проведении инструментального обследования спектральных характеристик ОУ аудиторий использовалось следующее средство измерения:

Спектрофотометр «SPEKTRA»

- Прибор индикатор спектра
- Набор соединительных кабелей для подключения к компьютеру

- Программа «Spektrofotometr» для персонального компьютера
- Интерфейс подключения к компьютеру – USB
- Напряжение питания – 9 – 12 В питание от USB
- Диапазон длин волн – от 300 до 1100 нм.
- Разрешающая способность – от 0,1нм в области 300 нм до 3 нм в области 1000 нм.
- Время накопления оптического сигнала от 0,1 до 1000 мс.

Спектры излучения люминесцентных и светодиодных ИС

В ходе второго эксперимента с помощью спектрофотометра «SPEKTRA» были получены и обработаны спектры излучения люминесцентных ИС в аудитории №1 и светодиодных ИС в аудитории №2. Данные приведены на рис. 4 и 5.

Максимумы излучения люминесцентных ИС приходятся на длины волн: 365, 405, 440, 540, 550 и 580 нм, что соответствует самым интенсивным линиям ртути и линиям люминофора. На рис. 4. наблюдается сплошной спектр с некоторыми ярко выраженными линиями. Он практически совпадает со спектральным распределением линий люминесцентной лампы (ЛЛ) белого цвета мощностью 65 Вт из справочной книги по светотехнике Ю.Б. Айзенберга [3] (рис. 6), что подтверждает верность данных, полученных в ходе эксперимента. В спектре присутствует много синего, зеленого, желтого, но мало красного цвета.

Максимумы излучения светодиодных ИС приходятся на длины волн: 450 и 570 нм. Спектр полосатый, наблюдается 2 интенсивные полосы: голубого и желтого цветов. В спектре совершенно отсутствует излучение фиолетового цвета, очень мало зеленого.

Также, наблюдались различные цвета стен в аудиториях №1 и №2. При включении ОУ в аудитории №1, стены такого же бежевого цвета, как при естественном освещении, а в аудитории №2 – бежевый цвет заметно сменяется на розоватый, хотя в спектре светодиодного ИС красный цвет не присутствует в большом количестве. Таким образом, наблюдается искажение цветопередачи из-за различия источников света в световых приборах.

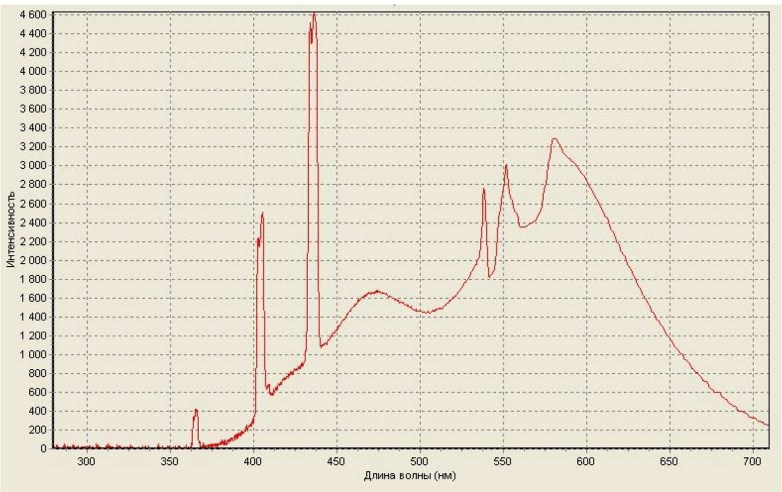


Рис.4. Спектры излучения люминесцентных ИС в аудитории №1

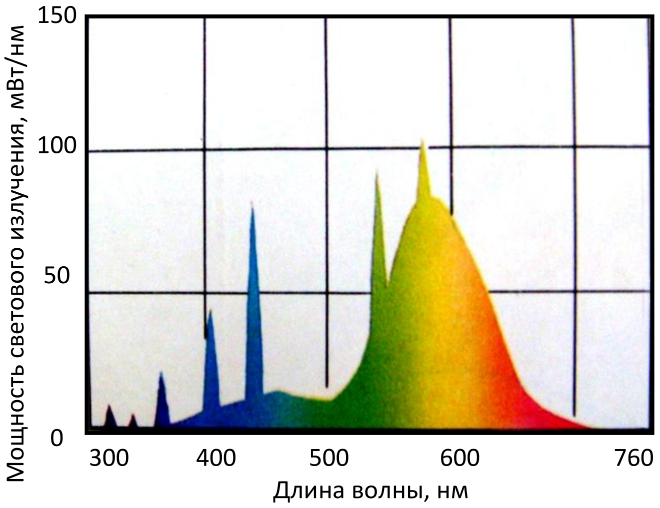


Рис.5. Спектры излучения светодиодных ИС в аудитории №2

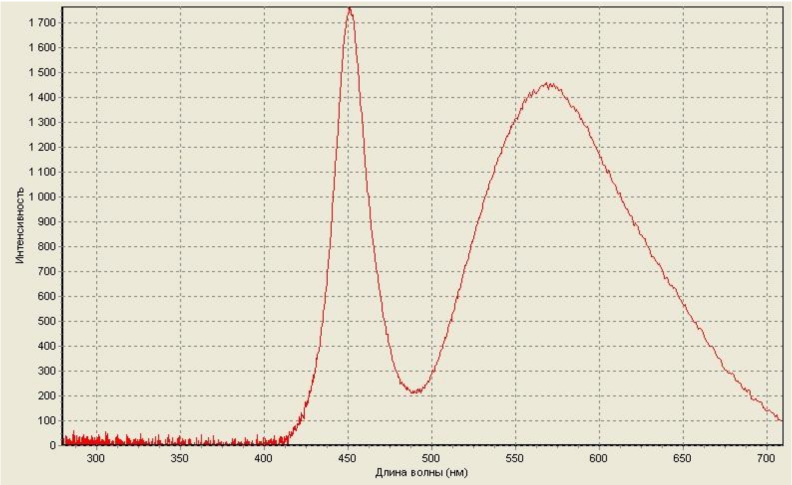


Рис.6. Спектральное распределение ЛЛ белого цвета мощностью 65 Вт

Расчет энергоэффективности светодиодной ОУ

В табл. 3 можно увидеть оценку экономии при внедрении СДС в аудитории №2.

Расчеты выполнены из учета стоимости электроэнергии для госучреждений в Томске (4,06 руб./кВт·ч с учетом НДС). Занятия в рассматриваемых аудиториях проводятся с 8:30 до 17:45 с понедельника по субботу. Время работы в год – 2 775 часов. Характеристики СП приведены в таблице 1.

Таблица 3. Оценка энергоэффективности ОУ в аудитории №2 (СДС)

$P_{ОУ}$, Вт	W, Вт/м^2	ΔP, кВт	ΔQ, кВт·ч/год	ΔC, руб/год	T, лет
$P_{ОУ\ (СДС)} = N_1 \cdot P_1 + N_2.P_2$ $P_{ОУ\ (СДС)} = 6 \cdot 30 + 6 \cdot 35 = 390$ Вт $P_{ОУ\ (ЛС)} = N \cdot P$ $P_{ОУ\ (ЛС)} = 12 \cdot 72 = 864$	$W = \frac{P_{ОУ}}{S}$ $W = \frac{390}{56{,}54} = 6{,}9$	$\Delta P = P_{ОУ\ (ЛС)} - P_{ОУ\ (СДС)}$ $\Delta P = 864 - 390 = 0{,}474$	$\Delta Q = \Delta P \cdot t$ $\Delta Q = 0{,}474 \cdot 2775 = 1315{,}35$	$\Delta C = \Delta Q \cdot q$ $\Delta C = 1315{,}35 \cdot 4{,}06 = 5340{,}32$	$T = \frac{C}{\Delta C}$ $T = \frac{60000}{5340{,}32} = 11{,}23$

$P_{ОУ\ (СДС)}$ – мощность ОУ со светодиодными светильниками, Вт

P_1 – мощность светильника ССОН СД В-О-01-110-30-001-IP20-УХЛ4, Вт

P_2 – мощность светильника ССОН СД В-О-01-140-35-001-IP20-УХЛ4, Вт

N_1 – число светильников ССОН СД В-О-01-110-30-001-IP20-УХЛ4, шт.

N_2 – число светильников ССОН СД В-О-01-140-35-001-IP20-УХЛ4, шт.

$P_{ОУ\ (ЛС)}$ – мощность ОУ с люминесцентными светильниками, Вт

P – мощность светильника 418 ARS/R 4×18, Вт

N – число светильников 418 ARS/R 4×18, шт.

W – удельная установленная мощность (УУМ), Вт/м^2

ΔP – экономия мощности, кВт

ΔQ – экономия электроэнергии (ЭЭ), кВт·ч/год

t – время работы ОУ, ч/год

ΔC – экономия средств на оплату ЭЭ, руб./год

q – тариф на ЭЭ, руб./кВт·ч

T – срок окупаемости, лет

C – стоимость энергосберегающего мероприятия, руб.

Таким образом, энергопотребление в аудитории №2 снизилось на 55% по сравнению с аудиторией №1, при этом возрос уровень освещенности. Следовательно, светодиодное освещение значительно экономичнее люминесцентного аналога. Окупаемость проекта по замене уже существующей ОУ на светодиодную достигается лишь в долгосрочной перспективе (11,23 года) вследствие высоких первоначальных затрат. Это связано с высокой стоимостью светодиодных приборов на данный момент. Однако уже сегодня на территории РФ строятся три завода, производственная деятельность которых направлена на разработку, изготовление и сборку светодиодных ИС, а так же проектирование ОУ, оптимизированных под потребности заказчиков. Таким образом, можно надеяться на снижение стоимости светодиодных ИС, и, как следствие, снижение срока окупаемости ОУ.

Список использованной литературы:

1. Федеральный закон от 23 ноября 2009 г. № 261-ФЗ «Об энергосбережении и о повышении энергетической эффективности и о внесении изменений в отдельные законодательные акты Российской Федерации» – Режим доступа: http://www.rg.ru/2009/11/27/energo-dok.html (дата обращения 05.02.2011).
2. СНиП 23-05-95. Естественное и искусственное освещение. / Минстрой России. – Изд. офиц. – Введены в действие с 1 января 1996 г. постановлением Минстроя России от 02.08.95 № 18-78; Взамен СНиП II-4-79. – М.: ГП ЦПП, 1995. – 35 с.
3. Справочная книга по светотехнике / под ред. Ю. Б. Айзенберга. – 3-е изд., перераб. и доп. – М.: Знак, 2006. – 972 с.
4. Фокин В.М. Основы энергосбережения и энергоаудита. – М.: Издательство «Машиностроение-1», 2006. – 256 с.
5. Федорищев А.Ю. Состояние и перспективы развития системы наружного освещения России // Светотехника. - 2010. - № 3. - С.4-6.
6. Билунд Л. Проект «Светодиоды для общего освещения» // Светотехника. - 2010. - № 5. - С.4-5.
7. Мохнаткин А.Э «Светлана-Оптоэлектроника» на пути прогресса в области светодиодов // Светотехника. - 2010. - № 3. - С.39-41.
8. Суетов А. Обзор зарубежного и российского рынков светодиодного освещения // Современная светотехника. - 2010. - № 6. - С.15-16. [Электронный ресурс]. – Режим доступа: http://www.lightingmedia.ru/magazine/archive/
9. Красножон Ю. Сказка о четырех долларах // Современная светотехника. - 2010. - № 6 . - С. 7-8. [Электронный ресурс]. – Режим доступа: http://www.lightingmedia.ru/magazine/archive/

СЕМИНАР

ОБУЧЕНИЕ ПРОФЕССИОНАЛЬНОМУ ИНОСТРАННОМУ ЯЗЫКУ СТУДЕНТОВ ТЕХНИЧЕСКИХ СПЕЦИАЛЬНОСТЕЙ С УЧЕТОМ ТРЕБОВАНИЙ МЕЖДУНАРОДНЫХ ЭКЗАМЕНАЦИОННЫХ АГЕНТСТВ. ИННОВАЦИОННЫЕ МЕТОДЫ ОБУЧЕНИЯ: CLIL ИЛИ МЕЖПРЕДМЕТНАЯ ИНТЕГРАЦИЯ.

Е.Л. Седюнина
Городской учебный центр «NUDO Education Centre», Россия, Новосибирск, ул. Нарымская, 27, 630132
E-mail narymskaya@jands.ru
Р.В.Дубатовка
Международный экзаменационный центр «J&S», Россия, г. Омск, ул. Щербанева, 25, 644024
E-mail study@jands.ru
У.А.Смирнова
Томский политехнический университет, Россия, г. Томск, пр. Ленина, 30, 634050
E-mail ulsmirnova@tpu.ru

Проблеме межпредметной интеграции в настоящее время уделяется большое внимание. Это вызвано необходимостью дать обучаемым представление об окружающем мире как о едином целом, характеризующемся общими процессами и управляемом общими законами. Английский язык также может внести вклад в решение задачи разностороннего, поликультурного развития личности. Интегрированные курсы помогают формировать у студентов технических специальностей более целостную картину мира, в котором сам иностранный язык выполняет специфическую функцию - служит средством познания и общения.

Кроме того, в условиях вступления России в общеевропейское образовательное пространство, обусловленное основными положениями Болонского процесса, наиболее актуально встает вопрос о готовности непосредственных участников этого процесса – молодых людей, выпускников учебных заведений к продолжению получения образования не только в вузах России, но и за рубежом.

Следовательно, высоким должен быть не только уровень владения иностранным языком, но и умение поддержать разговор в различных коммуникативных ситуациях на любую предлагаемую тему в рамках общих знаний. В связи с этим, необходимо не только формирование языковых умений и навыков, но и развитие учебно- интеллектуальных умений: обобщения, сравнения, экстраполяции (умения переносить сделанные выводы с одного языкового явления на другое); развитие способности к языковой догадке и умения мыслить абстрактными категориями; развитие коммуникативных умений логически излагать высказывание и обосновывать свою точку зрения.

Использование технологии CLIL (Content and Language Integrated Learning) на занятиях иностранного языка позволяет эффективно работать в этом направлении. Обычно под межпредметной интеграцией понимают объединение некоторых частей, массивов учебного содержания из различных предметов, в результате которого возникает новое знание.

CLIL **(Content and Language Integrated Learning) -** это метод, при котором обучение научной дисциплине осуществляется с помощью иностранного языка. Такой двойной (параллельный) подход позволяет сделать процесс обучения более эффективным по обоим направлениям, где язык используется одновременно как инструмент для получения знаний и как средство коммуникации.

CLIL может быть имплементирован в занятие двумя способами: 1) билингвальное погружение (сильный CLIL, когда предметы курса преподаются на языке), 2) интеграция содержания предмета происходит небольшими дозами с использованием иностранного языка (слабый CLIL) по широкому спектру дисциплин: биология, химия, физика, музыка, искусство, география, история и др.

Занятие в формате CLIL должно сочетать в себе 4 элемента:

1) Содержание (подразумевается расширение диапазона определенной области знаний);

2) Коммуникация – развитие коммуникативных навыков;

3) Когнитивные навыки – развитие общеучебных, познавательных навыков;

4) Культурологический компонент, способствующий формированию социокультурной компетенции (умение выделять общее и культурно-специфическое в моделях развития разных стран и др.).

На занятии такого формата должны отрабатываться все 4 языковых навыка (аудирование, чтение, письмо, говорение). Что касается говорения, то основной акцент ставится на беглость речи и её коммуникативную направленность, а не на правильность грамматического оформления.

На занятии в формате CLIL используются разные режимы работы (парная, групповая, и др). Кроме того, необходимо учитывать различные стили восприятия информации обучаемыми (аудиалы, визуалы, кинестетики и др.), необходимо также эффективное использование мультимедийных средств.

Интегрированное занятие позволяет развивать широкий спектр когнитивных навыков, в том числе и так называемые thinking skills (умение осмысливать ситуацию). Соединение с языком происходит следующим образом:

- ➢ Запоминание (recognising, listing, describing,naming,finding,describing)
- ➢ Понимание/интерпретация (comparing, explaining, classifying, understanding cause and effect, summarizing)
- ➢ Применение к новым ситуациям (planning, interpreting, carring out, drawing conclusions, reporting back).

Примечательной особенностью интегрированного занятия является организация полученной информации. С этой целью студенты используют графики, диаграммы, таблицы.

Внедрение вышеописанного метода стало наиболее успешным в последние 10 лет на всех ступенях обучения от начальной до высшей школы, поскольку он **позволяет:**

- ➢ развивать беглость речи и навыки коммуникации,
- ➢ более эффективно работать над развитием языковых навыков,
- ➢ развивать общеучебные познавательные навыки, такие как умение выделять ключевую информацию, резюмировать, конспектировать и др., необходимых для дальнейшего обучения и работы как в России, так и за рубежом,
- ➢ определить логическую и содержательную связь между учебными предметами.

Этот метод **способствует:**

- ➢ расширению кругозора и развитию творческого потенциала,
- ➢ повышению мотивации к изучению и использованию иностранного языка как средства коммуникации,
- ➢ систематизации знаний студентов.

Интегрированное занятие имеет также **ряд психологических преимуществ:**

- пробуждает интерес к предмету,
- снимает напряженность, неуверенность,
- помогает сознательному усвоению подробностей, фактов, деталей,
- обеспечивает формирование творческих способностей учащихся, так как позволяет вести не только учебную, но и исследовательскую деятельность.

Данный метод широко применяется за рубежом. В связи с этим, с целью оценки профессиональной компетенции преподавателей экзаменационным агентством Кембриджского университета Cambridge ESOL был разработан специальный модуль экзамена TKT (Teaching Knowledge Test):CLIL, который ориентирован не только на преподавателей английского языка, использующих этот метод, но и на преподавателей, ведущих технические дисциплины на английском языке.

В целом, этот метод позволит сформировать **будущего инженера**, способного успешно интегрироваться в мировое профессиональное, образовательное и информационное пространство.

1. Teaching Knowledge Test (TKT) Content and Language Integrated Learning (CLIL). *Handbook for teachers. - University of Cambridge ESOL Examinations, 2008.- 28 pp*
2. http://www.cambridgeesol.org/exams/tkt/index.html#tktclil

EFFECTIVE PRESENTATION: SUCCESSFUL CONTEMPORARY RESEARCHER

Lisa Donohoe Luscombe
Project Manager, English Language and Nonproliferation Program James Martin Center for Nonproliferation Studies Monterey Institute of International Studies, the U.S.A.

Posted by Lisa Luscombe, MIIS, Monterey, CA,USA on June 6, 2012

In this talk I'm going to focus on one message. My message is:

Everyone can give an effective presentation.

There are three main ways to do this:

1. **Dealing with your fear**
2. **Knowing your audience**
3. **Getting and keeping the attention of the audience**

Fear

Accept your fear.

You are not alone.

Start to manage your fear: acknowledge and accept the fear as something that is hard-wired in all of us. In fact, new research into cognitive development finds that you would be abnormal if you experienced no anxiety at all. "Instead of trying to eradicate the fear response, a more reasonable approach," says Berns, "is to examine the situations that set it off and try to inhibit it."

Reframe your fear. One of the situations that sets off public speaking fear is negative self talk. Replace negative emotions with positive ones. "If someone consistently perceives public speaking as an unpleasant event, the brain will default to this interpretation," says Berns.

Control your fear. The secret is practice. Lots of it.

Genius is 1% inspiration and 99% perspiration – Thomas Edison

The only way you can get over your fear of public speaking is by going ahead and speaking.

The longer we wait to do whatever it is that is causing the fear, the more intense our fear would become.

Enroll in public speaking groups or organizations like toastmasters club where you get to constantly challenge yourself and move out of your comfort zone.

When you are well prepared you are more confident that your speech would turn out well and this keeps you in a relaxed mode.

Public speaking is not an inborn talent but rather a skill which can be cultivated by anyone.

Relax in the in the last 15-30 minutes before delivering your speech.

Take criticism positively

Let go of the perfectionist in you

Bounce back

You learn a lot from your failures. Resist the temptation to give up and keep bouncing back

Celebrate your success

We often take our success for granted. Reward yourself for the success you have achieved however small it might be.

Don't rely on your slides to do the work for you.

Know your audience

Analyze your audience. Know what it wants. Know what it needs. Mingle beforehand if possible.

What keeps them up at night?

How can you solve their problem?

How can you reach them? Have something for everyone.

How will your audience resist?

Get and Keep the Attention of Audience

Interactive relationship.

Posture

Walk and stand like you are glad to be there.

Communicate enthusiasm.

Stand up straight and face the audience head-on.

Keep your posture open with arms relaxed and hanging down at your sides.

Make eye contact, or at least pretend to by looking toward the back of the room.

Do a passion check

Why are you stepping up to the podium? Do you have something to say?

Your need to be passionate about the truth you are going to impart can be understated; it can't be overstated.

That passion can be seen in the way you step in front of the audience, your excitement and even your opening words.

Be enthusiastic

The authentic emotion of enthusiasm breeds authentic enthusiasm. The opposite is also true. If you are not excited about what you are saying, the audience certainly is not going to be

Stay relevant

Relevancy, communicated through language, stories, humor and numerous other ways, has to be a thread that runs through the entire message, not just the first 30 seconds.

Tell a Story

Not just an encyclopedia of facts.

Strike a need

What need are you speaking to? What need does your research meet? What needs does your audience have?

Focus Your Message

In a 45-min talk, have only 3 points. In a 7 minute talk, have only one main point. Everything you say should be related to that point.

Back up abstract ideas with concrete examples.

Be conversational. Speak in a language that is familiar and appropriate to the audience members. If you have a mixed audience, you need to speak a language that all are comfortable with.

You Can Use Gestures Effectively

Gestures, a form of body language, are also a part of your overall visual picture. They are visual reinforcements of the words and ideas you are trying to communicate to your audience. Gestures include hand, arm, and head movements and can enhance your presentation or detract from it.

Movement

Speakers who spend their entire presentation behind the podium can be perceived as aloof.

Use movements to establish contact with your audience.

Get physically closer to your audience: This increases its attention and interest. It also encourages response if you are asking questions.

It will help to establish a good rapport with them.

The Eyes Have It

Effective speakers make eye contact with audience members.

Their reactions to you will help your performance as a presenter. If you sense boredom, you may have to pick up the pace; if you sense enthusiasm, it can help to pump you up. When you make eye contact, you are relating to your audience, which will help get your message across.

Think of the audience as sitting in a “Z” formation.

Facial Expressions

Smile!

Practice smiling and looking pleasant. That’s how you want to look during your presentations.

Get audience to participate.

Your first words are critical !

“The first 25 words you speak are the most important ones of your message.

Here are some of the most commonly used methods for successfully getting and keeping audience attention.

1. Asking a question.

You can ask a rhetorical question or something that involves everyone by getting him or her to think about the topic.

2.State an impressive fact.

Begin with a shocking, unusual or impressive fact connected to the theme of your presentation.

3. Tell a story.

Telling a personal story closely connected to the theme of your presentation is a great way to begin. People usually like to hear personal stories, which are not too long or try to glorify the narrator too much.

4. Cite a quotation.

Quotations are much used for presentations and they add a colourful touch to your personal style.

5. Tell a joke.

Jokes are wonderful for relaxing the audience and setting a cheerful mood. Relaxed audiences tend to be more interactive. This might make the presenters work somewhat easier.

The joke must be appropriate.

6. Get close to the audience.

Disturb the comfort zone of the audience by walking closer or going absolutely to one side.

In Conclusion

Everyone needs an attentive Audience

Be a good audience Member!

Come prepared to make your contribution as “the audience.”

It’s an active role, not passive. It means arriving alert (skip the double cheeseburger for lunch); having a positive attitude’ and doing what you can to make this possible for yourself, the speaker, and others in the audience.

Audience can fuel the speaker or deplete the speaker of energy.

Pay attention—and let the speaker know you are paying attention. Watch the speaker and really listen to what she is saying.

Be responsive. Make eye contact. Nod. Smile. Laugh at his jokes. Look serious when he tells a somber story. Let the speaker know he is getting through to you.

When the speaker tosses a question out to the audience, or does something that calls for a response, respond enthusiastically. Even if it just means giving a cheery, “Good morning!” in response to the speaker saying, “Good morning, everyone!”

Don’t look at your watch, check your email or text during the talk. The exception would be if it is appropriate to tweet updates from the presentation.

Don’t interrupt the presentation. Unless the speaker has indicated that you may ask questions at any time, hold your questions or comments until the end.

Ask good questions during the question and answer session. Don’t try to put the speaker on the spot, but ask a question that will help her to better develop a point she made during her presentation

PLUTONIUM AND ITS APPLICATION

P.V. Aksutin
Language advisor: PhD, Senior teacher Yu. V. Falkovich
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: aksutin.zgr@gmail.com

Abstract.

The given paper deals with the plutonium not only as an element, but also as an energy source for reactors or for bombs stuffing. Also will be considered methods of synthesis and fission. The author examines the impact of plutonium in the environment and human health.

The text is not technical, so it will be understandable for people with no knowledge of the plutonium and the technology of its application. For people who have first-hand knowledge about plutonium, this text will be useful and interesting too. This is because the author involves the use of plutonium in the high-tech devices such as radioisotope thermoelectric generators that are used as power sources for spacecraft. Also this report contains the most important historical dates in the study of plutonium.

This paper contains not all information about plutonium. It resonates with many other articles and sources, in which aspects of the application of plutonium consider in more details and depth. Thus the paper is the only entry in the vast world of plutonium and should encourage interested persons to study the mysteries of plutonium.

I. INTRODUCTION

Key words: project, plutonium, application, production, environment protection

Science: nuclear chemistry, nuclear physics

Nowadays the most popular fuel for nuclear reactors is Uranium-235. But scientists all over the world realize that Uranium-235 has a small potential in future, because found that the fission cross section of Plutonium-239 is 1.7 more than the Uranium-235. Natural uranium consists of three isotopes, such as U^{238}(99,28%), U^{235}(0,714%) , U^{234}(0,0006%). It’s because worlds reserve of Uranium-235 much less than Uranium-238 and Plutonium-239. There are a lot of different methods of Uranium enrichment, but it is not secret that in order to produce Uranium-235 much time and power inputs.

Reaction of synthesis Pu-239 :

$${}_{92}U^{238}+{}^{1}_{0}n\rightarrow{}_{92}U^{239}(\beta\text{-распад})\rightarrow{}_{93}Np^{239}(\beta\text{-распад})\rightarrow{}_{94}Pu^{239}$$

Reaction of fission Pu-239:

$${}_{94}Pu^{239}+{}^{1}_{0}n\rightarrow A+B+(2\text{-}3)\,{}^{1}_{0}n+E \text{ where } E=2{,}5*10^{7} \text{ (кило ватт часов)}$$

I believe that in future all secrets of Plutonium will be revealed and it will bring big benefit to the power engineering of humanity. Based on the goals and objectives were analyzed journalistic, educational and scientific literature, articles and websites. After analyzing all the material, was written this work.

II. GENERAL CHARACTERISTICS OF PU

Plutonium in its pure form is a very heavy, silver-colored, tarnish in air, its density is equal to 19,86-16 kg/m^3 according to modification, well-flying radioactive metal. Essentially all properties of plutonium were considered on Earth within the past six decades by human activities Plutonium have twenty isotopes modification, such as ${}_{94}Pu^{238}$, ${}_{94}Pu^{239}$, ${}_{94}Pu^{240}$, ${}_{94}Pu^{241}$, all of which are radioactive.

Plutonium was the second transuranium element of the actinide series to be discovered. It was first produced in 1940 by Glenn T. Seaborg, Joseph W. Kennedy, Edward M. McMillan and Arthur C. Wohl by bombarding an isotope of uranium, uranium-238, with deuterons that had been accelerated in a device called a cyclotron. This created neptunium-238 and two or free neutrons. Neptunium-238 has a half-life of 2.1 days and decays into plutonium-238 through beta decay. Although they conducted their work at the University of California in 1941, their discovery was not revealed to the rest of the scientific community until 1946 because of wartime security concerns, but in USSR plutonium have created in 1945 by I.Kurchatov and V. Khlopin.

In 1948, Edwin McMillan suggested calling the 93rd chemical element neptunium, as the planet Neptune - the first of Uranus. By analogy, has been named the plutonium because it is the second planet of uranium.

The world's nuclear-power reactors are now producing about 20,000 kg of plutonium/yr. By 1982 it was estimated that about 300,000 kg had accumulated. The various nuclear applications of plutonium are well known. Plutonium-238 has been used in the Apollo lunar missions to power seismic and other equipment on the lunar surface. As with neptunium and uranium, plutonium metal can be prepared by reduction of the trifluoride with alkaline-earth metals.

Plutonium have many different alloys modification for example: Pu-Ga, Pu-Al and others.

II.I.Isotopes

The main plutonium isotopes at Department of Energy (DOE) environmental management sites are Plutonium-238, Plutonium-239, Plutonium-240, and Plutonium-241. Except for Plutonium-241, these isotopes decay by emitting an alpha particle. Plutonium-241 decays by emitting a low-energy beta particle to Americium-241, an alpha- emitting radionuclide with a half- life of 430 years that is much more radiotoxic than its parent. The maximum activity of Americium-241 is about 3% of the initial activity of Plutonium-241 and occurs 73 years later. An extremely small fraction of the decays of Plutonium-236, Plutonium-238, Plutonium-240, and Plutonium-242, are by spontaneous fission (SF), as are about 0.1% of the Plutonium-244 decays. Plutonium-242 and Plutonium-244 are generally present in relatively minute activity concentrations.

Isotope	Half-Life	Specific Activity, (Ci/g)	Decay Mode	Radiation Energy (MeV)		
				Alpha (a)	Beta (в)	Gamma (γ)
Pu-236	2.9 yr	540	a	5.8	0.013	0.0021
Pu-238	88 yr	17	a	5.5	0.011	0.0018
Pu-239	24,000 yr	0.063	a	5.1	0.0067	<
Pu-240	6,500 yr	0.23	a	5.2	0.011	0.0017
Pu-241	14 yr	100	γ	<	0.0052	<
Pu-242	380,000 yr	0.0040	a	4.9	0.0087	0.0014
Pu-244	83,000,000 yr	0.000018	a	4.6	0.0071	0.0012
U-240	14 hr	940,000	в	-	0.14	0.0076
Np-240m	7.4 min	110 million	в	-	0.68	0.34

III. PRODUCTION AND APPLICATION

Plutonium is created from uranium in nuclear reactors. When Uranium-238 absorbs a neutron, it becomes Uranium-239 which ultimately decays to Plutonium-239.

${}_{92}U^{238}+{}_{0}^{1}n\rightarrow{}_{92}U^{239}(\beta\text{-распад})\rightarrow{}_{93}Np^{239}(\beta\text{-распад})\rightarrow{}_{94}Pu^{239}$

Different isotopes of uranium and different combinations of neutron absorptions and radioactive decay, create different isotopes of plutonium.

Plutonium metal used in nuclear weapons and is used as nuclear fuel.

The first is use plutonium as fuel for a nuclear reactor, because one kilogram is equivalent to about 25 million kilowatt hours of heat energy. Total world generation of reactor-grade plutonium in spent fuel is some 70 tonnes per year. About 1300 tonnes have been produced so far, and most of this remains in the used fuel, with some 370 tonnes extracted. About one third of the separated Plutonium (130 t) has been used in mixed oxide (MOX) fuel over the last 30 years. Currently 8-10 tonnes of plutonium is used in MOX fuel each year. MOX fuel is nuclear fuel, containing several oxides, nitrides, carbides of fissile materials. In general term applied to a mixture of oxides of plutonium and natural uranium, but many scientist think that in future we will be using fuel consisting of nitrides and carbides of plutonium and uranium.

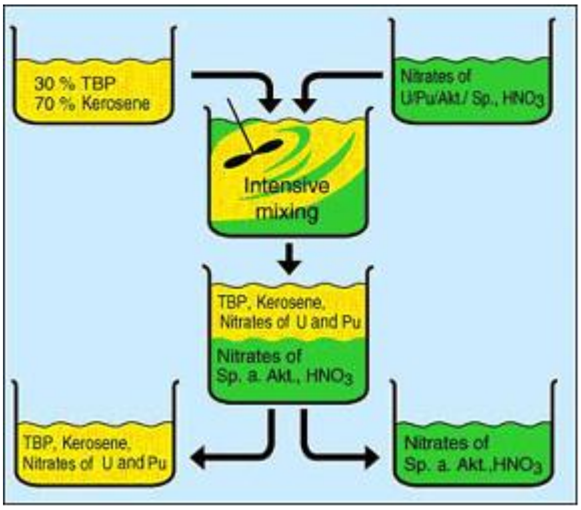
The second is made specially for the military purpose, because one kilogram of plutonium-239 can produce an explosion that would be equivalent to 20,000 tons of TNT. In June 2000, the USA and Russia agreed to dispose of 34 tonnes each of weapons-grade Plutonium by 2014.

Its importance depends on the nuclear properties of being readily fissionable with neutrons and its availability in quantity.

Moreover, plutonium-239 is used in spacecraft batteries, because the nuclei are capable of a nuclear chain reaction when exposed to neutrons. Therefore, this isotope can be used as a source of nuclear energy.

Despite all the advantages in the use of plutonium, there is a significant disadvantage is the problem of disposal of spent nuclear fuel. Discussions are progressing as to what should be done with spent fuel. Nowadays we have modern technological scheme for reprocessing spent fuel. These scheme based on extraction process.

Scheme of reprocessing spent fuel:

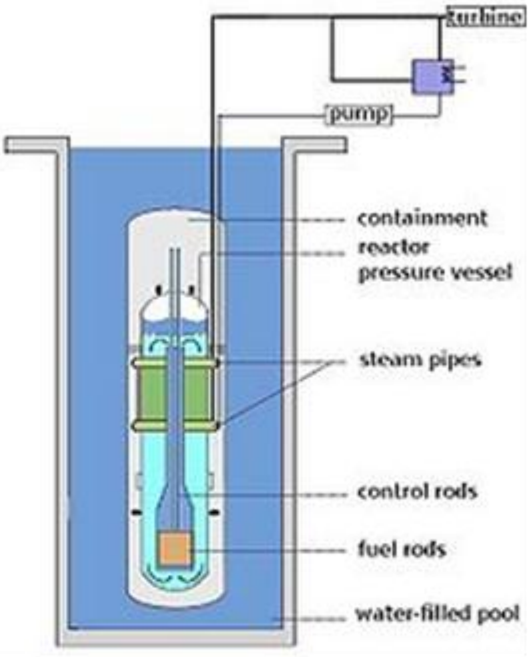


III.I. Plutonium and nuclear power

All Plutonium isotopes are fissionable with fast neutrons, though only two are fissile (with slow neutrons). For this reason all are significant in a fast neutron reactor (FNR), but only one – Plutonium-239 - has a major role in a conventional light water reactor(LWR).

The most common isotope formed in a typical nuclear reactor is the fissile Plutonium-239 isotope, formed by neutron capture from Uranium-238 (followed by beta decay), and which yields much the same energy as the fission of Uranium-235. Well over half of the plutonium created in the reactor core is 'burned' in situ and is responsible for about one third of the total heat output of a light water reactor (LWR).

A simple light water reactor



Plutonium-240 is the second most common isotope, formed by occasional neutron capture by Plutonium-239. Its concentration in nuclear fuel builds up steadily, since it does not undergo fission to produce energy in the same way as Plutonium-239. While of a different order of magnitude to the fission occurring within a nuclear reactor, Plutonium-240 has a relatively high rate of spontaneous fission with consequent neutron emissions.

Plutonium-238, Plutonium-240 and Plutonium-242 emit neutrons as a few of their nuclei spontaneously fission, albeit at a low rate. They and Plutonium-239 also decay, emitting alpha particles and heat. The decay heat of Plutonium-238 (0.56 W/g) enables its use as an electricity source in the radioisotope thermoelectric generators (RTGs) of some cardiac pacemakers, space satellites, navigation beacons, etc.

Plutonium can also be used in fast neutron reactors, where all the plutonium isotopes fission, and so function as a fuel. As with uranium, the energy potential of plutonium is more fully realised in a fast reactor. Four of the six 'Generation IV' reactor designs currently under development are fast neutron reactors and will thus utilize plutonium in some way.

III.II. Plutonium and weapons

The first in the history of the atomic bomb (she was given the name "Trinity") was collected in the summer of 1945. June 16, 1945 at the atomic test site in Alamogordo Desert (New - Mexico) was performed first in the world nuclear explosion. The bomb was placed in the center of the polygon on top of a steel 30 - meter tower.

But the USSR did not keep pace, and August 29, 1949 at the Semipalatinsk test site was the first Soviet nuclear explosion.

In the USSR, the production of weapons-grade plutonium, first performed at the plant "Mayak" (station area Kyshtym, Chelyabinsk region), then at the Siberian Chemical Combine in Seversk (formerly Tomsk-7), was opened later in the Krasnoyarsk Mining and Chemical Combine in Zheleznogorsk (also known as Krasnoyarsk-26).

An alternative to the chemical process of uranium enrichment is the creation of a "plutonium bomb" on the basis of the isotope plutonium-239, which is to increase stability and improve the physical properties of the compressibility of the charge is usually alloyed with a small amount of gallium. Plutonium produced in nuclear reactors during the prolonged irradiation of uranium-238 with neutrons.

$_{92}U^{238}+{}_{0}^{1}n\rightarrow{}_{92}U^{239}$(β-распад)→$_{93}Np^{239}$(β-распад)→$_{94}Pu^{239}$

It takes about 10 kilograms of nearly pure Plutonium-239 to make a bomb. Producing this requires 30 megawatt-years of reactor operation, with frequent fuel changes and reprocessing of the 'hot' fuel. Hence 'weapons-grade' Plutonium is made in special production reactors by burning natural Uranium fuel to the extent of only about 100 MWd/t (effectively three months), instead of the 45,000 MWd/t typical of LWR power reactors. Allowing the fuel to stay longer in the reactor increases the concentration of the higher isotopes of Plutonium, in particular the Plutonium -240 isotope. For weapons use, Plutonium-240 is considered a serious contaminant, due to higher neutron emission and higher heat production. It is not feasible to separate Plutonium-240 from Plutonium-239. An explosive device could be made from plutonium extracted from low burn-up reactor fuel, but any significant proportions of Plutonium-240 in it would make it hazardous to the bomb makers, as well as probably unreliable and unpredictable. Typical 'reactor-grade' plutonium recovered from reprocessing used power reactor fuel has about one third non-fissile isotopes (mainly Plutonium-240).

The International Atomic Energy Agency (IAEA) is conservative on this matter so that, for the purpose of applying IAEA safeguards measures, all plutonium (other than plutonium comprising 80% or more of the isotope Plutonium-238) is defined by the IAEA as a 'direct-use' material, that is, "nuclear material that can be used for the manufacture of nuclear explosives components without transmutation or further enrichment". The IAEA is not saying that all plutonium is suitable for making weapons, simply that on the basis of calculations and under certain technically-demanding conditions it might be made to explode. The 'direct use' definition applies also to plutonium which has been incorporated into commercial MOX fuel (PuO_2-UO_2; PuN-UN; PuC-UC), which as such certainly could not be made to explode type.

IV. DANGEROUS OF PLUTONIUM

Plutonium metal has a significant volatility under normal conditions and if it is to carry on the room that limits the maximum allowable quantities are exceeded. Plutonium is sometimes described in media reports as the most toxic substance known to man, although there is general agreement among experts in the field that this is incorrect. As of 2012, we haven't people, who died because to influence of plutonium. With the exception of death or killing A. Litvinenko in London, but it is hard to believe. Naturally-occurring radium is about 200 times more radioactive than plutonium.

IV.I. Environment

Atmospheric testing of nuclear weapons, which ceased worldwide by 1980, generated most environmental plutonium. About 10,000 kg were released to the atmosphere during these tests. Average plutonium levels in surface soil from fallout range from about 0.01 to 0.1 picocurie per gram (pCi/g).

Accidents and other releases from weapons production facilities have caused greater localized contamination. The most common form in the environment is plutonium oxide. Plutonium is typically very insoluble, with the oxide being less soluble in water than ordinary sand (quartz). It adheres tightly to soil particles and tends to remain in the top few centimeters of soil as the oxide. In aquatic systems, plutonium tends to settle out and adhere strongly to sediments, again remaining in upper layers. Typically one part of plutonium will remain in solution for every 2,000 parts in sediment or soil. A small fraction of plutonium in soil can become soluble through chemical or biological processes, depending on its chemical form. While plutonium can bioconcentrate in aquatic organisms, data have not indicated that it biomagnifies in aquatic or terrestrial food chains.

IV.II. Protection

Environmental Protection Agency (EPA) sets health-based limits on radiation in air, soil, and water. Federal government agencies are required to meet EPA standards the same as commercial industries. Using its authority under the Safe Drinking Water Act, EPA limits the amount of radiation in community water systems by establishing maximum contaminant levels. Maximum Contaminant Levels limit the amount of activity from alpha emitters, like plutonium, to 15 picocuries per liter.

EPA also protects people against exposure from soil and ground water from sites that have been contaminated with plutonium. We set criteria that soil and ground water from the sites must meet before releasing the sites for public use.

Rather than limiting the concentration of plutonium itself, the criteria limit the cancer risk the sites pose. A person's added risk of developing cancer is limited to no more than about 1-in-10,000 and if possible to 1-in-1,000,000, or less. Under the Clean Air Act, EPA limits the dose to humans from radionuclides to 10 millirem from emissions to air.

EPA sets standards for radioactive waste storage and disposal facilities. We can't treat plutonium or other radioactive materials to get rid of their radioactivity. We can only isolate and store them until they decay. The extremely long half-lives of some plutonium radioisotopes make the management of spent nuclear fuel, and wastes from nuclear weapons facilities a difficult problem.

EPA also responds to radiation emergencies. Additionally, EPA helps state and local governments during emergencies that involve radioactive materials. We provide guidance on ways to protect people from harmful exposure to radiation. We can also monitor radiation levels in the environment and assess the threat to public health. We also work with international radiation protection organizations to prepare for large scale foreign emergencies such as Chernobyl. EPA also works with law enforcement agencies to develop counter terrorism plans.

V. RESULTS

- application of plutonium as fuel for reactors is only beginning at this stage of development of nuclear technology;
- application of plutonium for military purposes;
- fast reactors have good potential in future;
- new types of reactors are developing;
- new types of nuclear fuel studied and introduced by many scientific organization in the world;
- plutonium has a negative impact on human health;

Day by day mankind is approaching the possibility of an energy crisis. The time of creation or discovery of a new energy source is approaching, too.

Thus, resuming all the above aspects it must be noted that this project can be used by persons who don't know nothing about plutonium.

1 U.S Department of Energy, “Plutonium: the first 50 years”, February 1996
2 U.S. Department of Energy, “Plutonium: Human Health Fact”, 2001
3 Fishlock, D., "Drama of Plutonium". Nuclear Engineering International, 2005
4 Rhodes, Richard, “The Making of the Atomic Bomb”. New York: Simon & Schuster, 1986. pp. 659–660.
5 H.V. Hendericz, “Plutonium: blessing or curse?”, Copper Beech 1998
6 Plutonium articles in Revue Generale Nucleaire, June 2008
7 Argonne National Laboratory, EVS. Human health fact sheet, august 2005
8 Thomas Jefferson National Accelerator Facility official website: http://www.jlab.org/
9 US Environmental Protection Agency(EPA) official website: http://www.epa.gov/
10 Federation of American Scientists official website: http://www.fas.org/
11 The International Commission on Nuclear Non-proliferation and Disarmament (ICNND) official website: http://www.icnnd.org/

X-RAY FLUORESCENT ANALYSIS IN THE NATIONAL EXPORT CONTROL SYSTEM OF THE RUSSIAN FEDERATION

E.V. Andreevsky, K.J. Kudryashova, A.E. Kurmanova, D.K. Alimova
Scientific Supervisor: PhD, Associate Professor Yu.V. Daneykin
Language advisor: Senior teacher N.V. Daneykina
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: eandreevsky@tpu.ru

Abstract.

There was conducted a detailed analysis of national export control system of the Russian Federation, then we selected X-ray fluorescent analysis, as belonging to the group of non-destructive methods of analysis and suitable for the determination of most elements of the periodic system in a wide dynamic range that allows to actively use it in the system of export and customs controls.

Keywords: X-ray fluorescent analysis, non-destructive analysis, export control, customs control

Research field: systems of export controls, non-destructive analysis

Related sciences: nuclear non-proliferation

I. INTRODUCTION.

Purposes: study of a national system of export controls in Russia; study of X-ray fluorescent method of nondestructive analysis as a method applicable to the system of export and customs controls. Objectives: a detailed analysis of national export control system of the Russian Federation; study of the measuring device «Spectroscan-Max-G», the designing of educational materials.

II. THE NATIONAL EXPORT CONTROL SYSTEM OF THE RUSSIAN FEDERATION.

The international regime of nonproliferation of weapons of mass destruction includes many components. It is based on relevant international treaties: the Treaty on the Non-Proliferation of Nuclear Weapons, the Wassenaar Arrangement on Export Controls for Conventional Arms, goods and dual-use technologies, the Vienna Convention on Civil Liability for Nuclear Damage, the treaties between Russia and the USA on the Reduction and Limitation of Strategic Offensive Arms, the Convention on the Physical Protection of Nuclear Material, the Convention on Nuclear Safety, etc. Important elements of the global non-proliferation regime are its instruments: the Zangger Committee, Nuclear Suppliers Group - NSG Control Regime Missile Technology - MTCR, Australia Group, as well as domestic export control system. [1]

Currently, the activities of the Russian export control system are aimed at implementing control regimes of the following goods and services:

- Products and Technologies that can be used to create weapons and military equipment.
- Disease agents (pathogens) of humans, animals and plants, genetically modified microorganisms, toxins, equipment and technology subject to export control.
- Equipment, materials and technologies that can be used to develop missiles with respect to export control.

- Chemicals, equipment and technologies that can be used to produce chemical weapons, and subject to export control.
- Nuclear materials, equipment, special non-nuclear materials and technologies subject to export controls.
- Equipment and dual-use materials and technologies used for nuclear purposes. [2]

One of the methods to maintain export control is a customs control of goods and technologies, which is held by customs authorities in accordance with the laws of the Customs Union and the Russian Federation. [3]

In order to reduce the time of customs control and increase its efficiency, technical means of customs control are used, inventory and order of application of which are installed by an authorized federal executive body. [4]

In order to identify the goods subject to export control, the customs clearance is carried out in customs control zones. The authorized customs official during the documentary Control analyzes the information stated in the customs declaration and specified in the annexed documents, identifying if the declared goods have signs of controlled goods. Ownership of goods to controlled goods is determined by matching their technical parameters and description to goods specified in the "Name" checklists. [5]

X-ray fluorescence analysis (XRF) - one of modern spectroscopic methods for the study of matter with a view to its elemental composition, ie, its elemental analysis. With it different elements from beryllium (or sodium, calcium - dependent on the spectrometer) up to uranium can be analyzed. XRF method is based on the collection and subsequent analysis of the spectrum obtained by acting on the material under X-rays.

III. PHYSICAL BASIS OF XRF.

Bremsstrahlung. The source of primary radiation in the XRF method is generally used X-ray tube. Electrons emitted by the cathode filament are accelerated by an electric field to the voltage U (voltage tube) and bombarded with a massive metal anode. As a result of inhibition of the electrons in the material of the anode there is a continuous (stopping) spectrum of X-rays. Less than 1% of the kinetic energy of the electrons is converted to the X-ray radiation. For example, in the case of a tube with a copper anode operating at 40 kV only 0.2% of energy consumed is converted directly to the x-rays. The remaining energy is spent on heating of the anode, so the pipes need to be cooled, and the flow of electrons (current between the cathode and anode) is bounded to an acceptable value. The output of X-ray radiation is providedthrough a thin beryllium window.

The characteristic radiation. While the bombardment of the anode with flow of accelerated electrons, braking characteristic X-rays occurs simultaneously. When the material is exposed to short-wave X-ray or gamma radiation, ionization of atoms may occur. In this case, electrons are released from the inner shell. This state of the atom is unstable, and electrons from outer shells fill vacancies formed, and the excess energy is emitted as a photon, or energy is transferred to another electron from the outer shells (Auger electron). Such a transition of an electron from a higher to a lower energy level causes a characteristic X-ray radiation of certain discrete wavelengths. The quantum energy of the characteristic radiation is equal to the difference between the energy states of electrons at the levels before the transition and after it. Because such differences in the atom are discrete and individual for each element, the characteristic radiation is represented by discrete wavelength lines. Energy levels of the atom, the allowed transitions and the systematics of names of the characteristic lines shown in Fig. 1.

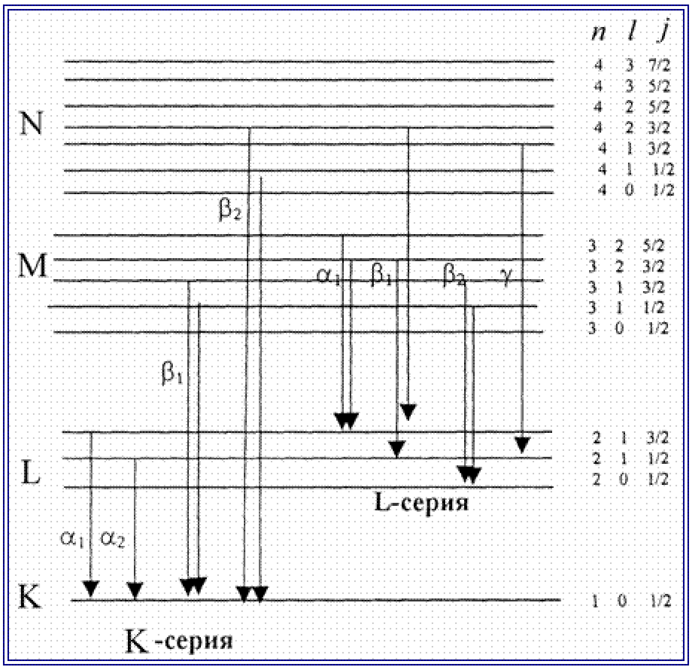


Fig. 1. Full scheme of energy levels and allowed transitions.

The absorption of X-rays. X-rays by absorption in the material are able to ionize the inner electron shells. This phenomenon is called the photoelectric effect. The photoelectric effect occurs when the energy of the X-ray photon E> Elimited. As a result, the electron leaves the atom, and the excess energy is released as X-ray photon. The resulting secondary X-ray emission is fluorescent. The excitation process is similar to X-ray fluorescence excitation of characteristic X-ray electrons. X-ray fluorescence spectra contain the information necessary to analyze the elemental composition of substances and materials. For qualitative analysis we determine the wavelengths of fluorescence lines, and then use the tables we set membership of registered lines to other elements.

Moseley Law. The energy difference between electron levels (ΔE) is individual for each atom of the element, so therefore on the Status of X-ray lines in the spectrum we can perform a qualitative analysis. Contact the wavelength (energy) of X-ray line with an atomic number of an element is described by Moseley Law

$$\Delta E = h\nu = \frac{2\pi^2 m_e e^4 (z-\sigma)}{h^2}\cdot\left(\frac{1}{n_0^2}-\frac{1}{n_1^2}\right)$$

where ν - frequency of x-ray lines, ME - mass of the electron, e - electron charge, h - Planck's constant, z - the atomic number of the element, s - continuous screening, n0, and n1 - principal quantum numbers of initial and final states.

IV. EQUIPMENT

The main components of modern spectrometers are:

- the source of primary X-rays to excite the fluorescence of the sample;
- Feeder and set of samples;
- spectrometric device for the selection of the spectral lines of a given wavelength λ;
- detection device;

- high-speed recording and computer equipment for determining the intensity of analytical lines and calculating the corresponding concentration of the element;
- the control unit.

In general, X-ray fluorescence spectrometers are classified into two types. Spectrometer with a wave dispersion (VD) - the most traditional type of devices. Typically, these devices have a higher spectral resolution and provide the best results for light elements. Energy dispersive spectrometry (ED) are characterized by small dimensions and weight, is much cheaper (about 5-10 times), and in some cases may provide more sensitive measurements than WD-spectrometers. ED spectrometers include, for example, a semiconductor detector spectrometers, devices, operating according to the method of the differential detector. There are also models that simultaneously uses both the principle of action, such as a spectrometer MDH1000 by "Oxford Instruments", in which there is a block device with the wave dispersion for the determination of light elements (from fluorine to calcium) and to determine the heavier elements (from calcium to uranium) - another block, which is an energy dispersive spectrometer type.

Spectrometer with a wave dispersion can be scanning (CDS) and multi-channel (MPC). Devices of the first type have a custom crystal monochromator, so you can consistently allocate the spectrum of radiation of any wavelength in the pre-selected spectral range (Fig. 2). Multichannel spectrometers have a number of spectral channels, each of which consists of its own monochromator, detector, and a set of recording equipment to measure the intensities of lines, each channel in the MPC is set to a specific line of analysis. The main purpose of IFA - a quick check of the contents of a limited number of elements in a production environment.

Fig. 2. X-ray fluorescence spectrometer, a scanning scheme

Sources of primary radiation. As a radiation source we can use X-ray tube, or the isotopes of any element. Because each country has its own requirements for import and export emitting isotopes in the production of x-ray fluorescence technique, in recent years manufacturers try to use, as a rule, X-ray tube. The tubes can be both rhodium and copper, molybdenum, silver, or other anode. The anode of the tube, in some cases, is selected depending on the type of tasks (items requiring analysis), the solution of which will be used by this device. For different groups of elements we use different values of current and voltage on the tube. For the study of light elements it is sufficient to establish voltage of 10 kV and 20-30 kV for medium to heavy - 40-50 kV. In addition, during the study of light elements a great influence on the spectrum has an atmosphere, so that the sample chamber is either evacuated or filled with helium. After the excitation, spectrum is recorded on a special detector. The better spectral resolution of the detector, the better it will be able to separate from each other photons of different elements, which in turn will impact on the accuracy of the device itself. At present the best possible resolution of the detector is 123 eV. In analyzing the elements of z from the 22-24 and above (λ <2,5 Å) the maximum intensity of analytical lines is achieved when working with tubes having an anode made of heavy metal (tungsten, rhenium, gold, platinum), which are characterized by high yield bremsstrahlung. In the analysis of light elements (z <17), an acceptable rate of secondary spectra can be obtained by using anodes of the elements that have intense characteristic lines at long wavelengths (chromium, scandium, etc.)

X-ray detectors. Analytical signal in quantitative XRF is the intensity of the characteristic X-ray element, measured in relative units. For measurement, the energy of the X-ray radiation with detectors is converted to a convenient form of processing and recording of electrical signals. In the XRF method we commonly use detectors, the average amplitude of the pulses at the output of which is proportional to the energy of the absorbed photon. These detectors include the discharge proportional, scintillation and semiconductor counters. The principle of operation of all types of detectors is based on the ability of X-rays to ionize the matter.

V. RESULTS: THE USE OF RFA IN THE EXPORT CONTROL

The advantages of RFA:

1) non-destructive analysis;
2) a short time of analysis;
3) ease of sample preparation (or lack thereof);
4) defines the contents of most elements in the periodic table
5) The lower limit of detection.

The elemental composition of the alloy can determine the brand of the alloy. As a rule, it uses a program containing a database of brands of alloys. After analyzing the values are compared with the database and the program searches for the closest mark. Then you can determine whether this brand of alloy is dual-use material.

VI. CONCLUSION

XRF is suitable for qualitative and quantitative determination of a significant part of dual-use materials, uranium, precious metals, which subject to export control.

1. Kirichenko, E.V.: Export control regime / / MIPT, Moscow, 2005.
2. Zhukov, E.F., Kapaeva T.I., Litvinenko, L.T.: International economic relations / / "Publisher Dan Unity", Moscow, 1999.
3. Federal Law of 18.07.1999 N 183-FZ (as amended on 07.18.2005) "On export control"
4. Federal Law of 27.11.2010 N 311-FZ "On the Customs Regulation in the Russian Federation"
5. Instruction on the procedure for customs officials check the declared information and decision-making in relation to goods which have characteristics of goods covered by the legislation of the Russian Federation in the field of export control / / Appendix to the Order of SCC of Russia of 26.12.2003 1545
6. List of equipment and dual-use materials and technologies used for nuclear purposes, subject to export control / / application to the Federal Law "On export control".

URANIUM EXTRACTION TECHNOLOGY

G.A. Apalkov, E.V. Savochkina
Scientific Supervisor: Assistant, A.S. Kantaev
Linguistic Advisor: Senior teacher, A.P. Eonov
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: glebaldo@mail.ru

Abstract.

The purpose of this work is to deal with the most important issues connected with the extraction of uranium and represent some theoretical and practical issues of this technological process.

The scope of this review includes basic concepts, processing technology and equipment of uranium extraction and purification. Also, there are main advantages and disadvantages of this method in this abstract.

The current work could be used as the basic information for scientific and industrial researches and processes. Also, it could be useful for people interested in the extraction of uranium or other rare and precious metals.

I. INTRODUCTION

“Uranium extraction” is the theme of my research course work. During it I’ve studied different characteristics of this process. So, in my report I’ll try to observe the main issues connected with the uranium extraction process.

Methods of purification of chemical compounds are very important in industry nowadays and the extraction purification process is one of them. Many compounds can be purified using such a technological process.

A solvent extraction is widely spread and used in the nuclear industry nowadays. This method of metals recovery and purification appeared in 1960s. Firstly the di-ethylhexyl phosphoric acid (DEHPA) (the DAPEX process) was used; later the tertiary amines (the AMEX process) extraction appeared. These compounds extract uranium, nevertheless, there are different impurities in the uranium ore (iron, thorium, phosphates and rare earths). But still, some metals (i.e. molybdenum and zirconium) could be also extracted with uranium during these processes [1].

II. EXTRACTION PRINCIPLES

Liquid–liquid extraction, also named as the solvent extraction, is a method of compound distribution between two unmixing solutions: water and organic phase. This type of extraction is used in laboratory in special funnels, when the necessary reaction is over [4].

The main spheres of solvent extraction application are the following ones: nuclear power industry, organic compound production, food industry, etc.

More than that, liquid–liquid extraction can occur in non-aqueous systems: i.e. different metals could be extracted from different molten salts. A mercury electrode is often used during metals reducing; metal amalgams increase the electrochemical characteristics [4].

Solvent extraction research started during “the Manhattan Project” time, when uranyl nitrate was firstly extracted for the nuclear reactors. So, this type of extraction can be used either in laboratory or in industry.

Nowadays the laboratory variant is not widely spread mainly because of the price of nuclear materials and special equipment [4].

There are various types of extracting solvent or extractants, but usually they are non-polar organic liquids. So, after shaking water and organic phases in the special reactor, we obtain a liquid phase divided into two layers: the upper layer is the organic phase with the valuable component, which moved from the water phase, and at the bottom we have the water phase with impurities, which stay there, because organic extractant is not selective for them. After it, the necessary component could be re-extracted from the organic phase, using special chemical reagents [3].

III. EXTRACTANTS

As it was mentioned before, such organic compounds are used during the process of uranium extraction. They are the alkyl phosphoric acids and amines, but amines are usually used because of the better properties. When uranium is leached or purified using sulfuric acid, such amines are used in industry; when the nitric acid is used, the neutral alkyl phosphate (TBP) can be applied [10].

Various types of extractants can be used in industry. Here is some brief information about such compounds.

Di-(2-ethylhexyl) phosphoric acid (DEHPA or HDEHP) is an organic phosphoric acid and its formula is the following - $(C_8H_{17}O)_2PO_2H$. It is a yellow liquid, which is widely spread in the uranium industry and rare metals technology.

DEHPA can extract uranium from sulfate, chloride, or perchlorate anion solutions. In industry this process is called the “Dapex procedure”. It extracts uranium in the form of the uranyl ion (UO_2^{2+}). Fe^{3+} ion is similar to uranyl ion, thus usually it is changed to Fe^{2+} in order to increase the extraction characteristics [5].

In some cases, engineers use DEHPA with other different compounds in order to obtain the best results during the extraction process and increase the extractant selectivity to uranium. Tributyl phosphate is often applied for this purpose. Also, dibutyl-, diamyl-, and dihexylphosphonates are used [5].

Secondary, tertiary, and quaternary amines could be used as the alternative extractants. Though, they can be more selective to uranium, but, nevertheless, DEHPA and other phosphates provide faster phase separation and the process could become more profitable in this case [5].

IV. MODIFIERS AND DILUENTS

Modifying reagents are used during the extraction because they [1]:

1) Can increase the distribution rate of a valuable component (uranium) between water and organic phases;

2) Can improve the solubility of solute and avoid the formation of temporary phase;

3) Can prevent the unnecessary waste formation.

Usually the choice and requirements for the modifier are determined during the experimental research. In uranium industry the most common additive agent is TBP; it is usually used with DEHPA. Sometimes amines can be used as modifiers to DEHPA. As for the alcohols, such compounds as isodecanol and tridecanol are also used during the solvent extraction of uranium. All these modifiers should be stable to oxidation.

Another important compound during the process of extraction is a diluent. It is used for the extractant dilution because it is not necessary to use the clear solution of the extractant. In this case, the mixture of particular diluents and modifier will have unique properties: it means that using another modifier in these diluents will change their properties. This fact is very important for choosing modifiers and diluents for extraction [1].

V. PROCESSING TECHNOLOGY

The control of the solvent extraction process is a very urgent issue for the engineers because it is very important to improve the effectiveness of the technological process, have a purified product for nuclear industry, reduce a possible environmental harm of such process, avoid the formation of unnecessary by-products and reduce the total cost of the operation [7].

The growth of the uranium industry, where the solvent extraction method has been used, is shown in figure 1:

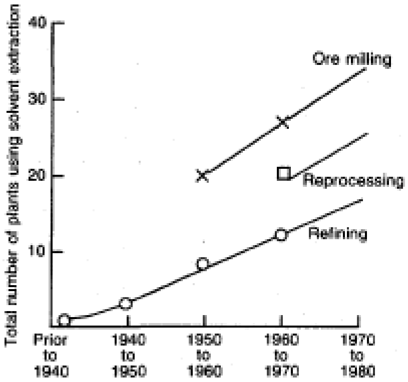


Fig. 1 [8]. Growth of uranium processing

There are four major consecutive steps in the extraction technology of uranium and other rare or precious metals. After them, the purified product will be obtained and a solvent and extractant will be recovered for further application; the process will be profitable and environmentally friendly. These operations are the following [6]:

- Extraction: distribution of metal between water and organic phase; metal transferring to the organic phase;
- Scrubbing: separation of different co-extracted impurities (metals, acids) from the valuable component;
- Stripping: metal transferring from the organic phase to another water phase;
- Solvent make-up: the purification and processing of the organic phase from unnecessary impurities for the further application and mixing it with the fresh organic phase [6].

The principal scheme of a solution purification using extraction is shown in figure 2:

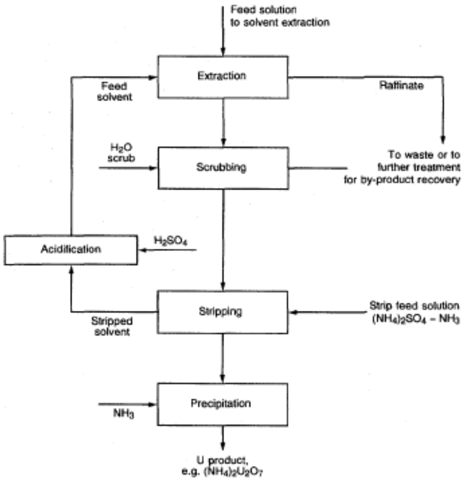


Fig. 2 [9]. Schematic flow sheet of purification by solvent extraction

VI. SOLVENT EXTRACTION EQUIPMENT

There are various types of the solvent extraction equipment nowadays. The basic principles of such reactors are shown in figure 3. The mixing section is for the water and organic phase handling and the settling section is for their separation. Fine mixing and separation can be obtained in mixer-settlers (Fig. 3(a)), but the service of such reactors is not good.

Packed column extractors are widely-spread because of their characteristics. They are high reliability, high stage efficiency, short contact times and small liquid inventory. They are easy in service and have simple design. The height of a such apparatus is 10-20 m, the diameter is 0,3-3 m (Fig. 3(b)).

As for the disadvantage of such columns, it is bad agitation and bad phase separation.

In pulsed columns (Fig. 3(c)) the mechanical agitation is very good, but it has poor phase separation. The organic and aqueous phases move between special perforated plates ("settling chambers"). All phases are dispersed into droplets; the water phase moves down the apparatus and the light organic phase rises and the component distribution occurs.

The mixer-settler battery and column extractor provides the phase separation not better than ~99%, it means that each phase contains some amount of droplets of the other phase. In this case centrifugal extractors (Fig. 3(d)) are sued, which give almost 100% separation efficiency. Their advantages are the following: good mixing, good phase separation, and very small hold-ups. The organic-water phase contact time in centrifugal extractors is shorter than in the other types of the extractors. The dimensions of such reactors allow to reduce the radiation decomposition [2].

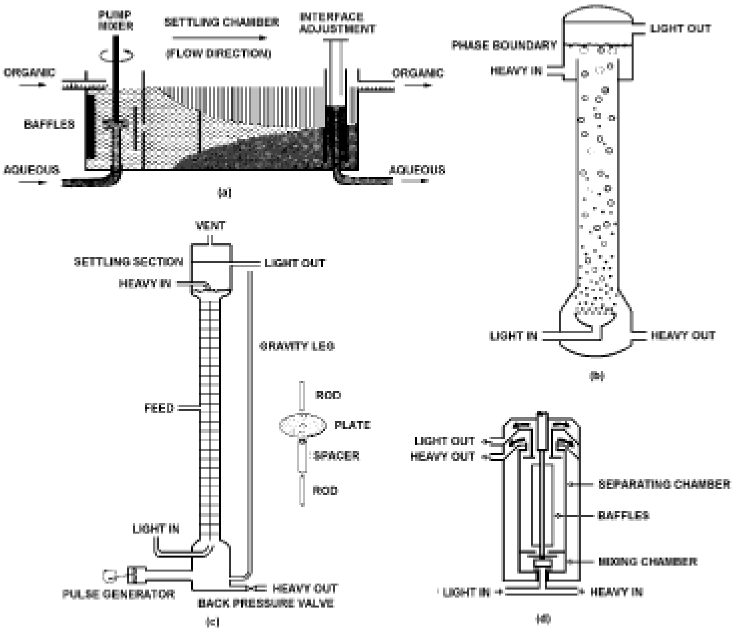


Fig. 3[2]. Different types of extraction equipment. (a) Mixer-settler. (b) Spray column. (c) Pulsed column. (d) Tubular centrifugal contactor.

VII. RESULTS: ADVANTAGES AND DISADVANTAGES OF EXTRACTION

Here are the advantages of liquid-liquid solvent extraction [3]:

- Selective separation and high effectiveness;
- Partition coefficient is not influenced by the concentration, so, the extraction can be applied to a wide range of concentrations.
- The process can be followed by the process of re-extraction and solution (organic phase) could be used in the further extraction processes;
- A wide range of organic extractants can be used, because of the “modifier-diluent” variations;
- Simple equipment; this process can be automated.

These are main disadvantages of liquid-liquid solvent extraction [3]:

- Harmful and ignitable solvents are used;
- Usually it takes a long period of time;
- Big financial amounts;
- Large organic compounds and solvents waste;
- Can be influenced even by a small amount of impurities in the solvent(s);
- Temporary emulsions formation can affect the phase-separation process;
- Radio colloids and fission fragments cannot be extracted and harm the extractant.

The method of extraction purification has some limitations, but it is widely spread all over the world nowadays and is considered to be one of the most efficient methods in uranium and rare earth metals technology.

VII. CONCLUSION

In my abstract I have represented the uranium extraction process, as a method of compounds purification used to a wide variety of uranium materials and other rare and precious metals. From my point of view, the aim to acquaint the readers with the concept and possible applications of this method was achieved. In this work, theoretical basis of extraction was regarded. Thereby, the issues connected with the experimental part and equipment were observed and, in this case, the correlations of physical and chemical processes during the extraction process were interpreted. Also, as the results both advantages and possible disadvantages of this process were mentioned in my work.

1. Uranium extraction technology, Technical report series No. 359, International Atomic Energy Agency, Vienna, 1993.
2. AK De, SM Khopkar, RA Chalmers, Solvent Extraction of Metals, Reinhold (1970).
3. Philip A. Schweitzer, Handbook of Separation Techniques for Chemical Engineers, McGraw-Hill, 1988.
4. Mackenzie, Murdoch, The solvent extraction of some major metals, Cognis GmbH. Retrieved 2008-11-18.
5. Di-(2-ethylhexyl) phosphoric acid - Wikipedia, the free encyclopedia, http://en.wikipedia.org/wiki/Di-(2-ethylhexyl)phosphoric_acid.
6. M B Mooiman, Review: The solvent extraction of precious metals, Precious Metals 1993 Newport Rhode Island USA June 1993 (1993).
7. Morss, L.R.; Edelstein, N.M. and Fuger, J., ed. (2006). The Chemistry of the Actinide and Transactinide Elements (3rd ed.). Netherlands: Springer. ISBN 9048131464.
8. Global Uranium Resources to Meet Projected Demand". International Atomic Energy Agency. 2006. Retrieved 2007-03-29.
9. «Uranium». The McGraw-Hill Science and Technology Encyclopedia (5th ed.). The McGraw-Hill Companies, Inc.. ISBN 0-07-142957-3.
10. Diehl, Peter. "Depleted Uranium: a by-product of the Nuclear Chain". Laka Foundation. Retrieved 2009-07-31.

NUCLEAR ENERGY MARKET IN RUSSIAN FEDERATION

K.E. Boltovsky

Language advisor: PhD, Senior teacher Yu. V. Falkovich

National Research Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050

E-mail: boltovsky90@gmail.com

Abstract.

This is no ordinary report therefore review which consists of two parts. The first chapter is concerned with some general provisions in nuclear energy sphere, like a safety, shortage of specialists & installation of the future. The second part includes develop of Rosenergoatom, the numbers and types of nuclear plants in the Russian Federation, demand for nuclear power in Russia and worldwide(in other words, the export) today.

Keywords: safety, shortage of specialists, installation of the future, Rosenergoatom, nuclear plants in the Russian Federation, export.

Research field, related sciences: safety of life, human psychology, geography, global interaction and global economy.

I. INTRODUCTION.

Purposes and objectives: to know the general provisions of the Nuclear Safety Program, the reasons of shortage of specialists, what's Rosenergoatom, how many working reactors in Russia, countries, which Russia exports.

II. SAFETY.

Even at depressed world prices, Russia relies on income from its oil and gas exports for a substantial portion of its budget revenues; accordingly, to free up hydrocarbons for export, Russia is looking to supply its future energy needs by increasing its nuclear-power program. [1]

Before moving on to market of nuclear energy, I'll start speaking with a some words about safety.

Two major accidents: the Three Mile Island incident in the US in 1979 and the Chernobyl catastrophe in the USSR in 1986. As a result by 1990 not only had the growth forecasts for nuclear power generation failed to materialize, but the whole future of the industry was in question. Some countries went so far as to start closing down their existing nuclear power stations and others decided not to build new ones.

However, the attitude towards nuclear power gradually has changed once again. Many countries found that they simply could not do without nuclear generating, which already produced a very high percentage of their electrical power, and the accidents had the salutary effect of making safety paramount in development and operation of nuclear reactors, helping to make them more acceptable to public opinion.

For safety has already done much in Russia:

-Huge amounts of money were invested in programmes to improve the safety of and modernize first-generation nuclear reactors;

-More attention was paid to the whole production cycle used by the nuclear industry, including the decommissioning of nuclear reactors and disposal of nuclear waste;

-Safety requirements began to be regulated at international as well as national level. [2]

III. SHORTAGE OF SPECIALISTS.

The current nuclear renaissance has made it clear to all developed nations that the nuclear industry needs to preserve and develop its human resources. In the recent past, negative public perception and unclear prospects made jobs in the nuclear power industry and nuclear science less prestigious and promising. As a result the industry has lost nearly a generation of engineers and specialists, who chose not to pursue careers in the nuclear industry. Russia also suffered the full impact of nuclear stagnation, exacerbated by cuts in military and research programmes. The crisis of the 1990s also made a negative contribution. All of Russia’s engineering professions have experienced shortages of trained staff, so that engineering positions in many industries, including nuclear, still have to be filled with older employees. If new nuclear technologies are to be developed and new power stations are to be built, the industry needs a long-term supply of skilled human resources. Transfer of knowledge from one generation of technicians to the next is a prerequisite for preserving and developing any high-tech industry, and there is a risk that the ageing generation of specialists in the nuclear industry will disappear, leaving few heirs. Attention is therefore being focused, as a matter of urgency, on training of new specialists and creation of a system that will attract and retain young engineers in the nuclear sector, thanks to adequate opportunities for social and professional development. [2]

IV.INSTALLATION OF THE FUTURE.

Nuclear power is not a renewable source of energy, and yet it is often viewed as an alternative to traditional energy generation technologies based on burning of fossil fuels. Economic development, increased competition in markets for energy resources, global climate change and a number of other problems have led to a renaissance of nuclear power worldwide. The presidential blog, maintained by Russian President Dmitry Medvedev, notes that ‘a decision has been taken to gradually increase the share of renewable energy sources in Russia’s overall energy production. The share of nuclear power will increase to 25% by 2030. [3]

V. DEVELOP OF ROSENERGOATOM.

The industry – nuclear power plants and their supporting organisations – belongs to MinAtom, which has tried to convert its military-industrial system into a number of viable commercial companies. Since 1992, all nuclear power stations, except for Leningrad which is independent, have been placed under the state company “Russian State Concern for the Generation of Electric and Thermal Power at Nuclear Power Plants” – Rosenergoatom. [4]

It was reorganized as the Federal Agency on Atomic Energy on March 9, 2004. According to the law adopted by the Russian parliament in November 2007 and signed by the President Putin in early December, the agency was transformed to a state corporation. [5]

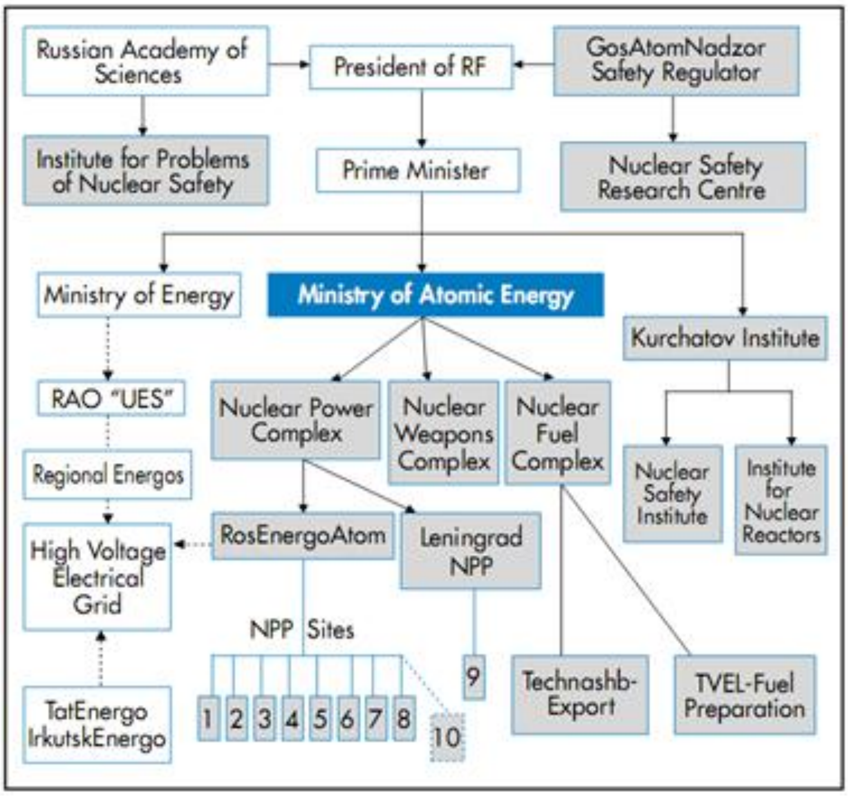


Figure 1. Organisation of Russian Nuclear Sector [4]

VI. POWER REACTIONS OF RUSSIA.

Map. 1 Nuclear Power Plants in Russia - Existing and Planned [4]

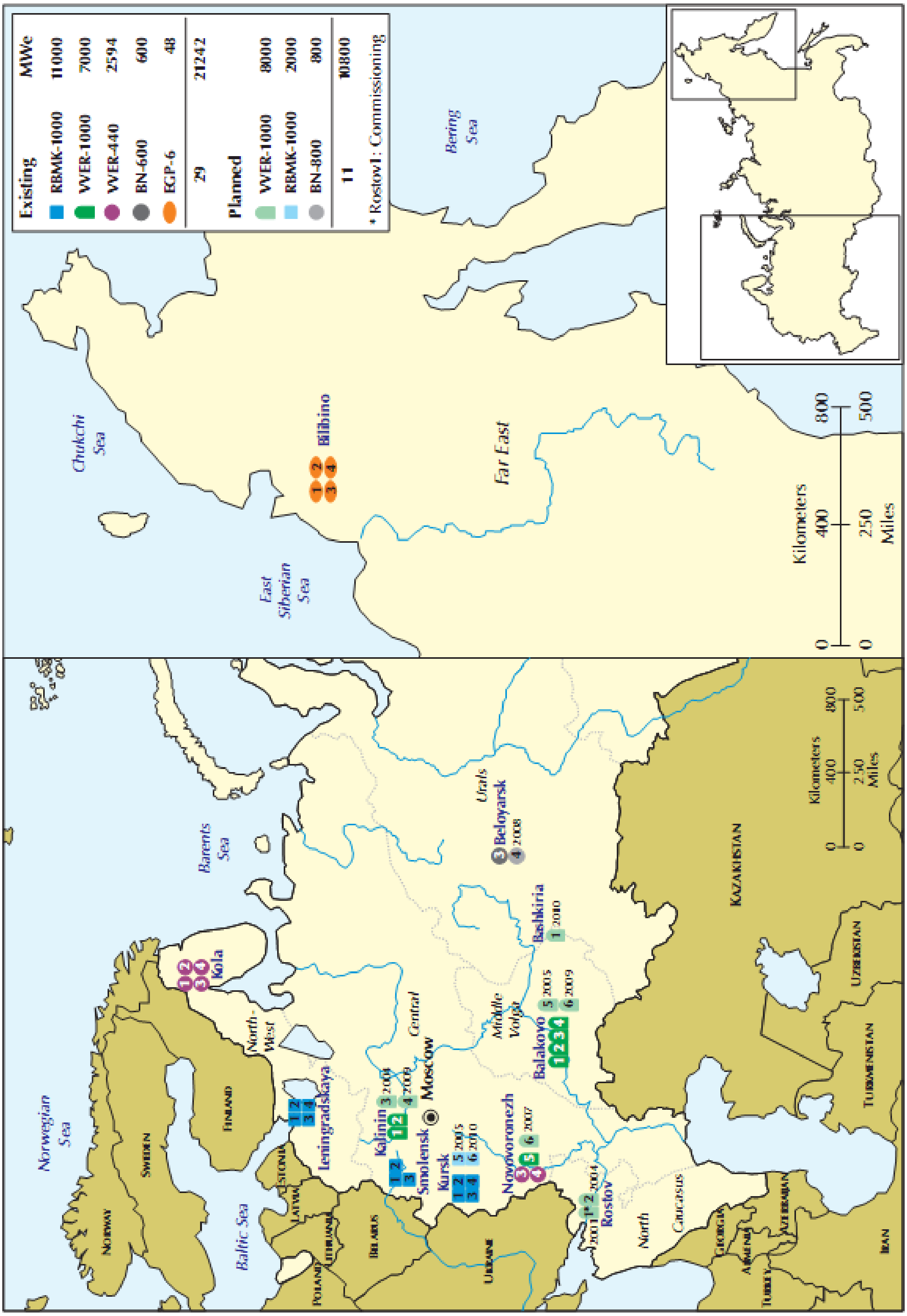
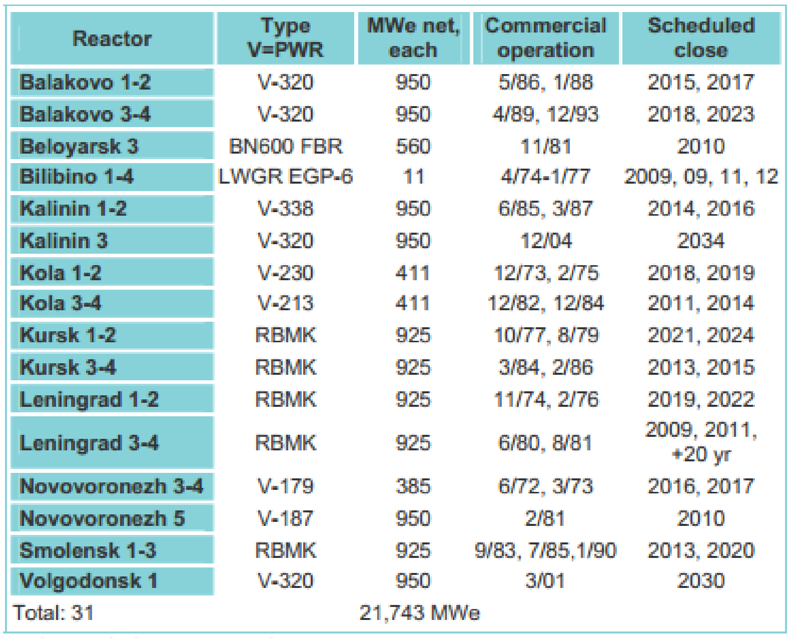


Table 1. Power Reactors in Operation [4]



Reactor	Type V=PWR	MWe net, each	Commercial operation	Scheduled close
Balakovo 1-2	V-320	950	5/86, 1/88	2015, 2017
Balakovo 3-4	V-320	950	4/89, 12/93	2018, 2023
Beloyarsk 3	BN600 FBR	560	11/81	2010
Bilibino 1-4	LWGR EGP-6	11	4/74-1/77	2009, 09, 11, 12
Kalinin 1-2	V-338	950	6/85, 3/87	2014, 2016
Kalinin 3	V-320	950	12/04	2034
Kola 1-2	V-230	411	12/73, 2/75	2018, 2019
Kola 3-4	V-213	411	12/82, 12/84	2011, 2014
Kursk 1-2	RBMK	925	10/77, 8/79	2021, 2024
Kursk 3-4	RBMK	925	3/84, 2/86	2013, 2015
Leningrad 1-2	RBMK	925	11/74, 2/76	2019, 2022
Leningrad 3-4	RBMK	925	6/80, 8/81	2009, 2011, +20 yr
Novovoronezh 3-4	V-179	385	6/72, 3/73	2016, 2017
Novovoronezh 5	V-187	950	2/81	2010
Smolensk 1-3	RBMK	925	9/83, 7/85,1/90	2013, 2020
Volgodonsk 1	V-320	950	3/01	2030
Total: 31		21,743 MWe		

Russia's nuclear plants, with 31 operating reactors totalling 21,743 MWe, comprise:

-4 first generation VVER-440/230 or similar pressurised water reactors,

-2 second generation VVER-440/213 pressurised water reactors,

-9 third generation VVER-1000 pressurised water reactors with a full containment structure,

-11 RBMK light water graphite reactors now unique to Russia (apart from a larger unit in Lithuania). The four oldest of these were commissioned in the 1970s at Kursk and Leningrad and are of some concern to the Western world. A further Kursk unit is under construction.

-4 small graphite-moderated BWR reactors in eastern Siberia, constructed in the 1970s for cogeneration (EGP-6 models on linked map).

-One BN-600 fast-breeder reactor. [6]

VII. DEMAND FOR NUCLEAR POWER IN RUSSIA TODAY.

Targets for increases in nuclear-power generating capacity are very ambitious. In January 2000, 29 commercial nuclear reactors operated within Russia at nine sites built between 1971 and 1993. Within the next eight years, all the units belonging to the first generation, which were designed before the issuance of basic safety regulations in 1973, will complete their planned lifetimes of 30 years. Units of the second generation will complete their lives over the next 9 to 19 years. Extensions beyond design lifetime are envisaged, and plans to increase nuclear-power generating capacity are very ambitious. Under a low-growth scenario, the plan for the next 20 years is to build almost as much new nuclear capacity, approximately 20 GW, as was built during the 1970s and 1980s. The goal is to reach annual nuclear electricity production of 235 TWh. The goals are even higher under a high-growth scenario, with a target of 30 to 32 GW of new plant capacity and annual output of 340 TWh, nearly three times that of 1999. [4]

Russian nuclear electric energy industry represents 5% of the world nuclear energy market, 15% of the world nuclear reactors market, 45% of the world uranium enrichment market, and 15% of the world market of spent fuel conversion. Russia also provides 8% of the world production of natural uranium. [7]

The most powerful & latter example was in last year. The Kalininskaya power plant – some 350 km from Moscow – launched a new reactor. It's be capable of supplying half of the capital's energy needs all by itself, saving up to 450 million tons of oil annually. [8]

VIII. EXPORT.

Soviet exports of enrichment services began in 1973, and Russia has strongly continued this, along with exports of radioisotopes. After 1990, uranium exports began, through Tenex.

Exports of nuclear fuel cycle goods and services topped US$ 2 billion in 1999, including $500 million in fuel assemblies and $1.6 billion in other goods and services. Exports were US$ 2.5 billion in 2001 and and rose to $3.5 billion in 2004. In 2006 they were again US$ 3.5 billion. [6]

The latter "Megatonnes to Megawatts" program supplies about 15% of world reactor requirements for enriched uranum and is part of a US$ 12 billion deal between US and Russian governments, with a non-proliferation as well as commercial rationale. However, Rosatom confirmed in mid 2006 that no follow-on program of selling

Russian high-enriched uranium from military stockpiles was anticipated once this program concludes in 2013. The 20-year program is equivalent to about 153,000 tonnes of natural uranium.

Rosatom claimed to be able to undercut world prices for nuclear fuel and services by some 30%. [6]

It was also pushing ahead with plans to store and probably reprocess foreign spent fuel, and earlier the Russian parliament overwhelmingly supported a change in legislation to allow this. The proposal involved some 10% of the world's spent fuel over ten years, or perhaps up to 20,000 tonnes of spent fuel, to raise US$ 20 billion, two thirds of which would be invested in expanding civil nuclear power. [6]

Rosatom took over building a reactor for Iran at the Bushehr power plant, a project commenced by Siemens KWU but then aborted. Then it sold two large new AES-91 power plants to China for Jiangsu Tianwan at Lianyungang (both now operating) and two AES-92 units to India for Kudankulam (under construction, start-up due in 2008). It is likely that ASE will build a second unit at Bushehr and agreements have been signed for two more at Tianwan in China, which may be VVER-1200 type. In 2007 a memorandum of understanding was signed to build four more units at Kudankalam (reaffirmed early in 2008) and more elsewhere in India.

Russia's policy for building nuclear power plants in non-nuclear weapons states is to deliver on a turn-key basis including supply of all fuel and repatriation of used fuel for the life of the plant.

When China called for competitive bids for four large third-generation reactors to be built at Sanmen and Yangjiang, ASE unsuccessfully bid the AES-92 power plant for these. [6]

Of China's 11 nuclear power plants, the oldest, Qingshan-1, only came online in 1991. While Western attention is focused on growing Chinese involvement in the global energy market, Beijing has already announced plans to spend $50 billion to build an additional 32 nuclear plants by 2020. Rosatom's involvement could generate far more revenue than issuing bonds in the deepest bear market in decades. [1]

In October 2006 its bid for two AES-92 units for Belene was accepted by Bulgaria. ASE leads a consortium including Areva NP and Bulgarian enterprises in the EUR 4.0 billion project.

ASE is reported to be under consideration by Fortum to supply Finland's sixth nuclear power reactor if it is built at Loviisa.

It is also considered a leading contender to build two large reactors in Belarus, and will almost certainly build the first of a series of small reactors (probably VBER-300) in Kazakhstan. [6]

A potentially wide-ranging memorandum of understanding with Enel of Italy is for cooperation on nuclear power projects in Eastern and Central Europe (where Enel has a major presence), using Russian technology. Most of these export prospects bring ASE into direct competition with western reactor vendors.

Since 2006 Rosatom has actively pursued cooperation deals in South Africa, Namibia, Chile and Morocco as well as with Egypt, Algeria, Vietnam and Bangladesh. Tenex has also entered agreements to mine and explore for uranium in South Africa (with local companies) and Canada (with Cameco).

In September 2008 ARMZ signed a MOU with a South Korean consortium headed by Kepco on strategic

cooperation in developing uranium projects. This includes joint exploration, mining and sales of natural uranium in the Russian Federation and possibly beyond.

In February 2008 ASE formed an alliance with TechnoPromExport (TPE), an exporter of all other large-scale power generation types. This will rationalize their international marketing. TPE boasts of having completed 400 power projects in 50 countries around the world totalling some 87 GWe. [6]

IX. RESULTS

The world needs nuclear power, so it is necessary to comply with safety, to make effective changes to existing rules and develop new ones. As a result more people will be have a aspiration to work in this sphere. Rosenergoatom was established in 1992 year as a center for regulating the production and operation of reactors, the investigation of nuclear energy. Russia has 31 reactors in view of the exhaust. Russian exports of nuclear energy in 15 major countries around the world.

X.CONCLUSION

Market for nuclear energy is sufficient demand both in Russia and around the world, so Russia has all chances to become a global supplier.

1. «Analysis: Russia's nuclear-energy ambition» by John C.K. Daly Washington, (UPI) Apr 22, 2009 from http://www.nuclearpowerdaily.com/reports/Analysis_Russias_nuclear-energy_ambition_999.html
2. «National Human Development Report in the Russian Federation 2009. Energy Sector and Sustainable Development». Moscow 2010. [Electronic version]
3. Report from www.kremlin.ru
4. INTERNATIONAL ENERGY AGENCY. «RUSSIA ENERGY SURVEY 2002.» IN COOPERATIONWITH THE ENERGY CHARTER. . [Electronic version]
5. "Rosatom State Corporation registered" from http://en.academic.ru/dic.nsf/enwiki/797564
6. «Nuclear Power in Russia» (17 July 2009). [Electronic version]
7. ENERGY STRATEGY of RUSSIA FOR THE PERIOD UP TO 2030 APPROVED by Decree N° 1715-r of the Government of the Russian Federation dated 13 November 2009 Moscow 2010
8. «Russia to play key part in nuclear comeback- RUSSIA TODAY», 12.05.2009 from http://www.russiaenergy.com/index.php#state=NewsDetail&id=1743

METHODS, TOOLS AND EQUIPMENT BAR CODE IDENTIFICATION IN THE PROBLEMS OF ACCOUNTING FOR AND CONTROL OF NUCLEAR MATERIALS

D.V. Chegodaeva
Scientific Supervisor: PhD, Associate Professor B.P. Stepanov
Linguistic Advisor: Senior teacher N.V. Daneykina
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: dasha.kabanovich@gmail.com

Abstract.

This article describes the principles of building bar-code identification system in system accounting for and control of nuclear material. And the use of information obtained in the automated data collection systems.

Key words: bar code, accounting unit, data collection, scanner, identification tag, physical inventory, human factor.

Research field: systems of accounting for and control of nuclear material, automated data collection system.

Related sciences: nuclear physics, process automation.

I. INTRODUCTION

One of the key tasks of systems of accounting for and control of nuclear materials is data collection for the physical inventory and the imperative need for its completion in a given time interval. [1, 2] On the way to a successful solution of these problems arise obstacles that have generalized name - the problem of the "human factor".

The problem of "human factor" is in the process of accounting for and control of nuclear materials procedures in the traditional way, the data is repeatedly passed through the human consciousness with:

- reading data with a label or tag;
- writing the reading data in the workbook;
- reading recorded in the workbook data;
- entering these data in a computer system with a keyboard.

The man has features which adversely affect the success of the implementation of the above transactions:

- sluggishness;
- propensity to commit errors (3 ... 4% - the normal level);
- increase the likelihood of errors in complicating the tasks;
- a low level of motivation for quality work of low-wage workers involved for data entry.

To obtain accurate and actual (timely) information on changes occurring with nuclear materials, you need to automate data collection, the advantages are:

- quickness;
- reliability;

- dose reduction factors for staff;
- removing the human factor.

For this created and maintained computer database, which with the help of automated identifier recorded information about - accounting units; - the location of accounting units; - weight; - material;-isotopic composition;-enrichment.

The most common technology of automated data collection - is bar coding.

Therefore, the aim was to rationale the applicability of the bar code data in automated systems of accounting for and control of nuclear material.

Consider the current at this time, the types of bar coding and types of codes.

Barcode - graphic label, which according to certain rules encoded informationusually, it is an alphanumeric code identifier. Bar code creates such a way that this information can later be read electronic device - bar code reader.

In addition to image the bar code label on the model may attend a field with alphanumeric equivalent of a bar code and additional text information that is used to read for humans.

The main types of codes - One-dimensional (linear) and two-dimensional (matrix).

A one-dimensional bar code is a series of rectangular strips separated by intervals (Fig. 1). The information is contained only in one dimension and can be read by conventional single-beam scanner. [3]

9 87654 32109 8

Fig. 1. An example of a one-dimensional code.

Two-dimensional bar code contains information on the entire plane of the bar code in two dimensions. (Fig. 2) It can be considered with the help of specialized scanners two-dimensional bar codes. They can be coded much greater volume of information, but because of the complexity of working with it and great cost of the equipment (scanners two-dimensional bar code) is still not widely used. [4]

Fig. 2. An example of a two-dimensional code.

When choosing a bar code for the purposes of accounting for and control of nuclear materials should focus on the characteristics of the selected code to the conditions of operation and ease of use in various procedures of nuclear materials, such as physical inventory, receiving and transmitting material, incoming inspection, the physical movement of material inside the object [1, 2, 5].

Materials for the application of bar codes can be different - paper, wood, metal, plastic, glass.

When you select should focus on properties of a material (color, strength, grip the surface with the dye, the operating conditions).

Bar codes can be applied:

- directly to the subjects;
- on the label;
- in the sticker labels;
- identification cards.

Concerning performance properties of the material, you need to focus on what material can be subjected to aggressive action of the medium. Should pay attention to the materials for printing, water-resistant and chemical, resistant to smearing and abrasion resistance, high temperature.

Just here should be taken into account operating conditions:

the presence of friction and the ability to wear;

the need for periodic decontamination;

potential damage to the shell barcode

Application technology of bar codes:

- ink jet;
- offset printing;
- flexography;
- photocomposition;
- squeezing;
- thermal printing;
- Laser:

- Laser printers in the office;
- Laser engraving on the films;
- Laser printing for special coverage. [1,6]

Devices for reading bar codes are an integral part of the system, they just serve as an identifier of data that were previously handled by a person during the physical inventory.

Scanner - a device emitting controlled light-flow, collects and converts the reflected light in the first analog and then digital electrical signal.

By reading device element bar code scanners are divided into:

- LED. Radiating element is LED readout - CCD.
- Laser. With the mechanism of scanning the laser beam through a system of mirrors.
- Image scanners. With a good range of reading linear and two dimensional bar codes.

By type of performance:

- hand;
- stationary, which are fixed in one place;
- conveyor, used in the industry.

The decoder - a device that analyzes the electrical signals from the scanner and converts it into ASCII form.

— determines whether the scanned object is a barcode;

— determines the type of bar code by analyzing the first and last few lines;

— compares the signal with templates (tables) in the memory and converts it to codes of ASCII;

— transmits data to a computer.

Interface - a device that provides electrical and logical decoder pair with the computer. [1, 6, 7]

A demonstration complex device of INTERMEC and programs to work with bar codes is complete enough to work with bar codes system. The structure of educational demonstration of the complex devices work with bar codes is shown in the diagram below. (Fig. 3)

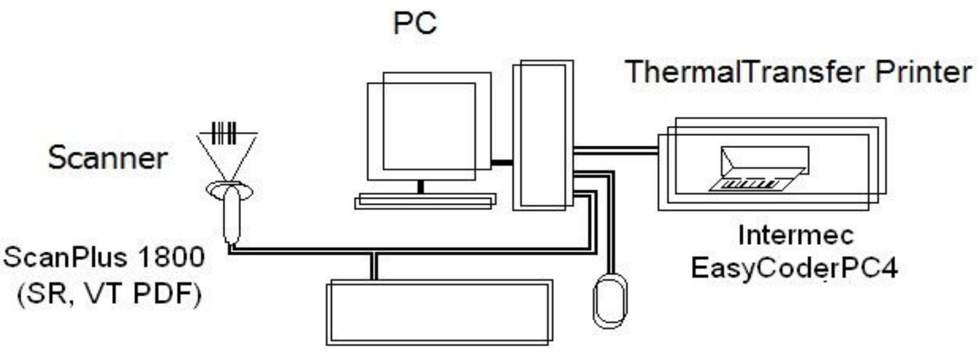


Fig. 3. Demonstration complex of instruments bar coding.

The complex includes:

computer;

— packages LabelShop and CorelDraw for designing labels with bar code symbol;

— stationary Intermec EasyCoder PC4 printer for thermal transfer labels;

— stationary barcode readers:

- Intermec ScanPlus 1800 SR;

- Intermec ScanPlus 1800 VT PDF.

Were analyzed the principles of building bar-code identification system in automated system accounting for and control of nuclear materials. And based on the prorated material was chosen the most suitable types of bar-coding – EAN[8, 9] and Data Matrix[10], and developed several labels, identifiers for the possible containers with nuclear material, which was laid down the following information: (Fig. 4, 5)

«03» lot number;

«013» - the number of accounting unit;

«35» - composition of nuclear material (U-235);

«091» - date of receipting a lot.

0 030130 350912

Fig. 4. Example of label-identifier based on the EAN code with decoding the encoded information

U325 enriched to 2.3%

The lot 264, shelves 4, line 2

The manufacturer «MSZ»

Date of receipt 25/05/2012

Figure 5. Example of label-identifier based on the DataMatrix code to decipher the encoded information.

1. «The basic rules of accounting and control of nuclear materials» (NP-030-05). Moscow, 2005.
2. Instructions for Accounting and control of nuclear materials in balance area KLN1. 01.YM.IR.0011.54
3. GOST 51294. 7-2001 (ISO / IEC 15416-2000) «Automatic identification. Bar-coding. Linear bar code symbols. Test requirements for print quality.».
4. ISO / IEC 16022-2008, «Automatic identification. Bar-coding. Symbology specification Data Matrix».
5. GOST 51294. 10-2002, "Automatic identification. Bar-coding. General requirements for the symbols of the linear bar code and two-dimensional symbols on the labels for shipping, handling and storage. "GOST R Certification System: a collection of documents. - Moscow: Publishing House of Standards, 2002.
6. Safarov, T. The technology of bar coding. Ufa Bashkortostan, 2000.
7. http://www.jasmi.ru/automation/automation.html#1
8. http://www.gs1.org/
9. http://www.gs1ru.org/
10. http://invx.com/

CALCULATION AND THEORETICAL ANALYSIS OF PREPARING TWO-COMPONENT SHS-SYSTEMS AND RADIOACTIVE WASTE IMMOBILIZATION USING THE TECHNIQUE OF SELF-PROPAGATING HIGH-TEMPERATURE SYNTHESIS

K.F. Galiev, A.V. Kononenko.
Principle investigator: Assistant A.O. Semenov
Language supervisor: Teacher Y.V. Ermakova
Tomsk polytechnic university, 30, Lenina St., Tomsk, Russia, 634050
E-mail: galiev@sibmail.com

Abstract.

In the present work was investigated the applicability of the methods for protecting boron-containing materials by SHS technology. A model of managing self-propagating high temperature synthesis based on the calculation and theoretical analysis the dynamics of temperature fields in the propagation of the combustion wave. We prove the applicability of this model for the synthesis of boron-containing materials of nuclear power plants. Also the possibility of immobilizing radioactive waste by SHS technology is considered.

I. INTRODUCTION

According to the development program of nuclear industry of Russia in 2007…2010 and until 2015 have been approved by the Russian government planned to implement an accelerated development of the nuclear power industry to ensure the country's geopolitical interests. This includes the issue of creating new materials for nuclear power plants for various of goods.

One technology is self-propagating high-temperature synthesis (SHS). This synthesis method has some specific features that distinguish it from existing methods for producing inorganic compounds: high temperatures and short times of synthesis, the small energy consumption, simplicity of equipment, the ability to manage the process of synthesis, and as a consequence, production of materials with a given combination properties[1].

Fundamentally the following ways to control the SHS are [2]:

1.Management in preparation of the bland.

2.Management during the process, which includes a thermal heating system.

3. Management during cooling of finished products consisting in changing the temperature regime of cooling and the type of atmosphere.

When management of the synthesis is the actual problem that needs a preliminary calculation and theoretical analysis parameters for the initial batch of components and of the process of SHS. To solve this problem should be modeling the main factors management self-propagating high-temperature synthesis.

II. IMMOBILIZATION

Borosilicate glass and aluminum phosphate are currently used for immobilization of HLW. However, glass-ceramics have many drawbacks: the lack of chemical and radiation resistance, low stability and heat resistance. Crystalline matrices, in which the radionuclides are minerals are included in the form of isomorphic impurities, are deprived of these shortcomings. In particular, the polyphase titanate ceramic Synroc offers exceptional chemical resistance, and, thanks to the wide isomorphism, we can accumulate a large number of different radionuclides.

As it is shown in the studies of Synroc, the main crystalline phase in the ceramics is zirconolyte. Zirconolyte is a phase with a nominal stoichiometry $CaZrTi_2O_7$ is regarded as a promising phase matrix for the immobilization of actinides, including plutonium and rare earth elements, components of radioactive waste.

There are several ways to obtain zirconolyte with a fixed RW. One of the most challenging and resource-efficient techniques is a method of self-propagating high-temperature synthesis. [2]

Creation of SHS-materials for various purposes causes a large number of these systems. Moreover, synthesis must be accompanied by obtaining of the final product, and certain conditions of SH-synthesis must be provided. This means carrying out a large number of experiments to establish the thermophysical parameters determining the mode of obtaining the materials. Therefore, the urgent task of design-theoretical analysis is to determine the principal features of the combustion process in a given system. It is also necessary to determine preliminary parameters for the initial blend of reactants and modes of SH-synthesis. To those, above all, include: the proportion in the system of initial reagents, the value of pressing pressure of reactive systems, which determines the density of the samples prepared in the synthesis, the temperature of preheating of the initial blend, changing which is one way of managing the IFOR. Along with this, obtained temperature distribution in the sample volumes suggests a possible phase composition of the final product, and therefore, makes it possible to choose the optimal regimes of fusion reactions to produce products of high purity.

III. CALCULATION AND THEORETICAL DEFINITION OF THE FUNDAMENTAL FEATURES OF THE SHS

Computational and theoretical analysis based on the determination of adiabatic combustion temperature of SHS materials was carried out to determine the principal features of SH-synthesis. Calculation of adiabatic temperature did not give an unambiguous answer to the question about the possibility of SH- synthesis, but in combination with an experimental study of SH-synthesizing materials of different classes, this approach allows to predict the possibility of combustion.

The procedure of calculating the adiabatic combustion temperature has been well studied. It is determined by solving the equation:

$$\int_{T_0}^{T_{ад}} C(T)dT = Q - \nu L,$$

- Where C, Q, L are the specific heat, heat of formation and heat of fusion product respectively, and ν is the proportion of liquid phase in the product of combustion.

According to the quantum model of the Debye heat capacity can be determined by the following equation:

$$C_v(T) = 9Nnk\left(\frac{T}{\theta}\right)^3 \int_0^{\theta/T} \frac{x^4 e^x dx}{\left(e^x - 1\right)^2},$$

where $\theta = \frac{hC_0}{k}\left(\frac{9N}{4\pi V}\right)^{1/3}$ is the Debye temperature; h is Planck's constant; k is Boltzmann constant; N is concentration of solute; n is the number of atoms contained in the N molecules; V is the volume occupied by the substance; C_0 is the speed of sound in this matter; T is the current temperature of the substance. [3]

For the calculation of adiabatic combustion temperature it is necessary to use the values of heat capacity at constant pressure.

The studies were conducted for different densities of pressing of the initial blend of components and initial temperature of preheating equal to 1200 K.

The dependence of the adiabatic temperature on the preheating temperature of the sample for various densities of pressing is also researched (Fig. 2)

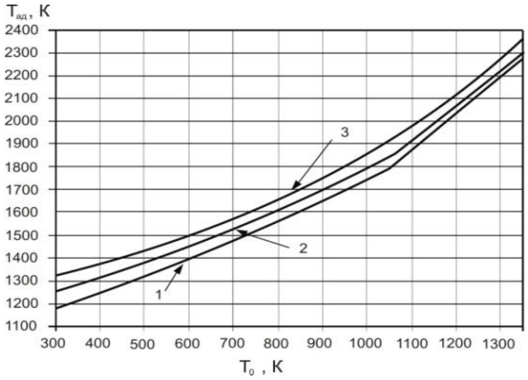


Fig. 2. Dependence of adiabatic temperature on the initial preheating temperature of the sample for various densities of compaction: 1 - 1200 kg/m3, 2 - 2400 kg/m3, 3 - 3600 kg/m3.

For determine of the principal features of SH-synthesis is carried out computational and theoretical analysis based on the determination of adiabatic combustion temperature $T_{ад}$ of SHS materials. Value $T_{ад}$ in combination with extensive experimental studies of SHS of different classes of materials gives the opportunity to ask criterial values of adiabatic temperature [3]:

- $T_{ад} < 1000\ K$ – combustion system is absent and the synthesis is not possible;
- $T_{ад} > 2000\ K$ – the reaction of combustion is in the system;
- $1000\ K < T_{ад} < 2000\ K$ – the further research are necessary.

The main condition for determining the adiabatic temperature is the equality of the enthalpies of the starting materials H at the initial temperature T_0 and of the final products at the adiabatic temperature. It means that all emitted by the reaction heat Q goes into heating the combustion products from the initial temperature to the combustion temperature and can be represented as:

$$\sum_{i=1}^{n}\left(H(T_{ад})-H(T_0)\right)_i = Q,$$

where n – number of precursors mixture of the component.

To solve this equation using a method based on the quantum Debye model that allows relating the specific heat with the parameters of the initial mixture of components in contrast to the classical model [4].

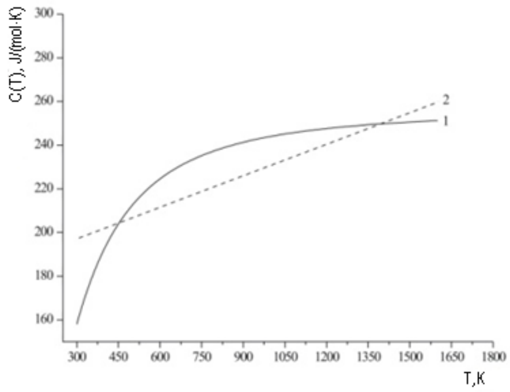


Fig 1. *Dependence of the heat capacity for tungsten boride, calculated using the Debye model (1) and the empirical method (2).*

Curves presented in Fig. 1 show a satisfactory agreement at low and medium temperatures compared with the classical method. In addition, the Debye model has no restriction in the field of high temperature and allows relating the heat capacity with the parameters of the state of the synthesized sample.

IV. MODELING THE DYNAMICS OF TEMPERATURE FIELDS IN THE DIRECTED SYNTHESIS

For modeling the dynamics of temperature fields is required to solve the heat equation:

$$a \cdot \left(\frac{\partial^2 T}{\partial r^2} + \frac{1}{r} \cdot \frac{\partial T}{\partial r} + \frac{\partial^2 T}{\partial z^2} \right) + \frac{q_V}{C(T)\rho} = \frac{\partial T}{\partial t},$$

where a – thermal diffusivity coefficient; ρ – density of the sample; q_V – volumetric heat source.

Equation is a boundary problem with the boundary and initial conditions:

1. $\lambda \frac{\partial T}{\partial r}\Big|_{r=R} = \pm\alpha\left(T_{r=R} - T_s\right) \pm \varepsilon\sigma\left(T_{r=R}^4 - T_s^4\right)$, $\lambda \frac{\partial T}{\partial t}\Big|_{r=0} = 0$;

2. $\lambda \frac{\partial T}{\partial z}\Big|_{z=H} = \pm\alpha\left(T_{z=H} - T_s\right) \pm \varepsilon\sigma\left(T_{z=H}^4 - T_s^4\right)R$, $\lambda \frac{\partial T}{\partial t}\Big|_{z=0} = T_\Gamma$,

where λ – thermal conductivity coefficient; α – heat transfer coefficient; ε – coefficient of "blackness" of the surface; σ – Stefan-Boltzmann constant; T_s – ambient temperature; T_Γ – preheating temperature of the sample; R – sample radius; H – height of the original sample.

On the basis of the calculated data laboratory experiments on the synthesis of tungsten boride were conducted.

V. IMPLEMENTATION OF MODELING THE MAIN FACTORS OF MANAGEMENT THE SHS AS AN EXAMPLE OF SYNTHESIS OF TUNGSTEN BORIDE

Material used as a control and protection system is a tungsten boride. The synthesis of materials based on tungsten boride was carried out by the following reaction:

$$W + B \rightarrow WB$$

Fig. 2 shows the thermogram of the combustion system tungsten-boron with equal initial conditions. The measurements were performed for the central point of the cylindrical sample. There is a satisfactory agreement between the experimental and calculated data. The difference amounts to different parts is about 5 to

12%, which agrees well with an error of calculation due to an error of the mathematical model used in the calculations of two-component systems.

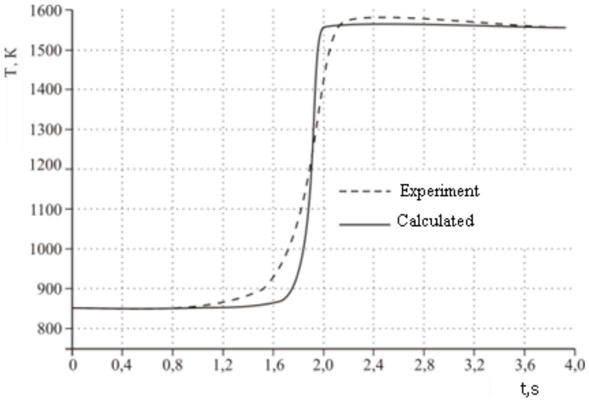


Fig. 2. Experimental and calculated thermograms SHS system WB

V. CONCLUSION

Satisfactory agreement between calculated and experimental data at this stage suggests the correctness of the numerical methods and the possibility of calculating the other two-component SHS systems.

1. A.G. Merzhanov, B.I. Khaikin. Combustion of a substance with a solid reaction layer. // Reports of the Academy of Sciences CAS. – 1967. T. 173. – № 6. – P. 1382–1385.
2. A.G. Merzhanov. Self-Propagating High-Temperature Synthesis / Physical Chemistry: Modern Problems. Yearbook. Ed. Y.M. Kolotyrkin - Moscow: Khimiya, 1983. - P. 6 - 45.
3. V.I Boiko, D.G. Demyanyuk, O.Y. Dolmatov, I.V. Shamanin, D.S. Isachenko. Self-Propagating High-Temperature Synthesis of absorbing material for nuclear power plant // Proceedings of the Tomsk Polytechnic University. - 2005. - T. 308. - № 4. - P. 78-81.
4. E.A. Levashov, A.S. Rogachev, V.I. Yuhvid, I.P. Borovinskaya. Physical chemical and technological bases of self-propagating high-temperature synthesis.- Moscow: Publishing Bean, 1999. – 176
5. M.A. Korchagin, Effect of mechanochemical treatment on the rate and extent of combustion processes of SHS / M.A. Korchagin, T.F. Grigorieva, A.P. Barinov, N.C. Lyakhov. - Jnt. J. SHS. - 2000. - Vol. 9. - № 3. - P. 307-320.
6. A.G. Merzhanov, I.P. Borovinskaya, Self-propagating high-temperature synthesis of refractory inorganic compounds. Report OIHK USSR Academy of Sciences, Chernogolovka, 1970. - 283.
7. V.I. Boiko, O.Y. Dolmatov, I.V. Shamanin, O.A. Nuzhin / / Combust. - 1996. - T. 32, № 1. - S. 58-65.
8. Reactor Materials. The authors. Ed. D.M. Skorova. - Moscow: Atomizdat. 1968. - 385.
9. T.I. Serebryakov. High-temperature borides. - Chelyabinsk: Metallurgy, 1991. - 367.
10. Refractory borides and silicides. - Kiev: Naukova Dumka, 1977. – 164.

OPTIMIZATION OF DISTRIBUTION SCHEME IN «DRY» STORAGE SYSTEM OF SPENT NUCLEAR FUEL FOR MINIMIZATION OF INDUCED ACTIVITY IN CONSTRUCTION ELEMENTS OF THE SYSTEMS

I.M. Gubaydulin
Scientific Supervisor: PhD, Associate Professor S.V. Bedenko
Linguistic Advisor: Senior teacher N.G. Novikova
National Research Tomsk Polytechnic University, 30, Lenin Avenue, Tomsk, 634050, Russia
E-mail: commander_tom@mail.ru

Abstract.

Computational studies of the neutron-physical characteristics of the systems of "dry" storage of spent nuclear fuel of the RBMK-1000 have been carried out. A range of practical recommendations for the optimization of the parameters of the systems and schemes of handling and placement of spent fuel in a "dry" storage have been developed.

Keywords: dry storage system, spent nuclear fuel, neutron-physical parameters, effective neutron multiplication factor.

Research field: Nuclear physics.

I. THE STATE OF RESEARCH

The pace of development of nuclear power industry is largely determined by external components of the nuclear fuel cycle and by the long-term storage of spent nuclear fuel (SNF) and its processing in particular.

After the decay of a significant amount of short-lived radio nuclides in the pre-exposure of spent nuclear fuel in water for the reduction of the heat and radioactivity emission, it appears advisable to switch to the "dry" method of storing spent nuclear fuel. Therefore, diverse research and scientific and technological development for the creation of the conditions for long-term "dry" storage of spent fuel are of a great practical interest.

The purpose of this research is scientifically rational and practical recommendations for creating a technology to optimize the neutron-physical parameters of the systems and schemes of placing spent fuel in the "dry" storage. Achievement of the stated goal leads to a better efficiency and safety of the "dry" storage of spent nuclear fuel.

II. SIMULATED MODEL OF THE «DRY» STORAGE SYSTEM CAMERA SPAN OF 12M

Storage of spent fuel in Russia is provided in special slots, where the hermetic containers with spent fuel are placed. Each camera has 242 storage slots of hermetic containers with spent fuel of RBMK-1000, located in the slot in two levels. About 3,503 tons (of uranium) of spent nuclear fuel of RBMK-1000 is located in each slot.

The slots are placed in a square lattice with a pitch of 1000 mm (the diameter of the slot 720 mm, thickness 7 mm). Canister (container) is a steel pipe with the size of 630 × 7 mm, length 4,1 m and the case is made from steel 10ChSND. Each pencil case has 31 ampoules with RBMK-1000 spent fuel assemblies (see Fig. 1.). Diameter of ampoules 92 × 2 mm, which are located at the distance of 96 mm from each other in a triangular lattice. Containers are placed in slots in two tiers, one above another.

Each slot of simulated models with canisters placed is a unit, to calculate the values of k_{eff} of simulates model is approximated as possible to the real storage system as much.

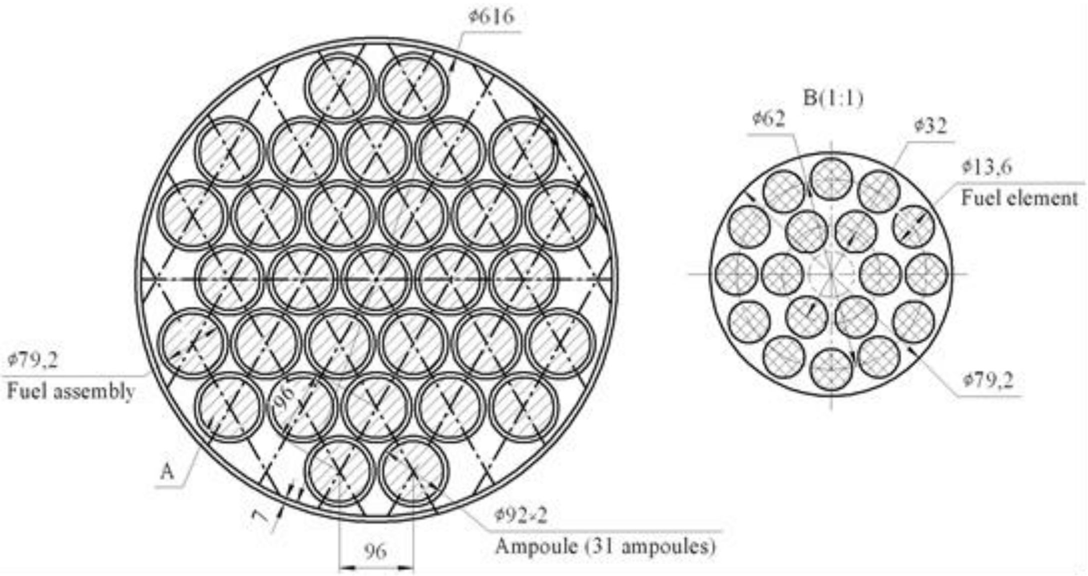
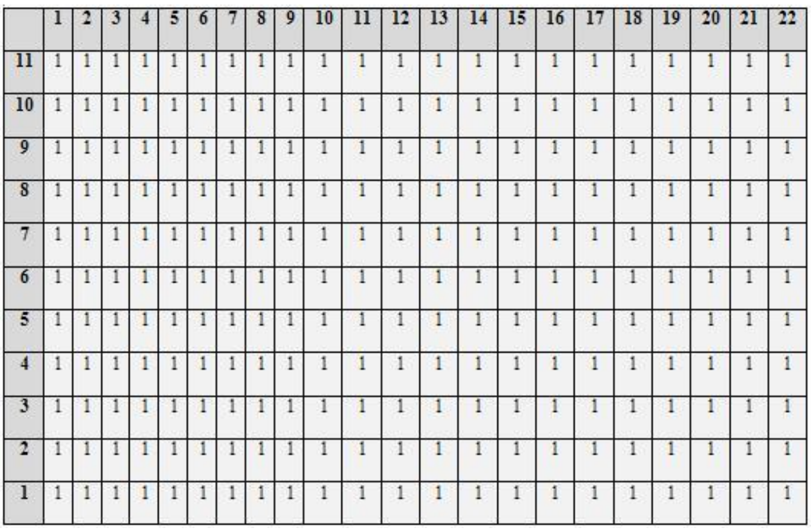


Fig. 1. Distribution scheme of ampoules with RBMK-1000 spent fuel assemblies in the case: B - distribution scheme of fuel elements in fuel assemblies.

To describe one cell of «dry» storage in SCALE 5.0 an equivalent cell was created, called a UNIT. An array with the size of 22 × 11 units was formed from this UNIT, which is processed by the program. The example of filling of array by UNITs is given in fig. 2.



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
11	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
10	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
9	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Fig. 2. The array in the size 22 × 11, consisting of one type of UNIT.

Additionally, the following approximations were made:

- Fuel in canisters is "fresh" (design accident).
- Analysis of nuclear safety for the beyond-design-basis accidents were made in view of burnup.

- From the main fission products only Sm^{149} is considered, secondary fission products are not considered.
- The main sources of spontaneous neutrons are isotopes of Pu, Am and Cm.
- The main sources of (α, n)-neutrons are the following dioxides: $Pu^{238}O_2$, $Am^{241}O_2$, $Cm^{242}O_2$ and $Cm^{244}O_2$.
- The system is a nuclear-safe only if $k_{eff} \leq 0,85$.

III. THE RESULTS OF CALCULATIONS OF KEFF OF CAMERAS SPAN OF 12 M DSSNF RBMK-1000.THE CASE OF "FRESH" FUEL.

The variants of design (fillings of the storage system with water, but water is absent in the canisters with ampoules) and beyond-design-basis accidents (filling of the storage system and all the ampoules with water, which are located in canisters).

Uranium fuel with enrichment of 1,6, 2,0, 2,4, 2,6 and 2,8% was used in the calculation of k_{eff} of «dry» storage system.

Results of the calculation of k_{eff} for fuel with initial enrichment of 1.6% for five different downloads:

1. In the «dry» storage system was one slot with canisters placed in the center. $k_{eff} = 0,1252 \pm 0,0004$.
2. The «dry» storage system is completely filled with the fuel. $k_{eff} = 0,2829 \pm 0,0008$.
3. In «dry» storage system was one slot with penal placed in the center. The «dry» storage system completely filled with water, water was everywhere except the slot with canisters. $k_{eff} = 0,3572 \pm 0,0010$.
4. The «dry» storage system completely filled with the fuel. The «dry» storage system completely filled with water, water was everywhere, but slots with canisters are not filled with water. $k_{eff} = 0,3867 \pm 0,0009$.
5. The «dry» storage system is completely filled with the fuel. We consider a beyond-design-basis accident, water filling the storage and all ampoules, which are located in canisters in the slot of the store. $k_{eff} = 0,8146 \pm 0,0014$.

Results of calculation of k_{eff} for fuel with another enrichment are given in the table 1. Numerals 1, 2, 3, 4 and 5 correspond to the downloads schemes, which are given above.

Table 1. The calculated values of k_{eff} of the «dry» storage system with different fuel enrichment.

Enrichment, %	1	2	3	4	5
1,6	0,1252	0,2829	0,3572	0,3867	0,8146
2,0	0,1299	0,3034	0,3779	0,4108	0,8942
2,4	0,1338	0,3277	0,4003	0,4319	0,9502
2,6	0,1355	0,3399	0,4058	0,4422	0,9756
2,8	0,1362	0,3499	0,4115	0,4492	0,9967

Thus, the emergence of self-sustaining fission reaction is possible for the fuel with the enrichment of 2,6% and 2,8%, and only in case of beyond-design-basis accident, when there is a filling of the storage and some of its parts with water. However, this event is impossible. In addition, in accordance with PNAE-G-14-029-91 [4], nuclear safety beyond-design-basis accidents should be justified in view of measure of burnup of spent nuclear fuel, as a really stored burnt fuel.

IV. THE CASE OF "BURNED" FUEL.

The «dry» storage system completely filled with RBMK-1000 spent nuclear fuel (enrichment - 2%, burnout - 19 740 MW · day / ton, confinement time- 180 days and 10 years). The neutron source (n / (s · ton)) was calculated according to [2, 5 - 7], the calculation method is presented in [6].

Effective multiplication factor of the «dry» storage system loaded by RBMK-1000 spent nuclear fuel is equal to $k_{eff} = 0{,}2229 \pm 0{,}0005$. The values of the neutron flux as a function of UNIT location in the array are presented below graphically in Fig. 2.1.

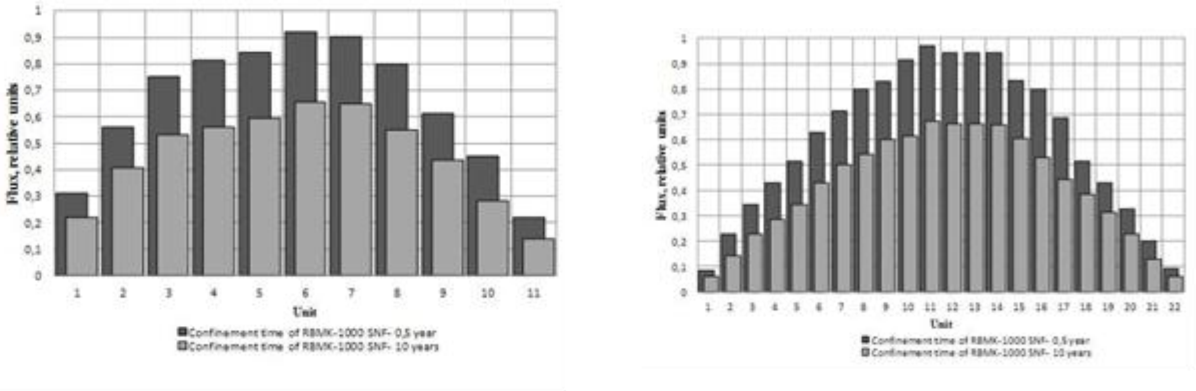
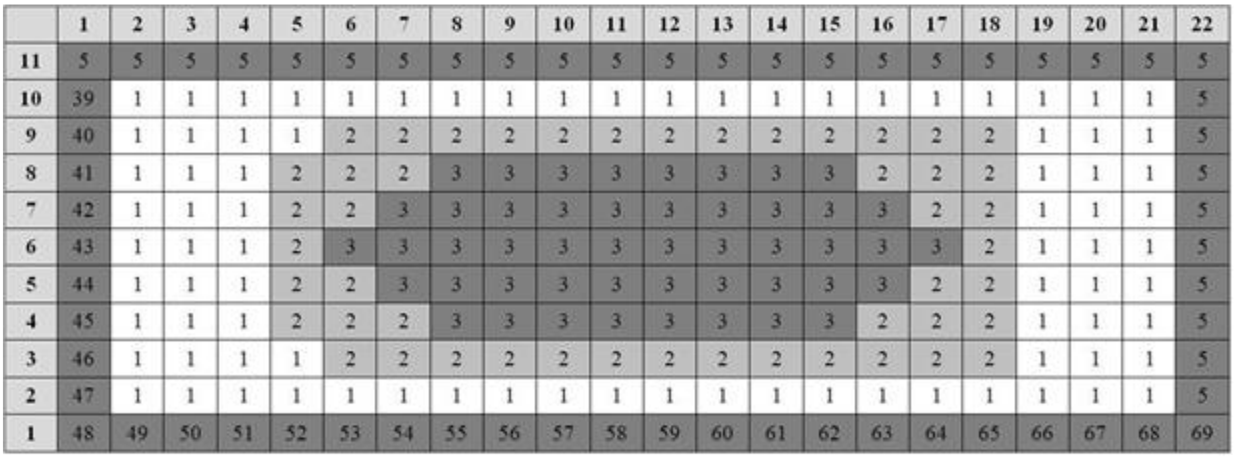


Fig. 2.1. The value of fast neutrons, depending on UNIT location in the array.

Calculations showed that burn-up will reduce the value of k_{eff} for 32% and as a result from the viewpoint of nuclear safety camera span 12 m of the «dry» storage system is deep subcritical system even in case of beyond-design-basis accidents, but level of neutron radiation at a fuel with burn-up of 19 740 MW · day / ton is greater than the maximum permissible value.

Thus, it is vital to optimize the distribution scheme in the dry storage system of spent nuclear fuel with different burn-up in order to reduce radiation exposure to personnel. One of the variant of filling is given below (see Figure 3.) It allowed to reduce the levels of neutron radiation at certain points of the storage system to limit values [4].

Effective multiplication factor of the «dry» storage system (see the array shown in Figure 3) is equal to $k_{eff} = 0{,}2148 \pm 0{,}0003$. Fluxes of the modeled system, depending on location in the array UNIT below (see Figure 3.1).



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22
11	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
10	39	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5
9	40	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	5
8	41	1	1	1	2	2	2	3	3	3	3	3	3	3	3	2	2	2	1	1	1	5
7	42	1	1	1	2	2	3	3	3	3	3	3	3	3	3	3	2	2	1	1	1	5
6	43	1	1	1	2	3	3	3	3	3	3	3	3	3	3	3	3	2	1	1	1	5
5	44	1	1	1	2	2	3	3	3	3	3	3	3	3	3	3	2	2	1	1	1	5
4	45	1	1	1	2	2	2	3	3	3	3	3	3	3	3	2	2	2	1	1	1	5
3	46	1	1	1	1	2	2	2	2	2	2	2	2	2	2	2	2	2	1	1	1	5
2	47	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	5
1	48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69

Fig. 3. An array of size 22 × 11. UNIT 1 - slot with canisters, burning 19 740 MW · day / ton; UNIT 2 - slot with canisters, burning 24 910 MW · day / ton; UNIT 3 - slot with canisters, burning 29 285 MW · day / ton; UNIT 5, 39 ... 69 - the empty slots.

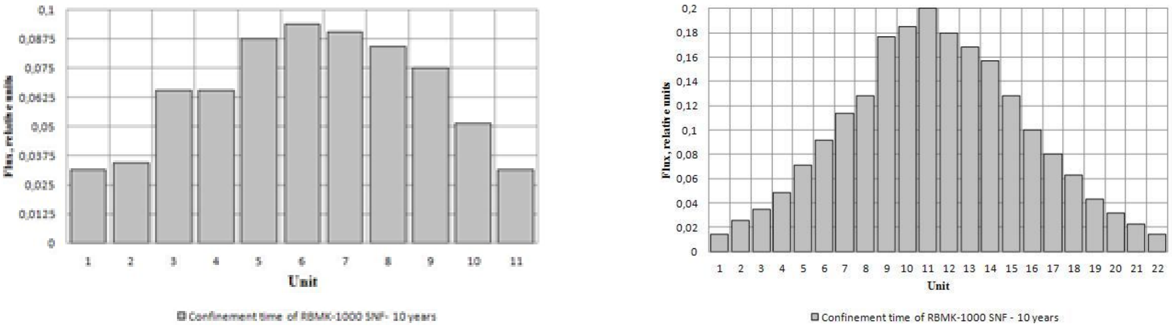


Fig. 3.1. The value of fast neutrons, depending on UNIT location in the array.

V. CONCLUSION

1. It was found that under proper operation and design-basis accidents the «dry» storage system of spent nuclear fuel is deeply subcritical system (scheme of loading - 1 ... 4, see Table 1.), with $k_{eff} \leq 0{,}45$.

2. Thus, it is necessary to optimize distribution scheme of spent nuclear fuel with different burn-up in dry storage system to reduce radiation exposure on personnel.

3. Variant of "downloading" of the «dry» storage system suggested in the researching work (see Figure 3.) will reduce the radiation levels at certain points in the storage to the maximum permissible values.

1. V.I. Bojko, V.N. Meshcherjakov, I.V. Shamanin, etc. “Perspective nuclear fuel cycles and reactors of new generation.” – Tomsk: Publishing house TPU. - 2005. - 490 p.
2. S.V. Bedenko, I.V. Shamanin “Neutron activity of the spent ceramic nuclear fuel”//News of high schools. Physics. - 2011. - T. 54. - № 11/2. - P. 51-56.
3. V.S. Vnukov “Measures of burnup as a parametre of nuclear safety of storage and transport packaging with the spent nuclear fuel.” - The atomic technique abroad. - 1990. - № 12. - P. 9 - 11.

4. I.V. Shamanin, V.I. Bulanenko, S.V. Bedenko “Neutron radiation field of different kinds of irradiated ceramic fuel” // News of high schools. Nuclear power. – 2010. - №2. – P.97-103.

5. S.V. Bedenko, F.V. Gnetkov, S.D. Kadochnikov “Dose characteristics of neutron field of different kinds of irradiation ceramic nuclear fuel” // News of high schools. Nuclear power – 2010. - №1. – P. 6-12.

6. I.V. Shamanin, S.V. Bedenko, A.O. Pavluk, V.A. Lazko “Using of ORGEN-APR program for calculation of a isotope composition of spent nuclear fuel “VVER-1000” reactor” // News of TPU.-2010. – T. 317. - №4. – P. 25-28.

7. I.V. Shamanin, P.V. Gavrilov, S.V. Bedenko, V.V. Martynov “The neutron activity of spent nuclear fuel at high depth of burn-up”// News of high schools. Nuclear power, – 2008, - №1. – P.68-74.

8. I.V. Shamanin, P.V. Gavrilov, S.V. Bedenko, V.V. Martynov “Neutron-physical aspects of manipulation problem with irradiated nuclear fuel at high depth of burn-up”. News of TPU.-2008. – T. 313. - №2. – P. 62-66.

9. I.V. Shamanin, P.V. Gavrilov, V.V. Martynov, S.V. Bedenko, S.A. Nefedov, F.V. Gnetkov “Field of neutron radiation and radiation background near the irradiated ceramic uranium fuels”// News of TPU.-2010. – T. 316. - №4. – P. 10-13.

10. I.V. Shamanin, P.V. Gavrilov, S.V. Bedenko “Dynamics of accumulation and drop of the induced activity in the construction elements of the container during of storing of spent nuclear fuel”// News of TPU.-2010. – T. 319. - №2. – P. 67-71.

STORAGE OF SPENT NUCLEAR FUEL

D.S. Ibrayeva
Scientific Supervisor: PhD, Associate Professor S.V. Bedenko
Linguistic Advisor: Associate Professor R.I. Tolbanova
National Research Tomsk Polytechnic University, Russia, Tomsk, Lenin str.,30, 634050
E-mail: dishon_2808@mail.ru

Abstract

The given project work consists of five sections. In the introduction information about the types of spent nuclear fuel (SNF) storage is presented. In the main part the concepts of SNF storage of power reactors after unloading from the reactor is described. In the second part an overview of the main technologies of dry storage of spent fuel, and a detailed explanation of the technology of SNF in water-filled pools is discussed. The main types of dry storage of spent nuclear fuel technology, different types of containers for dry storage and storage chambers are studied. In the conclusion a brief review of the problem of SNF storage is described. There is also a list of the references and a glossary in which some terms used in this work are given.

Key words: spent nuclear fuel, reactor, storage pools, dry storage, and accumulation of SNF.

Research field: nuclear physics, atomic physics, nuclear energy technologies.

Related sciences: physical energy devices.

I. INTRODUCTION

All nuclear reactors have pools for storing spent nuclear fuel that are directly related to the operation of nuclear reactors. In essence, this is the basic element of storage technology which is provided by reducing the activity of spent fuel and heat. Over time, storage near the reactor began to fill with a large number of spent nuclear fuels of different ages, approaching the level of its capacity, which threatens the continued operation of the power units. When you create a modern steel building it includes spacious pools, storage facilities, which should allow for unloading of spent nuclear fuel.

For this purpose two approaches are used. In the first case, an additional intermediate storage is created directly at the reactor site, but it is much larger and, in general, regardless of the reactor and storage near the reactor. Such storage may be either "wet" using one or more pools or "dry", which may or may not provide for transportation off-site. It is assumed that such "storage near the reactor" outside the reactor storage can act as long as a nuclear power plant operation, as well as during the recultivation period (from 50 to 100 years).

In the second case, outside the reactor storage is located outside the reactor area in a special place. The main part of outside the reactor storage is presented in the form of «pool» storage. Most of these storages (92%) relate to the storage of the «wet» type.

Both "wet" and "dry" storage technology must meet a number of basic requirements:

- a set of fuel assemblies must be maintained under controlled conditions and should not cause disturbances in the environment surrounding the repository;
- subcriticality of spent nuclear fuel must be maintained under normal conditions and in emergency situations;

- radiological protection should ensure safety of the personnel, population and environment in accordance with the applicable regulations [1].

II. SPENT NUCLEAR FUE

II. I. Basic information about SNF storage

Through the nuclear fission process, fuel assemblies become intensely radioactive and must be safely stored in the environment that sequester and contain the radioactivity. Essentially all nuclear fuel from nuclear power plants is used in ceramic form. A typical 1,000-megawatt nuclear power plant produces about 20 metric tons of spent uranium fuel per year. The country’s 103 commercial nuclear reactors together produce about 2,000 metric tons of used fuel annually.

Spent fuel radioactivity is generated by:

- fission products (e.g., isotopes of cesium and strontium);
- transuranic elements, also known as actinides (e.g., plutonium, americium, and neptunium);
- fission product of gases, such as krypton and xenon, trapped within used fuel rods and pellets;
- spent fuel assembly metals, such as cobalt, nickel, and niobium, which became radioactive in the neutron flux of an operating reactor.

The radiotoxicity of an isotope is a measure of its potential to cause damage to living tissue. Radiotoxicity depends on the residence time in the body and on the type of radiation emitted by the isotope. Radioactive decay of the waste is dominated for a few hundred years by highly radioactive fission products and after that by heavy elements in the actinide series, which are less radioactive (i.e., take a long time to decay). The decay of fission products also produces heat. Spent fuel that has just been removed from a reactor generates about 2,000 watts per kilogram. The heat rate drops after a year to about 10 watts; after 5 years to about 3 watts; and after 100 years to about 0.5 watts. After 1,000 years, the thermal output of the spent fuel is negligible [1].

II. II. Long-term disposal of nuclear waste is necessary

There are several main features of the repository environment to be considered for long-term geologic disposal. The NJFF group agrees with the technical group convened by the IAEA, which found that, typically, a suitable environment for deep disposal would display such properties as:

- long-term (millions of years) geological stability, in terms of major earth movements and deformation, faulting, seismicity, and heat flow;
- low groundwater content and flow at repository depths, which can be shown to have been stable for periods of at least tens of thousands of years;
- stable geochemical or hydro chemical conditions at depth, mainly described by a reducing environment and a composition controlled by equilibrium between water and rock-forming minerals;
- good engineering properties, which readily allow construction of a repository as well as operation for periods that may be measured in decades.

Some have explored finding alternate approaches to deep geological disposal. For example, a disposal in deep boreholes (over 2 km deep) drilled from the surface has received some study, but on the whole would require substantial research and development. Options other than geologic storage have been considered, including launching waste into space and disposal in deep sea beds. These have been judged too risky or infeasible, or they violate international treaties [2].

III. TYPES OF STORAGE

III. I. Storage Pools

When removed from a reactor, spent fuel is radioactively and thermally hot. It is stored in storage pools where active circulation cools the radioactive contents. As long as a nuclear reactor is operational, it requires a cooling pool for the hottest spent fuel.

About one-fourth to one-third of the total fuel load is removed to storage pools from the reactor every 18 to 24 months and replaced with fresh fuel. The spent fuel rods are immersed under at least 20 feet of water, thus providing adequate shielding from the radiation for anyone near the pool.

When a power plant’s pool storage capacity is limited, NRC may approve replacement of existing fuel storage racks with higher density racks constructed with neutron-absorbing materials. Almost all nuclear power plants employ high density racks now, but only a limited additional storage capacity is available through continued reracking. To allow for more newly discharged spent fuel to be added to pools, older and cooler fuel can be moved to dry cask storage [3].

III. II. Dry Cask Storage

In the late 1970s and early 1980s, the need for alternative storage began to grow when pools at many nuclear reactors began to fill up with stored spent fuel. Dry cask storage allows spent fuel that has already been cooled in the spent fuel pool for at least one year to be surrounded by inert gas inside a container called a cask. The casks are typically steel cylinders that are either welded or bolted closed. The steel cylinder provides a leak-tight containment of the spent fuel. Each cylinder is surrounded by additional steel, concrete, or other material to provide radiation shielding to workers and members of the public. Some of the cask designs can be used for both storage and transportation.

There are various dry storage cask system designs. With some designs, the steel cylinders containing the fuel are placed vertically in a concrete vault; other designs orient the cylinders horizontally. The concrete vaults provide radiation shielding. Other cask designs orient the steel cylinder vertically on a concrete pad at a dry cask storage site and use both metal and concrete outer cylinders for radiation shielding. Spent fuel is currently stored in dry cask systems at a growing number of power plants (Fig.1).

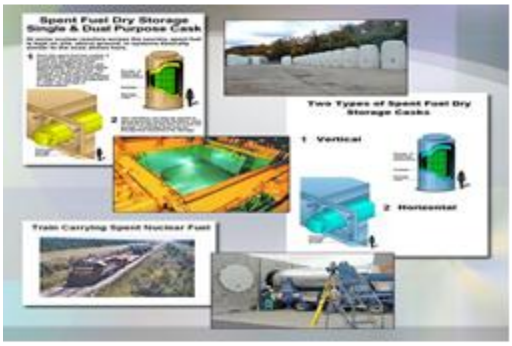


Figure 1. Storage of SNF

The main advantages of a dry spent fuel storage technology in comparison with technology in the storage pools (wet or water storage method) include:

- storage conditions (atmosphere of air or inert gas), in which the degree of minimal degradation of the fuel;
- passive way to remove heat from the stored fuel;
- low doses to personnel in the operations of loading / unloading of spent nuclear fuel storage and maintenance;
- lower the probability of environmental contamination that may occur only when the mechanical failure of the repository;
- lower capital cost for the construction of storage facilities;
- the possibility of increasing the capacity of the storage unit;
- easy to store maintenance and low operating costs;
- small amount of secondary waste.

However, the dry technology has certain shortcomings, which, as typically include:

- the need for a mandatory pre-cooling in the spent fuel pools exposure;
- minor experience operating dry storage;
- less density storage of spent nuclear fuel;
- the need to study the behavior of structural materials (concrete, metals) to confirm the possibility of prolonged use (at least 100 years) [4, 5, 6].

III. II. I. The basic technology of dry storage of spent nuclear fuel

In principle, distinguish the following types of dry spent fuel storage technologies:

Technology container storage and storage technology to the chamber. In addition, we can distinguish the dry storage borehole (mine) type, which are not widely available and dry storage, representing a monolithic concrete system.

The concept of dry storage of spent nuclear fuel in the chamber has been developed and used in the U.S., Britain, France, Hungary, etc. The chamber has a relatively simple design, spent fuel is cooled by natural convection of air. The chamber is made of reinforced concrete can be partially deepened. Chamber storage of spent nuclear fuel requires additional installation for the reception and packing assemblies in pencil cases and to verify their integrity.

In the chamber of the dry storage can be used to force air circulation. From a thermodynamic point of view camera with a cooled natural convection of air allows for higher ambient temperature and gives the possibility of a more compact storage. The concept of dry storage in cells allows for a modular solution set.

The system container storage has been used in almost all countries, having nuclear power plants (fig.2,).

Figure 2. The system container storage

Initially the container used for delivery purposes spent fuel from nuclear power plants in the regional storage or to final burial. Use containers as a means of dry storage was due to several factors. The possibility of placing directly on the area of NPP, or directly adjacent territories, low capital cost for the construction of container storage facilities, the possibility of a phased input power (making the required number of containers within a certain period of time). In addition, a very attractive idea was to use the same containers at once for two or more purposes, such as for storage and subsequent transportation.

At present, single-purpose containers destination (single purpose system), dual-purpose containers (dual-purpose system) and multi-purpose (multi-purpose system) are applied. The single-purpose containers are designed to perform a single function: storage, transportation or disposal of spent nuclear fuel. The dual-purpose containers are used for storage and transportation of spent nuclear fuel (fig. 3, 4), the multi-purpose containers means containers for storage transportation and final disposal of spent nuclear fuel.

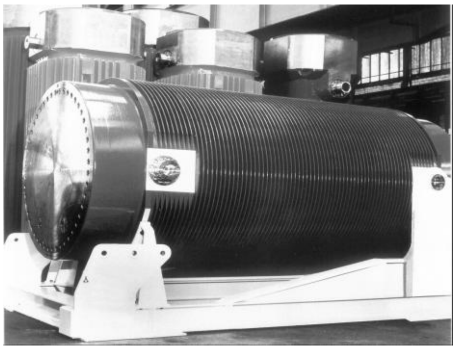


Figure 3. Dual-purpose containers

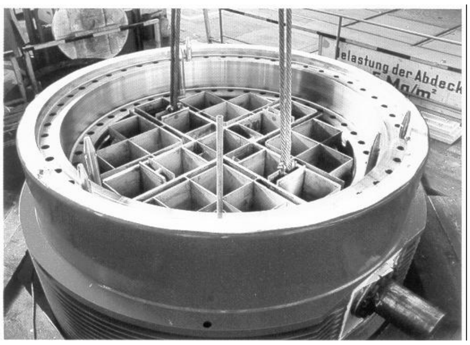


Figure 4. Dual-purpose containers with the cover removed

All of the existing dual-purpose and multi-purpose containers can be divided into two groups:

- the group of containers (cask-based), in which the container is complete a single system and performs all the functions for which it is designed (Storage, transportation, disposal);
- the group of containers (canister-based), in which spent fuel is contained in a sealed pencil case (sealed canister), and that the tight pencil case serves as a common component for storage, transportation and disposal. Usual for such systems is repackaging canisters for storage, transportation or disposal.

Container systems for storage, transportation and disposal of spent nuclear fuel as a whole perform the following functions:

- storage of radioactive substances;
- limitation of ionizing radiation in the environment;
- removal of decay heat from spent nuclear fuel;
- ensuring subcriticality of the system.

Containers should be designed in such a way that their structure integrity and thermal performance ensure all the necessary safety requirements. A pure container system (cask-based, one-piece flask) was derived from the transport containers. In the transport containers thick metal walls provide protection from radiation and protection against external influences. Many containers inside the cavity, which housed the spent fuel, can be filled with water, providing heat removal from spent nuclear fuel, and protection against neutron radiation.

For systems based on the use of hermetic casing (canister-based), safety features for each target (storage, transportation, final burial) are provided with special packages for the pencil case. The very tight pencil case (canister) may perform one or more security features. For example, a pencil case may include in its membership the cover, or other supporting structures that ensure subcriticality of the system as a whole in storage and during transportation and disposal of spent nuclear fuel. Sealed pencil case can, for example, perform the function of containment of radioactive materials in storage, but for transportation may require special packaging it pencil case [7, 8, 9].

IV. CONCLUSION

Obviously, for the further development of nuclear energy in the absence of a decision on reprocessing or final disposal of SNF from the sphere of human activity, requires a rational and efficient infrastructure of SNF.

Creation of new nuclear power plants with reactors of the new type and use of a new generation of fuel assemblies with a significant increase in the burn up will require additional studies, related to the definition of the minimum holding time in the wet storage (security during transportation) and the definition of allowable safe timing of wet and dry storage of spent nuclear fuel.

In any possible scenario, nuclear power development in Russia prior to the radiochemical processing and / or disposal of spent nuclear fuel, storage of spent nuclear fuel will remain an essential and necessary condition [10].

1. A Multi-Attribute Utility Analysis of Sites Nominated for Characterization for the 1st Radioactive-Waste Repository—A Decision-Aiding Methodology (DOE/RW-0074, May 1986).
2. Scientific and Technical Basis for the Geological Disposal of Radioactive Wastes.” Technical Reports Series No. 413. International Atomic Energy Agency, Vienna, 2003, p. v.
3. Dry Storage of Irradiated Fuel. CSA Standard N 292.2, 1996.
4. Multi-purpose container technologies for spent fuel management. IAEA-TECDOC- 1192, December 2000, Vienna, Austria.
5. Nuclear Europe World scan. 2000. V.20, N 3-4. W. - International Conference on Spent Fuel from Nuclear Power Reactor. Vienna, Austria, 19-22 June 2006.
6. Nuclear Europe World scan. 2000. V.20, N 5-7. W. - International Conference on Spent Fuel from Nuclear Power Reactor. Vienna, Austria, 19-22 June 2006.
7. M.Oda, N.Kumagai. Development of an Advanced Spent Fuel Storage System (HLW and Spent Fuel Storage Systems – Technologies and Experience. ICEM’99.
8. Survey of wet and dry spent fuel storage. IAEA-TECDOC-1100, July 2003, Vienna, Austria.
9. Dry Storage of Irradiated Fuel. CSA Standard N 292.2, 1996.
10. Retrieved December, 2007 from http://www.proatom.ru/modules.php?name=News&file=article&sid=770

STUDY OF SULFUR ISOTOPES BY VIBRATION SPECTROSCOPY AND QUANTUM CHEMISTRY

E.A. Ivanus
Scientific Supervisor: PhD, Associate Professor N.B. Egorov
Linguistic Advisor: Teacher A.A. Kyznetcova
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: e.ivanus@mail.ru

Abstract.

The results showing the dependence of the experimental and calculated frequencies in the Raman spectra from the molecular mass of the sulfur isotope. The effect of sulfur isotope shift on the change of thermodynamic parameters.

I. INTRODUCTION

Natural sulfur consists of a mixture of stable isotopes with mass numbers 32, 33, 34, 36, the relative content of which is respectively 95.04%, 0.75%, 4.20%, 0.015% [1]. Isotopes of sulfur applied in biology [2], geology [3], geochemistry [4, 5], ecology [6-8], agrochemistry [9], archeology [10] and medicine [11]. It is obvious that the information on the spectral and thermodynamic properties of stable sulfur isotopes is important for applied and scientific problems. In [12-15] studied in detail the vibration spectra of sulfur α-^{nat}S и α-^{32}S at low temperatures, and studied the effect of temperature on the infrared spectra of natural and izotopically-pure sulfur $^{32}S_8$. These experiments were done using a-single crystal of sulfur. However, in applied research often use not single crystals of sulfur, but its polycrystalline powders. Therefore, in this paper, we present the infrared spectra and Raman spectra of and izotopically-pure polycrystalline α-^{32}S, α-^{33}S, α-^{34}S. The experimental data are compared with theoretical calculations of the infrared spectra and Raman spectra, obtained by theory of functional density. In addition, in this paper shows the relationship between the change in Gibbs free energy and the mass of an isotope of sulfur.

II. EXPERIMENTAL SECTION

In the experimental work using isotopes of sulfur with an isotopic purity: ^{32}S - 99,9%; ^{33}S - 99,4%; ^{34}S - 99,9%. To obtain a chemically pure orthorhombic sulfur modification (α-S) the isotopes were subjected to triple distillation under vacuum with subsequent crystallization from carbon tetrachloride. Obtained in this way isotopes of sulfur have a chemical purity of not less than 99.9%. The IR spectra of polycrystalline samples of α-S in KBr tablets in the range 400-500 cm-1 were obtained using FT-IR spectrometer Nikolet 5700 at room temperature with a resolution of 2 cm^{-1}. Raman spectra were recorded on a spectrometer Nikolet 5700 with Raman module in the range 100-500 cm^{-1} at room temperature with a resolution of 1 cm^{-1}. In both cases used laser with Nd: YAG (λ=1064 nm, 514 mW).

The calculations of the S_8 molecules containing of the different sulphur isotopes were carried out using the GAUSSIAN'03 program package [8]. The geometries were first optimized at the gradient-corrected DFT level by using the three-parameter fit of the exchange-correlation potential suggested by Becke [9] in conjunction with the LYP[10] exchange potential (B3LYP). This method is now generally accepted to describe the thermodynamic properties and vibrational spectra, and gives results similar to the MP2 and GMP2 methods.

We have been used all electron 6-31G(d), and extended cc-PVTZ basis sets. The absence of imaginary vibration frequencies confirmed the stationary character of the structures.

Energy calculations have been corrected for zero-point vibrational energy and reduced to normal conditions (298,15 K, 1 atm) using thermal corrections to the enthalpy and free energy.The optimized geometries of these molecules have also been used for the calculations by the ADF'2004 (Amsterdam density functional) program. We have used the OPTX exchange functional [11] combined with the PBE correlation functional [12] using an all electron triple-ζ + polarization basis set of uncontracted Slater orbitals. Scalar relativistic effects have been considered using the zero order regular approximation (ZORA) [13].

III. RESULTS AND DISCUSSION

Fig. 1 shows the IR spectra, obtained for polycrystalline samples of isotope α-^{32}S, α-^{33}S, α-^{34}S и α-^{nat}S. According to [22], observed in the IR spectra absorption corresponds to the valence vibration (stretching vibration) - ν_5. Figures shows that the position of the lines of oscillations ν_5 for α-^{33}S and the α-^{34}S isotopes are shifted to the low-energy side, and a line corresponding to the isotope α-^{32}S, has a high-energy shift with respect to the spectrum of α-^{nat}S. This behavior can be explained by the fact that the provisions of the oscillation frequencies in the spectra directly affects the mass of the atoms oscillating around the equilibrium positions in the crystal lattice. This dependence has the form $\nu = \propto m^{-1/2}$.

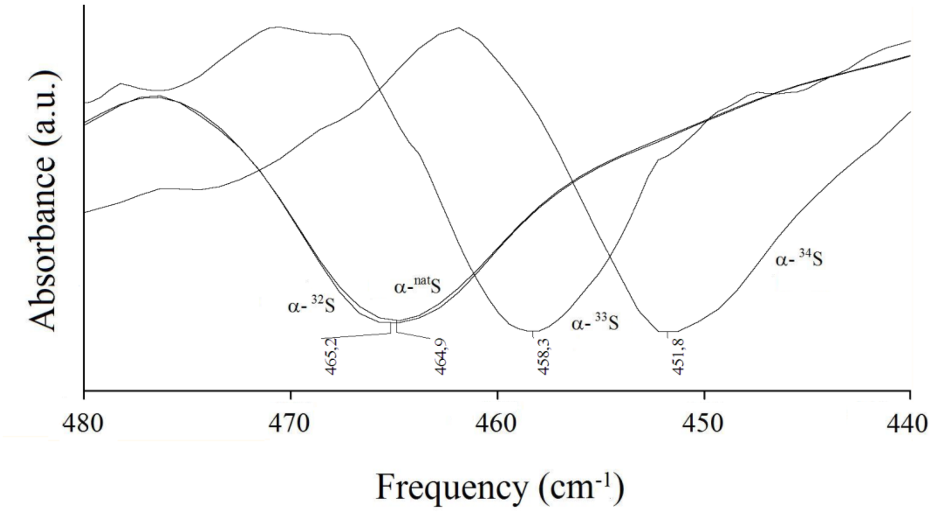


Fig.1. Raman spectra of the ^{32}S, ^{33}S, ^{34}S isotopes , and sulfur with the natural isotopic composition ^{nat}S.

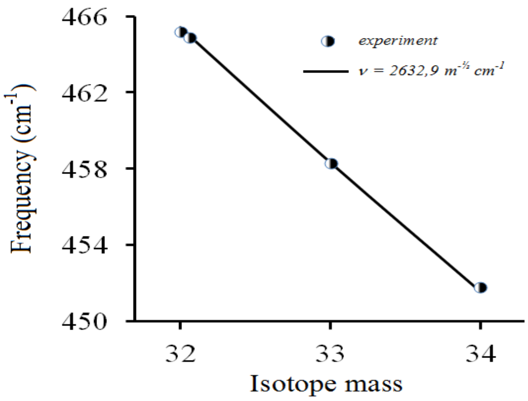


Fig.2. Isotopic dependence of the oscillation frequencies of α-S in the IR spectra

Isotopic dependence of the oscillation frequencies of α-S in the IR spectra shown in Fig. 2. Line shows the calculated dependence of the absorption frequency of the atomic mass of α-S isotope ($\nu=2632{,}9\ m^{-½)}$, which agrees well with experimental values. Fig. 3 shows the Raman spectra, obtained for polycrystalline samples of isotopes of α-S. In the spectra of isotopes observed all the absorption bands characteristic of α-S, but which according to the isotope shift depends $\nu = \propto m^{-½}$. Fig. 4 shows the experimental vibrational frequencies in the Raman spectra of the atomic mass of α-S isotope. As can be seen from the figure depending on the maxima provisions of the bands in the Raman spectra of sulfur isotopes are a linear function of the atomic masses of the isotopes.

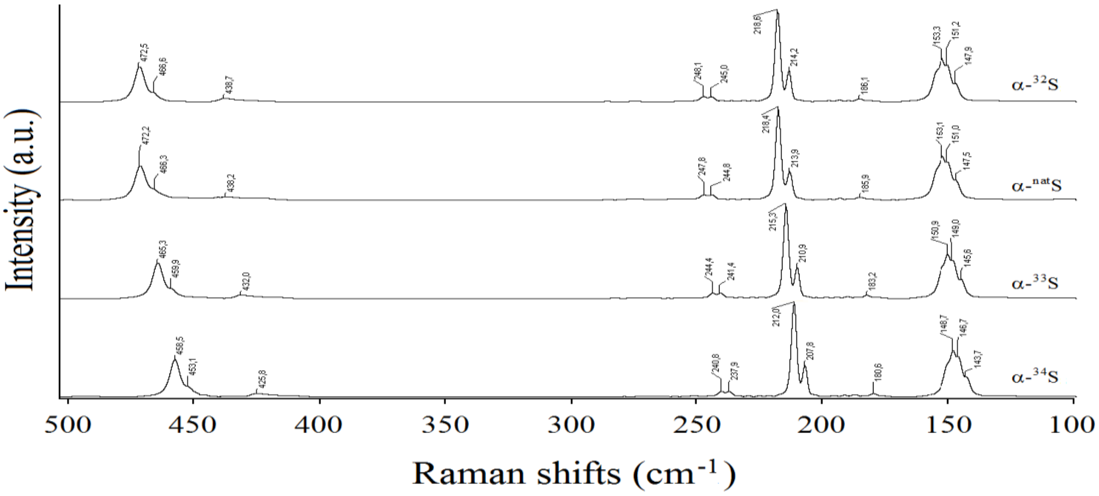


Fig. 3. Raman spectra of the isotopes α-^{32}S, α-^{33}S, α-^{34}S и α-^{nat}S

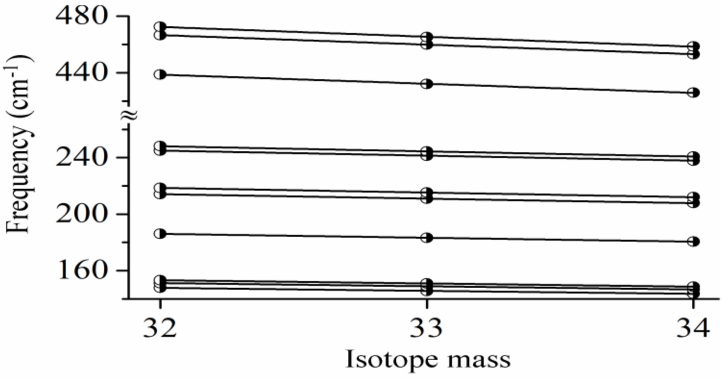


Fig. 4. Isotopic dependence of the oscillation frequencies of α-S in the Raman spectra

The obtained linear dependence on the known frequencies of isotope α-^{32}S, α-^{33}S, α-^{34}S allow to determine the oscillation frequency in the IR and Raman spectrum of sulfur isotope α-^{36}S, for which is difficult to obtain the vibration spectra due to its high cost associated with its low content in natural sulfur. Well known that cyclo-octa-sulfur can form three rystalline allotropic modifications, the first of which is stable at room temperature orthorhombic α -S [15]. Its structure was studied by X-ray analysis, and contains S8 as main structural elements, which are formed with each other like the columns [16].

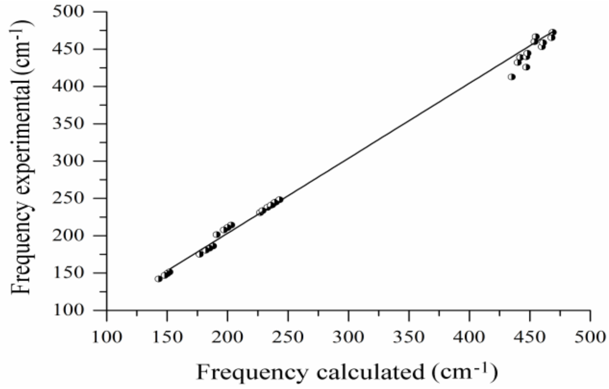


Fig. 5 The relationship between the experimental and calculated by B3LYP/6-31G method (d) frequencies of oscillation Raman spectra of sulfur isotopes α-^{32}S, α-^{33}S, α-^{34}S

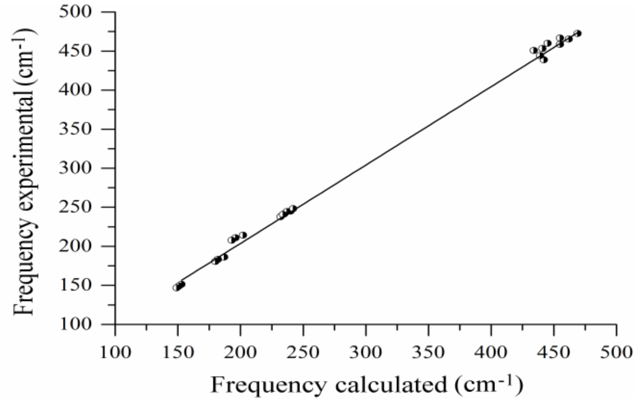


Fig. 6. The relation between the experimental and calculated by cc-PVTZ vibration frequencies Raman spectra of sulfur isotopes α-^{32}S, α-^{33}S, α-^{34}S

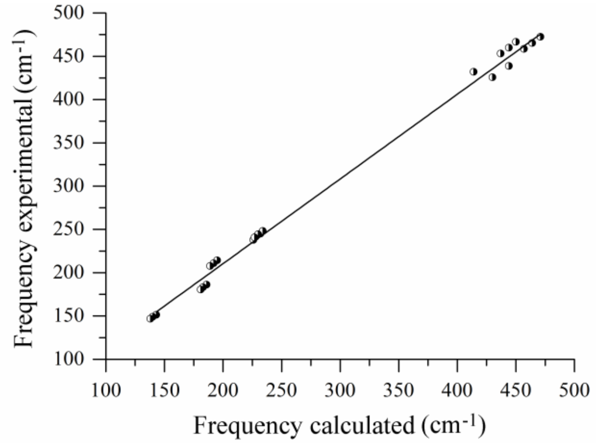


Fig. 7 The relation between the experimental and calculated by BP86/TZ2P+ oscillation frequencies of Raman spectra for sulfur isotopes α-^{32}S, α-^{33}S, α-^{34}S

Resistance of sulfur clusters is determined by the thermodynamic parameters. It should be noted that the experimental formation enthalpy of the transition from S_2 to S_8 virtually unchanged, while the entropy of formation varies considerably[18].

IV. CONCLUSION

1. IR spectra and Raman spectra of polycrystalline isotope α-^{32}S, α-^{33}S, and α-^{34}S are obtained.
2. Founded, that experimental frequencies of the vibrational spectra of the isotopes of sulfur decreases linearly with increasing mass of the isotope. From the experimental correlations, the oscillation frequencies for the isotope α-^{36}S are determined.
3. Obtained results demonstrate that the quantum-chemical calculations are sensitive to the isotopic shifts in the vibrational spectra of sulfur isotopes and are able to assess changes in their thermodynamic properties.

1. T. Ding, S. Valkiers, H. Kipphardt, P. de Bievre, P.D.P. Taylor, R. Gonfiantini and R. Krouse, Geochimica et Cosmochimica Acta, 65 (2001) 2433.
2. R.G.L. McCready, E.J. Laishley and H.R. Krouse, Archives of Microbiology, 109 (1976) 315.
3. J.W. Smith, S. Doolan and E.F. McFarlane, Chemical Geology, 19 (1977) 83.
4. H.G. Thode, J. Monster and H.B. Durford, Geochimica et Cosmochimica Acta, 25 (1961) 159.
5. R.R. Seal II, Reviews in Mineralogy & Geochemistry, 61, (2006) 633.
6. H.G. Thode, in H.R. Krouse and V.A. Grinenko (Eds.), Sulphur Isotopes in Nature and the Environment: An Overview/Stable Isotopes: Natural and Anthropogenic Sulphur in the Environment, John Wiley & Sons, Chichester, New York, Brisbane, Toronto, Singapore, 1991, Chapter 1.
7. H.R. Krouse, in P.W Rundel, J.R. Ehleringer and K.A. Nagy (Eds.), Stable Isotopes in Ecological Research, Springer-Verlag. New York, Heidelberg, Berlin, London, Paris, Tokyo, 1989.
8. T.E. Dawson, S. Mambelli, A.H. Plamboeck, P.H. Templer and K.P. Tu, Annu. Rev. Ecol. Syst., 33 (2002) 507.
9. Guidelines for the use of isotopes of sulfur in soil-plant studies, IAEA, Vienna, 2003.
10. M.P. Richards, B.T. Fuller, M. Sponheimer, T. Robinson and L. Ayliffe, Int. J. Osteoarchaeol., 13 (2003) 37.
11. I. Porras, Phys. Med. Biol., 53 (2008) 1.
12. M. Becucci, R. Bini, E. Castellucci, B. Eckert and H.J. Jodl, J. Phys. Chem. B, 101 (1997) 2132.
13. B. Eckert, R. Bini, H. J. Jodl, and S. Califano, J. Chem. Phys., 100 (1994) 912.
14. M. Becucci, E. Castellucci, P. Foggi, S. Califano and D.A. Dows, J. Chem. Phys., 96 (1992) 98.
15. R. Bini, S. Califano, B. Eckert, and H. J. Jodl, J. Chem. Phys. 106 (1997) 511.
16. M.J. Frisch, G.W. Trucks, H.B. Schlegel et al., Gaussian 03. Revision B03, Gaussian Inc PA, Pittsburg, 2003.
17. A.D. Becke, J. Chem. Phys., 98 (1993) 5648.
18. C. Lee, W. Yang and R.G. Parr, Phys. Rev. B., 37 (1988) 785.

CALCULATION OF THE THERMOPHYSICAL PARAMETERS OF FUEL TYPE IRT-3M

D.A. Ixanov, A.R. Sabekov, M.E. Torchasky
Scientific Supervisor: Assistant A.G. Naimushin
Linguistic Advisor: Teacher Ya.V. Ermakova
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: aikdanil@sibmail.com

Abstract.

This research work was carried out for to studying how fuel assemblies IRT-3M type behave them in active zone of "Sputnik" research reactor. Six- and eight-pipe fuel assemblies was calculated in special program, called TGRK (Thermo-Hydraulic Calculation of Channel). Squared in cross-section fuel elements were transformed into cylinders, because of program geometry requirements. Findings were compared with passport values of operating conditions. As results, on nominal power level of the Sputnik, temperature regimes of fuel assemblies are correspond to safety requirements.

I. INTRODUCTION

The active area of research reactor IRT-T [1], equipped only with instruments that allow to determine heat of the water coolant and the reactor thermal power in general. Determine the distribution of energy, the distribution of temperature fields on the reactor cells and fuel elements can only be with a program of neutron-physical calculations.

The purpose of this paper is the calculation of the thermophysical parameters of FA IRT-3M type in the IRT-T reactor core:

1) Preparation of input data for computer codes TGRK program;
2) The calculation of the temperature field;
3) Calculation of heat flows;
4) Critical parameters of the operation of fuel assemblies;
5) Preparation of a report and design report.

II. DEVELOPMENT, METHODOLOGY

Table 1 lists specified by the manufacturer (Novosibirsk Plant of Chemical Concentrates Plant) passport FA values of the operating conditions for the IRT-3M research reactor IRT.

Table 1. Legal values of the operating conditions of IRT-3M fuel assemblies for the research reactor IRT

Parameters	Value in normal operation
Position of FA in the core	Vertical
Coolant	Water
Direction of movement of the coolant	Top-down
Pressure of the coolant at the entrance to the FA, kPa	135 – 170
Pressure drop of the coolant at the core, kPa	35 – 70
Velocity of coolant, m/s	< 5.3
Temperature of the coolant at the entrance to the FA, °C	< 45
Maximum temperature on the surface of the fuel element, °C	< 100
Heat flux from the surface of the fuel element, kW/m^2	< 800
Boiling coolant on the surface of fuel rod	Not allowed

For other values of speed and coolant temperature at the inlet of the reactor power assemblies should be such that the maximum design temperature of the walls of the fuel rod (without mechanical coefficients) was less than 100 ° C.

In a technical report on the safety of the reactor IRT-3M indicates a more specific parameter values:

- The temperature of the coolant at the entrance to the active zone - 45 ° C;
- The pressure at the outlet of the reactor core - 133 kPa;
- Pressure drop across the core - 37 kPa.

Thermal calculation was performed for steady state reactor core during operation at nominal power level (6 MW).

As a result of neutron-physical calculations were obtained according to the calculated energy distribution of the cells of the active zone, height and azimuth of all FAs. Among them, for the thermal design of selected 8- and 6-tube bundle with the most intense settings. These distributions were input during the thermal calculation.

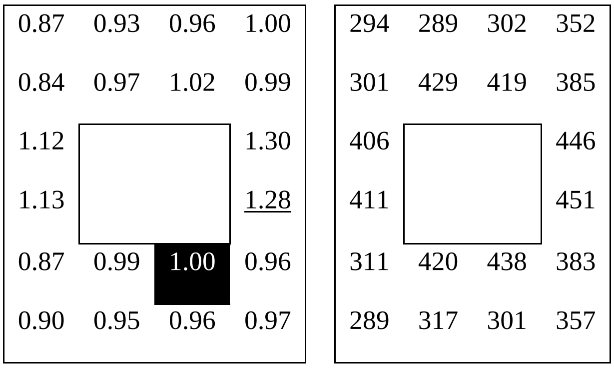
The temperature distribution of coolant and fuel element wall temperature on the height of the most intense FA were calculated in the approximation of one-dimensional cylindrical channel with coaxial fuel elements. The temperature of the coolant at the core inlet, the pressure in the volume of the active zone and the pressure drop across the core were set to be constant.

The calculations for the most intense high-altitude sections of the direction in azimuth and altitude of FA were determined:

- temperature of the coolant between the fuel elements,
- wall temperature of fuel elements,
- temperature limits shell-core fuel rods;
- maximum temperature of fuel-element cores;
- temperature of the onset of surface boiling
- supply of the surface prior to a boil,
- heat flow from the surface of the fuel elements,

III. RESULTS

The reactor core loaded with the IRT-T only fresh assemblies. The distribution of energy between the cells of the reactor is shown in Fig. 1. This figure also shows the estimates made by heat-flux density.



0.87	0.93	0.96	1.00
0.84	0.97	1.02	0.99
1.12			1.30
1.13			1.28
0.87	0.99	1.00	0.96
0.90	0.95	0.96	0.97

Energy release, rel. units.

294	289	302	352
301	429	419	385
406			446
411			451
311	420	438	383
289	317	301	357

The density of heat flow, kW/m^2

Fig. 1. The distribution of energy (normalized by the mean), and heat flux density over the cells of the active zone of the reactor IRT-T.

Of the most intense assemblies for thermophysical calculations have been selected (except for the power they had higher values of the coefficients of non-uniformity):

- among 8-tube FA - FA in the fourth row, right column (underlined);
- among 6-tube - third FA in the fifth row (highlighted in black).

The coefficient of uneven distribution of energy adjustment FA was:

- for 8-tube - 1.28;
- for 6-tubeh - 1.27.

In Fig. 2 shows the distribution of energy of height 8- and 6-tube FA.

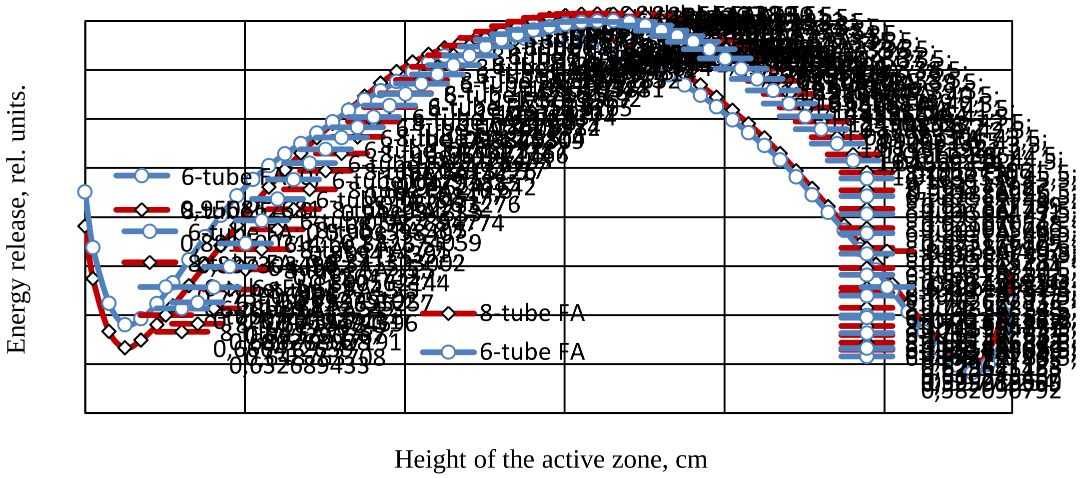


Fig. 2. The distribution of energy adjustment assemblies, normalized by the mean

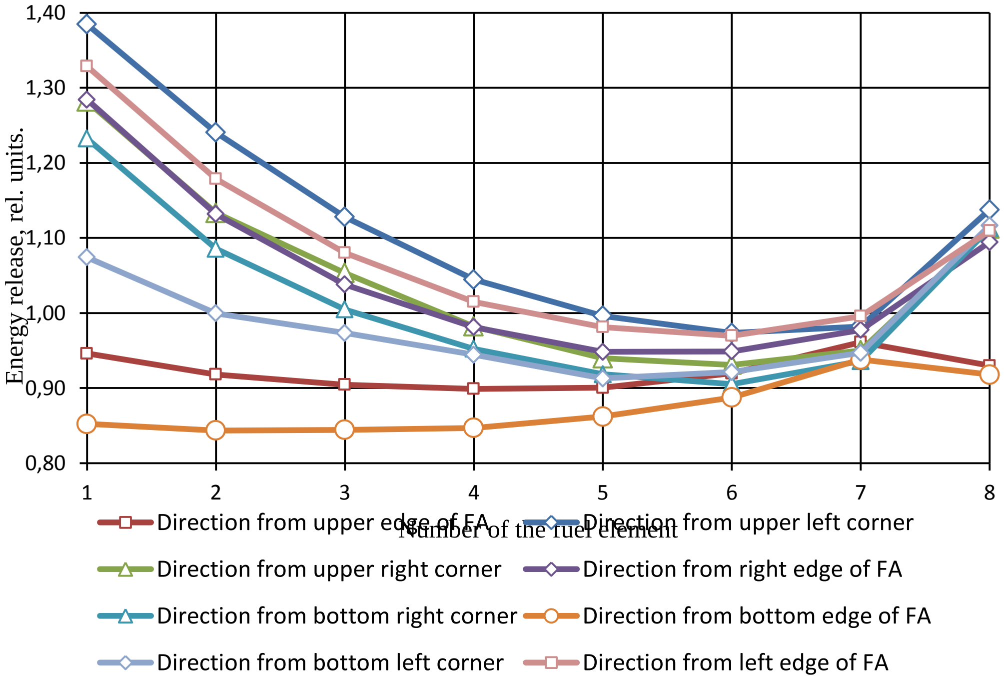


Fig. 3. The radial distribution of energy for the maximum weighted vosmitrubnoy FAs in different directions (normalized to the average of the fuel assemblies, fuel elements are numbered from the outer to inner)

Table 2. The radial distribution of energy for fuel elements

FA type	Number of the fuel element, measured from the outer							
	1	2	3	4	5	6	7	8
	Average (excluding azimuthal non-uniformity)							
8-tube	1,10	1,02	0,96	0,93	0,91	0,92	0,96	1,01
6-tube	1,03	0,99	0,97	0,96	0,98	1,02	--	--
	Maximum (of azimuthal directions)							
8-tube	1,37	1,23	1,12	1,03	0,99	0,96	0,97	1,12
6-tube	1,53	1,35	1,23	1,14	1,10	1,09	--	--

The average value of specific energy in the core fuel rod for vosmitrubnoy shestitrubnoy and FA in the maximum fuel assembly was loaded with 1.093 and 0.974 kW/cm^3 respectively.

With an average heating the coolant in the fuel assembly vosmitrubnoy 9,4 ° C the maximum temperature does not exceed 63,4 ° C. The highest power density in the fuel assembly has an outer fuel rods, so that in him and reached maximum values of fuel temperature (82,5 ° C), the surface of the shell (81,0 ° C) and maximum heat flux from fuel rod to coolant – 487 kW/m^2 – on the surface of the outer fuel element (evaluation stage of the physical calculation - 451 kW/m^2).

With an average heating the coolant in the fuel assembly shestitrubnoy 7,3 ° C the maximum temperature does not exceed 62,8 ° C. The highest power density in the fuel assembly has an outer fuel rods, so that in him and reached maximum values of fuel temperature (82,9 ° C), the surface of the shell (81,4 ° C) and maximum heat flux from fuel rod to coolant – 475 kW/m^2.

IV. CONCLUSION

The results of thermal calculations of fuel rods of the reactor core of the IRT-T prepared the data for computer codes TGRK program. It is shown that at rated power reactor fuel element temperature regimes fall within limits and comply with the requirements of technical safety justification.

1. Varlachev V.A., Gusarov O.F., Zabolotnov S.A. Issledovatelsky yaderny reactor IRT-T. Nuclear Research Reactor IRT-T. – Tomsk: TPU, 2002. – 56p.
2. Chertkov Yu.B., Ivanov A.A., Naimushin A.G.. Temperaturnye rejimi raboty tvelov reactor IRT-T. Temperature Work Regimes of Fuel Elements in Reactor IRT-T. – Tosmk: TPU, 2010. – 19p.
3. Kirilov P.L., Bogoslovskaya G.P. Teploobmen v yadernih energeticheskih ustanovkah. Heat Transfer in Nuclear Power Plants. – M.: Energoatomizdat, 2000. – 456p.
4. Dubovsky V.G.. Kriticheskie parametry system s delyashimisya veshestvami I yadernaya bezopasnost. Critical Parameters of Systems With Fissile Materials and Nuclear Safety – M.: Atomizdat, 1966. – 57 p.
5. Data base for research reactors // International Atomic Energy Agency. 2011. URL: http://nucleus.iaea.org/RRDB (Retrieved 13.05.2012).
6. Merzlikin G.Ya. Osnovy teorii yadernih reactorov. Fundamentals of the Theory of Nuclear Reactors. – Sevastopol: SIYa&P, 2001. – 273p.

7. Korotkih A.G., Shamanin I.V. Osnovi gidrodinamiki I teploobmena v yadernih reactorah: Uchebnoe posobie. Fundamentals of Fluid Flow and Heat Transfer in Nuclear Reactors: Manual. – Tomsk: TGU, 2007 – 91p.

8. Chirkin V.S. Teplofizicheskie svoistva materialov yadernoy tehniki: Spravochnik. Thermophysical Properties of Materials for Nuclear Technology: Handbook. – M.: Atomizdat, 1968.

9. Glushkov E.S., Demin B.E., Ponomarev-Stepnoy N.N., Hrulev A.A. Teplovidelenie v yadernom reactore. Heat Release in Nuclear Reactor. –□ M.: Energoatomizdat, 1985. □160 p.

10. Boiko V.I., Koshelev F.P., Shamanin I.V., Kolpakov G.N. Neitronno-fizichesky i teplogidravlichesky raschet reactor na teplovih neitronah. Neutron-physical and thermohydraulic calculation of reactor thermal neutrons: Handbook – Tomsk: TGU, 2002. –192 p.

ACCUMULATION OF AMERICIUM FOR TECHNOLOGICAL GETTING WEAPONS-GRADE PLUTONIUM

V.A. Lyamkin, N.B. Rachuk.
Principle investigator: PhD, Associate Professor K. V. Yushitsin
Language supervisor: Senior Teacher Y.V. Ermakova
Tomsk polytechnic university, 30, Lenina St., Tomsk, Russia, 634050
E-mail: lyamkin_vitaliy@sibmail.com

Abstract.

The isotope americium-241 are produced in industrial quantities in the decay of Pu241. Since Pu241 is usually present in the newly evolved in weapons-grade plutonium, Am241 accumulates in the medium with the collapse of Pu241 [1]. In industry, americium-241 used for a variety of test and research instruments, in particular, for continuous measurement of the thickness of the steel (0.5 to 3 mm) and aluminum (up to 50 mm) tape, and sheet glass. The apparatus of americium-241 used for the removal of electrostatic charges in the industry with plastics, plastic film and paper. It is also within some of the smoke detectors (~ 0.26 micrograms per detector) [2]. Considered the product obtained when U238 loaded into the reactor and subsequent exposure to thermal neutron flux. In this paper we consider the scheme of the Am241, and the calculated time of formation of the most efficient accumulation of the isotope. The results are presented in tables and graphs.

I. INTRODUCTION

Americium - silvery-white, malleable and ductile. Glows in the dark by its own α-radiation. Most of all he looks like a rare-earth metals family. It has two allotropic forms. In the low-temperature form has a double hexagonal close-packed structure, the density of 13.67, which at 1074 ° C is transformed into a face-centered cubic. The melting point - 1175 ° C.

II. APPLICATION OF AM

The most long-lived isotope of americium - Am243 has a half life of 8000 years and is used for radiochemical research and the accumulation of more remote transuranium elements up to fermium. Much more varied use of the first isotope of americium - Am241. It has a half life of 433 years. This isotope, decaying, emits alpha particles and soft (60 keV) gamma-rays (for example, the energy of hard gamma rays emitted by cobalt-60 - a few MeV). Protection against soft radiation of Am-241 is relatively simple and nonrecurrent: sufficient cm layer of lead. The industry uses a variety of control and measuring instruments, and research with the americium-241. In particular, for continuous measurement of the thickness of the steel (0.5 to 3 mm) and aluminum (up to 50 mm) tape, and sheet glass. The apparatus of americium-241 used for the removal of electrostatic charges in the industry with plastics, plastic film and paper. It is also within some of the smoke detectors (~ 0.26 micrograms per detector).

III. RECEIPT OF AMERICIUM

Am241 is now produced in commercial quantities in the decay of Pu241 as shown in Figure 1:

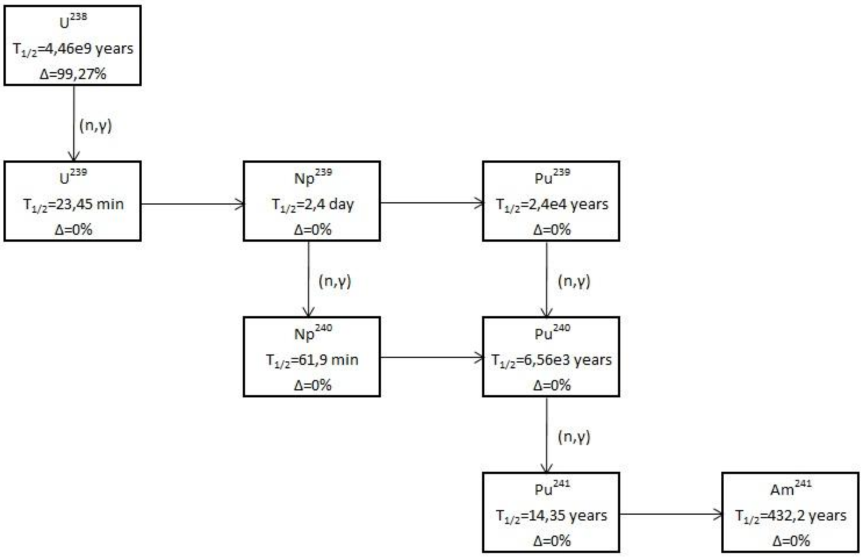
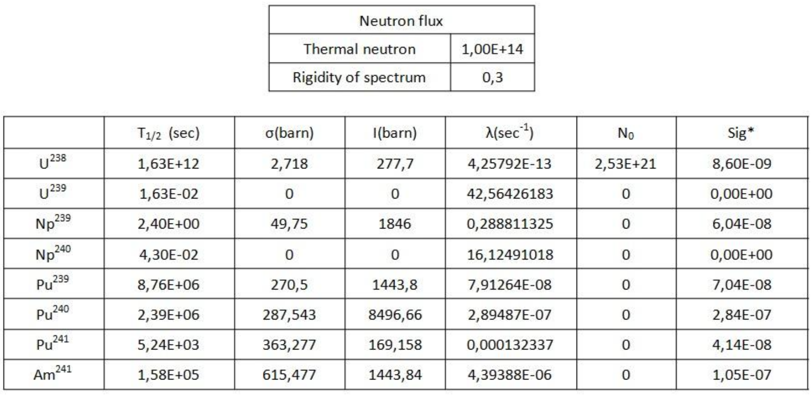


Fig. 1. *Accumulation chain of americium*

Since Pu-241 is normally present in the newly evolved in weapons-grade plutonium, Am-241 accumulates in the medium with the collapse of Pu-241. In this regard, it plays an important role in aging plutonevogo weapons. Svezheizgotovlenny weapons-grade plutonium contains 0.5-1.0% Pu-241 reactor-grade plutonium is from 5-15% to 25% Pu-241. After a few decades most of the Pu-241 decays to Am-241. Energetics of alpha decay of Am-241 and the relatively short lifetime of creating a high specific radioactivity and heat output (106 W / kg, for example, a Pu-241 thermal output of 3.4 W / kg). Most of the alpha-and gamma-ray activity of old weapons-grade plutonium is due to Am-241.

IV. MODELING THE DYNAMICS OF RECEIPT OF AMERICIUM

For these calculations were used the following table data

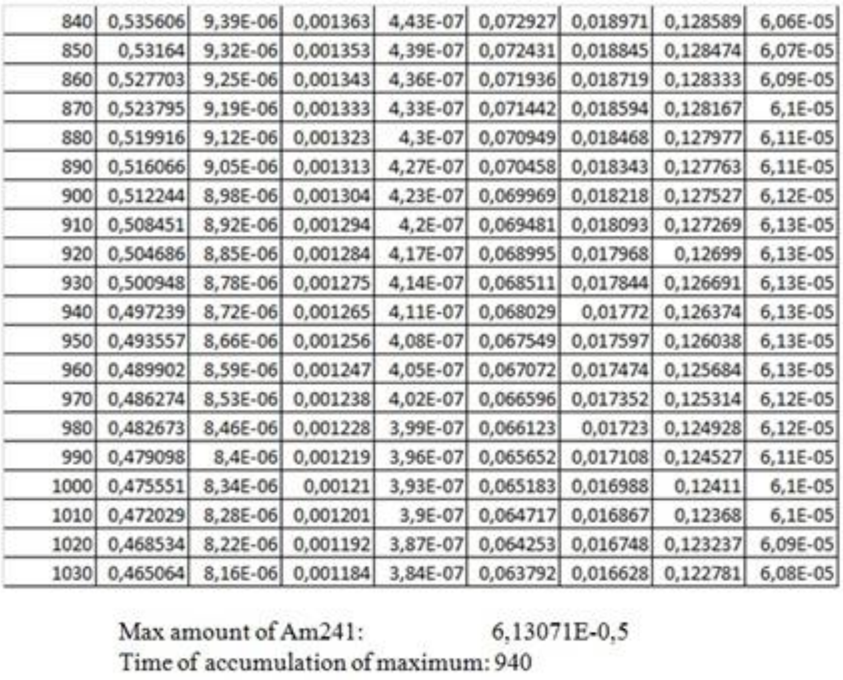


Neutron flux	
Thermal neutron	1,00E+14
Rigidity of spectrum	0,3

	$T_{1/2}$ (sec)	σ(barn)	I(barn)	λ(sec^{-1})	N_0	Sig*
U^{238}	1,63E+12	2,718	277,7	4,25792E-13	2,53E+21	8,60E-09
U^{239}	1,63E-02	0	0	42,56426183	0	0,00E+00
Np^{239}	2,40E+00	49,75	1846	0,288811325	0	6,04E-08
Np^{240}	4,30E-02	0	0	16,12491018	0	0,00E+00
Pu^{239}	8,76E+06	270,5	1443,8	7,91264E-08	0	7,04E-08
Pu^{240}	2,39E+06	287,543	8496,66	2,89487E-07	0	2,84E-07
Pu^{241}	5,24E+03	363,277	169,158	0,000132337	0	4,14E-08
Am^{241}	1,58E+05	615,477	1443,84	4,39388E-06	0	1,05E-07

Fig. 2. *Table data for calculations*

Calculations were performed in MS Excel. Outputs are shown in figure 3



840	0,535606	9,39E-06	0,001363	4,43E-07	0,072927	0,018971	0,128589	6,06E-05
850	0,53164	9,32E-06	0,001353	4,39E-07	0,072431	0,018845	0,128474	6,07E-05
860	0,527703	9,25E-06	0,001343	4,36E-07	0,071936	0,018719	0,128333	6,09E-05
870	0,523795	9,19E-06	0,001333	4,33E-07	0,071442	0,018594	0,128167	6,1E-05
880	0,519916	9,12E-06	0,001323	4,3E-07	0,070949	0,018468	0,127977	6,11E-05
890	0,516066	9,05E-06	0,001313	4,27E-07	0,070458	0,018343	0,127763	6,11E-05
900	0,512244	8,98E-06	0,001304	4,23E-07	0,069969	0,018218	0,127527	6,12E-05
910	0,508451	8,92E-06	0,001294	4,2E-07	0,069481	0,018093	0,127269	6,13E-05
920	0,504686	8,85E-06	0,001284	4,17E-07	0,068995	0,017968	0,12699	6,13E-05
930	0,500948	8,78E-06	0,001275	4,14E-07	0,068511	0,017844	0,126691	6,13E-05
940	0,497239	8,72E-06	0,001265	4,11E-07	0,068029	0,01772	0,126374	6,13E-05
950	0,493557	8,66E-06	0,001256	4,08E-07	0,067549	0,017597	0,126038	6,13E-05
960	0,489902	8,59E-06	0,001247	4,05E-07	0,067072	0,017474	0,125684	6,13E-05
970	0,486274	8,53E-06	0,001238	4,02E-07	0,066596	0,017352	0,125314	6,12E-05
980	0,482673	8,46E-06	0,001228	3,99E-07	0,066123	0,01723	0,124928	6,12E-05
990	0,479098	8,4E-06	0,001219	3,96E-07	0,065652	0,017108	0,124527	6,11E-05
1000	0,475551	8,34E-06	0,00121	3,93E-07	0,065183	0,016988	0,12411	6,1E-05
1010	0,472029	8,28E-06	0,001201	3,9E-07	0,064717	0,016867	0,12368	6,1E-05
1020	0,468534	8,22E-06	0,001192	3,87E-07	0,064253	0,016748	0,123237	6,09E-05
1030	0,465064	8,16E-06	0,001184	3,84E-07	0,063792	0,016628	0,122781	6,08E-05

Max amount of Am241: 6,13071E-0,5
Time of accumulation of maximum: 940

Fig. 3. *Outputs*

Processed data were obtained following graphs accumulation of americium by mass.

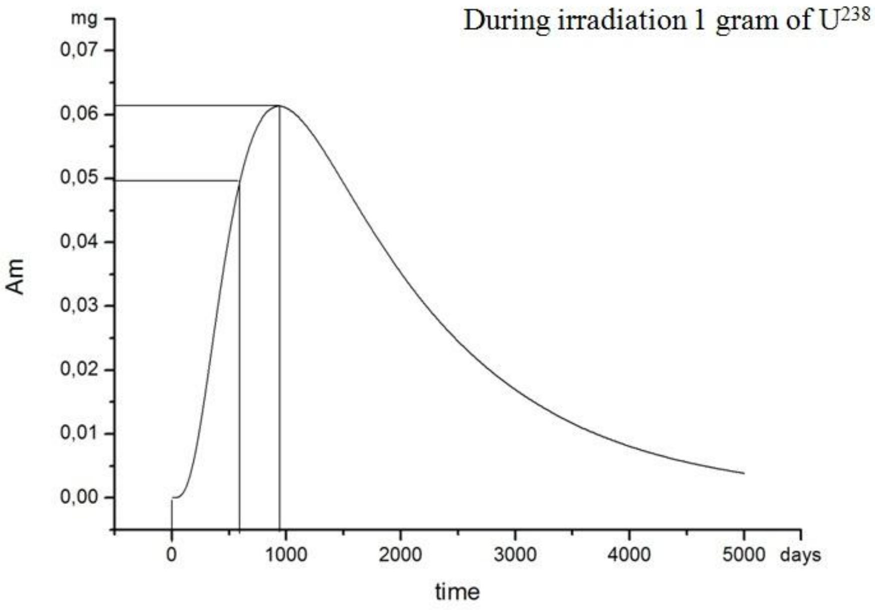


Fig. 4. *Accumulation of americium by mass*

The graphs show that 80% of the product is stored in half the time to achieve the maximum. The effective number of accumulated Am241:

$$m_{eff} = m_{max} * 0.8 = 6.13e\text{-}5 * 0.8 = 4.9e\text{-}5 \text{ g}$$

$$A_{eff} = A_{max} * 0.8 = 189 * 0.8 = 151 \text{ mkCi}$$

So much of the Am241 is accumulated in 580 days.

V. CONCLUSION

When downloading a gram of U238 the most advantageous time for producing the most effective amount of Am241 - 580 days During this time accumulated:

- 0.049 mg
- 151 mkCi

This Am241 enough for 188 smoke detectors.

1. WebElements Periodic Table of the Elements | Americium | crystal structures
2. Kharitonov.O., Isolation of americium-241 by size exclusion chromatography
3. Harmful chemicals. Radioactive substances: Ref. Ed. / VA. Bazhenov, LA Buldakov, IJ Vasilenko, etc. - Leningrad: Khimiya, 1990. 464 p.
4. "Chemical Encyclopedia", Moscow: Soviet Encyclopedia, 1988 pp. 125-126 vol.1
5. Encyclopedia of neutron data. Rosfond (Russian library of evaluated neutron data files).
6. Drits M E. Properties and other items. - Guide. - Moscow: Metallurgiya, 1985. - 672 p.V.I. Boiko, O.Y. Dolmatov, I.V. Shamanin, O.A. Nuzhin / / Combust. - 1996. - T. 32, № 1. - S. 58-65.
7. Plutonium - an article from the Encyclopedia of Physical
8. Radioactive substances / Eds. Acad. Academy of Medical Sciences LA Ilyin and others - Ref. ed. - L.: "Chemistry", 1990. - 464
9. Reactor Materials. The authors. Ed. D.M. Skorova. - Moscow: Atomizdat. 1968. - 385.
10. Miliukov, MS, NI Gusev, Sentyurin IG, Sklyarenko JS Analytical chemistry of plutonium. - Moscow: "Nauka", 1965. - 447 p.Refractory borides and silicides. - Kiev: Naukova Dumka, 1977. – 164.

PROCESSING OF POWDER MIXTURES OF REAGENTS WITH USING MECHANICAL ACTIVATION

S.A. Mamon, D.U. Voytenko, T.F. Subbota
Scientific advisor: Assistant A.O. Semenov
Language supervisor: Senior Teacher Y.V. Ermakova
Tomsk polytechnic university, 30, Lenina St., Tomsk, Russia, 634050
e-mail: elearr15@gmail.com

Abstract.

The title of the present work is "Processing of powder mixtures of reagents with using mechanical activation". This article is devoted to one of the most perspective materials technologies, the self-propagating high-temperature synthesis (SHS) and about the one of the ways of the management of SHS – mechanical activation. First of all, in given paper can be found information about purposes of application of SHS and main stages of this process. Next, article concern information about different types of mills, which used for hyperfine grinding, such as planetary, rotary, jet and vibration mills, principle of their work and constructions, and individual features. Besides this, can be found information about effect of mechanical activation - the changing of energy state of the substance in the process of grinding and its role in the self-propagating high-temperature synthesis. This paper may be useful for students who are interested in the modern methods of production of materials for nuclear industry.

I. INTRODUCTION

According to the development program of nuclear industry of Russia in 2007…2010 and until 2015 have been approved by the Russian government planned to implement an accelerated development of the nuclear power industry to ensure the country's geopolitical interests. This includes the issue of creating new materials for nuclear power plants for various of goods.

One technology is self-propagating high-temperature synthesis (SHS). This synthesis method has some specific features that distinguish it from existing methods for producing inorganic compounds: high temperatures and short times of synthesis, the small energy consumption, simplicity of equipment, the ability to manage the process of synthesis, and as a consequence, production of materials with a given combination properties[5].

Fundamentally the following ways to control the SHS are [6]:

1.Management in preparation of the bland.

2.Management during the process, which includes a thermal heating system.

3. Management during cooling of finished products consisting in changing the temperature regime of cooling and the type of atmosphere.

When management of the synthesis is the actual problem that needs a preliminary calculation and theoretical analysis parameters for the initial batch of components and of the process of SHS. To solve this problem should be modeling the main factors management self-propagating high-temperature synthesis.

II. TECHNIQUE OF EXPERIMENT

Synthesis of materials by using SHS includes the following steps:

- Mixing powders of the starting reagents according to the stoichiometric calculation of the corresponding equations for the reactions;
- Grinding of powders in a planetary ball mill;
- Drying the initial mixture of reagents in a technical vacuum;
- Mixing in the mill-type screw;
- Pressing the initial mixture of reagents into cylindrical tablets of different diameter and height variations in the values of the density of the material of samples by changing the compaction pressure;
- Implementation of SHS process in a laboratory setting and to obtain samples of functional materials;
- Processing of the samples.

III. DIRECTED SYNTHESIS

In the Tomsk Polytechnic University in recent years, the foundations of natural science of technology for production of new materials by self-propagating high temperature synthesis are being developed. These include materials based on tungsten boride and boron carbide, which are used in nuclear technology for the manufacture of protection against ionizing radiation combined flow and control systems and protection of physical and energy units (FEU) [1].There are several ways to control propagating high-temperature synthesis, which should be considered in relation to specific stages, and it changed settings. The main stages of the SHS is considered to be the preparation of the initial mixture, the synthesis mode propagate and the stage of cooling the combustion products, including the burning of. In this paper the method of SHS exposure on the course by changing the parameters of the initial components of the charge, namely the mechanical activation of charge and varying compaction pressure of the initial sample.

IV. MECHANICAL ACTIVATION

Currently, the grinding of the hyperfine features:

Planetary mill

Planetary mills represent an aggregate of several mills drum mounted on a vertical cage. On the axis of each mill planted gears that are meshed with a fixed gear. When you rotate the drum drove the mill rotate about the axis of carrier, as well as around its own axis. Grinding bodies in drums, have additional effects of centrifugal forces generated by rotation of the drum about the axis of carrier. In laboratory practice long used the planetary mill small batch. Mills developed a continuous process, ie Loading and unloading of material occurs on the move [2] .Figure 2.1 Diagram of the planetary ball mill AGO-2The main elements of the mill design are: a cylindrical body, with drums beating them placed in the steel balls, centrifuge, and capacity for grinding steel balls. The rotation of the centrifuge by means of an electric motor. Change the frequency of rotation can be either with the use of transmission shafts, or by using the inverter.

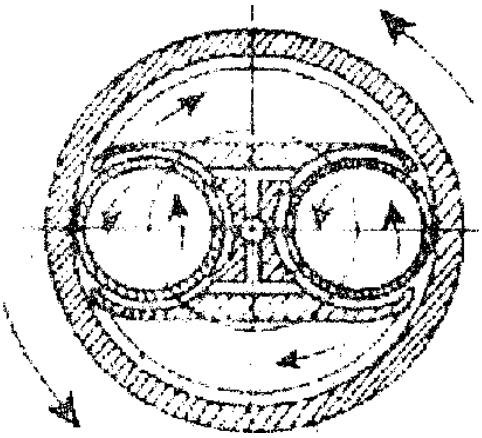


Fig. 1.The scheme of planetary ball mill AGO-2

Rotary mills

The principle of operation of these mills is based on the dispersal of material to be ground up to high speeds and their further impact on either the mill or scold each other. There are a lot of structures of these mills. All of them are characterized by high speed parts that break up the material, a large variety of different elements involved in the refinement [2].

Jet mills

Effect of jet mills is based on the kinetic energy of the gas or vapor. Gas or vapor passing through the nozzle, gets great speed, which is used to disperse the particles of crushed material. The grains of the material at a speed of 50-200 m / s moving in the gas stream and are destroyed on impact with a special "Demolition" plate, or as a result of mutual collisions of particles with tangential feed gas stream into the grinding chamber, or in collisions of oppositely directed jets of the grains [2] .

Vibration mills

Mixer Mill is a chamber filled with load, consisting of the material, the medium (gas or liquid), and special processing bodies (spheres, cylinders, rods, cylinders, pipes, etc.). Load reported by the motion of the periodic vibration of camera shake, or located in its special bodies. As a result, there is relative motion of the particle load in the zones of contact are high mechanical stresses, which lead to the destruction of solid particles [2].

At the core technologies of mechanically activated powder mixtures based on the method of mechanical activation using a planetary ball mill. The acceleration is calculated at the inner surface of the drum, the closest to the axis of rotation. In the process of grinding the material is subjected to high strain high degree. The high level of internal stresses created due to a large extent made during the deformation of the dislocations, disclinations, vacancies and other lattice defects. Despite the return of the structure, which takes place at lower temperatures, the internal stress level remains high. In preparing the mixture for later use in the process of SHS should be borne in mind that the main requirement for the mechanical activation process is to obtain the initial components of the structure with a large number of defects, but did not receive the product. Elementary structure of the starting point for the synthesis of N-charge shall be mechanical composite consisting of nano-structured source components. The presence of mechanical synthesis may slow down the processes of high-temperature synthesis and impairment of control over the process of composite materials. In this situation, the control parameters may be the time of mechanical activation, and the mill power density, which is determined by the centripetal acceleration of rotating drums [2]

Among the shortcomings of their designs include abrasive wear of the working bodies and the low efficiency of grinding. However, the principle of particles autogenous grinding during multiple high-speed collisions with each other in the jet and rotary mills should be considered positive, as this is realized the high power density (bulk density of mechanical energy is introduced into the grinding zone), flexibility and versatility Grinding installed in a wide range of technological properties of the crushed materials. Changing technological properties (reactivity) of fine fractions is achieved by dynamic adjustment and loosening the structure of the ground material. Changes in energy state of matter in the grinding process is called the effects of mechanical activation. According to modern physical concepts, mechanical activation - is a form of automatic excitation of activity of a substance at the stage of spontaneous destruction (self-destruction) loaded solids [3,4]. The level is determined by the type of mechanical activation mechanism and the mode of destruction, altering the depth of the disordered structure of the crushed material. Effects of mechanical activation during grinding attach great importance due to the increased rate of production and quality of end products for enrichment, sintering, briquetting, combustion, chemical and hydrometallurgical processing of minerals. Technological properties, in practice, evaluate different options, depending on the technological conversion of crushed products: binding properties, durability of products, dissolution rate, reaction temperature, flow rate of reactants, the degree of disclosure of valuable minerals, the efficiency gain.

1. V.I. Boiko, O.Y. Dolmatov, I.V. Shamanin, O.A. Nuzhin / / Combust. - 1996. - T. 32, № 1. - S. 58-65.
2. A.G. Merzhanov, I.P. Borovinskaya, Self-propagating high-temperature synthesis of refractory inorganic compounds. Report OIHK USSR Academy of Sciences, Chernogolovka, 1970. - 283.
3. Reactor Materials. The authors. Ed. D.M. Skorova. - Moscow: Atomizdat. 1968. - 385.
4. Kirsanov VV, The processes of radiation defect formation in metals. - M.: Energoatomizdat, 1985. – 395.
5. A.G. Merzhanov, B.I. Khaikin. Combustion of a substance with a solid reaction layer. // Reports of the Academy of Sciences CAS. – 1967. T. 173. – № 6. – P. 1382–1385.
6. A.G. Merzhanov. Self-Propagating High-Temperature Synthesis / Physical Chemistry: Modern Problems. Yearbook. Ed. Y.M. Kolotyrkin - Moscow: Khimiya, 1983. - P. 6 - 45.
7. E.A. Levashov, A.S. Rogachev, V.I. Yuhvid, I.P. Borovinskaya. Physical chemical and technological bases of self-propagating high-temperature synthesis.- Moscow: Publishing Bean, 1999. – 176
8. M.A. Korchagin, Effect of mechanochemical treatment on the rate and extent of combustion processes of SHS / M.A. Korchagin, T.F. Grigorieva, A.P. Barinov, N.C. Lyakhov. - Jnt. J. SHS. - 2000. - Vol. 9. - № 3. - P. 307-320.
9. V.I. Boiko, O.Y. Dolmatov, I.V. Shamanin, O.A. Nuzhin / / Combust. - 1996. - T. 32, № 1. - S. 58-65.
10. T.I. Serebryakov. High-temperature borides. - Chelyabinsk: Metallurgy, 1991. - 367.

IMPROVEMENT OF EDUCATION IN NUCLEAR SPHERE

S.A. Edreev, A.E. Kolchev, A.A. Mekhovich
Scientific Supervisor: Prof., Dr. V.V. Larionov
Language advisor: O. S. Glushakova
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: Edreev.stas@yandex.ru

Abstract.

The aim of this project is to make a contribution into nuclear industry by involving multimedia technology in educational process of students of nuclear sphere. One should be aware of the fact that it will make the process of learning much easier than it is and as consequence will improve quality of knowledge of students. Besides, this project is focused on the understanding of different basic nuclear physics processes with help of Microsoft flash animation.

The first part deals with the detailed description of visual aids during a lesson as well as with the problem of understanding of physics processes among the average student in the technical and non technical universities.

The second part covers the flash project which includes the example of multimedia in education.

After all the basic aspects being highlighted, the results of approbation and basic conclusion will be presented in detail.

I. INTRODUCTION

Key words: project, education, Microsoft flash, visual aids (animation)

Science: nuclear physics

Related science: computer science, methodology

Innovative approach in nuclear industry requires new approaches in the sphere of education of appropriate specialists. Science and technology developing allow introducing new methods of studying. It must be pointed that one of this methods is introducing educational multimedia animation programs. That is why the aim of this project is to create multimedia educational program (for nuclear physics).

The example of the program suggested in this work presents the project created on the basis of Microsoft flash to make the process of getting new skills in nuclear physics area more simple and feasible for every student owing to implementation of illustrative and animated theoretical material.

II. MODERN APPLICATION OF VISUAL AIDS DURING A LESSON IN RELATION TO THE PROBLEM OF UNDERSTANDING THE PROCESSES OF NUCLEAR PHYSICS

Today’s education requires a lot of innovational ideas to improve the process itself, to make educational process easier for students and for teachers and lecturers. Unfortunately, today only few students attend the library to take the books and learn “How it works”. Moreover, the high speed of the Development of the Internet and mass media leads to changes in people’s mind. Besides, al the high tech technologies contribute to the changes in the way of perception of new information.

The fact that should be taken into account is that there are some subjects in the university which are very hard even with using of books and lectures. For example, studying of physics as well as some of the physical processes isn’t very hard and they are intuitively clear for students such as low of uniform and direct motion. However there are a lot of processes in physics such as nuclear processes and thermodynamics processes which are extremely difficult for students even for students of technical specialties.

Thus, it leads to the idea that educational process must be improved anyway.

Multimedia technology is one of the easiest ways to solve the problem which was discussed above. The most of lecturers got used to apply the multimedia technology; in general it’s Microsoft PowerPoint presentations. It makes them free from writing and gives time to explain the slides and the process which is described. What is more a lot of teachers use the educational movies, and different cassettes with information (last point in general for teachers of different languages).

Without any doubt it makes make the process of perception of information a lot easier.

There is one very useful program which helps to create multimedia animation projects – Macromedia Flash.

III. “NUCLEAR TRANSFORMATIONS” – THE PROJECT IN NUCLEAR PHYSICS ON THE PLATFORM OF MF

Thus, if taking all stated into account it was decided to create multimedia Flash Project on the basis of Macromedia Flash to contribute to understanding nuclear physics processes. This project shows common nuclear reactions, include nuclear fusion and nuclear decay. In addition project contains schematic example of nuclear reactor and thermonuclear reactor. And as example of innovations, it contains the experimental thermonuclear reactor which was created in Tomsk Polytechnic University by the group of engineers.

So the example of such a project is about nuclear processes and it will show how ease can physics be:

1) The first step is to start the program. Here the first page of the project is presented. First page contains information about authors and supervisor

The next step is to start main menu – there student can choose the theme of nuclear physics. Very user-friendly interface and this program can show to even a little child the processes in the atom.

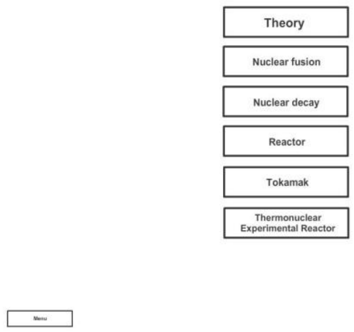


Fig.1 Main menu of project

2) After that to know all the processes in detail the theory of the topic is given.
3) Then the example of nuclear reactions is presented to help students to acquire new knowledge and understand all the nuisances. Any user can choose the process and push the button. All the processes will be shown, all the reactions will be on the panel.

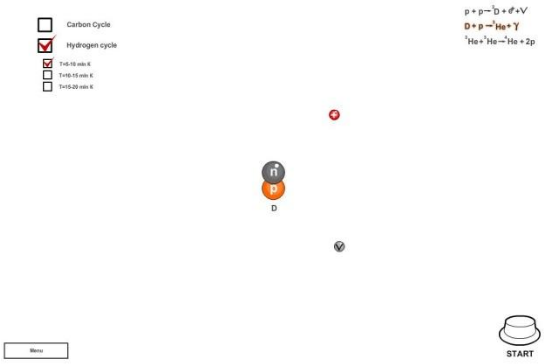


Fig. 2 Example of nuclear reaction

4) The next step is to give information about nuclear factory and to show clearly “how does it works”. You will see the way of working of a nuclear plant with the help of animation which makes the cognitive processes work and establish gooв connections between the image and theoretical information.

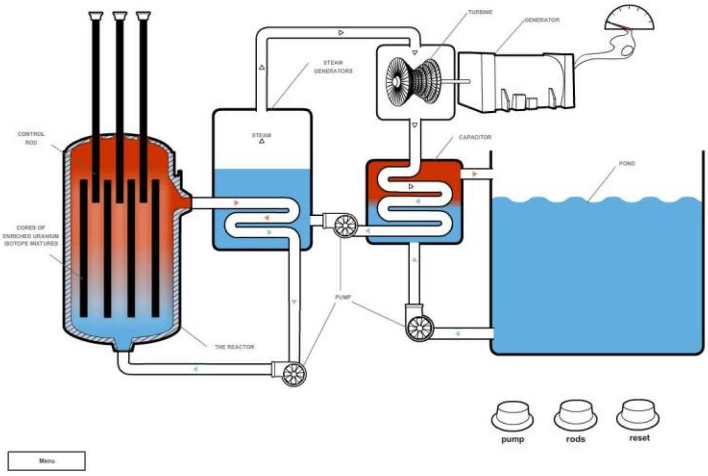


Fig.3 Model of nuclear reactor

5) By continuing using the menu we can easily the information about thermonuclear device. There is still not working models in the world. But the potential of such a device is incredible!

IV. RESULTS

The educational program was created with the intention to simplify the process of acquiring knowledge in the sphere of nuclear physics. The results were approbated on different faculties of Tomsk Polytechnic University.

To make the situation clear it should be stated that the results of approbation met all requirements as long as the program:

- is very simple in use;
- does the nuclear processes very clear to all students of the group;

- enhances students’ motivation in studying physics;
- contributes to the development of visual-image thinking;
- acts as means of increasing attention to the assimilation of the definite educational material;
- allows to specify the theoretical issues;
- makes the scope of practical application of material under study much broader;
- creates opportunities for modeling a number of processes;
- establishes lasting connections between the form of the theoretical material and its content;
- helps to enhance learning and cognitive activities of students.

Thus, resuming all the above aspects it must be noted that this project can be used by the students of non-technical faculties and even the students in high schools to simplify the process of studying.

1) Vitale, M. R., & Romance, N. R. (2000). Portfolios in science assessment: A knowledge-based model for classroom practice. In J. J. Mintzes, J. H. Wandersee & J. D. Novak (Eds.), Assessing science understanding: A human constructivist view. San Diego, CA: Academic Press.
2) Tsien, J. Z. (2007). The memory, Scientific American, July, 52-59.
3) Sperling, G. (1960). The information available in brief visual presentations, Psychological Monographs: General and Applied, 74(11), 1-30.
4) Sperling, G. (1963). A model for visual memory tasks, Human Factors, 5, 19-31.
5) Poenaru D. N. (1996) Nuclear Decay Modes. Institute of Physics, ISBN 0 7503 0338 7
6) http://www.yteach.com/page.php/resources/view_all?id=nuclear_fusion_atomic_mass_energy_thermonuclear_combustion_hydrogen_pellet_chamber_controlled_t_page_15&from=search
7) http://phns.mpei.ac.ru/scine1.htm
8) http://physics.ru/
9) www.vatican.va/.../rc_con_ccatheduc_doc_19831101
10) James L. M. (2004) Flash MX. Purdue University

APPLICATION OF GRS-METHOD FOR EVALUATION OF UNCERTAINTY OF LEVELIZED COST OF DEVELOPING NUCLEAR POWER SYSTEM

N.N. Oligerov
Scientific Supervisor: PhD, Associate Professor A.A. Andrianov
Linguistic Advisor: Associate Professor E.A. Avramova
National Nuclear Research University «Mephi» Obninsk Institute for Nuclear Power Engineering, Russia,
Obninsk, Studgorodok, 1, 249040
E-mail: oligerov_n@mail.ru

Abstract

The work presents the approaches and software developed for multi-objective optimization of nuclear power structures: the modules for energy planning package MESSAGE intended for modeling purposes of developing nuclear power systems and multi-objective evaluation of its effectiveness. Some results of implementation of these tools for multi-objective optimization of nuclear power structures are shown.

Keywords: *multi-objective optimization; scenarios of nuclear power development; pareto-effective set; advanced nuclear systems*

Nomenclature:

ACR Advanced CANDU Reactor, AFBR Advanced Fast Breeder Reactor, AFBR (Th) Advanced Fast Breeder, Reactor with Th blankets, ALWR Advanced Light Water Reactor, BN-K Sodium Cooled Fast Reactor, BR Breeding ratios, FBR Fast Breeder Reactor, FR Fast Reactor, MCDM Multi-Criteria Decision Making, HWR Heavy Water Reactor, NFC Nuclear Fuel Cycle, LWR Light Water Reactor, LWR (Th) Light Water Reactor with 233U oxide fuel, RBMK High Power Channel-type Reactor, VVER Water-Water Energetic Reactor, VVER(m) Modified Water-Water Energetic Reactor, SNF Spent Nuclear Fuel

I. INTRODUCTION

Currently, there is a growing understanding of the fact that the problem of optimizing the structure of the nuclear power industry is a multi-objective one [1]. There is a growing understanding that the problem of optimizing the structure of nuclear power system is multi-objective. At the same time, the criteria characterizing resource consumption, economy, the risks of unauthorized proliferation and waste management, are conflicting by nature. This means that improving the value of one criterion leads to a decrease in the values of other criteria.

This approach to solving the problem of optimizing the nuclear power system structure in the multi-objective formulation allows to search for compromises between conflicting system factors determining the nuclear power system development; to evaluate the impact of regional specifics on the whole range of efficient indicators; and, with the use of a calculation tool, to carry out comparative multi-objective analysis of options for nuclear power system development, taking into account the dynamics of development, the structure and the organization features of nuclear fuel cycle (NFC) and the most important system constraints and restrictions.

II. MAIN PART

These circumstances bring urgency to the development of multi-objective program systems to solve the problem of optimizing the structure of nuclear power system in multi-objective formulation. Software systems of this kind could provide a basis for decision support systems for multi-objective evaluation of the effectiveness of nuclear power system development scenarios, allowing multi-factorial comparison of its various structures to be made. One such software system is the MESSAGE code.

MESSAGE software (Model for Energy Supply Strategy Alternatives and their General Environmental Impacts) is a large-scale dynamic system engineering optimization model used for medium-and long-term energy planning, energy policy and energy development scenarios analysis [2]. The software was originally developed by the International Institute for Applied Systems Analysis. Currently, this software is supported by the IAEA, and is used in the toolbox of the INPRO project. MESSAGE software is a flexible modeling environment that allows the user to formulate a linear programming problem, to find the optimal solution and process the calculation results.

Despite the fact that the MESSAGE allows a multi-objective optimization based on the reference trajectory method, which is a variation of goal programming approach, this feature is not implemented in due measure. Moreover, this method in its present form does not allow carrying out a representative approximation of the efficient solutions set, a basis for interactive approaches to support the multi-objective decision-making. It should also be noted that the form of data input into the model does not allow to efficiently implement both traditional and state-of-the-art methods of multi-objective optimization and to take into account the uncertainty in the initial data. The latter is necessary to enhance the validity degree of recommendations made on the basis of calculations.

As part of the multi-objective optimization software systems development for multi-objective optimization of nuclear power systems, the following methods have been tested and implemented as computation modules for energy planning software MESSAGE:

methods of effective solutions selection through single criterion optimization (linear direct weighting of criteria and criteria constraints methods);

goal programming method;

reasonable goals method, which is an interactive method of multi-criteria decision-making support. Let us dwell briefly on the developed software modules.

The reasonable goals method was designed by the Computing Centre of the Russian Academy of Sciences [3]. The basis of the method is visualization of many possible feasible vectors by imaging it through bi-criterion slices. The use of the method is mainly intended for computationally complex cases of infinite number of possible solutions and vectors.

One of the goal programming method’s weak points lies in the fact that the ideal vector is given without taking into account the real system capabilities. Therefore, the attainable values of figures, even the closest to a given ideal, may prove to be far from it. The given method seeks to overcome this shortcoming. In accordance with this method, a set of practically feasible vectors is accessible for decision-makers in a clear, easy for perception form. One can choose a certain compromise among them.

The program module ParSAM (Pareto Set Approximation Module) for an energy planning software MESSAGE is designed for automation of the approximation and visualization of Pareto set as well as for accounting of uncertainties in system parameters. With the ParSAM, a user can create a base project set of linear programming problems, which are based on the criteria linear convolution method, and the solution of which conforms to the Pareto efficiency condition. With the created initial data set, the module allows serial calculations, processing the calculation results and presenting them in tabular and graphical form. All the sources, intermediate, and the resulting files are compatible with MESSAGE environment file formats. This allows, if required, making the necessary adjustments through MESSAGE environment.

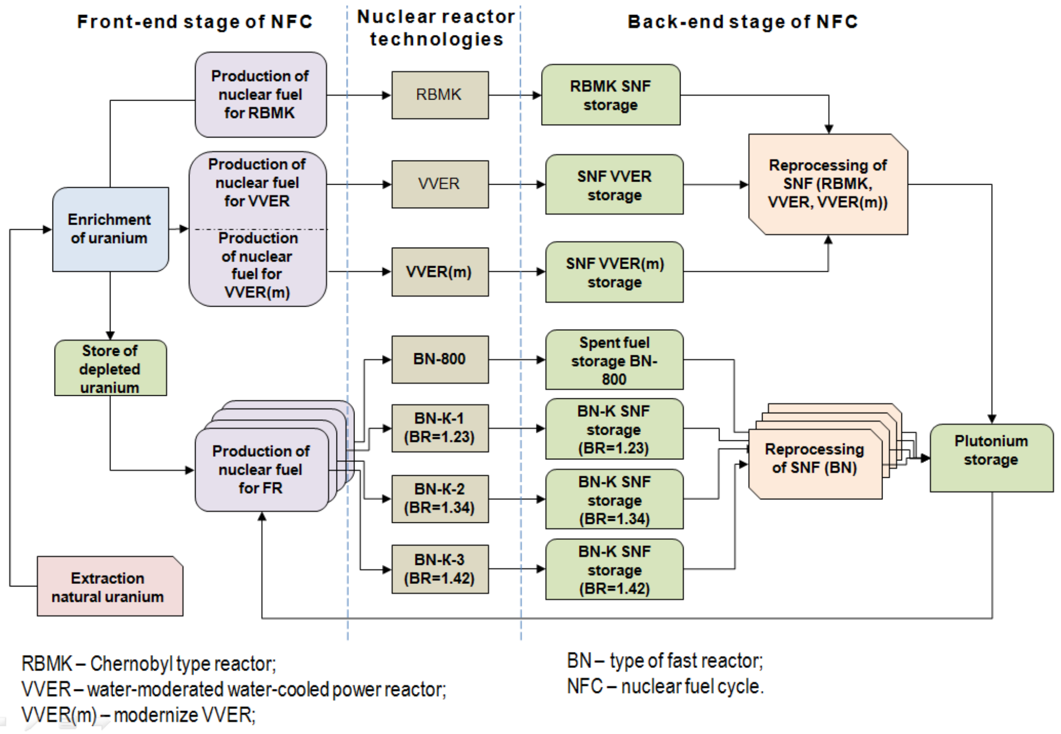
The basic functionality of the module:

forming a set of matrices for solving a parametric linear programming problem;
forming a set of files for post-optimization processing of calculation results;
controlling the MESSAGE modules to improve efficiency of the Pareto set approximation;
different ways of weights generation for the Pareto set approximation;
different ways of the Pareto set visualization.

Information on the Pareto set can be used to estimate the marginal rate of substitution, which can effectively support the selection of the most preferred criteria point in multi-objective problems.

The main programming language was chosen as C# which combines object-oriented and aspect-oriented concepts and was developed in 1998–2001 by Microsoft as a primary application development language for Microsoft platform .NET [4]. The choice of .NET technology is based on the following features: it allows efficiently developing applications for Windows, web-applications and web-services, and at the same time the .NET platform provides simultaneous support for designing and implementing software using different programming languages.

Using the reasonable goals method, the studies on Russian nuclear power with fast reactors with different breeding parameters were carried out to establish a compromise development strategy on a set of conflicting criteria (Figure 1).



RBMK – Chernobyl type reactor;
VVER – water-moderated water-cooled power reactor;
VVER(m) – modernize VVER;
BN – type of fast reactor;
NFC – nuclear fuel cycle.

Fig.1 Settlement scheme of NFC

The NP structure for the beginning of the prediction period consists of thermal reactors of the VVER and RBMK type. As initial data on quantity of spent nuclear fuel (SNF) being stored, and warehouse stocks of the allocated plutonium in model values of 16 thousand t (from them 9 thousand t of SNF RBMK, 7 thousand tons of SNF VVER) and 40 tons are used, respectively. In the long term, the structure of generating capacities can be completed with reactors of the following types - VVER, VVERm, using uranium fuel, FR-800, FR - K-1 (BR=1.23), FR - K-2 (BR=1.34), FR - K-3 (BR=1.42), using MOX fuel. The forecasting horizon is 150 years. Conditional values approximately corresponding to characteristics of the reactor installations VVER-1000 and FR-1200 and their fuel cycles were used as input data for material balances of nuclear reactors of model.

The ParSAM module was used to perform a multi-objective optimization of Russian nuclear power structure on the criteria of minimizing total discounted costs, total consumption of natural uranium, total amount of spent nuclear fuel and capacities of «sensitive» NFC technologies. For this set of criteria, a set of effective solutions was built demonstrating the upper productive limits of a given reactor technologies mix, and allowing choosing a compromise strategy of Russian nuclear power development on the set of criteria mentioned above.

For example, Figure 2 shows the so called alternative profiles of the four non-dominated solutions demonstrating the changes in integral indicator values for the last year's forecasting for four possible nuclear power structures. As can be seen from Figure 2, the improvement of an indicator is achieved by the deterioration of another, which corresponds to the condition of Pareto optimality.

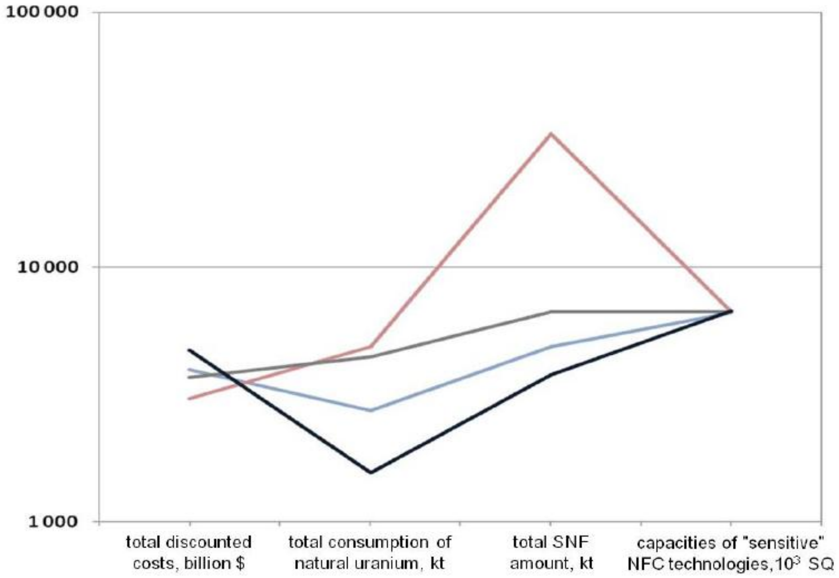


Fig.2. Profiles for four various nuclear power structures

III. RESULTS

The estimates performed showed the principal opportunity to solve the problem of finding a perspective nuclear power structure compromised from a set of indicators. It should be noted that a more diverse structure of nuclear power formed based on different reactor types allows getting closer to the desirable compromise goal. This approach, in contrast to the method of criteria restrictions, provides an opportunity to directly assess trade-offs between conflicting indicators.

The quantitative analysis performed shows that the considered scenarios are statistically

indistinguishable (90% confidence intervals of uncertainty of the levelized cost for various scenarios overlap). This suggests that it is impossible to make definitive judgments about the prospects of one or other structure on economic indicators, taking into account the existing uncertainties in the unit cost data.

The program modules developed for the MESSAGE power planning environment are intended for modeling of developing nuclear power systems and a multi-objective assessment of efficiency of their functioning taking into account uncertainty of the basic data.

Experience in the use of program modules showed that they are a convenient and reliable tool to help solve problems of the multi-objective optimization arising in the field of systems-analytical and predictive research to validate the nuclear power system development priorities.

IV. CONCLUSION

The developed software enables solving such optimization problems in multi-objective formulation. This allows searching for compromises between the conflicting system factors that determine the nuclear power system development; to evaluate the impact of regional development differences on the whole range of efficiency indicators; and, with the use of a unified calculation tool, to carry out comparative multi-criteria analysis of alternatives for nuclear power system development, taking into account development dynamics, the structure and the organization of NFC and the most important system constraints and restrictions.

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1. IAEA-TECDOC-1362, IAEA, Vienna (2003).
2. S. Messner, M. Strubergger User’s guide for MESSAGE III, WP-95-69, IIASA (1995).
3. V.V. Tokarev. Methods of optimum decisions, book 2: Handbook (Physmatlit, 2010).
4. A. Lotov, V. Bushenkov, and G. Kamenev. Interactive Decision Maps. Approximation and Visualization of the Pareto Frontier: (Kluwer, Boston, 2004).
5. A.N. Rymantcev Safety forecasting in nuclear power. Atomic energy, (2007), p.80-85.
6. http://msdn.microsoft.com
7. A.A. Andrianov, Yu.A. Korovin, E.V. Fedorova. Closed nuclear fuel cycles with fast reactors: scenarios of worldwide nuclear power expansion/ Paper 9231. Proceedings of Global 2009. (Paris, France, September 6-11, 2009).
8. A.A. Andrianov, Yu.A. Korovin, E.V. Fedorova. Method of criteria restrictions in problems of optimization of structure of global nuclear power in the environment of MESSAGE / News of higher educational institutions. Nuclear power: Handbook (2010), p. 165-175.
9. A.A. Andrianov, V.V. Korobeinikov, E.V. Poplavskaya, E.N. Rachkova, E.V. Fedorova Optimizing researches of structure of nuclear power industry of Russia with reactors on thermal and fast neutrons with use of a package of MESSAGE / News of higher educational institutions. Nuclear power: Handbook (2010), p. 156-164.
10. Advanced Nuclear Fuel Cycles and Radioactive Waste Management OECD, Nuclear Energy Agency.

DEVELOPING THE CONCEPT OF A SPECIALIZED REACTOR FOR NUCLEAR DOPING OF SILICON BLANKS

A.I. Perov, E.V. Belov
Scientific Supervisor: PhD, Associate Professor, Yu. B. Chertkov
Linguistic Advisor: Senior Teacher Y.V. Ermakova
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: perovindahouse@mail.ru

Abstract.

This article is about neutron-transmutation method of silicon doping.

In this scientific work is presented the main aspects of conception of special reactor for silicon doping of large blocks.

The first part describes approximate material composition of reactor core, moderator, coolant and reflector.

In the second and main part is given information about calculation and results which was made during researches of layout of the reactor.

Parameters such as neutron flux density, coefficient of irregularity and neutron fluence are presented.

Based on received data and dependences was made conclusions about optimal configurations of the projected reactor, in particular material content and layout.

I. INTRODUCTION

Radiation doping of silicon (RLC) is one of the stages of the production technology of semiconductor materials that are used for the manufacture of electronic circuits and power devices. When irradiated with neutrons produced silicon alloying element - phosphorus. Neutron doping of silicon in a nuclear reactor is currently the most advanced methods of radiation doping of semiconductors[4].

The basis neutron transmutation doping (NTD) are the nuclear reactions that occur in a silicon crystal. Under the influence of the thermal neutron flux is formed of a radioactive isotope ^{31}Si and its subsequent decay with the formation of stable phosphorus 31P. The resulting ^{31}P creates an n-type conductivity.

$$^{30}Si\ (n,\gamma)\ ^{31}Si \xrightarrow[2{,}64\ hour]{} {}^{31}P$$

The efficiency of neutron techniques to a large extent determined by the quality of the available neutron sources, primarily neutron flux density. The main types of neutron sources to date are nuclear reactors - continuous sources used to produce neutrons by uranium fission chain reaction.

The main purpose of the work is developing the concept of the reactor, providing the effective value of the neutron flux density of 10^{14} n/cm^2 · to the siting case with silicon blanks with diameter of 450 and a thickness about 130 mm. The maximum thermal power of the reactor during operation must not exceed 20 MW. The geometry of the foam and the siting of the parameters of the neutron field in place should ensure uniformity of doping in terms of procurement, as close to the theoretical value. The developed concept should contain sufficient information to begin work on designing a specialized reactor for nuclear doping of silicon blocks of big sizes[4].

II. PROGRESS OF DEVELOPMENT

At the first stage of the work has been selected the materials of the reactor, a reactor designed with the specifications required for a particular spectrum and neutron flux density in the core.

Since one of the limitations of the designed reactor is to ensure nuclear non-proliferation and elimination of the possibility of use of weapons-grade plutonium, the fuel is imposed restriction on enrichment of uranium-235 - no more than 20%.

Since the reactor power is limited to 20 MW and the flow not be less than 10^{14} n/cm^2 · s, moderator material must absorb neutrons weakly, and small enough to ensure the active zone. As a result, eliminated the use of graphite (small retarding capacity) and light water (high neutron absorption).

Therefore was chosen the following material composition of the reactor core:

1) Dispersion fuel elements with oxide uranium fuel enriched to 19.8% uranium-235.

2) Heavy water and (or) beryllium as a moderator and reflector.

3) Coolant - light water.

In the second stage made of neutron-physical calculations to find the optimum geometry and dimensions of the reactor to produce the desired neutron flux in the volume of pieces of silicon. Two models were considered by the layout of the reactor:

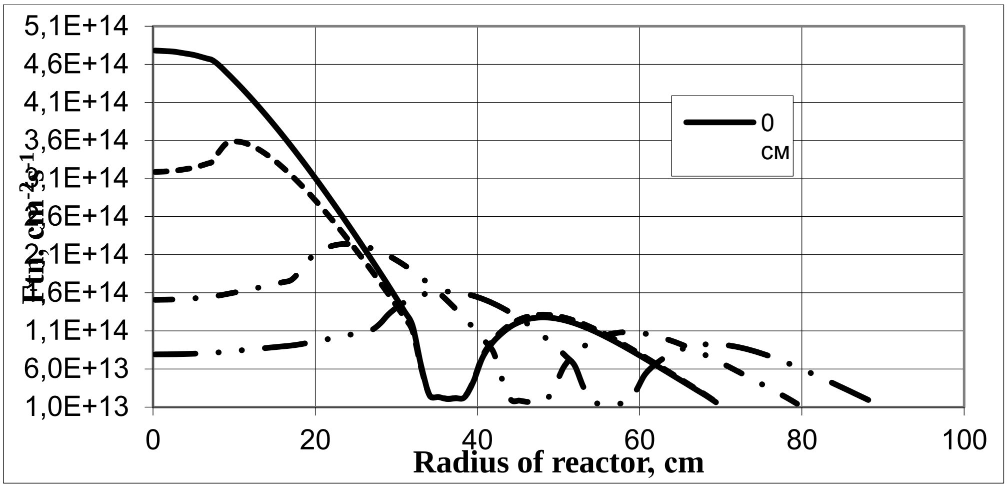
1) In the center of the core is the only channel with silicon surrounded by fuel cells dispersed in the volume of the moderator.

2) In the center of the core are three channels of silicon surrounded by fuel cells dispersed in the volume of the moderator.

The space in the center (between the channels of silicon) is filled with iron, which allows you to align the flow in the center of the core. Neutron calculations for all three variants were carried out in the layout program Wims-D5 c using a cylindrical geometry. For the first model, the layout of the reactor were calculated thermal neutron flux density, varying depending on the diameter of a silicon block.

Calculations were performed for the central silicon block diameters 15, 35, 55 cm, while maintaining the thickness of the surrounding ring of heavy water - 25 cm ring core - 7.5 cm, and the heavy reflector - 30 cm.

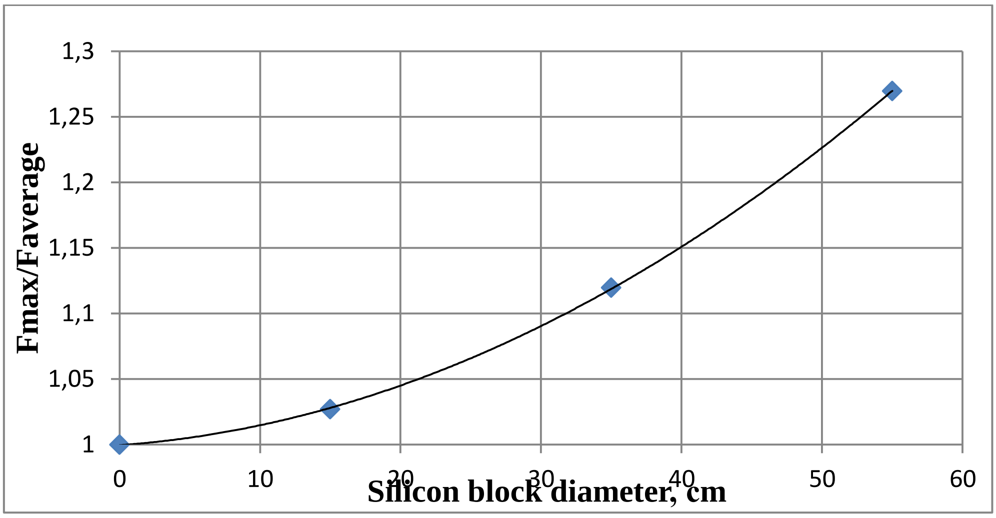
The graph below is illustrating the calculated neutron flux along the radius of the reactor.



[1]Fig. 1. Dependence F_{tn} from radius of reactor with single silicon block

The larger the diameter of the silicon block, the lower the density of the thermal neutron flux in it. The rigidity spectrum in the investigated range of diameters of blanks satisfies the allowed values for the doping of silicon.

Coefficient of irregularity of the flux density along the radius of the reactor, calculated as the ratio of maximum flux to the average radial:

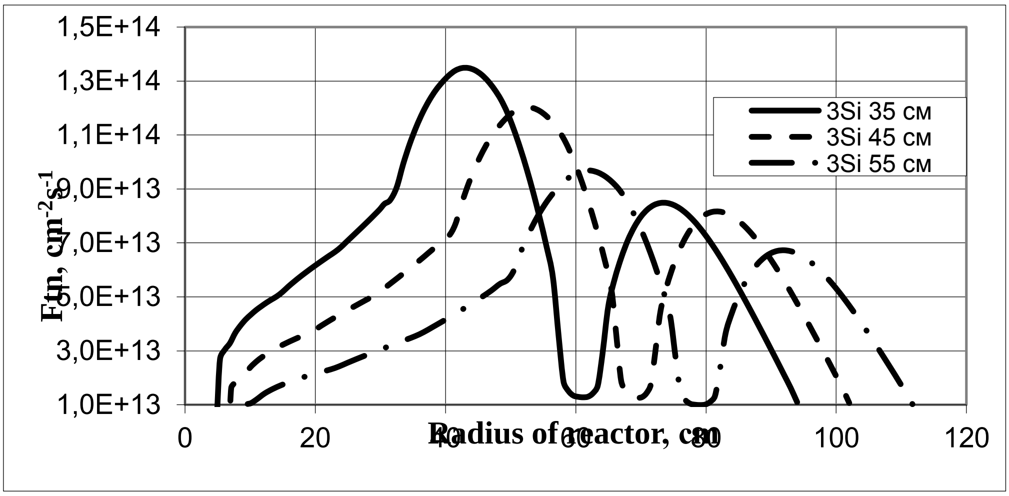


[1]Fig. 2. Cofficient of irregularity

Irregularity coefficient increases sharply with increasing diameter of the sample. A serious disadvantage of placing the sample in the center of the reactor is the inability to align the neutron fluence at the sample means of the rotation.

For the second model, the layout of the reactor was calculated thermal neutron flux density, varying depending on the diameters of the three identical silicon blocks. Calculations were performed for three diameters of silicon ingots 35, 45, 55 cm each, while maintaining the thickness of the surrounding ring of heavy water - 25 cm annular core - 7.5 cm, and the heavy reflector - 30 cm in the central space between the silicon block is hollow iron rod, which serves for a linear decay of neutron flux density in the silicon block.

The graph below is illustrating the calculated neutron flux along the radius of the reactor.

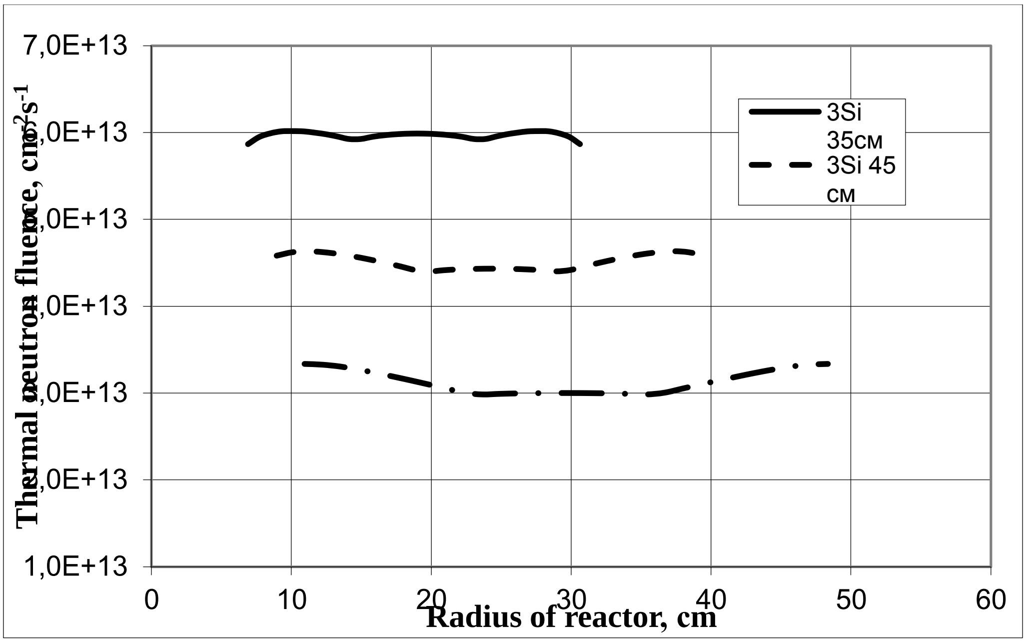


[2]Fig. 3. Dependence F_{tn} from radius of reactor with 3 silicon blocks

The density of the thermal neutron flux in this model, the layout of the reactor is significantly lower than the previous version. With increasing diameter of the silicon block decreases the flux density of thermal neutrons in its volume.

This graph illustrates the almost linear decrease of neutron flux density in the volume of silicon. This allows you to align the neutron fluence in silicon by means of block rotation.

The neutron fluence per unit time during the rotation of silicon blocks is shown in the graph below.



[2]Fig. 4. Thermal neutron fluence in 3 silicon blocks

Coefficient of irregularity in this case is obtained to be satisfactory for blocks with diameters of 45 cm and below.

III. CONCLUSION

Thus it can be concluded that for a given material composition of the reactor, the optimum from the standpoint of the uniformity of the neutron fluence at the silicon sample is the method of placement three blocks of silicon in the center of the reactor. However, in this case, the average neutron flux in the sample is much lower than the placement of a single sample.

1. WIMS-D LIBRARY UPDATE. IAEA. Vienna, 2007. Pub1264_web.pdf .http://www.oecd-nea.org/tools/abstract/detail/nea-1507
2. Report of the Institute of Atomic Energy. Kurchatov "in the program WIMSD ES-1040 inv 35/90479, 1979
3. Bat G.A, Kochenov A.S, Kabanov L.P «Nuclear research reactors» textbook for high schools. Atomizdat, 1972, 272 pp.
4. http://www.megabook.ru/Article.asp?AID=645934 «Neutron doping of silicium»
5. VL Aksenov. Pulsed neutron research reactors. Physics particles and atomic nuclei. 1995, Volume 26, no. 6, p. In 1449.
6. Koenraad, Paul M.; Flatté, Michael E. (2011). "Single dopants in semiconductors". Nature Materials 10 (2): 91–100. Bibcode 2011NatMa..10...91K. DOI:10.1038/nmat2940. PMID 21258352.

7. P.E. Schmidt and J. Vedde, "High Resistivity NTD Production and Applications," Electrochemical Society Proceedings, Vol.98-13, 3 (1998).
8. B. J. Baliga, Modern Power Devices, p.32, John Wiley & Sons, New York (1987).
9. K.V.Shalimova, Physics of Semiconductors, Energoatomizdat, 1985
10. Dharma Raj Cheruku, Battula Tirumala Krishna, Electronic Devices and Circuits, 2nd edition, 2008, Delhi, India, ISBN 978-81-317-0098-3

MODELLING OF SPONTANEOUS HIGH-TEMPERATURE SYNTHESIS

I.E.Shabalin
Scientific Supervisor: PhD, Associate Professor D. S. Isachenko
Linguistic Advisor: Senior Teacher Y.V. Ermakova
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: ill-leech@rambler.ru

Abstract

The need for unconventional technical approaches, allowing synthesizing materials with preset properties has appeared lately.

The process of self-sustaining high temperature synthesis (SHS) has high potential from the point of obtaining of new materials, which may turn out to be the base for solution of numerous problems of nuclear industry.

SHS, or combustion synthesis, is the process designed for production of diverse ceramics via direct synthesis of refractory inorganic and intermetallic compounds during exothermal reaction between chemical elements.

Along with safety and efficacy in achievement of set goals, any research should be conducted with the lowest costs possible. Therefore, any experimental work requires theoretical computation.

The objective of this project work is to develop numerical model of combustion process during SHS process. To achieve the goal C# programming language was used. Current project work is meant to satisfy needs of nuclear industry, but the field of research is adjacent to programming, quantum physics, numerical methods, and thermal physics

I. INTRODUCTION

The gist of SHS process is as follows. The result of local reaction initiation in a thin layer of solid reagents is the spontaneous propagation of combustion wave all over the system. This process goes by means of thermal conductivity. SHS has number advantages over conventional processes of sintering. These advantages are: electricity consumption is greatly reduced due absence of necessity to maintain high temperatures for a long time; high efficiency; high purity of obtained specimens [1].

A variety of promising materials have been attained by means SHS. On top, some regularities of combustion and structure formation in powder-like mixtures of chemical elements, depending on initial conditions and the mode of reaction, have revealed themselves in the following products: carbides, borides, intermetallides, and sulfides [4].

It is hardly possible to obtain all the variety of material only in laboratory. Hence, the necessity of preliminary design-theoretical analysis of SHS arises. In such a case it is necessary to compute the regularity of combustion wave propagation in observed SHS-systems and the initial conditions in a furnace.

Hence, the following purpose arises. It is obligatory to supplement experimental base with a theoretical–computational one. It includes the following subparagraphs.

1. Brief introduction to SHS theory and its basic features.
2. Acquaintance with numerical method for solution of second order differential equations called sweep method.

3. Use of this method in case of non-linear non-uniform equation of thermal conductivity
4. Obtaining the solution of the equation with sweep method with C # package.

II. METHODOLOGY

As the combustion wave moves through the specimen, its substance undergoes a reaction, which results in a change such properties as: density, thermal capacity, thermal conductivity and etc. The combustion wave represents itself as narrow zone (its width is less than 1 mm), where the synthesis takes place along with the release of large amount of thermal energy. This energy goes to sustain synthesis reaction and heating of zone of preliminary heat-up. Therefore, to solve the problem it is necessary to solve the following non-linear, non-uniform thermal conductivity equation [2]:

$$a\left(T\right)\cdot\left(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\cdot\frac{\partial T}{\partial r}+\frac{\partial^2 T}{\partial z^2}\right)+\frac{q_V}{C(T)\cdot\rho}=\frac{\partial T}{\partial t} \tag{1}$$

where $a(T)$ — thermal diffusivity, $C(T)$ — specific thermal capacity, ρ — density, q_V — specific heat release.

The equation (1) is a boundary problem and it demands boundary condition if any particular solution is to be found.

1. $$\lambda\frac{\partial T}{\partial r}\Big|_{z=R}=-\alpha\cdot(T_{z=R}-T_S)-\varepsilon\sigma(T^4_{z=R}-T^4_S)$$
   $$\frac{\lambda\cdot\partial T}{\partial r}\Big|_{z=R/2}=0$$
2. $$\lambda\frac{\partial T}{\partial z}\Big|_{z=H}=-\alpha\cdot(T_{z=H}-T_S)-\varepsilon\sigma(T^4_{z=H}-T^4_S)$$
   $$\frac{\lambda\cdot\partial T}{\partial z}\Big|_{z=H/2}=0$$

where α — heat transfer coefficient, ε — emissivity, $\sigma\left[\frac{J}{\sec\cdot m^2K^4}\right]=5,67\cdot10^{-8}$ — Stefan-Boltzmann constant, T_S — ambient temperature, T_{in} — preliminary heat-up temperature.

This equation (1) does not have analytical solution. It can only be solved by means of numerical methods. The finite-difference sweep method is used to solve it.

The gist of the method is as follows. The continuous argument is replaced with finite amount of joints. This system is called grid. Functions of discrete argument, which exist only in joints of grid, and which are called grid functions, are used instead of continuous functions. Derivatives included in differential equation and boundary conditions are replaced with their discrete analogs – linear combinations of grid function values in different joints of the grid. Eventually, the boundary problem is replaced with discrete boundary problem (difference scheme), which is finite a system of linear and non-linear algebraic equations. The solution of differential scheme (it is presumed to persist) is considered to be an approximate solution to the boundary problem.

It is necessary to remember that thermal diffusivity is a function of temperature:

$$a(T)=\frac{\lambda(T)}{C(T)\cdot\rho(T)}$$

With such dependency of thermal diffusivity, the solution of the equation (1) is a difficult and tiresome problem. It is known that the dependency of specimen density on temperature is weak; therefore its change can be neglected. Because the computation has the purpose of valuation, then hereafter thermal conductivity will be deemed independent from temperature. And the average value along the work temperature range will be used.

However, temperature dependency of thermal capacity will be used. This dependency will be taken into account through the use of Debye quantum model.

According to quantum model of Debye, thermal conductivity can be determined the following way:

$$C_V(T) = 9 \cdot N \cdot n \cdot k \left(\frac{T}{\Theta}\right)^3 \cdot \int_0^{\Theta/T} \frac{x^4 \cdot e^x dx}{(e^x - 1)^2} \qquad (2)$$

where $\Theta = \frac{hC_0}{k} \cdot \left(\frac{9 \cdot N}{4 \cdot \pi \cdot V}\right)^{1/3}$. – Debye temperature.

To compute the integral in (2) it is necessary to use numerical methods, scilicet trapezium method can be used. This method is that the whole area to be integrated is split into small equal intervals, where the value of the integral is determined.

Debye model lets to connect thermal conductivity with properties of the synthesized specimen. In addition, Debye's model is not limited in the range of high temperatures. Therefore, Debye's model is more preferable than polynomial approximation to describe thermal state of the specimen.

III. RESULTS

The model built allowed to estimate general dependency of the process on initial parameters like preheating temperature or initial density of the mixture. As an example, the following dependency on density was obtained.

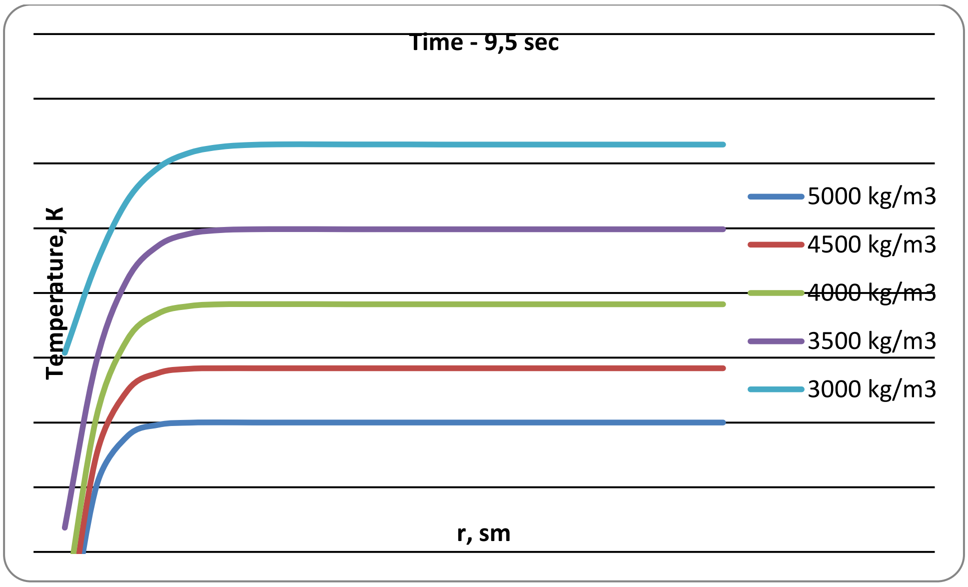


Fig. 1. – Dependence of combustion temperature on density of mixture

Therefore, it can be concluded that, the higher the density is (in current intervals) the lower the temperatures of specimen during the reaction (it corresponds to experimental data [6]).

Computation in the intervals of lower densities does not yield reliable information due to some flaw of the model leading to a mistake. The flaw is to be fixed in future versions of the model.

Dependence of combustion on preheating was also taken into account. The computations coincide with experimental data [6].

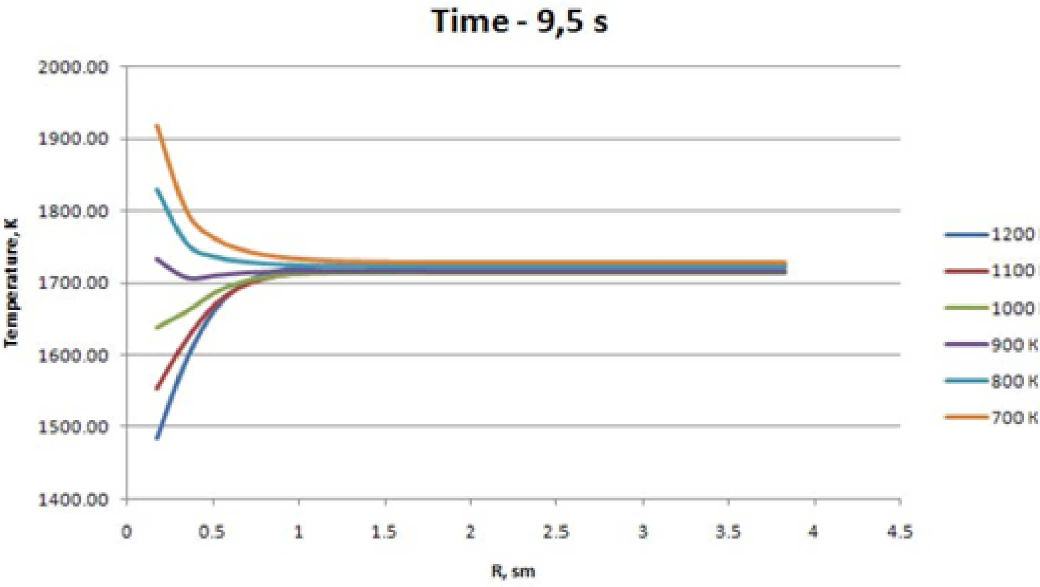


Fig. 2. – Dependence of combustion temperature on preheating temperature

It can be seen that the lower the preheating temperature is, the more the center of the specimen is overheated. It happens due to higher heat transfer on boundaries of the specimen. Therefore, the preheating temperature should not be lower than 900 K.

IV. CONCLUSION

The SHS process – the process of spontaneous high temperature synthesis was studied during this work. It is used to obtain diverse refractory ceramic materials. The numerical method of radial combustion computation is shown in this work. The approach, used to solve the equation, describing the process, is called sweep method. This method can be used for any second order differential equations. Computations are necessary, because they allow significant reduction of costs and used material. The problem of the method discussed, is the lack of experimental data on physical properties needed to create accurate models. Therefore, experiments and modeling depend on each other. The following goals were achieved during the work.

1. SHS theoretical basics have been studied. SHS is a process of spontaneous exothermal chemical reaction in a powder-like mixture of refractory elements.
2. The SHS process is described with non-linear non-uniform thermal conductivity equation. This equation doesn’t have analytical solution, therefore the numerical methods are required to achieve it. One of these methods is called sweep method.
3. This method was applied to thermal conductivity equation the following way. First, spatial coordinates were separated and sweep coefficients were found for each variable independently. Then, using the method of reverse sweep temperatures were computed.
4. The solution of the problem was implemented on C # package..

1. A.G Merzhanov, B.I. Khaikin. Prog.Energy Combust. Sci. 14, 1-98. 1988.
2. Y.I. Yershov, S.B. Shikhov. Matematicheskiye osnovi teorii perenosa. V1 Osnovi. – Moscow Energoatomizdat, 1856. – 232.
3. A.P. Hardt., R.W. Holsinger. Combust. Flame. 21, 91-97. 1973.
4. V.I. Bojko, O.Yu. Dolmatov, I.V. Shamanin, K.V Yushitsin. High-current emitters synthesized by technological combustion // Instruments and Experimental Techniques. – V. 36. – № 5. 1993. – P. 790–792.
5. Fizicheskiye Velichini: Handbook. A. P. Babichev, N.A. Babushkina – M.: Energoatomizdat, 1991.
6. V.I. Bojko, O.Yu. Dolmatov, I.V. Shamanin, B.E. Kadlubovich. A composite explosive emission cathode made from a metal ceramic with lanthanum and titanium borides // Instruments and Experimental Techniques. – V. 38. – №2, 1995. – P. 272–274.
7. M. Thompson, J Wrights. Nuclear Materials V. 16, 1965. – p. 146
8. T.I. Serebryakova, V. A. Neronov, P.D. Peshev. Visokotemperaturniye boridi, 1991.
9. I.V. Gordeyev, D.A. Kadashev, A.V. Malishev. Yaderno-fizicheskiye konstanti. – M.: Gosatomizdat, 1963. – p. 507
10. Tugoplavkiye materiali I soyedineniya: Handbook. – M.: Metallurgiya, 1970.
11. Spravochnik po electrokhimicheskim prosessam / B.I. Yemlin, M.I. Gasik. – M.: Metallurgiya, 1978. – p 288.
12. Yu.D. Tretyakov, Kh. Lepis. Khimiya tverdofaznih materialov. Vol. 1. – M.: MSU, 1985, – p 254.

REALIZATION OF AN INTEGRATED APPROACH TO THE METHODS OF DYNAMICS SIMULATION AND PARAMETER SPACE INVESTIGATION IN MEDNES

L. I. Swetlichnyy, A. A. Andrianov
Scientific Supervisor: PhD, Associate Professor A.A. Andrianov
Linguistic Advisor: Associate Professor E.A. Avramova
Obninsk institute for nuclear power engineering NNRU «MEPhI», Russia, Obninsk, Stydgorodok, 1, 249040
E-mail: l.swetlichnyj@ya.ru

Abstract.

In this message described is an integrated approach based on the method of system dynamics and parameter space investigation, allowing the problem of optimizing of nuclear energy system structure in multi-criteria formulation to be solved. Also described is realization of this approach in software package MEDNES v1.0

Keywords. Multi-criteria optimization, Scenarios of nuclear energy system development, Pareto-effective set.

I. INTRODUCTION.

There is a growing understanding that the problem of optimizing the structure of nuclear energy system is multi-criteria [1]. At the same time, the criteria characterizing resource consumption, economy, the risks of unauthorized proliferation and waste management, are conflicting by the nature. This means that improving the value of one criterion leads to decrease in the values of other criteria.

These circumstances make urgent the development of multi-criteria program systems to solve the problem of optimizing the structure of nuclear energy system in multi-criteria formulation. Software systems of this kind could provide a basis for decision support systems for multi-criteria evaluation of the effectiveness of nuclear energy system development scenarios, allowing multi-factorial comparison of its various structures to be made.

II. METHODOLOGY. INTEGRATED APPROACH BASED ON THE SYSTEM DYNAMICS AND PARAMETER SPACE INVESTIGATION METHODS.

In spite of the considerable pool of existing models, approaches and software tools for system studies of the nuclear energy system development, active researches are now being done to find new ways of solutions for the problems of this class. This is due to a significant increase in the scope of functions and in the range of factors that will determine the future of nuclear energy system development. These include such factors as non-proliferation, waste management and safety. Whereas, the existing models of developing nuclear energy systems consider mainly the economic aspects.

It should be also noted that the limited application scope of models implies the problem of obtaining the final result, determining the most efficient scenario of its development. So far, no generally accepted algorithms and no methodological approaches have been suggested there.

The described below integrated approach allows to partly compensate for these shortcomings. It was developed on the basis of system dynamics and parameter space investigation methods; and allows to solve the problems of the nuclear energy system structure optimization in the multi-criteria formulation.

III. SYSTEM DYNAMICS APPROACH FOR NUCLEAR ENERGY SYSTEMS DEVELOPMENT

According to the general methodology of modeling in the system analysis framework it is necessary to identify the following typical stages: 1) generation of the constraint equations reflecting the actual “physical” limitations; 2) the determination of exogenously defined objective functionals reflecting the concept of efficiency of the relevant object functioning and 3) if necessary, equations that close the system.

The initial system of constraint equations represents in an aggregated differential form the process of nuclear reactors fueling in a particular region (the capacity increase must be supply by fuel of a given form and amount)

$$F_{ik}^{j}(t)\frac{dN^{c}{}_{i}^{j}(t)}{dt}+B_{ik}^{j}(t)N_{i}^{j}(t)=q^{e}{}_{ik}^{j}(t)+q^{r}{}_{ik}^{j}(\vec{N}(t)),$$

where i=1…n – reactor type number, j=1…m – region number, k=1…l –fuel type number.

The left side of the equation determines the demand for fuel of given form. The demand is composed by the needs to provide new capacities (first component) and to replace burnt-up fuel in the nuclear reactors in operation (second component). The right side of the equation sets an offer for a certain fuel type. It is determined by the existing fuel supply structure of nuclear energy system in the relevant region, and by the possibility to import fuel components from other regions. From now on the following conventional signs are used: - initial fuel loading into the reactor, - the annual refueling of reactor. The functional dependence of the equation parameters on time takes into account possible technology updating.

Let us introduce the following notation: - are respectively installed capacity of reactors in year t, the total capacity of reactors put into operation by the year t, and the total decommission of reactors by the year t. These values are related by:

$$N(t)=N^{c}(t)-N^{d}(t);\qquad N^{d}(t)=N^{c}(t-T_{l});\qquad N^{d}(t)=\sum_{i=1}^{[\frac{t}{T_{l}}]}N(t-iT_{l}),$$

where [•] - the integer part.

Taking into account for this fact is necessary for correct modeling of the real need for the introduction of new nuclear reactor capacity, caused not only by increasing demand for nuclear power, but also by decommission of worked-out reactors.

Structural and organizational features of the NFC can be taken into account as additional equations and constraints. In particular, the following conditions can be considered: the nuclear materials supply from other regions and other types of reactors; delays on various stages and capacities of NFC facilities; property changes in fuel materials and possible technological modifications of the NFC facilities in the nuclear energy system deployment.

Incoming and outgoing flows can be defined in two ways. Firstly, additional equations can be introduced for linking with the definable variables and ultimately closing the initial fuel balance system. In general case, the model will appear as a set of differential equations with retarded argument.

Secondly, if the objective functional is set, a part of the flow can be defined by solving the corresponding optimal control problem, whereas the others - by solving the closing system of equations. Various constraining on the variables acceptable region of models or functionals calculated with their help, allows taking into account the system constraints directly. Thus, the calculations will not lead into non-physical solution region.

Thirdly, this simulation method can be effectively integrated with the described below method of the parameter space investigation that allows solving the nuclear energy system structure optimization problem in the multi-criteria formulation.

IV. THE PARAMETER SPACE INVESTIGATION METHOD.

The parameter space investigation method was suggested by I.M. Sobol and R.B. Statnikov, who demonstrated its wide opportunities in solving engineering optimization and optimal control problems [2, 3]. The method is intended to solve multi-criteria nonlinear programming problems and is based on the idea of random search, where so-called low-discrepancy sequences are used as the random numbers.

The parameter space investigation method consists of three phases:

- formation of test tables – that is, a set of calculated values of the criteria for a given set of testing points that satisfy a given system of equations and system of constraints;
- selection of criteria constraints and choice of solutions to satisfy them;
- checking the solvability of the problem and formation of an effective solutions set.

The developed methodology allows taking into account nonlinear constraints and nonlinear functionals on model variables, to approximate the Pareto set in the case of multi-criteria problems. The internal mechanism of alternatives selection helps identify the most effective directions; and the dynamic character of the model assists in evaluation of the transition to the asymptotic scenarios.

V. MEDNES SOFTWARE.

The described integrated approach is implemented as a MEDNES software system (Multi-criteria Evaluator of Developing Nuclear Energy Systems). MEDNES is designed to solve multi-criteria problems, e.g. structure optimization, parameters identification, control, etc. MEDNES is intended for construction of the feasible solutions set during interactive dialogues between expert and computer. MEDNES is applicable for analyzing the dependence of criteria on the parameters; criteria on the criteria and constraints correction. MEDNES can be used for analyzing different structures of nuclear power system. It is available because of integrated interactive constructor of structures. An expert can add, edit and remove any facilities to the structure using this tool (fig.1)

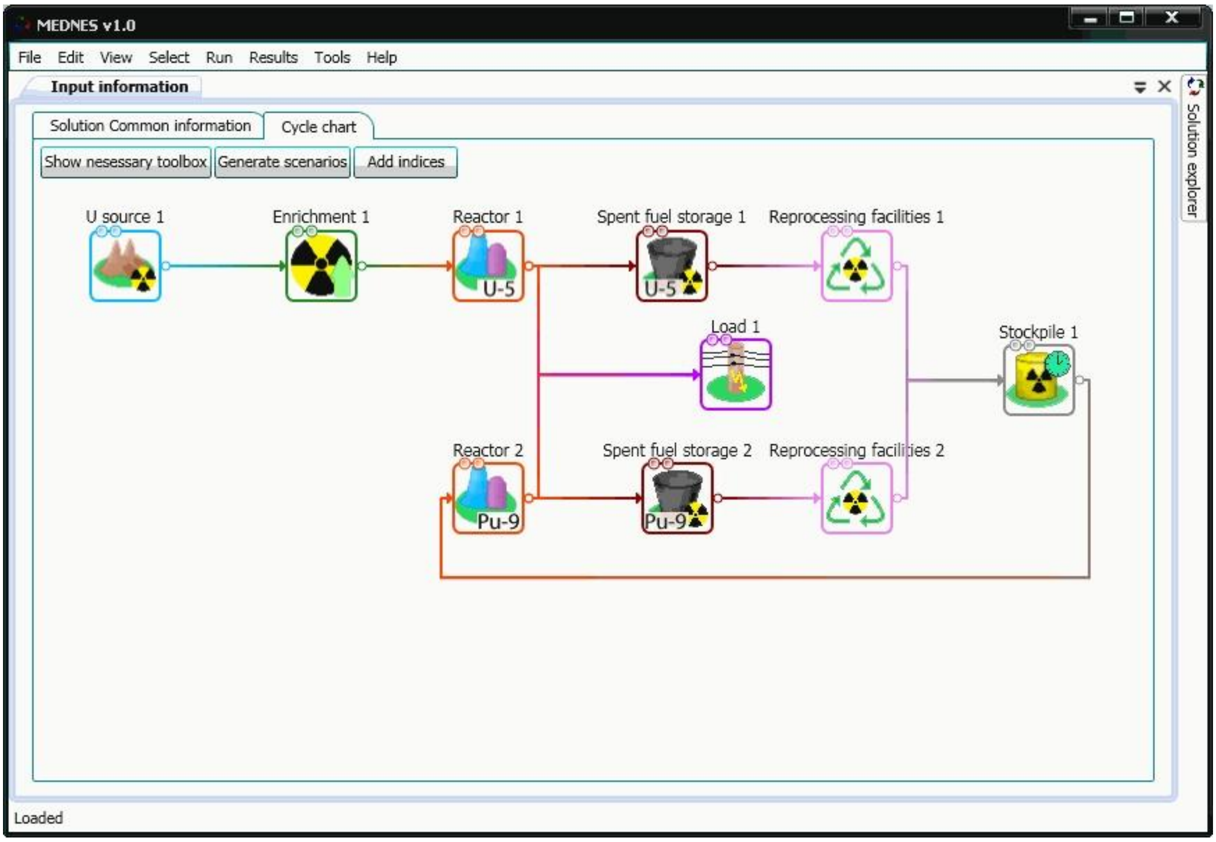


Fig.1 Interactive board for editing structure of nuclear power system.

The number of variable parameters depends on sample points generator used. Different sample points generators can be used. Currently, implemented are the generators of Holton, Sobol and Faure low-discrepancy sequences. The standard pseudorandom number generators and uniform sequences can also be used.

The expert chooses the most preferred solution on a basis of feasible set and Pareto set analysis. MEDNES includes the following analysis tools:

- test tables;
- feasible and Pareto-optimal solutions table;
- tables of vectors not satisfying functional constraints;
- “criteria-parameters” and “criteria-criteria” plots reflecting the criteria sensitivity to parameters and criteria dependence on the criteria.

There are integrated interactive tools for visual analyses of Pareto-optimal set (fig.2)

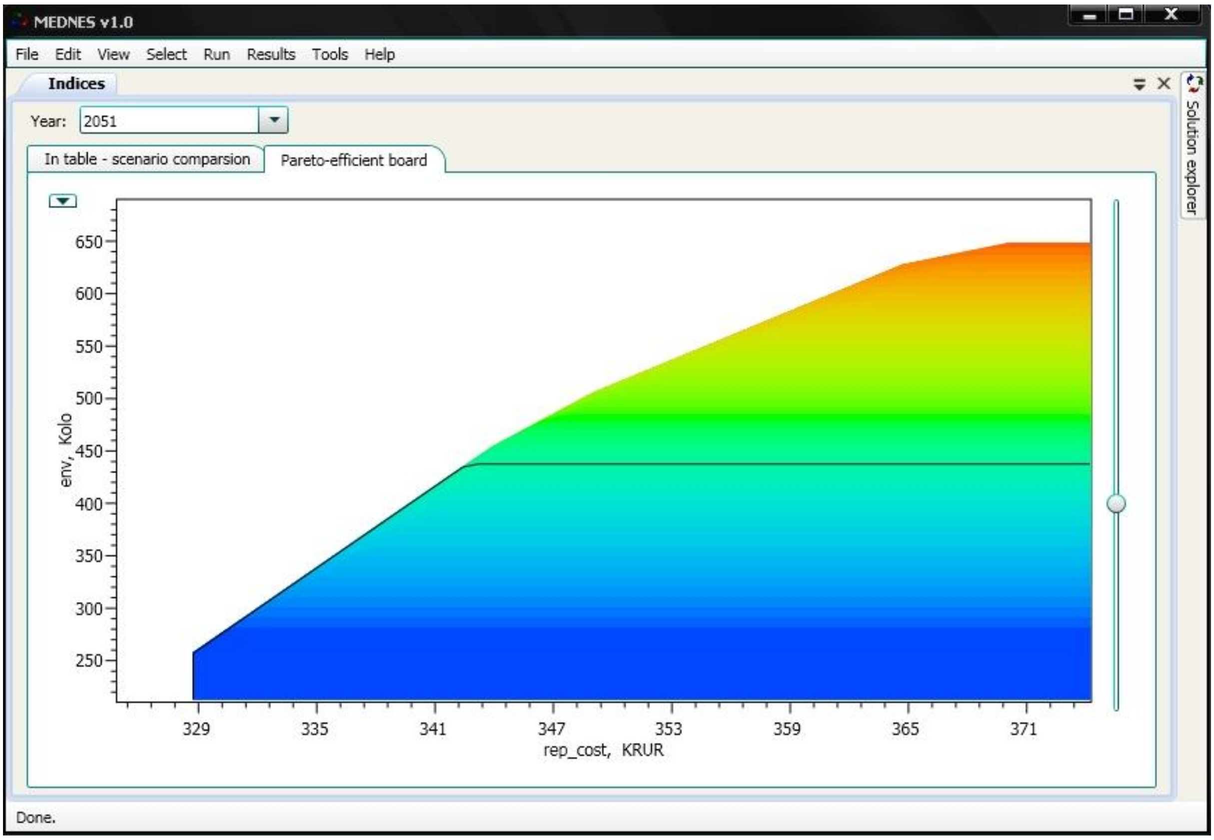


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Fig.2 Tool for analyzing Pareto-optimal set.

Because the multi-criteria problems with high parameter vector dimensionality require a lot of computer time, the possibility is provided to run MEDNES in parallel mode.

The main programming language was chosen C# which combines object-oriented and aspect-oriented concepts and was developed in 1998-2001 by Microsoft as a primary application development language for Microsoft platform .NET [4]. The choice of .NET technology is based on the following features: it allows efficiently developing applications for Windows, web-applications and web-services, and at the same time the .NET platform provides simultaneous support for designing and implementing software using different programming languages. The data in software systems are stored in XML-based format and SQL-database.

1. IAEA-TECDOC-1362, IAEA, Vienna (2003).
2. Statnikov R.B. and Matusov J.B. Multicriteria Analysis in Engineering. Dordrecht/ Boston / London: Kluwer Academic Publishers, 2002.
3. Statnikov R.B. Multicriteria Design. Optimization and Identification. Dordrecht/ Boston / London: Kluwer Academic Publishers, 1999.
4. http://msdn.microsoft.com

RESEARCH NEUTRON-PHYSICAL CHARACTERISTICS OF THE REACTOR CORE IRT-T WITH FRESH HEU FUEL

S.N. Yelpashev, A.K. Lihonov, D.A. Ixanov
Scientific Supervisor: Asst. A.G. Naymushin
Linguistic Advisor: PhD. Ya.V. Ermakova
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: igrok646@sibmail.com

Abstract.

Developed the detailed calculation model of the research reactor core IRT-T. Presented neutron-physical characteristics of IRT-T active zone with a load of fresh HEU (High Enrichment Uranium) fuel. Shown that the duration of the company with such a HEU fuel load of 383 days.

I. INTRODUCTION

Currently is an issue of the conversion of research reactors. Translation of the reactor with highly enriched fuel (HEU) - the enrichment of U235 over 90% of the fuel to low enriched (LEU) - less than 20%. At the same time the reactor can change the neutron-physical characteristics that determine the efficiency of the reactor and not always for the better. To explore the possibility of transition to low-enriched fuel is necessary to conduct a detailed analysis of how existing active zone and the zone with the new fuel. Currently, such work is carried out in the TPU and they concern the reactor IRT-T [1].

The reactor IRT-T using a pool-type as a moderator, coolant, and the upper layer of protection of light water. The reactor core (Fig. 1) consists of fuel assemblies IRT-3M type: 8-tube (12 FA) and 6-tube (8 FAs). In a 6-tube assemblies are placed rods control and protection around the perimeter of the core blocks are beryllium reflector. Controll rods include the following groups of rods: SHIM-1, SHIM-2, SHIM -3, by two automatic control rod (AR) and an automatic control rod is located in the beryllium reflector.

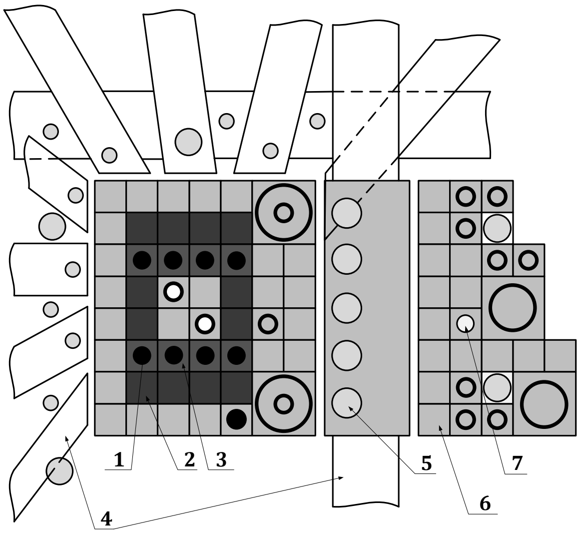


Fig. 1. Scheme of the reactor core IRT-T: 1) control rods, and 2) an 8-tube assemblies, and 3) a 6-tube assemblies, and 4) horizontal experimental channels, 5) vertical experimental channels, 6) beryllium blocks, 7) experimental channels with water

II. DEVELOPMENT, METHODOLOGY

For the calculations have been developed a detailed model of the IRT-T program in the MCU [2]. Each fuel element has been isolated in a separate area of the material, the reflector of the reactor was a fresh neotravlenny beryllium poisoning during which payments are not taken into account, the density of beryllium - 1.84 g/cm3; impurities in it are not taken into account. To determine the power distribution in height of the core in a separate calculation of the registration area distinguished by height in increments of 1.

The calculation was performed for a reactor with a fresh load, which includes 300 grams of uranium-235 for the 8-tube assemblies, and 263.7 grams for a 6-tube of highly enriched (90%), the total load of 5.7 kg of U235. The capacity of each fuel assembly has its value, and when the reactor is constantly changing, but the total value of the power of the reactor will be constant and it is 6 MW.

At the beginning of keff is 1,2776 ± 0,0006, fraction of delayed neutrons 0,0076, poisoning Xe^{135} equally 3,68 β_{eff}. The statistical error of the calculations of jet parameters is 0,025 β_{eff}.

The efficiency of the reactor is determined by the margin of reactivity, Figure 2 shows the dependence of the reactivity of the reactor operation time.

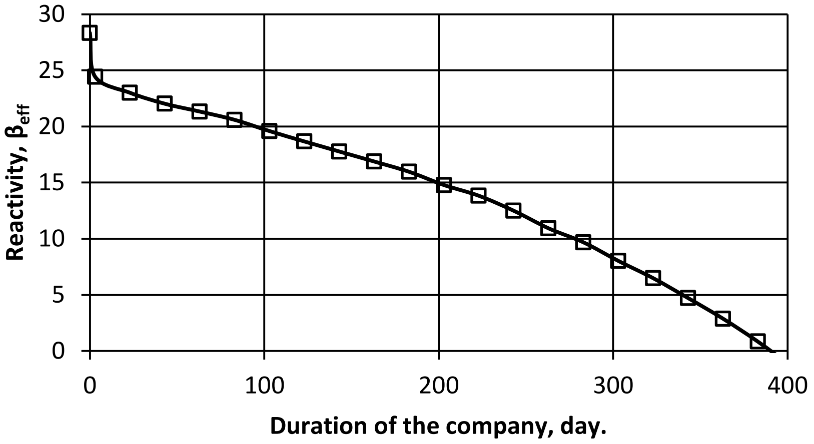


Fig. 2. The change in the reactivity of the reactor

From the graph we can conclude that the duration of the company amounts to 383 days, while the reactivity of the end of the company will be equal to 0,83 βeff. The distribution of the heat capacity of the cells in the core at the beginning of the company is represented in Figure 3. The total capacity of 6 MW.

260	280	289	299
251	291	305	297
335			390
340			385
260	296	301	288
269	285	287	292

Fig. 3. The distribution of the thermal reactor power at the beginning of the company, KW

Effectiveness of the use of control rods is determined by their effect on the reactivity margin of the active zone (the weight of the rods). Weight control rods at the beginning of IRT-T, defined by means of calculation are given in Table 1.

Table 1. Weight control rods

Roud	Weight, β_{eff}
АЗ	4,80
АР	0,41
КС1	3,85
КС1-1	1,84
КС1-2	2,26
КС2	4,61
КС2-1	2,85
КС2-2	1,99
КС3	4,49
КС3-1	2,51
КС3-2	2,49

In Table 1, clearly presented, that the weight of the rods distinguished from each other, because of their location in the core and the influence of pulsating flow in the reactor. Weight automatic control rod (AR) is much smaller than the others, because This bar is located in the beryllium block. Heat flows from the surface of the fuel elements are of great importance in the study of thermophysical properties of the active zone, as If the heat flux exceeds the established rules of the FA value (800 kW/m2) [1], it will lead to a crisis of heat - boiling surface [4]. To estimate the maximum heat fluxes from the surface of fuel rods used in the values obtained for the reaction rates in each section of the fuel element.

Figure 4 shows that the most intense fuel assemblies are the building closest to the center of the core, this dependence is due to the fact that in the center of the core are four blocks of the beryllium reflector. In operation, the reactor heat fluxes from the surface of the fuel elements is constantly decreasing, and hence as a reference point for calculating the maximum flow is taken at the beginning of the company. One of the most intense is the FAs in cell number 10, in which the maximum heat flux from the surface of the fuel element is 446 kW/m2. Here are the axial (Fig. 5) and radial (by fuel elements, Fig. 6) uneven distribution of energy in the fuel assemblies.

The beginning of company				The end of company			
294	289	302	352	274	303	296	307
301	429	419	385	289	377	363	338
406			446	347			325
411			451	334			328
311	420	438	383	299	363	369	323
289	317	301	357	276	293	297	298

Fig. 4. The maximum heat fluxes from the surface of fuel rods at the beginning of the company and at the end of the company, kW/m2

The Fig. 5 shows that the greatest pressure cartridges are tested in the central part of the assemblies kz = 1,29. This is explained by the fact that in the central part of the assemblies lowest value of leakage neutrons.

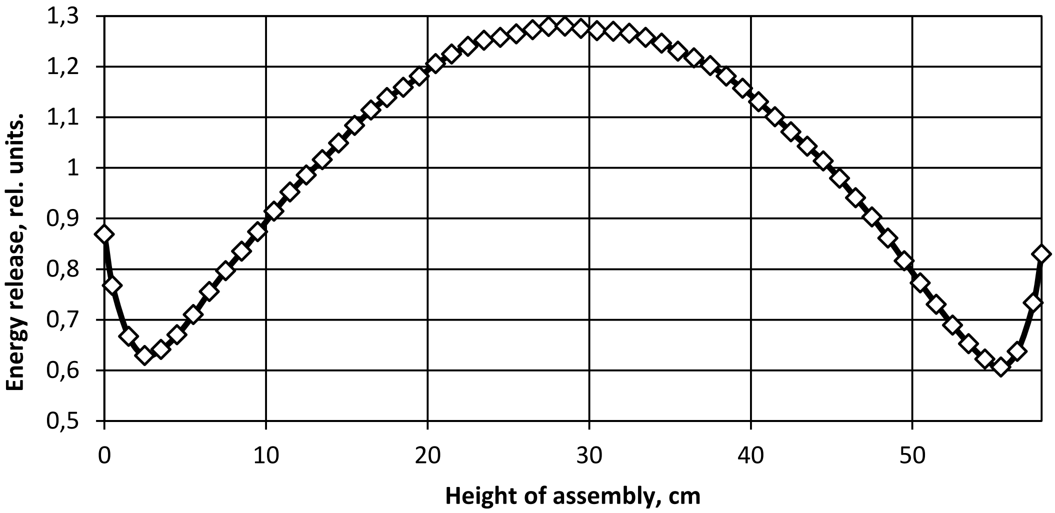


Fig. 5

The distribution of energy height in the cell number 10 fuel assemblies, normalized by the mean

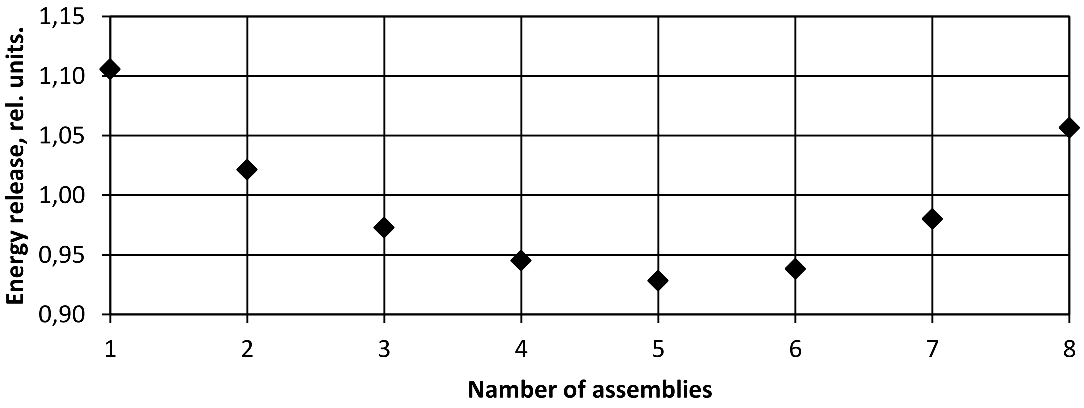


Fig. 6. The distribution of energy to fuel elements (from outer to inner) fuel assemblies in the cell number 10, is normalized by the mean

The most intense are the inner and outer fuel rods. In the internal fuel rod smallest leakage of neutrons, and the external fuel rod facing the beryllium reflector, and has the largest water-fuel ratio, which increases the number of neutrons initiating fission process in these fuel elements. Also, we calculated the coefficients of nonuniformity of energy release for each fuel assembly at the beginning and end of the company: high altitude (kz), radial (kr), which are presented in Figure 7.

The beginning of company				The end of company			
1,28	1,29	1,29	1,29	1,16	1,16	1,15	1,15
1,26	1,27	1,27	1,27	1,14	1,12	1,12	1,12
1,28			1,29	1,16			1,10
1,28			1,29	1,12			1,11
1,26	1,26	1,27	1,27	1,14	1,12	1,11	1,13
1,28	1,29	1,29	1,29	1,16	1,15	1,15	1,15

a. The coefficients of uneven height (k_z)

The beginning of company				The end of company			
1,09	1,13	1,14	1,11	1,02	1,02	1,03	1,01
1,04	1,04	1,04	1,05	1,01	1,00	1,00	1,00
1,11			1,11	1,00			1,01
1,10			1,12	1,01			1,01
1,04	1,04	1,04	1,06	1,01	1,01	1,01	1,00
1,09	1,13	1,13	1,12	1,02	1,03	1,04	1,02

b. The coefficients of the radial non-uniformity (k_r)

Fig. 7. The coefficients of nonuniformity of fuel elements per fuel assembly at the beginning of the company and at the end of the company, rel. units.

The figure 7 shows that by the end of the leveling of uneven energy both in height and the radius. The uneven distribution of neutron flux density in the core leads to an uneven burn uranium-235. Regulations established that the maximum fuel burn-paged IRT-T should be 60% [1]. Figure 8 shows the distribution of fuel assembly burn-U235 at the end of the company (383 days).

42,93	45,67	46,79	47,35
46,47	51,96	53,60	52,21
52,30			58,00
53,13			57,31
49,68	52,72	53,03	50,98
44,11	46,45	46,62	46,52

a.

45,33	49,71	50,83	50,61
47,54	53,00	54,85	53,72
55,36			61,06
55,86			60,60
55,10	53,95	54,04	52,55
46,59	50,43	50,52	49,84

б.

Fig. 8. Distribution of burn-U235 for assemblies: a) average burnup in each fuel assembly, b) the maximum burnup of fuel assemblies

The average burn-up in cell number 10 is 58%, but considering the fuel rods can be seen in isolation, that burn in one of the rods was 61.06%. For the next company to unload the cell number 10 and 12. Burn-U235 for reactor has a linear dependence. When the reactor produced transuranic elements, which are also able to share with the release of thermal energy, reducing the cost of U235 to produce a megawatt per day. Schedule of costs for the company's U235 is shown in Figure 9.

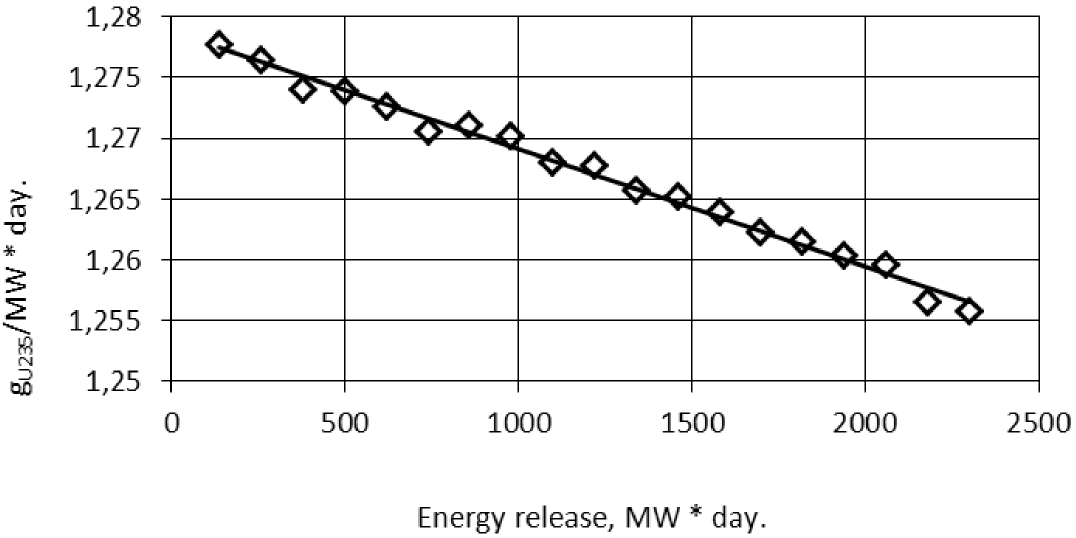


Fig. 9. Costs per unit U235 • MW per day

The figure 9 shows that during the company's U235 reactor costs to produce 1 MW of thermal energy per day • virtually no decline and remain within the average value of 1.27. This is because, in the core using HEU fuel, and the accumulation of Pu239 is negligible. When working in the reactor accumulate different nuclides, many of whom make a significant impact on the properties of the core propagate even at very low concentrations. Most important for the reactor nuclides, their impact and focus on the end of the Company are presented in Table 2.

Table 2. The share of the neutron absorption nuclides at the end of the company

Nuclide	Share acquisitions,%	Weight, g
Materials of construction		
AL	1,46	32441,8
Fission products		
Xe^{135}	4,03	0,02
Xe^{133}	0,03	1,79
Xe^{131}	0,48	33,64
I^{129}	0,02	9,51
Sm^{152}	0,30	8,65
Sm^{151}	0,47	0,57
Sm^{150}	0,16	17,17
Sm^{149}	1,01	0,20
Sm^{147}	0,03	3,17
Pm^{149}	0,02	0,18
Pm^{148M}	0,24	0,16
Pm^{148}	0,02	0,13
Pm^{147}	0,61	22,27
Eu^{155}	0,09	0,23
Eu^{154}	0,09	0,47
Eu^{153}	0,13	4,27
Pr^{143}	0,03	4,41
Pr^{141}	0,07	72,40
Ce^{141}	0,06	10,13
La^{139}	0,07	89,86
Cs^{135}	0,02	17,33
Cs^{134}	0,04	3,55
Cs^{133}	0,50	84,80
Cd^{113}	0,01	0,00
Pd^{105}	0,03	9,37
Rh^{105}	0,09	0,05
Rh^{103}	0,62	23,71
Ru^{101}	0,08	53,06
Tc^{99}	0,32	59,29
Mo^{97}	0,03	59,29
Mo^{95}	0,12	39,57
Zr^{93}	0,04	60,37
Nd^{147}	0,05	1,36
Nd^{145}	0,26	56,06
Nd^{144}	0,01	41,67
Nd^{143}	1,58	69,10
Kr^{83}	0,11	4,02
Transuranic elements		
Pu^{241}	0,06	0,88
Pu^{240}	0,12	2,27
Pu^{239}	0,66	10,62
Pu^{238}	0,02	0,96
Np^{237}	0,12	9,95
U^{237}	0,01	0,60
U^{236}	0,75	450,86
U^{234}	0,38	52,86
U^{238}	0,73	548,98
U^{235}	83,64	2870,23
The combined effect	99,81 %	

The main structural material in the core is Al, whose mass is 32.4 kg (fuel cladding, CPS channels, the head and shaft assemblies, etc.). The absorption cross section is relatively small and is about 1.79 barns for the thermal field, but because of its large share of the predominance of the active zone of absorption of neutrons is about 1.5%. During the operation of the reactor fission products are formed and some of them have a strong negative effect on reactivity. These nuclides can be attributed Xe135, for which at a mass 0.02 grams, the percentage of acquisitions is 4%. Another reactor is a poisoner Sm149, which, when the mass of 0.2 grams is 1% of the absorbed neutrons. In addition to fission products in the core to form transuranic elements. Some nuclides, with a significant weight at the end of the company, do not have a big impact, such as U236, also a large accumulation of this nuclide indicates that about 450.8, the U235 has absorbed neutrons in the reaction (n, γ), is not bringing beneficial effects for the reactor. A positive impact on the ability to propagate the active zone is making Pu239 and Pu241. But since for loading of the reactor used HEU fuel, the accumulation of these nuclides is insignificant: 10.62 grams and 0.88 grams of Pu239 Pu241, and, consequently, the percentage of absorption of neutrons in the core is small, 0.66% and 0.06% respectively.

III. CONCLUSION

When calculating the IRT-T with fresh fuel was set duration of the company, which is 383 days, some burning fuel assemblies reached 58%. The maximum heat flux from the surface of the fuel element is 451 kW/m^2, were also calculated coefficients of no uniformity of energy release for height and radius. The calculated results will be used for comparative analysis of neutron-physical characteristics of IRT-T at startup low-enriched fuel (less than 20%).

1. Varlachev V.A., Gusarov O.F., Zabolotnov S.A. Issledovatelsky yaderny reactor IRT-T. Nuclear Research Reactor IRT-T. – Tomsk: TPU, 2002. – 56p.
2. Chertkov Yu.B., Ivanov A.A., Naimushin A.G.. Temperaturnye rejimi raboty tvelov reactor IRT-T. Temperature Work Regimes of Fuel Elements in Reactor IRT-T. – Tosmk: TPU, 2010. – 19p.
3. Kirilov P.L., Bogoslovskaya G.P. Teploobmen v yadernih energeticheskih ustanovkah. Heat Transfer in Nuclear Power Plants. – M.: Energoatomizdat, 2000. – 456p.
4. Dubovsky V.G.. Kriticheskie parametry system s delyashimisya veshestvami I yadernaya bezopasnost. Critical Parameters of Systems With Fissile Materials and Nuclear Safety – M.: Atomizdat, 1966. – 57 p.
5. Data base for research reactors // International Atomic Energy Agency. 2011. URL: http://nucleus.iaea.org/RRDB (Retrieved 13.05.2012).
6. Merzlikin G.Ya. Osnovy teorii yadernih reactorov. Fundamentals of the Theory of Nuclear Reactors. – Sevastopol: SIYa&P, 2001. – 273p.
7. Korotkih A.G., Shamanin I.V. Osnovi gidrodinamiki I teploobmena v yadernih reactorah: Uchebnoe posobie. Fundamentals of Fluid Flow and Heat Transfer in Nuclear Reactors: Manual. – Tomsk: TGU, 2007 – 91p.
8. Chirkin V.S. Teplofizicheskie svoistva materialov yadernoy tehniki: Spravochnik. Thermophysical Properties of Materials for Nuclear Technology: Handbook. – M.: Atomizdat, 1968.
9. Glushkov E.S., Demin B.E., Ponomarev-Stepnoy N.N., Hrulev A.A. Teplovidelenie v yadernom reactore. Heat Release in Nuclear Reactor. – M.: Energoatomizdat, 1985. 160 p.

10. Boiko V.I., Koshelev F.P., Shamanin I.V., Kolpakov G.N. Neitronno-fizichesky i teplogidravlichesky raschet reactor na teplovih neitronah. Neutron-physical and thermohydraulic calculation of reactor thermal neutrons: Handbook – Tomsk: TGU, 2002. –192 p.

ION-EXCHANGE URANIUM CONCENTRATION

N.V. Zinchenko, S.V. Kochur

Scientific Supervisor: Assistant, A.S. Kantaev

Linguistic Advisor: Senior teacher, A.P. Eonov

Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050

E-mail: the_nightmare@mail.ru

Abstract.

The purpose of this work is to deal with uranium ion-exchange concentration from underground leaching sulphate solutions. It is also aimed to describe basic principles, special substances and apparatus of uranium sorption process.

In the presented work there are fundamentals of ion exchange process and the information about ion exchangers used in uranium technology. In this work, the description of gel-type and macroreticular-type ion-exchange resins is represented at greater length. The functionality classification of these types of ion-exchange resins is also covered in the given work. Moreover, the characteristics of the macroreticular Purolite A500/2788 anion-exchange resin are given in this abstract. But the special attention in the abstract is paid to the description of the equipment for uranium sorption and to the flowsheet of this process.

The current work could be used as the basic information for scientific and industrial researches and processes. Also, it could be useful for people interested in uranium or other rare and precious metals technology.

I. INTRODUCTION

Nowadays, the questions of the ecological situation and fuel raw materials' limitedness are very important. Therefore, the world atomic power engineering keeps and increases its positions as one of the basic perspective energy sources.

The fifth part of the electric power in the world is generated by atomic power stations, the fuel elements of which consist of uranium dioxide. The growth of atomic power stations contribution in electric power industry is connected with a number of advantages of atomic power stations prior to thermal power stations working on natural gas, oil and coal.

Uranium use in nuclear technologies is based on the specific properties of uranium, which are different from properties of many other nonferrous and rare metals. Uranium has a property of radioactive decay and ability to be split by the influence of neutrons with the emission of huge amounts of energy.

Thermal power stations exert harmful influence on the environment. Every year, they throw out a considerable quantity of carbon dioxide, nitrogen oxides, sulfur dioxide and ashes containing radioisotopes. Atomic power stations use allows generating electric power without burning atmospheric oxygen and gas emissions.

Moreover, raw materials for thermal power stations are also needed for an organic synthesis. And the application of nuclear power stations allows us to save these materials for such a valuable purpose.

The growth of world needs for fuel and energy at resource and ecological restrictions of traditional power engineering makes the growth of atomic power stations contribution in the world energy production very urgent.

In connection with the listed above, the questions of extraction and processing of uranium raw materials are very urgent today and have a great value for the nuclear industry.

In the given work, I will report about the ion-exchange uranium recovery from the uranyl sulphate solution of underground leaching.

II. FUNDAMENTALS OF ION EXCHANGE

Ion exchange is the process of a stoichometric interchange of one sign ions between an ion exchanger and a solution[1].

Ion exchangers are solid high-molecular substances capable of absorbing positive or negative ions from an electrolyte solution in exchange for an equivalent quantity of other ions of the same sign[1].

Every ion exchanger consists of a skeleton (matrix) connected by a valent or crystal lattice forces. In a matrix there are fixed ions which create a positive or negative charge on it. This charge is compensated by a charge of mobile ions of an opposite sign (counter-ions). Counter-ions freely move in ion exchanger's pores and can be replaced by other counter-ions. The ions in an electrolyte solution which have the same charge as fixed ions are called co-ions[1].

Subject to a sign of exchanging ions' charge, ion exchangers are divided into cationites and anionites. Bipolar ion exchangers are called ampholytes and have both cation-exchange and anion-exchange groups[1].

Ion exchange reactions can be represented by equations 1.1 and 1.2.

$$M^-A^+_{solid} + B^+_{solution} \leftrightarrow M^-B^+_{solid} + A^+_{solution} \qquad (1.1)$$

$$M^+A^-_{solid} + B^-_{solution} \leftrightarrow M^+B^-_{solid} + A^-_{solution} \qquad (1.2)$$

In the listed above equations, M^- and M^+ are insoluble fixed anionic and cationic groups. Cations A^+ and B^+ (1.1) and anions A^- and B^- (1.2) are exchanging counter-ions.

For an ideal ion exchange process, the ion exchanger must have the following characteristics [1]:

- a hydrophilic structure of a matrix;
- effective ion-exchange capacity;
- high exchange rate;
- physical and chemical stability in the medium of a process;
- steady particle size;
- effective surface area.

There are various types of ion exchangers: mineral, synthetic inorganic ion exchangers, synthetic ion-exchange resins, and also coal-based ion exchangers. Nowadays ion-exchange resins are the most widespread.

III. ION-EXCHANGE RESINS

Coal and phenol-based ion-exchange materials were industrialized in 1930s. Polystyrene-based cation exchangers with sulphonate groups and anion exchangers with amine groups were developed a few years later. But these two types of ion-exchange resins are still the most frequently used nowadays [2].

The matrix of ion exchange resins consists of abnormal high-polymeric spatial grid of hydrocarbonic chains (alkanes and benzene rings). In certain places of a matrix active ionogenic groups, capable to dissociation, are fixed.

As a result of dissociation, fixed ions, attached to a matrix, and mobile counter-ions, circulating in pores of a matrix, are formed. Ion exchanger's matrix is hydrophobic because the polystyrene (the basis of many ion exchange resins) is insoluble in water. The insertion of active groups means insertion of hydrophilic group into a waterproof matrix. The ion exchanger becomes a polyelectrolyte that is capable of swelling. When swelling, the volume of ion exchanger increases owing to insertion of water into ion exchanger's grains [3].

Thus, synthetic ion-exchange resins are polyelectrolyte gels capable of swelling. Their swelling capacity is limited by the cross-section bonds.

Properties of synthetic ion-exchange resins are defined by a number and type of active groups and also by a matrix structure (first of all - quantity of cross-section bonds). A number of active groups defines the available capacity of a resin. Ion exchanger's capacity and quantity of cross-section bonds define the swelling degree, which determines the counter-ions mobility and ion-exchange processes' rate.

The structure of a matrix determines chemical and thermal resistance of ion-exchange resin, i.e. their service life. The important role is also played by the type of active groups[1].

The functionality of resins is classified by the nature of fixed ions[1]:

- Strong acid cation – sulfonate, SO_2;
- Weak acid cation – carboxylate, COO^-;
- Strong base anion (Types 1, 2):

Type 1 – benziltrimethylammonium, - $CH_2N(CH_3)_3^+$;

Type 2 – benzildimethylethanolamine, - $CH_2N(CH_3)_2(CH_2CH_2OH)^+$;

- Weak base anion – tertiary amine, - $CH_2NH(CH_3)_2^+$.

It is possible to covert an ion exchange resin to any counter-ion form. Most ionic forms can be obtained by the interaction between an ion-exchange resin and a concentrated acid or alkali solution, containing an appropriate ion, during 20-30 minutes [4].

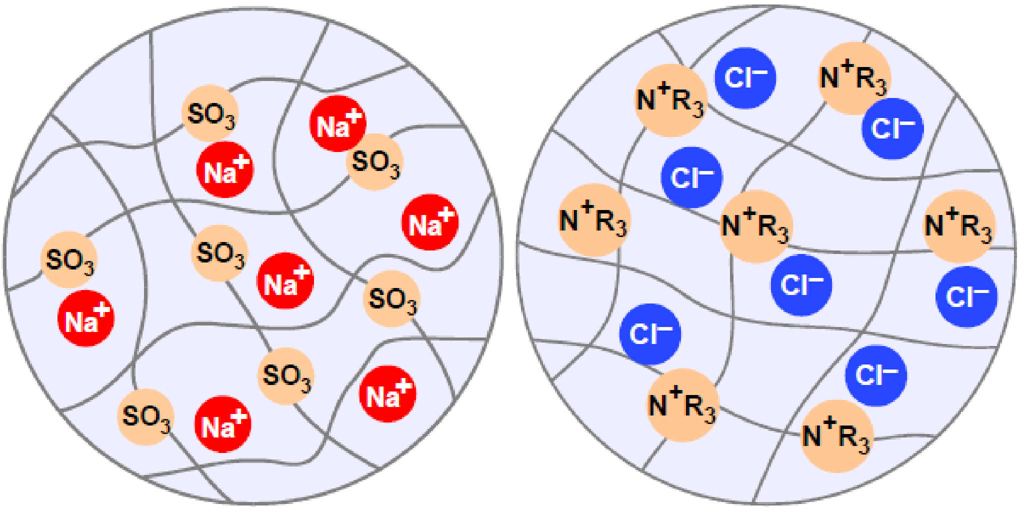


FIG. 1. Schematic cation-exchange and anion-exchange resins' particles

In figure 1 [4], there are schemes of ion-exchange resin beads. The dark lines shows the polymeric skeleton of the resin's particles, which are porous and contain water. The fixed ions of cation exchange resin in Figure 1 are sulphonates (SO_3^-). Sulphonates are attached to the skeleton of the resin. Counter-ions of the cation exchanger are cations of sodium (Na^+). The most widespread form of cation exchangers is the sodium one. The functional group of the anion exchanger in Figure 1 are cations of quaternary ammonium ($N^+R_3 = CH_2N(CH_3)_3^+$). The counter-ions of anion exchanger are chloride anions (Cl^-). The chloride form of anion exchange resins is the most widespread for anionites [4].

IV. ION-EXCHANGE IN URANIUM TECHNOLOGY

Uranium underground leaching solution contains uranyl bisulphate ($UO_2(SO_4)_2^{2}$) and uranyl trisulphate ($UO_2(SO_4)_3^{4-}$) complex ions [5].

The uranyl trisulphate complex ion prevails in most cases of acidic leaching solutions. The bisulphate complex anion is formed in case of pH level is close to 2 and the concentration of SO_4^{2-} is low. The sulphate anion complexes are strongly sorbed by weak and strong base resins [5].

In case of a carbonate uranium leaching, the solution contains uranyl bicarbonate ($UO_2(CO_3)_2^{2-}$) and uranyl tricarbonate ($UO_2(CO_3)_3^{4-}$) complexes. These carbonate complexes are also stongly adsorbed by weak and strong base resins, but still ion exchange from acidic uranium solution is prevalent [5].

The functions of ion-exchange resins are to concentrate uranium complexes and to purify them from different impurities. A resin should absorb valuable complexes selectively from underground leaching solution containing anionic complexes of many impurities. It is very important to perform this process rapidly and reversibly for uranium can be recovered later by the elution process. The ion exchanger's loading capacity and ion-exchange kinetics are very important because the volume of a resin which is needed for obtaining a certain amount of product depends on these factors. The purity of the end product of uranium obtaining is also depends on resin's total capacity and selectivity to a valuable compound [5].

Gel-type resins have been used in most cases of uranium ion-exchange. The polymer matrix of gel-type resins is a continuous phase. It is substantially uniform throughout the beads [5].

Nowadays macroreticular resins are the most preferable. These resins have both a continuous gel phase and a continuous pore phase. Such macroreticular structures are obtained by the processes of monomers' polimerization in the medium of non-polymerizable dissolvents. The structure with opened pores shortens the diffusion path of a metal and improves the diffusional kinetics. It means that macroreticular resins have better kinetics than gel-type resins have [5].

But uranium loading capacities of macroreticular resins are lower than gel-type resins' capacities. True wet densities of macroreticular resins are also lower than true wet densities of gel-type resins [5].

During the process of ion exchange, the fouling of the resin's pores by silica brings to some problems. The fouling of pores can substantially reduce loading rates. The uranium loading capacity of a fresh resin rapidly decreases during the first few operation cycles. Then uranium capacity decreases more slowly due to [5]:

- Resin's chemical structure changes;
- Some impurities' irreversible adsorption.

The adsorption of impurities is called resin poisoning. Common resin poisons in the uranium technology are: molybdenum, silica, sulphur, titanium, zirconium, thorium and organic materials [5].

These resin poisons can be removed by caustic soda or by strong (12N) sulfuric acid solutions (12N). Sulfuric acid is successfully used for the regeneration of resins that are fouled with titanium, zirconium, thorium and organic materials [5].

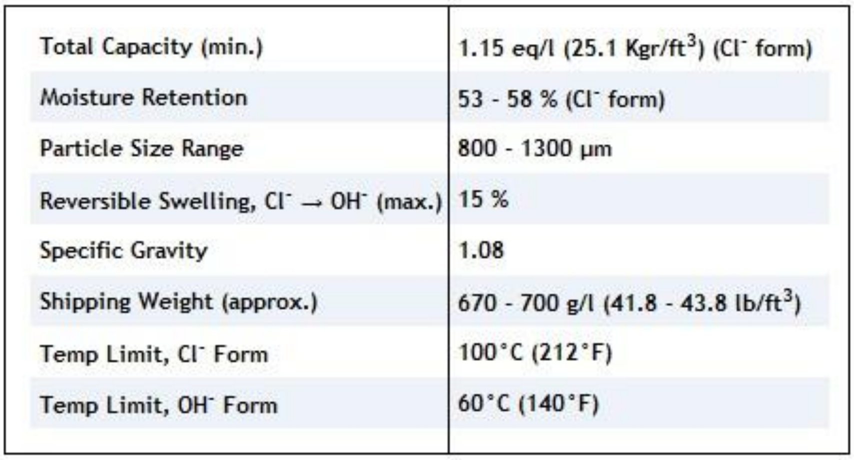
Further in this work, the macroreticular Purolite A500/2788 ion-exchange resin will be considered for the process of uranium ion-exchange concentration.

Purolite A500/2788 is a macroreticular-type strong base anion exchange resin efficient for the extraction of uranium complexes in underground leaching or heap leaching methods. Thanks to its specially graded particle size, this resin is particularly suitable for use in these processes. The macroporous structure of the resin ensures regeneration efficiency and lower volume of eluates, while eluates have high uranium concentrations. **Purolite A500/2788** shows high resistance to osmotic and thermal shock and mechanical attrition.

The basic features of Purolite A500/2788[6] are:

- Application: uranium and gold mining;
- Polymer structure: macroporous polystyrene crosslinked with divinylbenzene;
- Appearance: spherical beads;
- Functional group: quaternary ammonium;
- Ionic form: Cl^-.

The other characteristics of this resin are presented in Figure 2.



Total Capacity (min.)	1.15 eq/l (25.1 Kgr/ft^3) (Cl^- form)
Moisture Retention	53 - 58 % (Cl^- form)
Particle Size Range	800 - 1300 µm
Reversible Swelling, $Cl^- \rightarrow OH^-$ (max.)	15 %
Specific Gravity	1.08
Shipping Weight (approx.)	670 - 700 g/l (41.8 - 43.8 lb/ft^3)
Temp Limit, Cl^- Form	100°C (212°F)
Temp Limit, OH^- Form	60°C (140°F)

FIG. 2. Purolite A500/2788 characteristics

For Purolite A500/2788 uranium ion exchange is represented by equation 3.1[1]:

$$2(R_4N)_2SO_4 + UO_2SO_4 \leftrightarrow (R_4N)_4[UO_2(SO_4)_3] \tag{3.1}$$

V. APPARATUS AND FLOWSHEET OF URANIUM ION-EXCHANGE CONCENTRATION PROCESS

To realize the process of uranium ion-exchange concentration, (to adsorb $UO_2(SO_4)_3^{4-}$ anions at ion-exchange resin) the special apparatus is needed. There are a lot of different devices for uranium sorption (i.e. periodic ion-exchange column, sorption-forcing column, column of continuous sorption, pulsating sorption column, sorption-desorption column, Higgins contactor and ion-exchange pachuca). But speaking about the underground leaching method of uranium mining, the most widespread device for uranium sorption is sorption-forcing column. The reasons for such a wide application of this device are availability of this device in the market and its characteristics. Columns of this type have high productivity (180-300m^3/h) and allow performing the process in a semicontinuous mode with small time consumption for loading and for unloading of uranium enriched and regenerated ion-exchange resin portions. Moreover, the column design allows to automatize all operations connected with its service and to carry out maintenance and improvement works easier[7-10].

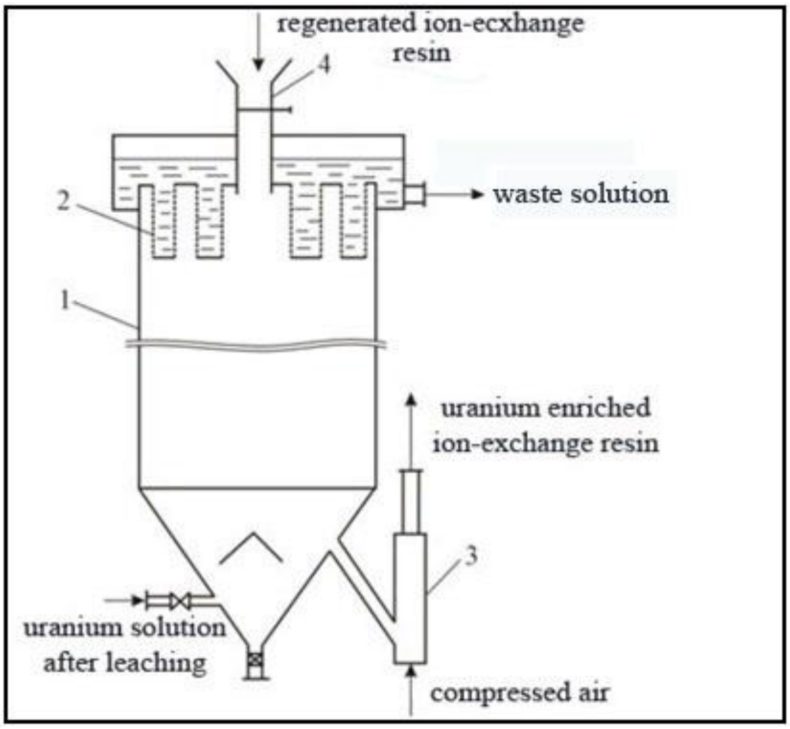


FIG. 3. Schematic sorption-forcing column

1 – body; 2 – filters; 3 – airlift; 4 – ion-exchange resin feeding box

Characteristics of sorption-forcing column are the following:

Height: ~10 m;
Diameter: ~3 m;
Solution velocity: 25 - 30 m/h;
Productivity: 180 – 300 m^3/h.

During the process of ion exchange, there are three layers of ion-exchange resin in the column. In the upper part of the column there is a layer of fresh (uranium depleted) resin. It provides the decreasing of uranium concentration in the flowing solution. In the middle of the column there is a layer of operative concentrations. The height of this layer is 5-6 meters. It depends on the concentration of uranium in the solution and on the solution velocity. In the bottom of the column there is a layer of uranium enriched resin.

Sorption-forcing columns work in parallel mode in connection with other columns. Manufacturing scheme of uranium ion-exchange concentration often consists of ten sorption columns.

In Figure 3, there is the flowsheet of uranium ion-exchange concentration process. Uranium solution after leaching process is transferred to ion-exchange concentration process to the bottom of sorption-forcing columns (1).

The columns work in a parallel mode. The movement of solutions is carried out countercurrently from the bottom to the top of the columns against the resin's movement. The process is controlled by the uranium concentration in a waste solution. The acceptable concentration of uranium in a waste solution is less than 2 mg/l. After getting waste concentration of uranium, the overload of the resin is carried out. The uranium enriched resin is unloaded from the bottom part of the columns. After that the regenerated resin is loaded into the columns in the same volume. The unloaded rich resin is transferred to the buffer capacity (3).

The waste solution is taken out from the top of the sorption-forcing columns through filtering cartridges and transferred to shaker riddles (2) for catching the resin slipped through filtering cartridges. After that the waste solution is transferred to the leaching process. The caught resin goes to the buffer capacity. The rich ion-exchange resin is taken out from the bottom of the buffer capacity and transferred to the further processing.

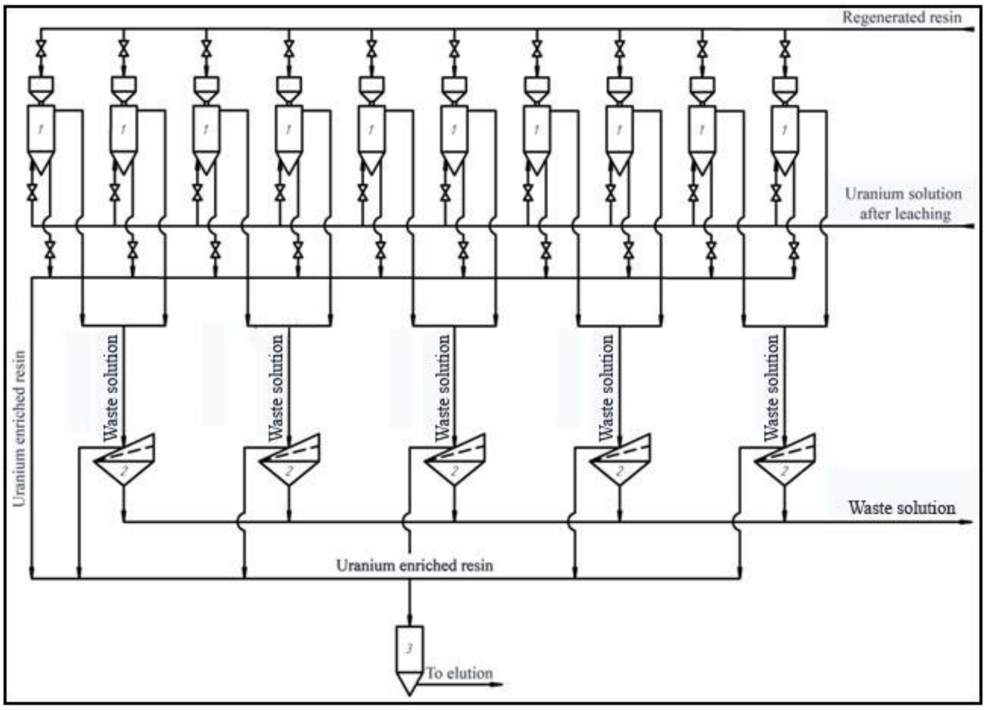


FIG. 4. Uranium ion-exchange concentration process

VI. CONCLUSION

On the basis of considered fundamentals of ion exchange, the next summary was made:

- Ion exchange occurs between a solution and the internal surface of a solid and it can be viewed as a special type of the sorption process;
- During the ion exchange, the ions being exchanged are reversibly removed from the solution and transferred to the ion exchanger;
- Ion exchange is a physical separation process, in which the ions exchanged are not chemically altered;
- Ion exchange in uranium technology is associated with the removal of uranyl trisulphate ($UO_2(SO_4)_3^{4-}$) complex ions from the solution after leaching and their transfer to the ion exchanger;
- Since the ion exchanger only collects the valuable ions, the spent exchanger must be regenerated at the end of a cycle;
- The regeneration of the ion exchanger is carried out by contacting the spent exchanger with a concentrated solution of an ion (such as Cl^- or other), which can replace the ions adsorbed on the exchanger during the sorption process.

It was also marked, that nowadays for uranium ion-exchange process macroreticular ion-exchange resins are mostly used. The basis of uranium sorption at such a type of ion exchangers was also considered in this work. Moreover, in the given work, apparatus and the flowsheet of uranium ion-exchange concentration process were described.

1. Harland, C.E. Ion Exchange Theory and Practice. Royal Society of Chemistry Paperbacks, UK, 1994;
2. Alchin, D. Ion-exchange Resins, New Zealand, 2001;
3. Helfferich, F. Ion Exchange, Dover Science Books, USA, 2005;
4. Rohm and Haas. Ion Exchange, USA, 2008;
5. Uranium extraction technology, Technical report series No. 359, International Atomic Energy Agency, Vienna, 1993;
6. Purolite® A500/2788. Retrieved May 20, 2012, from http://www.purolite.com/default.aspx?RelID=606288&ProductID=210;
7. Philip A. Schweitzer, Handbook of Separation Techniques for Chemical Engineers, McGraw-Hill, 1988.
8. Global Uranium Resources to Meet Projected Demand. International Atomic Energy Agency. 2006. Retrieved 2007-03-29.
9. «Uranium». The McGraw-Hill Science and Technology Encyclopedia (5th ed.). The McGraw-Hill Companies, Inc.. ISBN 0-07-142957-3.
10. Diehl, Peter. "Depleted Uranium: a by-product of the Nuclear Chain". Laka Foundation. Retrieved 2009-07-31.

RENEWABLE AND UNTRADITIONAL ENERGY SOURCES

I.S. Gavryushenko, E. A. Zaitsev

Scientific Supervisor: Senior teacher A. V. Astapenko

Linguistic Advisor: Teacher A.V. Tsepilova

National Research Tomsk Polytechnic University, 30, Lenin St., Tomsk, Russia, 634050

E-mail: egor1290@yandex.ru

Abstract.

Renewable and untraditional energy sources. The main purpose of the article is to tell about sources of energy that must substitute conventional energy sources in near future. Article is not difficult to read for people that don't know anything about energetics. But text include a big amount of useful information about reserves of conventional and untraditional energy sources, best prospect renewable sources of energy such as geothermal and solar energy. Data in the text carefully structured to facilitate the perception. First part is short introduction about reserves and problems of conventional energy sources. We can find some about necessity of searching new sources of energy, too. After that we can see proposition of author in field of new energy sources. The author tells about geothermal way (i.e. obtaining the energy from heat of the Earth), solar energy, mini hydroelectric power stations (using the energy of small rivers), nuclear fusion and wave energy. So we can read about main principle, potential, searching and experiments in field of alternative energy sources. The author writes about successful application of some sources, too. Then the author gives information about prospects and reasons for the reluctance to use renewable energy sources. And finally we can read about condition of application of alternative sources of energy.

There are a lot of publications, articles and texts on this theme. But this article is little bit unusual and slightly stands out from the rest due to the peculiarities of presentation of information. This article can be useful for people beginning studying this subject.

I. INTRODUCTION

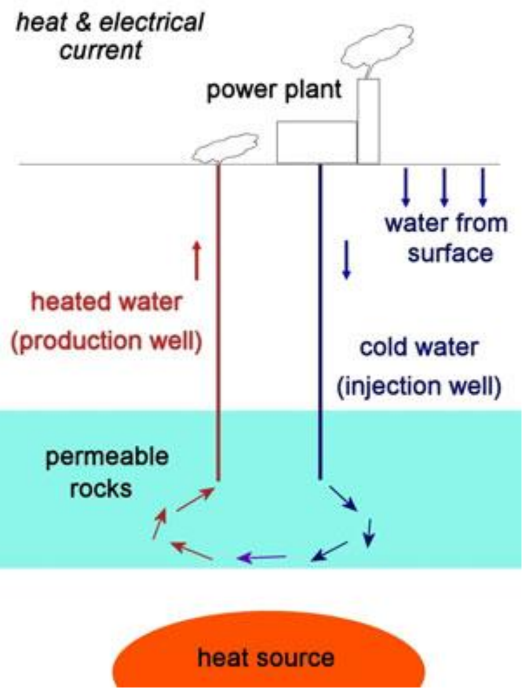
In the present article we'll try to consider energy, and exactly the renewable (or alternative) energy sources and types of its obtaining. Beginning a narration about energy, we'd like to cite a famous expression about money, but it can be referred to the energy as well: «it can't suffice, it can be enough, but it never happens much...».

To start with, we'd like to familiarize you with an unfavourable statistics, it is as follows: scientists calculated that the reserves of conventional energy sources have been steadily decreasing, for example coal suffices for 200 years, oil - for 90 years, gas - for 50 years, uranium - on 27-80 years. But that's not all, when we use the traditional sources of energy, we increase environmental contamination, break the atmosphere heat balance and it gradually leads to global climate change. For instance, power plants operated on fuel burning are the main pollutants. They deliver anthropogenic carbon (mainly in the form of CO_2), about 50% of sulfur dioxide, nitrogen oxides, 35% and the same amount of dust into the atmosphere. According to some data, thermal power plants pollute the environment by radioactive substances 2-4 times more than nuclear power plants of the same capacity. On the assumption of the mentioned facts, it can be noted that humanity is gradually lead to the so-called "deadlock" and to prevent this we should take some measures. One of the ways is starting to develop alternative energy sources as fast as possible. Firstly, they are much more ecological than traditional ones and, secondly, they are practically inexhaustible.

II.

We'll try to describe renewable (alternative) ways of energy production. We believe that the problem does not consist only in energy generating, but in its reasonable use. It is necessary to develop and introduce technologies with low consumption of electricity. But, as always the problem is money, or the absence of it.

Let us consider renewable (alternative) sources of energy obtaining. The first place is given by us to a geothermal way, i.e. obtaining the energy from heat of the Earth. There are a lot hot wells on our planet. In some countries, geothermal energy accounts for a considerable part of a power balance of the country (for example, Iceland). Geothermal plants are not necessary to be built near the hot wells. One can build a power plant and at any other place, but it will cost more. It is necessary to dig a hole of several kilometers. Earth's temperature should be about 350° C or higher. Two tubes are put down into the hole. The water comes through one tube and the steam comes back through the other one.



The installation has the following form: (picture 1)

Besides it is possible to obtain not only energy, but the heat as well that would be more effective because for heat it is not necessary to dig so deeply. We are sure that such an installation will cover the expenses very quickly. And impact on environment is minimal. There are already such stations in the world. For example, in the USA there is a place where there are no any hot wells, but the described station is operating.

The second place is given to the solar energy. Less than 1 % of a stream of solar energy is concentrateв in biomass annually. However this energy considerably exceeds the one that obtained by a man from various sources now and will be obtained in the future. Biomass can be easily recycled into other types of fuel, such as biogas or spirit. The spirit received from biological resources is more and more widely used in internal combustion engines. For example, since 70-ies Brazil transferred a significant part of vehicles to the spirit fuel or a mixture of spirit and gasoline. Experience in using spirit as an energy carrier is available in the USA and other countries.

Pic.1 Geothermal plant

We’d like to give the third place to the so-called mini hydroelectric power stations. We believe that power resources of the average and small rivers (length from 10 to 200 km) are used extremely insufficiently. There are more than 150 thousand of such rivers only in Russia. In the past the small and average rivers were the major source of obtaining the energy. Small dams on the rivers do not break but optimize the hydrological regime of rivers and adjacent areas. They can be considered as an example of environmentally conditioned nature management, soft intervention in natural processes. Water storage basin built on the small rivers, usually do not extend beyond the channels. Such water storage basins dampen vibrations of water in rivers and stabilize levels of underground water under the adjacent inundated areas. It favorably affects efficiency and stability of both water and inundated ecosystems.

One has calculated that on the small and average rivers it is possible to receive energy not less than on modern large HYDROELECTRIC POWER STATIONS. Now there are the turbines, allowing to obtain energy, using a natural current of rivers, without building dams. Such turbines are easily mounted on the rivers, and if it is necessary they are moved to other places. Although the cost of energy received by such installations it is significantly higher, than by large HYDROELECTRIC POWER STATIONS, or the nuclear power plant, but a high ecological compatibility makes its obtaining reasonable.

Next we'd like to consider a way of energy obtaining which has not existed yet. But we believe that it is very promising. It will serve as the replacement of existing nuclear power stations. Modern nuclear power is based on the splitting of atomic nuclei into two lighter ones, releasing energy in proportion to weight loss. Source of energy and the decay products are radioactive elements. The basic environmental problems of nuclear industry are connected with them.

A grater amount of energy is released in the process of nuclear fusion in which two nuclei collide into one heavier nucleus, but also with the loss of mass and energy release. The initial element for the synthesis is hydrogen, the final is helium. We refer this way of energy obtaining to renewable because the products of reactions (hydrogen) are almost inexhaustible. But this way of obtaining the energy has one essential minus: it is the most ecologically dangerous way of obtaining the energy.

The result of nuclear fusion is the energy of the sun. This process is simulated by a man at explosions of hydrogen bombs. It is a problem to make the nuclear fusion controlled and to use its energy properly. The main difficulty consists in that nuclear fusion can occur at very high pressures and temperatures of about 100 million °C. There are no materials used to make reactors for performing superhigh-temperature (thermonuclear) reactions. Any material at the same time melts and evaporates. Scientists went by the way of search of reactions performing possibilities in the environment unable to evaporate. For this purpose two ways are now being tested. One of them is based on the retention of hydrogen in a strong magnetic field. Installation of this type is called tokamak (toroidal chamber in magnetic field). Such chamber is developed at the Institute of Kurchatov. The second way provides the use of laser rays in order to obtain the necessary temperature and to deliver hydrogen to the places of their concentration.

Despite some positive results of the realization of controlled nuclear fusion, there are opinions according to which in immediate prospects it will be hardly used to solve power and environmental problems. It is connected with pendency of many questions and with necessity of enormous expenses on further experimental, and furthermore industrial designing.

Next we'd like to consider the energy that is produced by the waves. There are several projects on the use of wave energy. In the UK, Dr. Art. Salter from Edinburgh University invented the most advanced wave energy converter. This is a machine with blades longer than 18 m, diverging at an angle from a general axis and shaking together with waves. St. Solter`s device is a unique one, using energy of both horizontal and vertical movement of waves. Thanks to this its EFFICIENCY comes nearer to 85 %. As calculations showed, a 1-metre section of a wave "bears" from 40 to 100 kw of energy, suitable for practical use.

Wave energy on a small scale is already used in Japan. There are more than 300 buoys and beacons are fed by the electric power produced by generators, driven by sea waves. In the port of Madras in India, a floating beacon on which the electricity generator is driven by energy of sea waves is successfully operating. Nowadays wave generators are used more often for energy supply of navigating buoys and radio beacons. Japan started their operation in 1965 and later built an experimental wave ES with capacity of 125 kW, with a perspective to 1250 kW. Works on creation of stations of this kind are guided in Russia, Sweden, the USA, England and other countries. In Norway, in 1985 the first station of this type with capacity of 200 kW was built near Bergen, where in the future it is expected to install a series of such units and to significantly increase the capacity. Difficulties on creation of wave power stations are connected with non-uniformity of their work, biological and other pollution of working parts and water throughput channels (accretion seaweed, cockleshells, salts), destruction owing to rust, etc. Their advantage is full ecological purity and operation possibility in an automatic mode.

III CONCLUSION

At the end we'd like to represent a table of power supplies considered in the given article, their condition, development prospects:

Power supply	*Prospects for the use*
Hydro energy	Resources of 890 mln. t. of oil equivalent
Geothermal energy	Inexhaustible, promising
Solar energy	Almost inexhaustible, promising
Wave energy	Practically inexhaustible
Nuclear fission energy	Physically inexhaustible

Table 1. development prospects of power supplies

In the conclusion we'd like to highlight the reasons for the reluctance to use renewable energy sources:

1) financing - perhaps, the most important problem.
2) many renewable energy sources are little-studied
3) low efficiency factor
4) different administrative barriers

As for our country, Russia ranks almost the last in all types of renewable energy sources. There is no industry that brings together all the disparate development of a unified strategic plan. In the concept of Fuel and Energy Ministry the renewable energy sources play the secondary and supporting role. In the concepts of Russian Academy of Sciences, of leading institutions, as reflected in the "Clean Energy" (1993), there are practically no any strategies for the full transition to alternative energy and it still relies on small, independent power in the very distant future. This certainly affects the economic backlog of the country, and also the environmental situation both in the country and all over the world.

1. Antropov, P.Y. The fuel and energy potential of Earth. (Moscow, 1994)
2. http://www.science-award.siemens.ru
3. Technology development of renewable energy sources, as well as secondary energy. 1998, RINKCE
4. http://solar-battery.narod.ru/
5. Controlled thermonuclear fusion in plants with a dense plasma, G.I. Budker, "Nature», № 5, 1974.

SINGLE-WIRE TRANSFER OF ELECTRIC ENERGY

R.S. Gladkih, E.N. Glushkov, I.A. Kopylov.
Scientific Supervisor: Prof., PhD. phys.-mat. V.F. Myshkin
Language Supervisor: Teacher A.V. Tsepilova
Tomsk Polytechnic University, 30, Lenin str., Tomsk, Russia, 634050
E-mail: ruslangladkikh@mail.ru

Abstract.

In the given article the method of energy transfer by one wire is considered. The work contains experiments and calculation some characteristics of the facility.

I.

We cannot imagine modern technocratic society without numerous electronic devices. Also, for production of electric energy a lot of recourses are consumed. Efficiency coefficient of modern lines of electricity transfer equals 90-95 percent. With all newest technologies total looses equal 5-10 percent. Evidently, the problem of decrease of electric energy transfer losses is very important and it is necessary to look for some ways to solve it. Nowadays, the problem of conservation of resources has leading positions in world.

II.

The objective of our work is realization of transferring electric energy by a single wire with high coefficient of efficiency and explanation of processes taking place at transmission.

In his well-known experiment the Russian researcher S.V. Avramenko transferred power equal to approximately 1,3 kilowatts. He used a car generator with frequency equal to 8 kilo-Hertz as power supplier. The length of the wolfram wire is 2,75 m. with a diameter of 15 micrometers. The resistance of such a wire is much more then the one of a cuprum wire with the same length. It means that this wire must radiate heat and have big losses. But the researcher claimed that the wire was cold. That is why transfer line «didn't have resistance» likes a «superconductor» under standard conditions. But in this work there are no results of such research. [1]

For test operation we made two experimental assemblies. The first assembly (Figure 1) consists of a generator and a wire diagram, which is the convertor of direct-current voltage to alternating voltage. Transformer T is fed by convertor. Transformer has the following characteristics: a bobbin with 1-6 coils of cuprum wires with diameter equal to 0,15 millimeters, a bobbin with 2- 20 coils of cuprum wires with diameter equal to 0,2 millimeters, bobbin with 3- 1800 coils of cuprum wires with diameter equal to 0,12 millimeters.

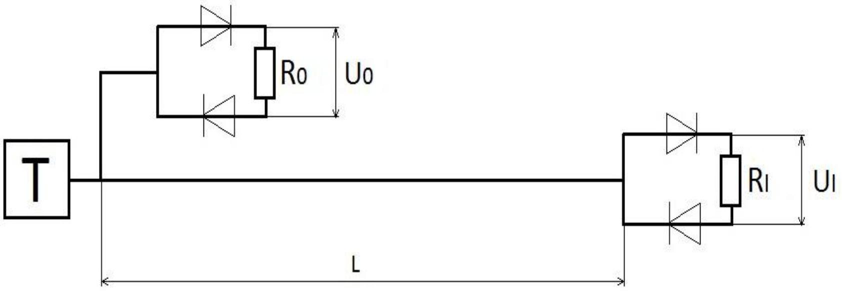


Fig. 1. Measuring wire diagram of first facility

We use cuprum wire with diameter equal to 0,12 millimeters as transfer line. In rags of lines we fixed diode plugs, as a load. We fixed the resistance of 75 Ohms in every plug. The length of transfer lines was changed from 1 meter to 40 meters. The voltage measured by oscillograph in accordance with figure 1. Simultaneously we measured a time delay of voltage relatively to one an other. We directed a voltage equal to 5 Volts with current strength equal to 500 milliamps to the input of transformers. Current strength is measured in millimeter.

In figure 2 there is a voltage-length diagram.

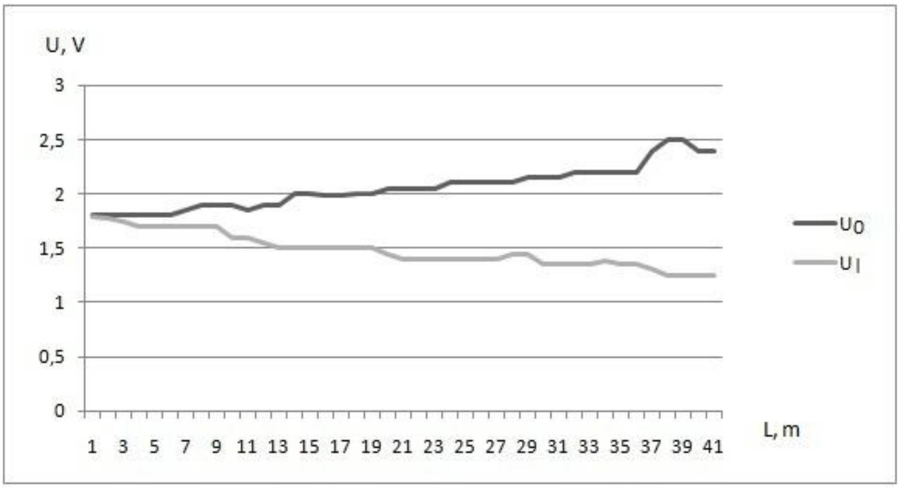


Fig. 2. Voltage-length diagram.

U_0 is the voltage in plug at the start of the line.

U_l is the voltage in plug at the end of the line.

When the length of the wire was equal to 10 meters, we registered a decrease of voltage in the first plug. This is why we calculated average voltage and average capacity in the first plug.

$W_{0average}=U_0^2/R_0=2.056^2/75=0.0564$ Vats

After it, we calculated the capacity in the second plug by length l L=20 meters and L=40 meters.

$W_{L=20}=0.027$Vats Coefficient of efficiency=47.9%

$W_{L=40}= 0.021$ Vats Coefficient of efficiency=37.2%

Previously scientists gave theoretic assumptions about these results. For example, this effect accounts for bias current and resonance phenomena's- coincidence of frequency voltage of power source and inherent frequency of ripple and atomic lattice (if it's possible). In 1830-th years Faraday wrote about instantaneous current in a single line in compliance with Maxwell's electrodynamics. Polarization current occurs without emission of Joule heating; it means that the conductor offers no resistance. [2]

The second experimental facility consists of a high-frequency generator with the following characteristics: output voltage equal to 15 kilowatts, capacity equal to 1,5 Vats; decrease transformer without slog, with coefficient of transformation equal to 166; double-half period rectifier composed of diodes 1N4007; resistors equal to 910 Ohm and 4,7 kilo Ohm; and capacity of 0,5 microfarad. The scheme of this facility is presented in figure 3.

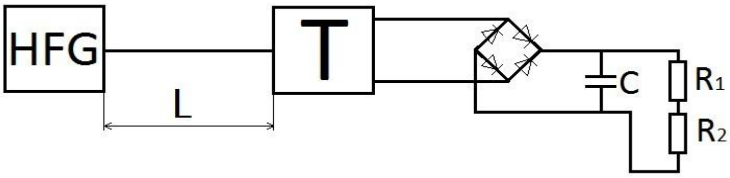


Fig. 3. Wire diagram of second facility

We used two wires. The length of first wires equals 27 meters with a diameter of 0,15 millimeters. The length of the second wire equals 35 meters with diameter equal 2,7 millimeters. For measurement we used an oscillograph connected to resistance of 910 Ohm.

In course of our experiment we obtained the following results: 1) in measurement without transfer line (generator to measurement scheme) the voltage was equal to 6 Volts; 2) in measurement with transfer line with a length of 35 meters the voltage was equal to 0,9 Volts; 3) in measurement with transfer line with a length of 27 meters the voltage was equal to 4 Volts.

Calculating capacity formula: $P = (U*K)^2 / R_1 + U^2 / R_2$. K is ratio of resistors, is equal to 5,2.

For the first case: $P = (6*5{,}2)^2 / 4700 + 6^2/910 = 0{,}25$ Vats

For the second case: $P = (0{,}9*5{,}2)^2 / 4700 + 0{,}9^2/910 = 0{,}0055$ Vats

For the third case: $P = (4*5{,}2)^2 / 4700 + 4^2/ 910 = 0{,}1095$ Vats

It is seen, that with increasing wire diameter, voltage and capacity decrease. Voltage is not impulse, consequently, resulting capacity is active. During measurement, we fixed two frequencies 100 kilohertz (10 microseconds) and 25 kilohertz (40 microseconds). Registered frequencies near few centimeters equal 133 kilohertz (7,5 microseconds) and 25 kilohertz (40 microseconds).

Few advantages of single-wire transfer of energy in the future: the amount of metal used for producing of wires will decrease several times; short circuit will be excluded; the risk of fire will be excluded. In our future work we plan to set up to resonance our high-frequency generator with receiver. It will allow to increase the coefficient of efficiency of our device.

1. Zaev N. Technique to youth N1, 1995
2. «Electro and resonance generators»: http://www.skif.biz
3. N. Tesla «Tesla about electricity», autobiography, Minsk, 1970
4. R.V. Pol' «Doctrine about electricity», PolScience, Warsaw, 1975.
5. Innovations in electricity/ 06.1995, scientific magazine «Electricity», Moscow.
6. Wireless transfer of electricity/ 4(31)/2009, scientific magazine «PRO electricity», Moscow.

PLASMA CURRENT CONTROL-ORIENTED LINEAR MODEL FOR TOKAMAK KTM

V.S. Khokhryakov, A.V. Malakhov
Scientific Supervisor: PhD, Associate Professor V.M. Pavlov
Linguistic Advisor: Teacher A.V. Tsepilova
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: vasiltmt@sibmail.com

Abstract.

This work deals with plasma current control-oriented modeling for KTM tokamak – the essential stage of plasma current control loop design.

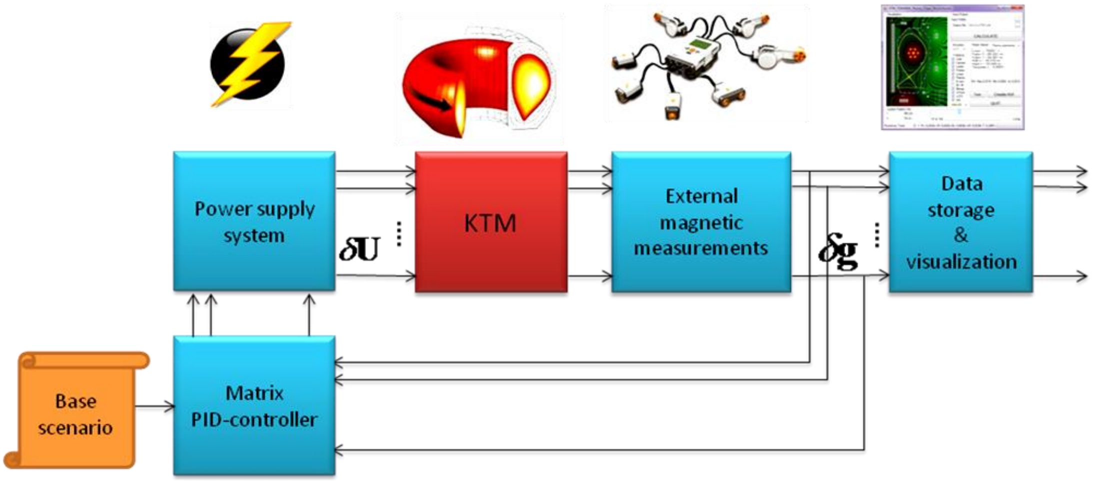
As a practical result, two different linear models based on a state space methodology were designed. It was shown that accuracy of a linear model made in Matlab/Simulink is enough for further feedback control loop with matrix controller adjustment. It was revealed that the model parameters are significantly different from the one operating point to another. It means that choosing different operating points leads to different matrix coefficients of the linearized object, but it is sufficient to conduct one linearization procedure at a point corresponding to the middle of the main discharge phase for an adequate control object description in the main discharge phase when the plasma current's plateau is maintained.

This article is intended for students who study physics, automation, control theory. It would be useful for those who are interested in modern innovations in the thermonuclear field of industry.

Keywords: Tokamak, plasma, linear model, control system, diverter, limiter.

I. INTRODUCTION

Coordination of the Kazakhstan Tokamak for Material testing studies (KTM) supports ITER project in plasma material interaction investigations [1]. It can give an important investment to the elongated plasma confinement database. Thus KTM software support becomes extremely urgent. In particular, the development of a control-oriented linear model for the control of plasma current as a part of KTM Automated Research System (ARS) software support becomes vitally essential task.



Picture. 1. KTM ARS system

Moreover, linear control theory as the most developed control theory will help to select and adjust a linear matrix controller applied to multi-input and multi-output (MIMO) object [2, 3].

II. OBJECTIVE

The objective of this work is to design a linear computer model of plasma that adequately describes a control object (plasma current) behavior during a discharge. A computer model should be constructed using terms of state space methodology.

A state space-model methodology allows to present a mathematical model of a physical system as a set of input δU, output δg and state δI variables represented as a system of differential equations (1) according to the Kirchhoff's second law.

$$\begin{cases} L^{*}\dfrac{d}{dt}(\delta I)+R\,\delta I=\delta U \\ \delta g=C\,\delta I \end{cases} \qquad (1)$$

where,

$\delta U = U\text{-}U_0$ – control coils voltage variation, [7x1]-matrix-vector;

$\delta g = g\text{-}g_0$ – plasma shape parameters variation, [5x1]-matrix-vector;

$\delta I = I\text{-}I_0$ – control coils currents variation, [7x1]-matrix-vector;

$L^* = L+M$ – a numerical [7x7]-matrix of inductance.

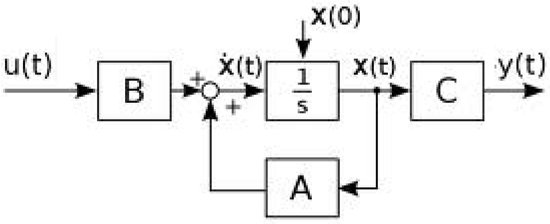
L – a diagonal [7x7]-matrix of coils self-inductance.

M – mutual coil-to-coil inductanc**e** [7x7]-matrix.

R – coils' resistance diagonal [7x7]-matrix.

C – a numerical "observation" [7x7]-matrix.

Inputs δU, outputs δg and states δI are expressed as vectors. Additionally, as far as the dynamical system is linear, the differential and algebraic equations may be written in matrix form. Operator block-diagram of a state space-model in a canonical form is show in the picture 2.



Picture. 2. The operator block-diagram of a state space-model

Conversion of model parameters to the canonical form leads to the following expressions:

$$A = -L^{-1}R$$

$$B = -L^{-1}$$

III. SYSTEM IDENTIFICATION

Standard procedure of system identification includes two stages:

- linearization;
- factorial experiment.

The first step is to derive linear form of a control object mathematically. Linearization procedure is conducted in the particular operating point – a set of initial inputs I_0.

The second step connected with generating informative data for full factorial experiment. A full factorial experiment allows to obtain elements of the “observation” matrix C independently from each other with a minimal error for any operating point I_0.

It is shown in [4] that the control of plasma current and shape calls for a MIMO approach because of the strong output coupling between the controlled parameters. The “observation” matrix (***C***) reflects plasma parameters response to coils currents changing. This matrix described in the Figure 3 where multivariable input (***I***) and multivariable output (***G***) are matrix-vectors.

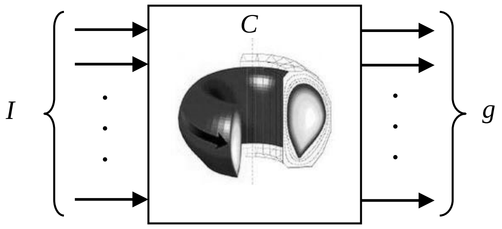


Fig. 3. «Observation» matrix ***C*** *as a MIMO object*

IV. FACTORIAL EXPERIMENT

In order to provide independent calculation of each element C_{ij} a full factorial design with seven factors was organized. An application designed in MS Visual C++ 2005 automates the data processing arranged in «Yates order» (named for scientist Frank Yates, who formalized factorial design analysis). Table 2 shows an arrangement of the experimental data.

Exp №	x_0	Factors - **I**				Response - **g**			
		x_1	x_2	...	x_m	y_1	y_2	...	y_n
1	+1	+1	+1	...	+1	y_{11}	y_{12}	...	y_{1n}
2	+1	–1	+1	...	+1	y_{21}	y_{22}	...	y_{2n}
3	+1	+1	–1	...	+1	y_{31}	y_{32}	...	y_{3n}
4	+1	–1	–1	...	+1	y_{41}	y_{42}	...	y_{4n}
...	…	…	…	...	…	…	…	...	…
$N=2^m$	+1	–1	–1	...	–1	y_{N1}	y_{N2}	...	y_{Nn}

Table 1. Experiment data arranged in «Yates order»

Elements C_{ij} can be evaluated using the following formula:

$$\tilde{N}_{ij} = \frac{1}{N}\sum_{u=1}^{N} y_{uj}\cdot x_{ui}, i \in [1,m], j \in [1,n]$$

where,

x_{ui}– coded factors value:

$$x_{ui} = \frac{I_{ui} - I_{0i}}{\Delta I_i}$$

Variation ΔI was chosen to be 0,5 kA for each factor. Initial levels I_{0i} depend on the type of magnetic configuration.

V. MODEL VALIDATION

The linear model with the parameters calculated above was implemented in two development **environments**: Matlab/Simulink and Mathematica 5.2.

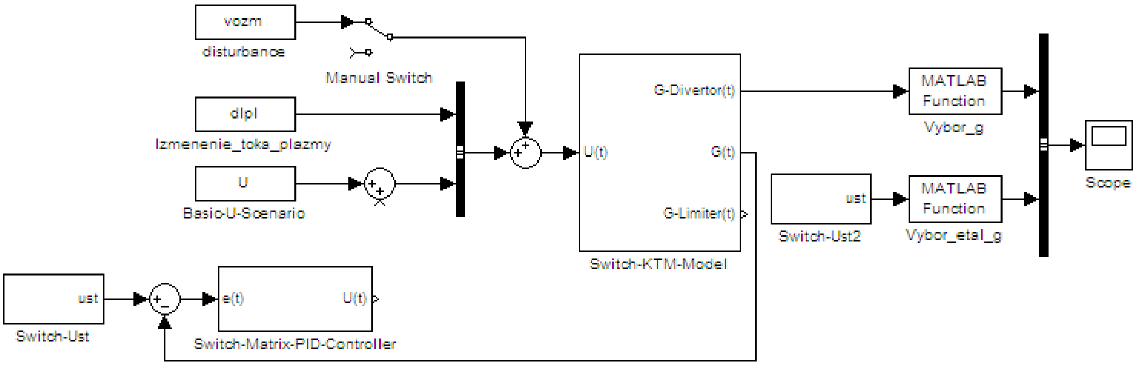


Fig. 4 Block-diagram of a linear model in Matlab/Simulink

VI. RESULTS

Figure 5 compares simulation results made with two models:

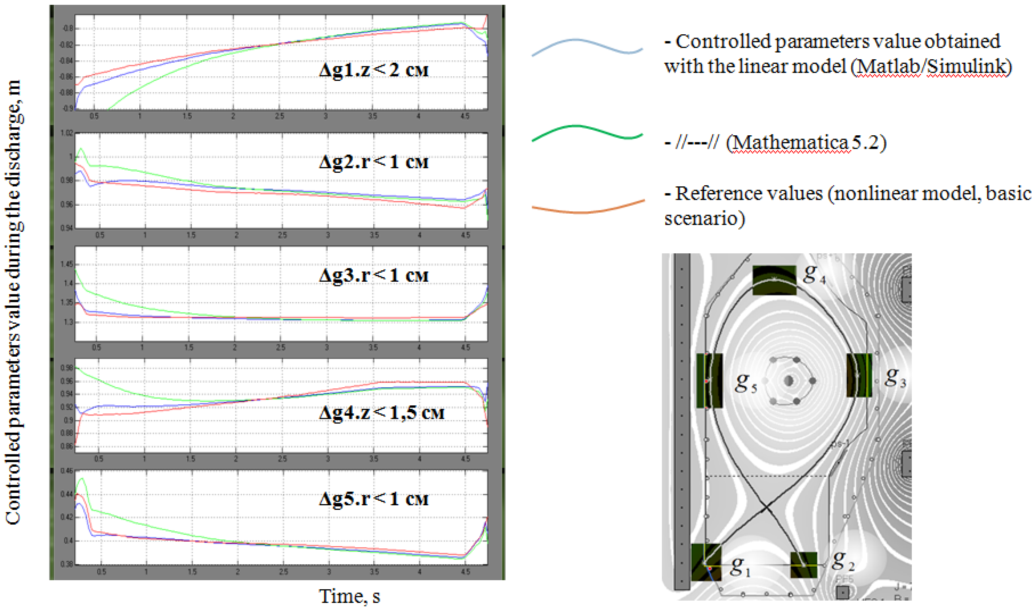


Figure 5 – Simulation results comparison with nonlinear reference values (diverter magnetic configuration, basic scenario)

Model adequacy was checked using the term of adequacy dispersion:

$$\sigma^2_{par} = \frac{1}{N-1}\sum_i \left(\bar{y}_i - \hat{y}_i\right)^2$$

where,

$\bar{y}_i$ – observed value (nonlinear);

$\hat{y}_i$ – predicted value (linear);

The adequacy checking results are shown in table 2. It can be argued static linear model gives acceptable accuracy for diverter magnetic configuration only.

Parameter	Magnetic configuration type	
	Divertor configuration	Limiter configuration
σ_{g1}	0,52 sm	1,9 sm
σ_{g2}	0,27 sm	20,65 sm
σ_{g3}	2,7 sm	9,8 sm
σ_{g4}	5,7 sm	–
σ_{g5}	1,3 sm	–
σ_{k}	–	0,05 r.u.
σ_{Zc}	–	4,1 sm

Table 2. Model adequacy checking results

From the table 2 it can be concluded that the linear model more accurately describes the behavior of the control object in the divertor magnetic configuration.

VII. CONCLUSION

A special application for static linear model parameters calculation was designed using described statistical and control theory methods. It was revealed that the model parameters are significantly different from the one operating point to another. It means that choosing different operating points leads to different matrix coefficients of the linearized object, but it is sufficient to conduct one linearization procedure at a point corresponding to the middle of the main discharge phase for an adequate control object behavior description in the main discharge phase when the plasma current's plateau is maintained.

Further work will focus on the implementing the designed model in a control loop for adjusting the multivariable matrix-controller.

1. Azizov E.A. KTM project (Kazakhstan Tokamak for Material Testing), (Moscow, 2000).
2. Gasparyan O.N. (2008). Linear and Nonlinear Multivariable Feedback Control – A Classical Approach.
3. Fairman F.W. (1998). Linear control theory.
4. Ariola M., Pironti A. (2008). Magnetic Control of Tokamak Plasmas, Springer.
5. Garrido A.J. Linear models for plasma current control in tokamak reactors, Control Automation Robotics & Vision (ICARCV) 11th International Conference, Dec. 2010.
6. Megretski A. (2004). Multivariable Control Systems, MIT OpenCourseWare.
7. Atherton D. Control Engineering – An introduction with the use of MATLAB, Ventus Publishing ApS, 2009.
8. Jinping Q. Equilibrium Reconstruction in EAST Tokamak, Plasma Science and Technology, Vol.11, No.2, Apr. 2009.
9. Zwingmann W. (2003). Equilibrium analysis of steady state tokamak discharges, Nucl. Fusion 43 842.
10. Barana O. Real-time determination of internal inductance and magnetic axis radial position in JET, Plasma Phys. Control. Fusion 44, 2002
11. Zabeo L. A versatile method for the real time determination of the safety factor and density profiles in JET, Plasma Phys. Control. Fusion 44**,** 2002

PLASMA HEAT GENERATOR BASED ON HIGH-FREQUENCY JET PLASMATRON

R.S.Korotkov
Scientific Supervisor: PhD, Associate Professor A.G. Karengin
Linguistic Advisor: Teacher A.V. Tsepilova
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: rskorotkov@gmail.com

Abstract..

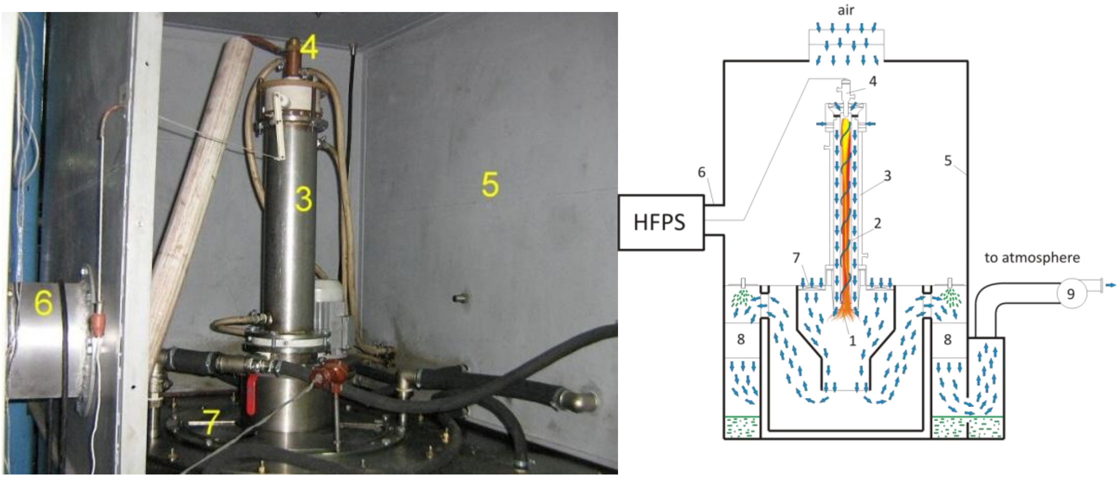
There are the results of experimental researches of plasma module operating modes based on high-frequency jet plasmatron, which is designed for plasma utilization of combustible compositions on the basis of oil sludge in terms of non-equilibrium high-frequency jet discharge air plasma in this article. Also it is suggested to use it for industrial production of heat energy from combustible wastes. For the calculations software package ANSYS FLUENT 6.3 was used, which has an extensive database of gaseous, liquid and solid fuel materials, and enable to calculate of multiphase laminar and turbulent flows, heat transfer and chemical reactions.

I.

In Russia, the volume of accumulated combustible industrial wastes (oil and coal sludge, oily liquid, bituminized residues, waste oils) reaches the millions of tons, and the payments for their location and storage are billions of rubles per year [1,2,6]. Existing traditional technologies (mainly thermal) do not solve the problem of recycling and disposal of such wastes, and lead to the formation of various hazardous and toxic compounds [3,4]. It should also be noted that these wastes have a significant heating value and can be used as fuel for industrial production of low-cost heat and even electricity [2,5].

II.

At the department "Technical Physics" of the National Research Tomsk Polytechnic University a plasma module was created, which is based on high-frequency jet plasmatron, designed for testing of environmentally safe oil [7] and other combustible industrial waste recycling technology in a non-equilibrium air plasma high-frequency jet discharge. Picture 1 shows the plasma module (a) and its scheme (b).



a) *b)*

Fig.1 Plasma module based on high-frequency jet plasmatron.

The plasma module consists of a power source with a high-frequency generator (1) of the vibrational power about 60 kW and an operating frequency of 13.56 MHz, high-frequency jet plasmatron (2) for generating of high-enthalpy non-equilibrium air plasma flows, plasma-catalytic reactor 3, the impeller reactor (4) with a variable inlet area of Simp = 165 ... 1155 cm^2 in increments of 165 cm^2, the host of "wet" cleaning for exhaust gases from the reactor (5), high-pressure exhaust fan (6) ВР 240-26 (№ 4), also site of preparation and filing in the reactor fuel compositions on the basis of oil sludge.

In the first phase of research were carried out the calculations of burning indicators for fuel compositions on the basis of oil sludge for the wide range of concentrations of oil, solids and water. Figure 1 shows the dependence of the adiabatic combustion temperature t_{ad} on the contents of combustible composition, which allows to determine the optimum compositions of ≥ 1200 ° t_{ad} to ensure environmentally safe incineration.

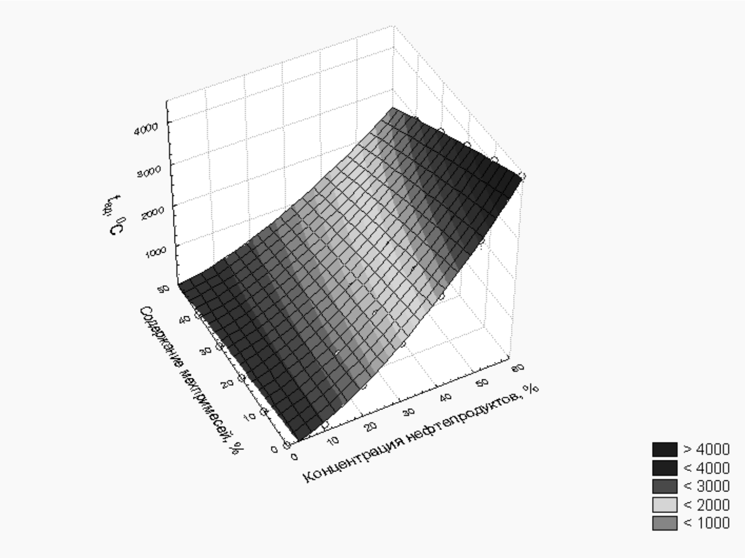


Fig. 2. Influence of oil content and impurities in the adiabatic combustion temperature of flammable compounds on the basis of oil sludge.

For example, the optimum fuel-air composition on the basis of oil sludge with the initial 10% solids content should consist of at least 40% of the oil, the rest – water

For assessing the capacities for rapid pre-heating of the reactor were investigated modes of jet plasma generator, providing (without feeding into the reactor of waste oil) increase in temperature of exhaust gases from the reactor than the flash point of these wastes. In pic. 3 it's shown the influence of the generator anode current (power of jet discharge) and the reactor impeller inlet area on the temperature of the reactor off-gases.

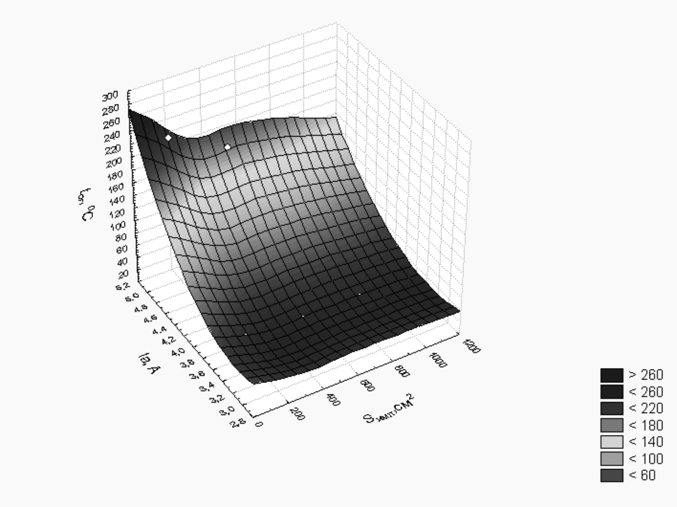


Fig.3. The influence of the generator anode current and the input area of the reactor impeller on the exhaust gas temperature.

From this graphic dependence it follows that the rapid heating of the reactor and the increase in temperature of the exhaust gases from the reactor more than the flash point of combustible compositions and can be achieved only when the generator anode current $I_a \geq 5\ A$ and the reactor impeller inlet area of is not more than 330 cm^2.

According to this, for improving of the plasma unit efficiency its work should be started at the "Warm-Up" mode ($I_a \geq 5A$). It means the fast heating of the reactor and the increase in temperature of the reactor off-gases to the flash point of combustible waste. And after the reactor was prepared for submission to the fuel composition and ignition of a plasma reactor module must be translated into the "Work" mode ($I_a \leq 3{,}0\ A$) for the efficient operation of the plasma unit on a given technological regime.

The initial parameters for the calculation of the reactor are presented in table 1.

Table 1. Metrics for PFB reactor valuation

Parameter	Values range	Sampling increment
Air flow rate at reactor inlet, Vaf	30…100 m/s	10 m/s
Air flow swirl angle at the reactor inlet, φ	30…60^0	15^0
Air plasma jet rate at the reactor inlet, Vpj	5…20 m/s	5 m/s
Temperature of the air plasma jet at the reactor inlet, Tpj	2000…4000 K	500 K
CWFC droplets size at the reactor inlet, V_{CWFC}	$10^{-6}…10^{-5}$ m	$2·10^{-6}$ m
CWFC droplets rate, V_{CWFC}	1…10 m/s	1 m/s
CWFC droplets temperature at the reactor inlet, T_{CWFC}	300…600 K	100 K
CWFC flowrate at the reactor inlet, W_{CWFC}	500…1500 l/h	500 l/h

For PFB reactor valuation a software package ANSYS FLUENT 6.3 was used, which has a large database of gaseous, liquid and solid fuels and allows to estimate multi-phase laminar and turbulent flows, heat transfers, chemical reactions.

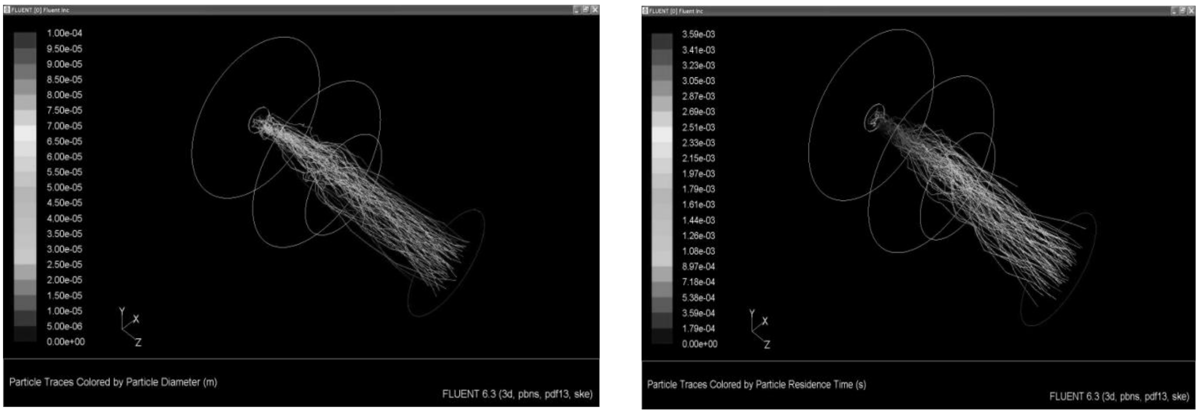
For PFB reactor valuation non-premixed combustion model was chosen.

DCC droplets motion inside the reactor was estimated using discrete phase model.

Exchange of momentum, heat and mass between the gas and droplets included in the calculation, alternating with the valuation of droplets trajectories and the continuity equation of the gas phase.

The initial conditions of the input into the PFB reactor were set by the disperser surface with uniformly distributed on its finite number of point sources.

Picture 4 shows the typical trajectory of dispersed combustible compositions droplets of different sizes from disperser surface (a) and shows the influence of dispersed combustible compositions droplets size during their stay in the reactor (b).

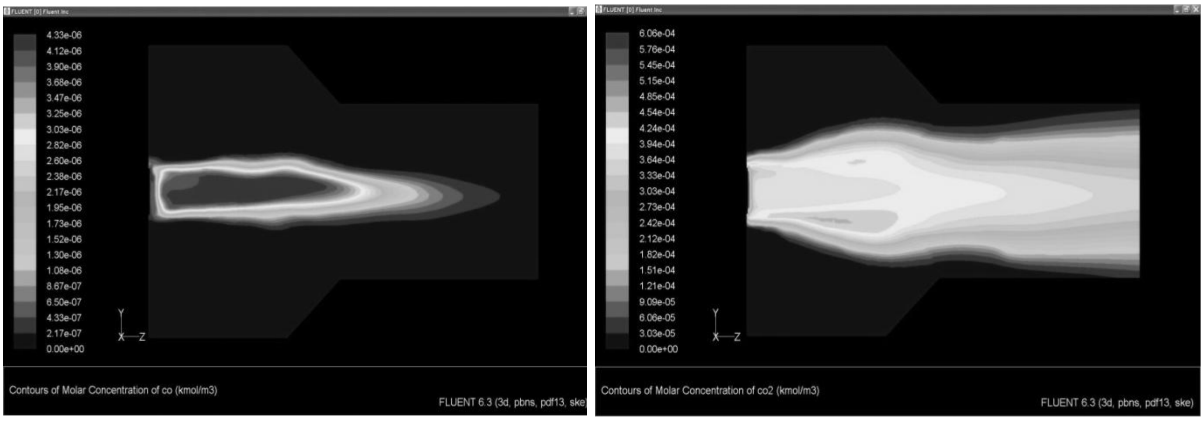


a) b)

Fig 4. Modes of disperser work for dispersing of combustible compositions.

The analysis of the results shows that in the whole range of input parameters for the calculation of the reactor (Table 1) the size of generated droplets (10^{-6} ... 10^{-5} m) has little effect on the size of the atomization jet for the dispersed fuel compositions on the basis of oil sludge and the staying time of drops in the reactor.

Picture 5 shows a characteristic distribution in the reactor longitudinal section of the molar concentration of CO (a) and CO_2 (b) in plasma burning of oil sludge in the form of dispersed combustible compositions of optimal compound.



a) *b)*

Fig.5. The content of CO and CO_2 in the combustion products of dispersed combustible compositions of optimal compound.

Analysis of the results shows that in the whole range of input parameters for the calculation of the reactor (Table 1) in plasma combustion of oil sludge in the form of dispersed combustible compositions of the optimal compound the formation of CO occurs only in a limited area at the entrance of the reactor during the interaction of the plasma air jet and dispersed combustible compositions droplets, and then CO completely transformed into CO_2. This confirms the environmentally safe recycling of oil sludge in the form of dispersed combustible compositions of optimal compound.

Picture 6 shows the typical temperature distribution in the reactor longitudinal section during plasma burning of oil sludge in the form of dispersed combustible compositions of optimal compound.

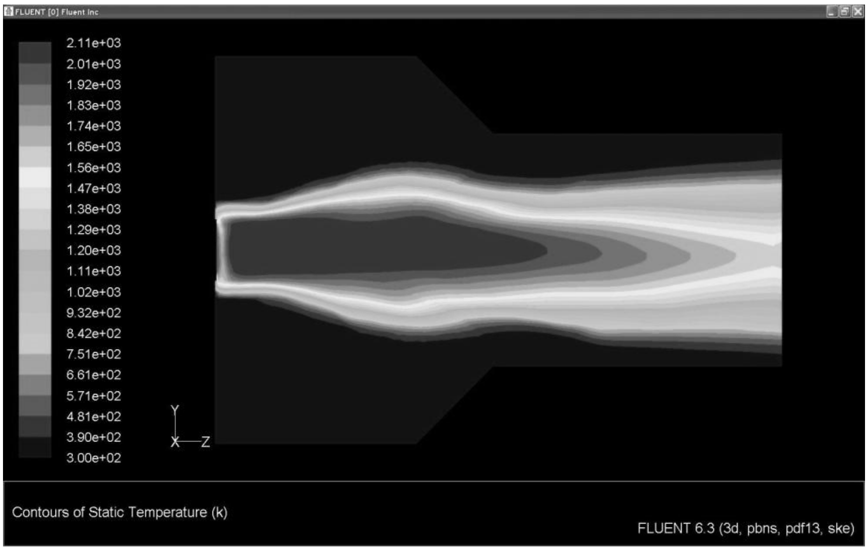


Fig.6. The temperature distribution in the reactor longitudinal section of dispersed combustible compositions of optimal compound.

According to the results of the spent valuations and the analysis of the received results are defined and can be recommended for practical realization following reactor operation rates for environmental-friendly used oil combustion as DCC of an optimal composition (22% used oil BM4 : 78% water):

- $T_{PJ} = 3000$ K
- $V_{PJ} = 20$ m/s
- $V_{AF} = 80$ m/s
- $T_{DCC} = 600$ K
- $W_{DCC} = 1000$ l/h
- $V_{DCC} = 3$m/s
- $\varphi = 30^0$

1. Karengin A.G., Sergeev D.V., Varfolomeev N.A. Ultrafine combustion activators for waste oils utilization. Physical chemistry of ultrafine systems. Collection of Scientific Papers V All-Russian Conference.– Publ.house: Institute of Electrophysics URO RAS,. P.2. P. 161-166.

2. Karengin A.G., Sergeev D.V., Varfolomeev N.A.. Thermocatalytic recycling of uranium-bearing waste oils

//Mag. Proceedings of the TPU. – Pub. TPU. T. 305, Iss. 3. – 2002. P. 101-104.

3. Karengin A.G., Lyakhova V.A., Shabalin A.M. Plant for the plasmacatalythic utilization of oil sludge. // Mag. Equipment and technologies for oil and gas industry. №4, 2007, P. 10-12.

4. Karengin A.G., Shabalin A.M. RF patent for an invention №2218378. Method of oil sludge utilization and plasma-catalytic reactor for its implementation. Declared 09.12.2002; Published 10.12.2003, Bul. № 34. − 14 p.

5. Ecology of oil and gas / volume 1, edited by A. Vladimirov M: Oil and Gas, 2003.

6. Bernadiner MN, Shurygin AP Fire refining and disposal of industrial waste. Moscow: Khimiya, 1990.

7. Mazalov EA Meshcheryakov S. The problems of sludge disposal and recycling methods. Moscow: Publishing House "Noosphere", 2001.

THE STUDY OF HYDROGEN ABSORPTION IN TITANIUM AND TITANIUM-BASED MATERIALS

V.S. Kudryavceva, A.S. Selyanin, D.S. Kovalenko
Scientific Supervisor: Assistant D.V. Savostikov
Linguistic Advisor: Teacher A.V. Tsepilova
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: valerija_kud@mail.ru

Abstract.

The paper considers the main ways to store hydrogen using metal hydrides and carbon-metal systems. To study the sorption properties of of materials used the transformed equation Polanyi-Wigner and developed a program for its solution.

Hydrogen, hydrogen storage, hydrogen adsorption, the adsorption energy, sorption capacity, chemical adsorption, physical adsorption, diffusion of hydrogen, hydrides, nanotubes, nanomaterials, nanostructures, physics, kinetics, alternative energy, hydrogen energy.

I.

Hydrogen as a highly efficient and environmentally friendly source of energy has great potential for widespread use in the energy sector especially as a fuel for vehicles. [1] One of the main barriers is the lack of effective methods of storage and transportation.

II.

The urgency and insufficient development of the above-mentioned areas have led to the choice of the topic, definition of the purpose and the objectives of the given work.

Accumulation of hydrogen, based on the reversible adsorption of hydrogen, is one of the most perspective and widely studied methods. Most commonly \ hydride metals and intermetallic compounds are considered as a hydrogen-accumulating matrix and prepared various varieties of activated carbon. In recent years, nanofibers and nanotubes have been studied from the point of view of the possibility to use them as sorbents. Mesoporous compounds have very large pores and channels, which is a disadvantage for the sorption of relatively small size of gas molecules. At the same time, mesoporous compounds have a very developed surface with a huge area, which puts them in line with other porous materials to attractiveness for the sorption of gases.

In [2,3,4] there is an overview of the current state of research in sorption properties of carbon nanotubes (CNT), considering the structural features of CNTs determining their sorption properties and mechanisms of sorption of gaseous and condensed substances by such structures.

Estimates of sorption ability of the nanotubes relative to hydrogen are based on the idea of the physical sorption of molecules of the surface of carbon nanostructures. Table 1 shows the sorption capacity of the wiring harness nanotubes depending on their diameter.

D, nm	0.4	0.6	0.8	1	1.5	2
η_n, %	3.3	3.56	3.9	4.4	5.4	6.5
D, nm	3	4	5	6	8	10
η_n, %	8.6	10.6	11.2	14.5	18	21.3

Table 1. The maximum concentration of hydrogen in the bundle nanotubes of different diameters. The distance between the surfaces of neighboring nanotubes is equal to d = 0,335 nm.

A noticeable increase of the sorption capacity of graphite nanostructures relative to molecular hydrogen can be expected in two cases: when filling the hollow graphite containers with a minimum diameter of 2-3 nm and more, using the effect of chemical rather than physical adsorption molecules of hydrogen with graphite surfaces.

In [5] considered diffusion of hydrogen in disordered metals and alloys is considered. Using the generalized Gaussian distribution, an explicit expression for the diffusion coefficient of hydrogen in amorphous metals and alloys up to the quadratic terms of its concentration is obtained in the work. The dependence of the diffusion coefficient of hydrogen in nanocrystalline palladium on its concentration is shown in Figure 1.

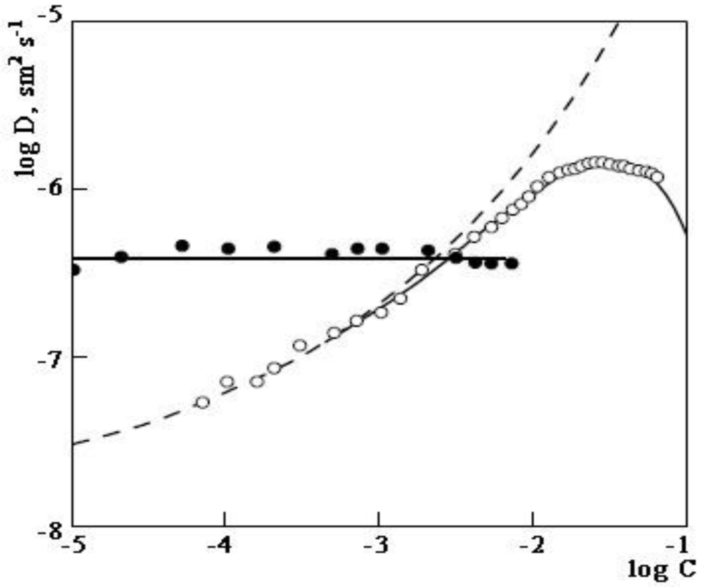


Fig. 1. The dependence of the diffusion coefficient D of hydrogen in nanocrystalline palladium (light circles) from its concentration C. Dark circles show the experimental data for single-crystal sample of palladium with hydrogen.

Droping of D for C> 0,03 H/Me due to the mutual repulsion of protons was also confirmed in [6,7].

The study of hydrogen adsorption on low index surfaces of B2 - titanium alloys depending from the end of surface and position of adsorbent is carried out in [8,9]. Energy of adsorption and binding energy calculated in this work, equilibrium positions of hydrogen on the surface ending with titanium or other metal, are shown in Table 2.

Position	$-E_{ad}$, eV	$-E_b$, eV	h_0, A
H-Ti/TiFe(001)	0,52(0,75)	2,90(3,12)	0,38(0,48)
H-Fe/TiFe(001)	0,50(0,73)	2,88(3,09)	0,56(0,76)
FM H-Fe/TiFe(001)	0,43(0,56)	2,81(2,94)	0,45(0,74)
H-Ti/TiCo(001)	0,64	3,02	0,41
H-Co/TiCo(001)	0,24	2,60	0,64
H-Ti/TiNi(001)	0,72	3,09	0,30
H-Ni/TiNi(001)	0,28	2,66	0,60
H-Ti/TiPd(001)	0,53(0,34)	2,91(2,72)	0,39(0,52)
H-Pd/TiPd(001)	0,10(0,28)	2,48(2,66)	0,53(0,52)
H-Ti/TiPt(001)	0,30	2,68	0,68
H-Pt/TiPt(001)	-0,20	2,18	0,59

Table 2. Adsorption energy E_{ad} *and binding energy* E_b*, the height of the adsorbate over the surface layer* h_0*, for patching H-position calculated by the pseudopotential method.*

After analyzing the works considered above and studying the techniques they used to process the results of adsorption of hydrogen, we chose a method based on solving the transformed equation of Polanyi-Wigner:

$$\frac{E}{kT_j} = \ln\left(\frac{T_j^2}{\psi_j}\right) + \ln\left(\frac{n_0^{i-1}\cdot s\cdot k\cdot g\left(E/kT_j\right)}{\beta\cdot E}\right) \quad [10]$$

where E is energy of activation;

Tj is temperature corresponding to the value of the function at the points of different heights of the peak;

k is Boltzmann constant;

i is the order of reaction;

ψ_j is «characteristic time»;

β is the rate of heating of samples

n_0 is number of particles involved in the reaction at the initial moment of time;

s is the coefficient of proportionality;

g(E/kTj) is incomplete gamma function of the second kind.

The solution of the equation is complicated by the fact that the form of the function describing the dependence of the concentration of the gases released on the time or temperature is frequently unknown.

For this reason, a program which allows to solve this problem was developed.

The program allows you to perform the following tasks:

11. to construct a graph of the concentration of the gases released from the sample temperature;
12. to search for peaks and their identification, that is, to determine the form of the equation to describe them;
13. to determine the temperature corresponding to the maximum concentration of the gases released;
14. to determine the order of the reaction and calculate the basic kinetic parameters (activation energy, frequency factor) for each peak.

With this program, were calculated the kinetic parameters of the process of carbon monoxide from the surface of dispersed iron (Fig.2): desorption occurs on the first order with an activation energy of 83,356 J/mol, the desorption peak is observed at a temperature of 859,3 ° C.

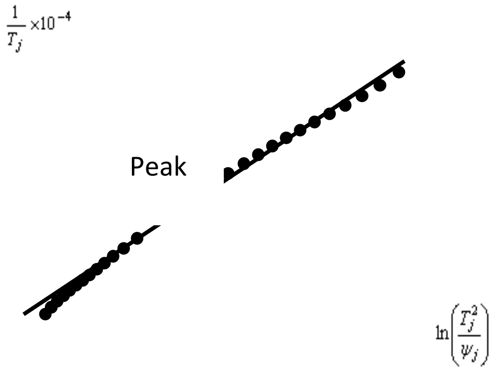


Fig. 2. Graph analysis of the measured peak of thermal desorption carbon oxide

The works considere show that hydrogen is adsorbed on carbon nanomaterials both chemically and physically. More hydrogen is absorbed in chemical adsorption, but desorption negatively affects carbon nanomaterials due to thermal loads. At physical sorption, amount of adsorbed hydrogen is less, but the conditions of sorption and desorption are close to normal, which facilitates the creation of technological installations.

The diffusion of hydrogen into the metal and increase of the hydrogen content in the metal also increases the brittleness of the metal, which can lead to its destruction, so the most perspective hydrogen storage devices seem to be metals «hardened» structures based on carbon.

11. V.P. Semenov, N.F. Dubovkin, L.N. Smirnova, ed. D.U. Hamburg, N.F. Dubovkina, «Hydrogen. Properties, production, storage, transportation, usage»: Ref. ed., Moscow: Khimiya, 1989, 672;
12. A. Eletskii «Sorption properties of carbon nanostructures» UFN Volume 174, № 11, 2004.
13. A.V. Gapontsev, V.V Kondrat'ev «Hydrogen diffusion in disordered metals and alloys», UFN, 173, № 10 (2003);
14. Mutschele T., Kirchheim R., Scipta Metall. 21 (2) 135 (1987);
15. S.S. Bags, S.V. Eremeev, S.E. Kulkova: Hydrogen adsorption on low index surfaces of B2 - titanium alloys;
16. Shapovalova O., Babenko, E.P., «The influence of carbon on the hydrogen content of titanium powders», Theory and practice of metallurgy 5-6, 2010;
17. D.M. Newns, Phys. Rev. 178, 1123 (1969);
18. Davydov, S., S. Troshin, «Adsorption on metals and semiconductors: Anderson model - Newns and Haldane - Anderson» Solid State Physics, 2007, vol 49, no. 8;;
19. F.D.M. Haldane, P.W. Anderson, Phys. Rev. 13, 2553 (1976);
10. Aart A. van Gorkum. A new method for analyzing 1st and 2nd order desorption spectra and glow curves. J. Appl. Phys., Vol. 51, No. 5, p. 2594-2601 May 1980.

INCREASE EFFICIENCY TECHNOLOGIES PHOTOELECTRIC CONVERTER

J.K. Kuneev
Scientific Supervisor: Dr, Professor B. V. Lukutin
Linguistic Advisor: PhD, Associate Professor G.A. Nizkodubov
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: vip.kuneev@mail.ru

Abstract.

Worldwide demand for electricity is growing in scale and speed never imagined before. For various reasons we are seeing a strong push for renewable energy sources (RES) with power generation is becoming more widespread and more and more generations, far from the center of the load. At the same time, demanding economic goals, as well as commitments to reduce greenhouse gas emissions must be implemented. During the joint work was to obtain new samples of materials for photovoltaic cells. Data are shown for reference only, basic materials, technology, the scheme will not be available. Since most of the experiments take place in a laboratory at the University of Berlin, and is paid by the German Government. How it works is that the operating panel absorbs almost the entire spectrum of radiation from ultraviolet to infrared.

I. INTRODUCTION.

Transportation received energy should flow to consumers with low losses. It is known that the transition from position about 800 km using a high voltage direct current (HVDC) cost than a conventional three-phase transmission. First, generate hydroelectric generators, of course, the three voltages of the system. As the figure shows a simplified, using transformers, high voltage is generated, which then uses a rectifier to a high DC voltage, typically ± 500 kV. Results of operations: From 1 m2 panel we get 800 - 1000 watts of power! At a temperature of 20-40 0C.

II.

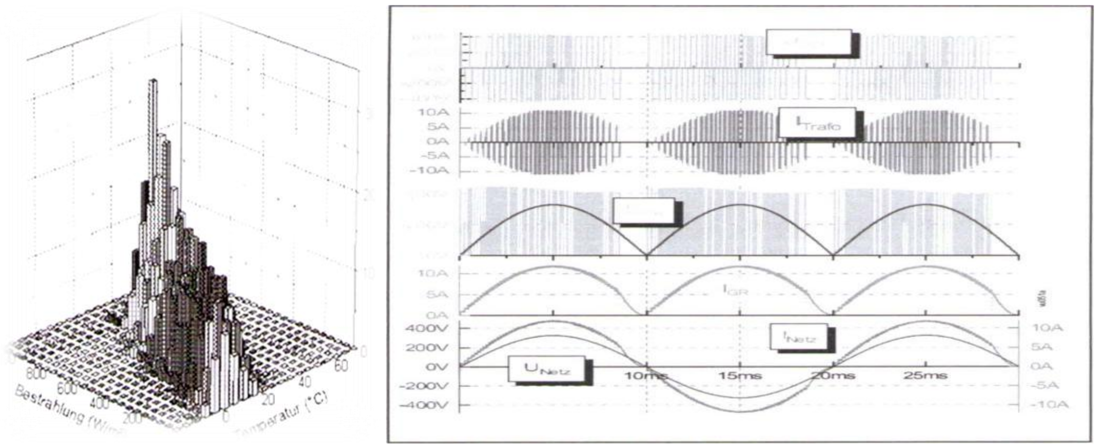


Fig. 1. Results of tests of inverters.

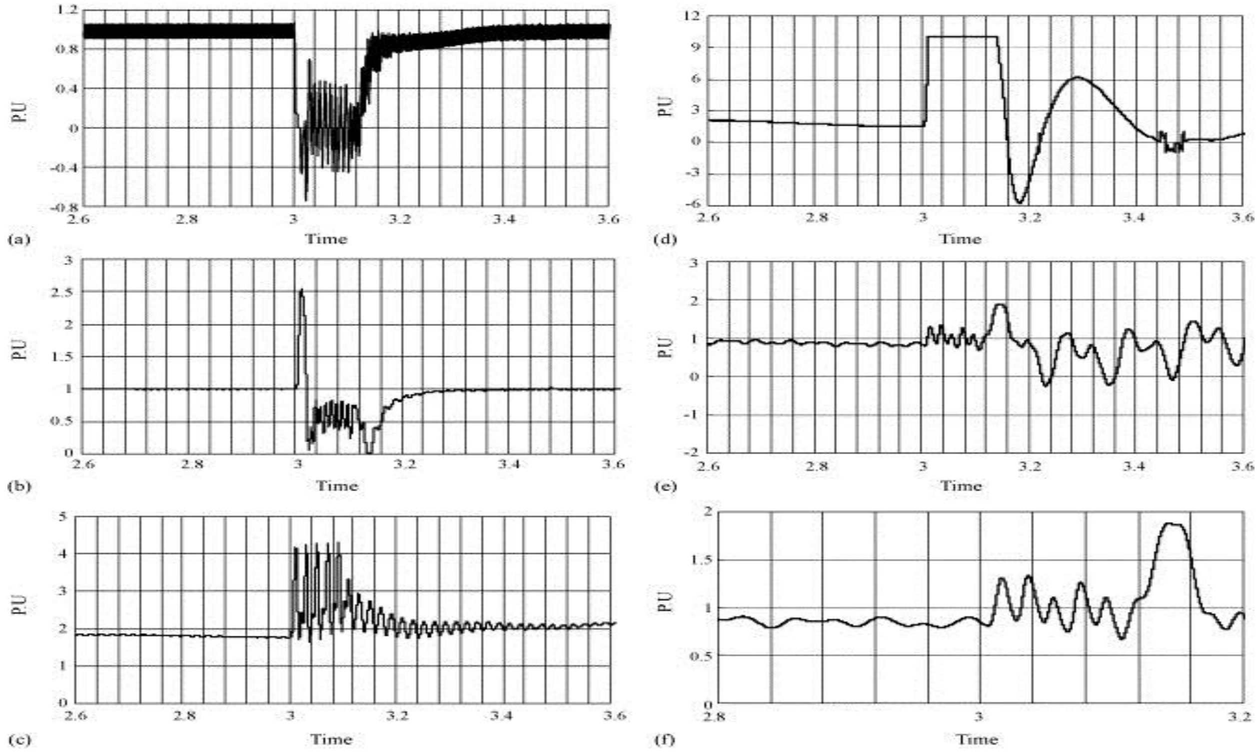


Fig. 2. schedule of transient of the inverter

Technology in Russia:

The advantage of cascading nanogeterostrukturnyh photovoltaic cells (solar cells) are: - increased efficiency (more than 37%) of cascade solar cells based on semiconductor nanoheterostructures GaInP / GaInAs / Ge. - The possibility of converting the 1000-fold concentrated solar radiation. - Decline in 1000 semiconductor materials consumption is proportional to the degree of concentration of solar radiation.

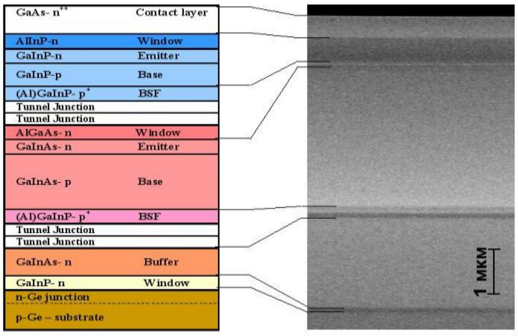


Fig.3 The structure and image of GaInP / GaAs / Ge ensuring efficiency> 35%

Nanotechnology component in the cascade phototransformator (FEP): Nano-sized (20-30 nm) AlGaInP wide-front "window" to ensure that the photosensitivity to the ultraviolet. Nano-sized (10-50 nm) layers of the tunnel p + - n + transitions connecting the photoactive area of the various stages in the heterostructures. Built in the heterostructure Bragg mirror (on the basis of periodic structures formed by layers with thicknesses of 50-70 nm), providing a reflection in the photoactive region "subzone" of photons. The basic technology used in the production of cascade nanoheterostructures is the method of vapor-phase epitaxy from organometallic compounds (MOCVD).

III. CONCLUSION.

We may add that the future of renewable energy comes on the heels of the traditional sources. Already the next 20-40 years, we can enjoy the cars, planes that use a large-scale production of environmentally clean and free energy. Also, get a cheaper and technically simpler energy.

IV In this article, available data are the results of experiments Masters gr. 5am14 Kuneeva J., Tomsk Polytechnic University (Tomsk), and Master Bekboeva M. Beuth Hochschule für Technik University (Berlin). Scientific Supervisors: Prof. Boris Lukutin and Professor Mathias Kipke (Kipke, Matthias, Prof. Dipl.-Ing).

1. A. Laboratory work on the FEP.
2. Lukutin BV "Renewable energy in a decentralized electricity supply."
3. Professor Lectures: Kipke, Matthias, Prof. Dipl.-Ing «Wechselrichter für Photovoltaikanlagen»
4. http://pvlab.ioffe.ru/Technology/fep.html

RESEARCH OF POTASSIUM TETRAFLUOROBROMATE SOLUBILITY IN BROMINE TRIFLUORIDE

A.V. Rybakov
Scientific Supervisor: PhD, Associate Professor R.V. Ostvald
Linguistic Advisor: Senior teacher N.G. Novikova
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: Andrey374@mail.ru

Abstract.

The perspective of using alcaline metal tetrafluorobromates (MeBrF$_4$) as BrF$_3$ carrier agent in fluorinating processes was described. An analytical method of KBrF$_4$ solubility determination in bromine trifluoride (BrF$_3$) at moderate temperature of 25-70 ^{o}C was offered. The diagram of solubility was introduced. The received data can be used for creating corresponding fields of phase diagram systems of BrF$_3$-KF. KBrF$_4$ was prepared using alcaline metal chloride (KCl) and BrF$_3$. The synthesized solution KBrF$_4$ in BrF$_3$ was analysed for KF quantity.

Key words: potassium tetrafluorobromate, bromine trifluoride, phase diagram, solubility, uranium.

I. INTRODUCTION.

One of the most widely applied method of technical ores in nuclear industry is oxidative fluorinating. There are many types of fluorinating agent such as F$_2$, BrF$_3$, ClF$_3$, XeF$_4$. Bromine trifluoride is the most convenient for using because it is a liquid under ordinary conditions. This fact explains wide application of BrF$_3$ in uranium industry for uranium and rare-earth elements fluorinating [1]:

$$UO_{2(solid)} + 2BrF_{3(liq)} \rightarrow UF_{6(gas)} + Br_{2(gas)} + O_{2(gas)}$$

But in practice one of the most disadvantage of bromine trifluoride is mixture compounds formation that difficult to separate.

II.

Potassium tetrafluorobromate (KBrF$_4$) is a complex compound of BrF$_3$ with KF, which was recently proposed for the use as alternative to BrF$_3$. At room temperature KBrF$_4$ is a stable powder and has much lower chemical and corrosive activity therefore it is much more convenient for the work and storage and is much safer to handle compared to liquid BrF$_3$ [2,3].

Metals with tetrafluorobromates are forming soluble complex compounds during fluorination [4,5]. Potassium tetrafluorobromate is an effective fluorinating agent which has relatively high fusing point (330 °C), but hereby rather low BrF$_3$ vapor pressure above fusion (90 mmHg at a temperature of 356 °C) [6,7]. These physicochemical properties allow to fluorinate elements in a liquid phase at relatively high temperatures. Thus, tetrafluorobromates are convenient for this application and, moreover, fail-safe during storage and transportation [8,9].

Alcaline metal tetrafluorobromates are the special case of BrF$_3$-MeF system [10]. Different solutions and mixtures of potassium tetrafluorobromate in bromine trifluoride can be used in fluorination processes, thus the information about equilibrium composition of this system is of both theoretical and practical interest.

III. METHODOLOGY.

$KBrF_4$ saturated solutions were prepared according to method [4] which was modified for more convenient application. Potassium chloride powder was added by small portions into fluoroplastic vial with certain amount of BrF_3. This chemical reaction passes in the received solution:

$$6KCl + 8BrF_3 \rightarrow KBrF_4 + Br_2 + 3Cl_2$$

Some amount of the released gases were dissolved in the mixture, therefore, after large $KBrF_4$ precipitation the vial was vacuumed for bromine and chlorine stripping. Later the mixture was kept in a thermostat at a constant temperature and being agitated (±0,1 °C) during 2 hours. Saturated solution was sampled from the middle of the vial. Sample was hydrolyzed by distilled water. Hydrolysate comprised KF, HF, Br_2 as well as BrO_3^-, BrO^- ions. The potassium amount was analyzed by the following techniques [10]:

$$K^+ + ClO_4^- \rightarrow KClO_4\downarrow$$

The mixture was heated up to 250 °C and all highly volatile acids and water were evaporated. After the ignition solid substance represents pure potassium perchlorate.

IV. RESULTS.

By this moment trustworthy analytical data about potassium tetrafluorobromate after series of experiments (table 1) have been received by the research team. Graphic diagram of the solubility in terms of KF depending on temperature is shown in figure 1.

Table 1. KF solubility in BrF_3

Temperature, °C	KF concentration, g KF/100 g solution
25	4,73
26	4,731
39	4,734
46	4,578
57	5,065
69	5,392
70	5,38

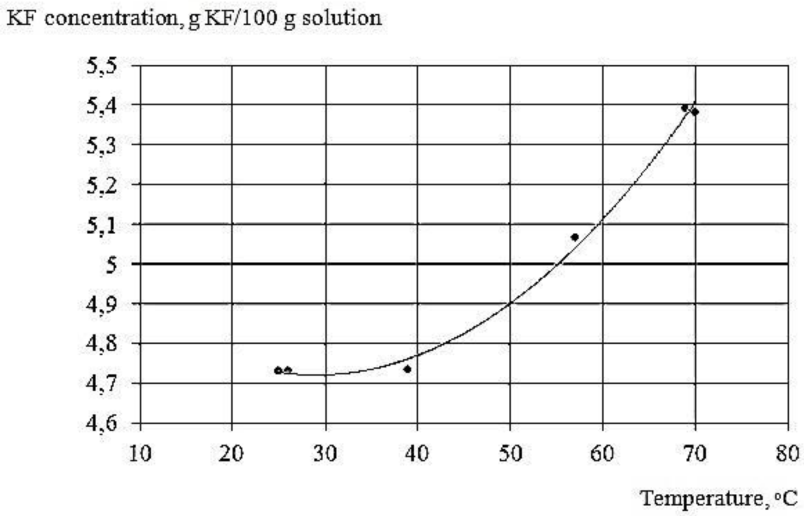


Figure 1. Dependence of solubility KF in BrF$_3$

V. CONCLUSION

In the near future it is planned to make similar research of sodium, rubidium and cesium tetrafluorobromates solubility and then compare received dependences, construct a graph phase diagram which have great practical importance in getting different BrF$_3$-KF system conditions in noble metal sample preparation for their further analytical determination.

1. Mitkin V.N., Savalskii V.M., Kamelin A.I. (1999), Extraction of impuruties of rare-earth elements from uranium dioxide using bromine trifluoride for their preconcentration and analytical determination, 268-288.
2. Sharpe A. G. and Emeleus H. J. (1948) , Per- and poly-fluorinated aliphatic derivatives of the main-group elements, Journal of the Chemical Society, 2135.
3. Mitkin V.N. (2000), Fluorination of Iridium Metal and its Application Possibilities in the Synthesis, Analysis and Recovery Technology for Secondary Raw Materials, Journal of analytical chemistry, 377-390.
4. Ginzburg S.I., Ezerskaya N.A., Prokofieva I.V. and others, Analiticheskaya himiya platinovih metallov: Analytical chemistry of platinum metals. (Nauka, Moskow,1972), p. 616.
5. Mitkin V.N. (2001), Ftorokislitely v analiticheskoy himii blagorodnih metallov: Fluorine oxidizers in analytical chemistry of noble metals, Journal of analytical chemistry, 118-142.
6. Mitkin V., Zayakina S., Tsimbalist V., Journal of analytical chemistry, 22-33 (2003).
7. Tsutomu Sakurai and Matae Iwasaki, J. Phys. Chem., 1491-1497 (1968).
8. Nicolaev N.S., Suhoverhov V.F. and others, Himiya galloidnih soedineniy ftora (Nauka, Moskow, 1968), p. 348.
9. Mitkin V.N., Zayakina S.B., Tsimbalist V.G., Galizky A.A. (2003) Application of potassium tetrafluorobromate to the rapid decomposition and determination of noble metals in chromites and related materials, Spectrochimica Acta, 297-310.
10. Zayakina S.B., Anoshin G.N. (2001) Determination of Gold, Silver and Platinum - Group Elements in Geochemical Reference Materials by Direct Atomic Emission Spectral Analysis Using a Multichannel Analyser Recording Device, Geostandards Newsletter: The Journal of Geostandards and Geoanalysis, 57-66.
11. Vinogradov A.P., Analiticheskaya himiya rubidiya i ceziya: Analytical chemistry rubidium and cezium, (Nauka, Moskow, 1975), p. 224.

AMMONIUM TETRACHLORIDOCOBALTATE THERMAL SUSTAINABILITY EXPLORATION

D.D. Amanbayev
Scientific Supervisor: PhD R.I. Kraydenko
Linguistic Advisor: PhD, Senior teacher Yu. V. Falkovich
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: daleramanbayev@gmail.com

Abstract.

Ammonium tetrachloridocobaltate(II) (ATC) synthesis, identification and thermal analyses have been implemented. ATC *decomposition temperature and enthalpy of decomposition to cobalt(II) chloride have been determined.*

Key words: nickel, cobalt, nickel ore, ammonium, chloride, tetrachloridocobaltate, thermal sustainability, thermal analyses.

I. INTRODUCTION

Ammonium chloridometalates are forming as intermediates during oxidized nickel ore (ONO) processing with the use of ammonium chloride as an opening agent [1, 2]. Content of cobalt(II) chloride in ONO exceeds 0.1%, therefore it's segregation is considered to be advantageous [3, 4]. Ammonium tetrachloridocobaltate is an intermediate of ONO reprocessing technology currently being developed [5]. $(NH_4)_2CoCl_4$ decomposition temperature and enthalpy of decomposition to cobalt(II) chloride values are required to calculate the ore chlorination energy.

II. OBJECTIVES

There is no appropriate data about ATC thermal characteristics in reference sources, thus the objective of this research is:

1. Ammonium tetrachloridocobaltate(II) (ATC) decomposition temperature determination;
2. Enthalpy of ATC to $CoCl_2$ decomposition determination.

Next operations were performed to achieve the purpose:

1. ATC synthesis;
2. Reaction products identification;
3. ATC thermal analyses.

III. DEVELOPMENT

ATC synthesis.

Ammonium chloride and cobalt(II) chloride hexahydrat were dissolved in pure alcohol in stoichiometric ratio:

$$CoCl_2 \cdot 6H_2O + 2NH_4Cl \rightarrow (NH_4)_2CoCl_4 \cdot 6H_2O$$

Synthesis were performed in a rotary evaporator Hei-Vap Precision under pressure 25 kPa, temperature 67 °C and evaporator chamber rotation frequency 40 rpm with simultaneous solvent removal. As a result violet powder was obtained.

Chemical reaction products identification.

To prove the synthesis of coordination complex the IR spectroscopy and powder diffraction methods were applied (fig. 1).

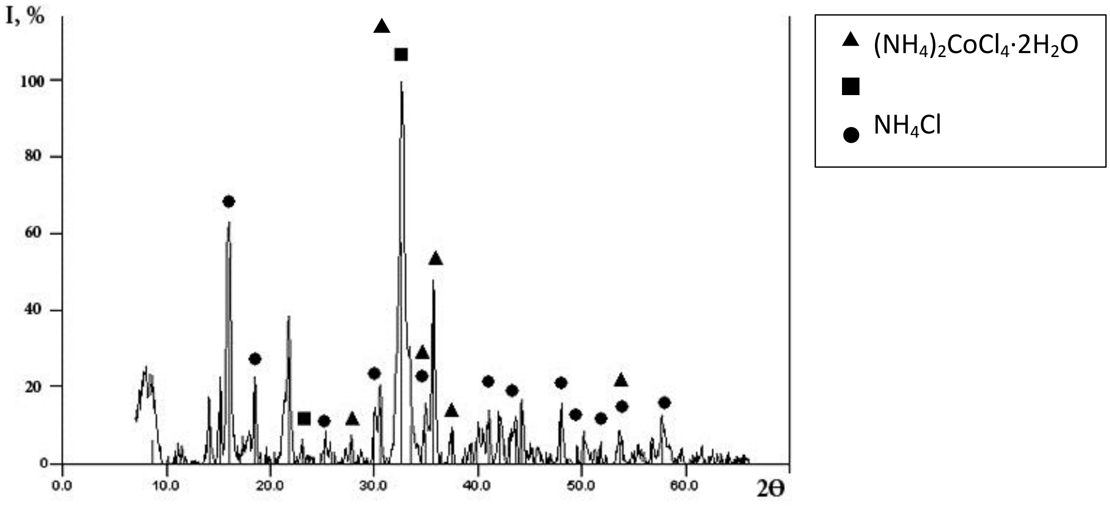


Fig. 1. ATC powder diffraction roentgenogram.

The methods data indexing revealed that the powder 99% consists of ammonium tetrachloridocobaltate dehydrate (table 1).

Table 1. ATC powder diffraction data index.

Powder ($2NH_4Cl+CoCl_2 \cdot 6H_2O$)		■ - NH_4Cl		▲ - $(NH_4)_2CoCl_4 \cdot 2H_2O$	
2θ	I, %	2θ	I ,%	2θ	I,%
32.674	100	32.657	99		
				33.281	99

ATC thermal analyses.

To determine the temperature and enthalpy of $(NH_4)_2CoCl_4$ to $CoCl_2$ decomposition a differential thermal analysis (DTA) and differential scanning calorimetry (DSC) on the combined TGA / DSC / DTA analyzer SDT Q600 with software data processing TA instruments Universal V4.2E were carried out.

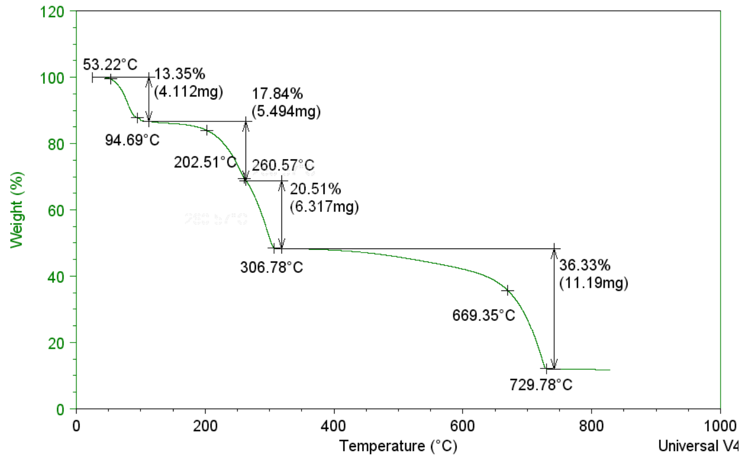


Fig. 2. Differential thermal analysis of $(NH_4)_2CoCl_4{\cdot}2H_2O$.

To implement DTA/DSC analysis 30.8 mg of $(NH_4)_2CoCl_4{\cdot}2H_2O$ were used. The chamber heating was accomplished from 20 to 850 °C at a speed of 5 °C per minute under a stream of argon.

According to the data obtained crystalline water molecules removal into the gas phase starts at a temperature of 53 °C. By increasing the temperature to 140 °C NH_3 and HCl are removed. In the temperature range 260–307 °C removes the remainder of the ammonia and hydrogen chloride (fig. 2, fig. 3).

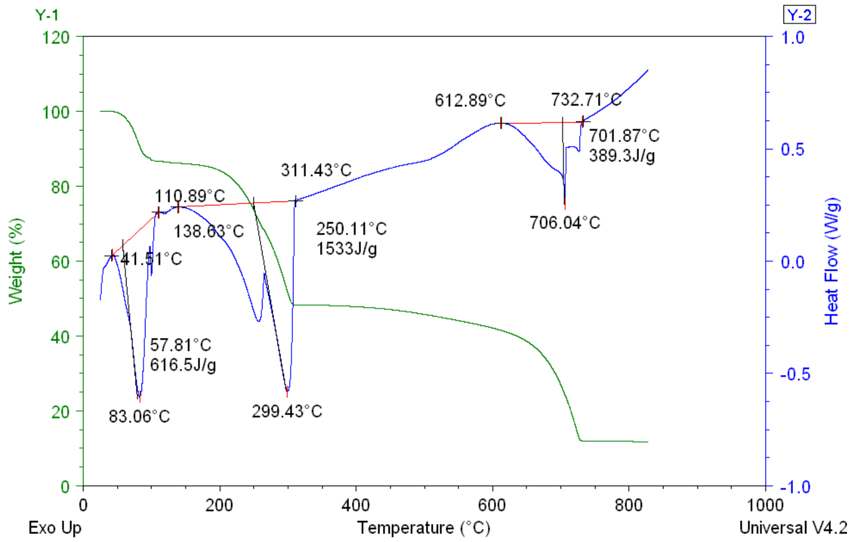


Fig. 3. DTA/DSC analysis of $(NH_4)_2CoCl_4{\cdot}2H_2O$.

The process of $(NH_4)_2CoCl_4{\cdot}2H_2O$ to $CoCl_2$ decomposition passes through three stages (each stage proceeds with the absorption of heat), corresponding to removal of water and consistent removal of ammonium chloride in the form of ammonia and hydrogen chloride. Enthalpy of ammonium tetrachloridocobaltate to cobalt chloride decomposition is 1533 kJ/kg:

1. $(NH_4)_2CoCl_4{\cdot}2H_2O \xrightarrow{53\ °C} (NH_4)_2CoCl_4 + 2H_2O\uparrow,\qquad \Delta h = 616{,}5\ \text{kJ/kg};$

$$\left.\begin{array}{ll} 2. & (NH_4)_2CoCl_4 \xrightarrow{140\ °C} NH_4CoCl_3 + NH_3 + H \\ 3. & NH_4CoCl_3 \rightarrow CoCl_2 + NH_3 + HCl. \end{array}\right\} \Delta h_{dec} = 1533\ \text{kJ/kg};$$

IV. RESULTS.

1. Ammonium tetrachloridocobaltate(II) (ATC) decomposition temperature:

   t_{dec} = 140 °C;

2. Enthalpy of ATC to $CoCl_2$ decomposition:

   Δh_{dec} = 1533 kJ/kg.

The values can be considered as correct for ATC obtained both as a result of laboratory synthesis and as a result of ONO opening, because there are no allotropic modifications for ATC [6].

V. CONCLUSION.

ATC decomposition temperature and enthalpy of ATC to $CoCl_2$ decomposition were determined. These values allow calculating the ore chlorination energy and conditions, which in turn allows us to refine the process flow chart [7].

ATC decomposition temperature t_{dec} = 140 °C suggests that the use of standard facilities is possible (there is no need to use special apparatus, which is expensive). It is another advantage of ONO reprocessing technology currently being developed [5].

1. A. A. Andreev, A. N. Dyachenko, R. I. Kraydenko (2010, February). Pererabotka okislennih nikelevih rud s primeneniem hlorida ammoniya, Oxidized nickel ores processing using ammonium chloride, from Himicheskaya tehnologiya, p.91 – 96.

2. A. A. Andreev, A. N. Dyachenko, R. I. Kraydenko (2011, January). Hlorid ammoniya v himicheskoy tehnologii, Ammonium chloride usage in chemical technology, from Himicheskaya tehnologiya, p.8 – 13.

3. R. I. Kraydenko (2008, November). Videleniye cennih komponentov iz medno-nikelevih koncentrata hlorammoniynim metodom, Isolation of valuable components from copper - nickel concentrate with the use of ammonium chloride, from Himicheskaya promishlennost segodnya, p.13 – 17.

4. A. N. Dyachenko, R. I. Kraydenko (2009, June) Hlorammoniynoye obogasheniye rud cvetnih metallov, Chloride-ammonium dressing of base metals ores, from Obogasheniye rud, p. 3 – 6.

5. A. A. Andreev, A. N. Dyachenko, R. I. Kraydenko (2008, April). Hlorammoniynaya tehnologiya pererabotki okislennih nikelevih rud, Ammonium chloride oxidized nickel ores processing technology, from Tyazhelie metalli, p.18 – 21.

6. R. D. Willett, Crystal Structure of $(NH_4)_2CoCl_4$, J. Chem. Phys. 41 (1964) 2243–2244.

Pat. 88994 RF, Tehnlogicheskiy kompleks dlya hlorammoniynoy pererabotki okislennih nikelevih rud, Technological complex for Chloride-ammonium processing of oxidized nickel ores, A. A. Andreev, A. N. Dyachenko, R. I. Kraydenko, 27.11.09.

LIFE CYCLE ASSESSMENT OF PET BOTTLE AS A WAY OF SAVING ENERGY

Amos Ncube
Scientific Supervisor: PhD., Associate professor Yu.V. Borodin
Linguistic Advisor: PhD., Associate professor Yu.V. Borodin
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
amocube@rocketmail.com

Abstract.

With increasing concerns over waste and the need for saving energy, it is necessary to carry out LCAs of products and this will help manufacturers take the first steps towards energy savings and designs by assessing their product's life cycle.

Life Cycle Assessment (LCA) is a process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment, and to assess the impact of those energy and material used and released to the environment. This assessment includes the entire life cycle of the PET bottle, processes encompassing materials and energy acquisition, manufacturing, use and waste management. In the inventory analysis component of a LCA, data on inputs and outputs to and from the system under study were compiled and presented. The following four major components of an LCA study as described in the International Organization for Standardization (ISO) 14040/44 were used: Goal definition and scoping; Life-cycle inventory (LCI), Life-cycle impact assessment (LCIA), and Interpretation of results. Developing and providing sound environmental data using a life-cycle assessment approach will assist those and the targeted audience to pursue environmentally preferable alternatives. Identification of impacts from the life-cycle of PET (Polyethylene terephthalate) can encourage industry to implement pollution prevention options, such as development and demonstration projects, and technical assistance and training. Industry can use the tools and data in this study to evaluate the health, environmental, and energy implications of the PET bottle.

Keywords: LCA, Environment, PET, Waste

I. INTRODUCTION

I. I. Overview

Nowadays, world population has been increasing rapidly. The rapid growth of a population in a country can contribute to high production of waste. Municipal waste and industrial waste can bring unhealthy and unpleasant environment or even diseases to human beings if the wastes are not managed properly.

As a government, it is unreasonable to limit the number of children for a family just in order to control the high production of waste. Therefore, one of the methods to reduce the production of waste is by understanding the Life Cycle Assessment of the products itself. Basically, Life Cycle Assessment is not a tool to reduce the production of waste. Instead, by conducting a Life Cycle Assessment, the researcher can comprehend the environmental attributes of a product from raw materials to landfill disposal or recycle as a new product, across its entire life.

Life Cycle Assessment (LCA) is a process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment, and to assess the impact of those energy and material used and released to the environment (Allen et. al., 1993). The assessment should include the entire life cycle of the product, process or activity encompassing materials and energy acquisition, manufacturing, use and waste management. In the inventory analysis component of a LCA, data on inputs and outputs to and from the system under study are compiled and presented. Solid waste may be treated by different processes; land filling and incineration are the most common. Through Life Cycle Assessment, researcher will be able to know which things contribute to pollution and how the pollution occurs and thus finally take an appropriate way to solve the problem.

In this case, bottles from PET will be thoroughly investigated because bottle waste is one of the major problem components in municipal solid waste management in Tomsk. There has been least past research that discusses on the subject of Life Cycle Assessment (LCA) of PET bottles in Tomsk, Siberia. In addition, PET bottles are predominantly employed in packaging of beverages such as beer and water. The first commercial plastics were developed over one hundred years ago. Now plastics have not only replaced many wood, leather, paper, metal, glass and natural fiber products in many applications, but also have facilitated the development of entirely new types of products. The plastic fraction in municipal solid waste consists mainly of polyethylene (PE), polyethylene terephthalate (PET), polyvinyl chloride (PVC) and polypropylene (PP) and polystyrene (PS). Different types of plastics will perform differently in the environment, e.g. Polyethylene terephthalate (PET) has caused concern because of its potential to cause environmental harms.

Plastic products like PET bottles are durable, although having functional benefits, can cause problems at the end of their products’ lives. As PET bottles have found more markets worldwide, the amount of PET bottles produced increases as well. This phenomenal growth was caused by the desirable properties of PET bottles and their adaptability to low-cost manufacturing techniques. The life cycle of PET includes production, transportation, use and disposal which have contributed to the release of waste emissions. This results in toxins exiting in the water, air and food chain, bringing the people around the polluted area severe health problems. Recently, environmental groups are voicing serious concern about the possible damaging impacts of PET on the environment. PET bottles end products and materials eventually contribute to the solid waste stream.

Since reliable scientific data has been lacking on the study of PET bottles in the Tomsk region, an experimental investigation is therefore required upon which this study will be based.

By improving either products or end-of-life schemes of PET bottles, impacts and risks could thus be mitigated and investigated. Life cycle assessment (LCA) intends to aid decision-makers in this respect, provided that the scientific underpinning is available. Strategic incentives for product development and life cycle management can then be developed.

I. II. Problem Statement

In the last decades, with the increment of the world population and the society of consumption, the amount of waste generated has exponentially increased. Waste collection centers have been created culminating with the generation of epidemics and rodents, besides increasing the environmental contamination level. These facts generate the necessity of developing and using more rational methods for final waste disposal and energy saving.

Over the past 20 years, environmental issues have gained greater public recognition. Production, use and disposal of virtually all goods present potential health and environmental impacts. The general public has become more aware that consumption of manufacturing products and marketed services, as well as daily activities of our society, adversely affects supplies of natural resources and the quality of the environment. These effects occur at all stages of the Life Cycle of a product, beginning with raw material acquisition and continuing through material manufacture and product fabrication. They also occur during product consumption and a variety of waste management options such as composting, biogasification, incineration, burning, landfilling and recycling. At each of these steps, pollutants may be released into the environment with ecological consequences. Ecological consequences among other things also include the effects on the environment. The impacts on the environment due to waste and emission release can occur during the life cycle stages, particularly manufacturing and disposal, for all consumer and commercial products. As public concern has increased, both government and industry have intensified the development and application methods to identify and reduce the adverse environmental effects through LCA.

I. III. Objective of the Study

The aim of the study is to evaluate the environmental performance through energy savings of polyethylene terephthalate (PET),

The specific objectives are:

a) To evaluate environmental burdens associated with PET bottle product, process or activity by quantifying energy and wastes released to the environment.

b) To determine the main environmental burdens of PET.

c) To expand the analysis on the improvement areas of the PET bottle “end of life” for the purpose of lowering the environmental burdens focusing on recycling and disposal.

I. IV. Scope of the Study

Scope of the study should cover the entire life cycle of the PET bottle encompassing raw material processing, manufacturing, transportation, use, recycling and disposal. This study will concentrate only on air emissions released within the life cycle of PET bottle which contributes to the impact of global warming. Therefore, this paper will focus on the bottle from the LCA perspective. PET bottle was chosen because of lack of scientific data on the life cycle flow of the PET bottle in the Tomsk region of Siberia. Life Cycle Assessment (LCA) is going to be used as a tool to evaluate the impacts associated with all stages of a product’s life cycle from cradle to grave both downstream and upstream. The basis of an LCA study is an inventory of all the inputs and outputs of industrial processes that occur during the life cycle of a product. This includes the production phase and the life cycle processes including the distribution, use and final disposal of PET bottle product. In each phase the LCA inventories the inputs and outputs and assesses their impacts. Once the inventory has been completed, a LCA considers the impacts. This phase of the LCA is called the impact assessment: LCAs can be very large scale studies quantifying the level of inputs and outputs but due to limited funding and financing this study will aim to focus on a small scale case study of the Tomsk city and the data obtained may therefore be used to make predictions and analysis in general. This LCA therefore will be limited in scope to a basic inventory whose results will be used to evaluate the environmental impacts of the PET bottle in the Tomsk region of Siberia, Russia.

I.V. Significance of the Study

An LCA will help decision makers select the product or process that result in the least impact to the environment and more energy savings. This information can be used with other factors, such as cost and performance data to select the best product or process. LCA data identifies the transfer of environmental impacts from one media to another and from one life cycle stage to another. If an LCA is not performed on PET bottles, the transfer might not be recognized and properly included in the analysis because it is outside of the typical scope or focus of product selection processes.

The ability to track and document shifts in environmental impacts can help decision makers and managers to fully characterize the environmental trade-offs associated with product or process alternatives. LCA also allows the plastic companies to identify effective ways of designing and manufacturing the products themselves. LCA helps companies to keep a step ahead of rapidly changing regulatory requirements on solid waste, persistent toxic chemicals, emissions and effluent discharges. In addition, life cycle strategies for pollution prevention and minimizing energy costs are beginning to reveal economic benefits in terms of more efficient production, improved product quality and minimization of the environmental risks.

II. METHODOLOGY

II. I. Introduction

An analysis of the flow of energy involved in the production of a product is one aspect of a life cycle assessment, an objective process of analysis that attempts to evaluate the environmental burdens associated with a product, process, or activity by:

- Quantifying the quantities of energies and materials used and the quantities of waste emissions released into the environment.
- Assessing the impact of energy and emissions releases on the environment.
- Evaluating opportunities to effect improvements in the final disposal of the product.

The assessment, if at all possible, should consider all the activities related to the manufacture of a product or operation of a process; this includes activities such as processing of raw materials, manufacturing, transportation and distribution, use/reuse, recycling, and final disposal.

II. II. Life Cycle Inventory

In the inventory stage, the study was conducted to define all aspects of the materials and manufacturing process. Steps in the manufacturing process were followed, and individual processes are evaluated to determine the materials used and emissions released to the atmosphere.

The environmental profile of manufacturing processes, use of product, recycling and disposal have been collected from various sources, and the following Life Cycle Stages were being considered.

1. Manufacturing stage

Plastic molding processes

2. Use stage

The environmental impact of the plastic product has been analyzed considering a 10 year period.

3. Recycling / Waste management stage

Disposal to landfill and energy recovery through 100% waste incineration of PET bottle product were calculated.

II. III. Life Cycle Impact Assessment

Once the inventory has been completed, a LCA considers the impacts. This phase of the LCA is called the impact assessment: LCAs can be very large-scale studies quantifying the level of inputs and outputs. This LCA is limited in scope to a basic small scale inventory. Based on the inventory information, the required environmental impacts are assessed. Additionally, the effect and extent of recycling is determined. The energy demands for the process are then added.

II.IV. Life Cycle Interpretation

Assessments of all impacts are made for each material or process. The alternative that provides some proper waste disposal improvements over other alternatives is selected. Improvement is defined as compliance with saving of energy required while increasing performance and quality in terms of lesser production of emissions.

II. V. Assumptions

The following assumptions were made:

- All calculations have been made on a 1kg weight of PET bottle.
- All PET bottles that were distributed by road required 0.001 MJ/kg/km.
- The PET bottle will have the product life of 10 years.

II. VI. Life Cycle Assessment Boundaries and limitations

The Life Cycle Assessment (LCA) approach is widely accepted in industries as a method to evaluate the environmental impacts of a product, and to identify the resource and emission-intensive processes within a product’s life cycle. The method is defined in the ISO standards 14040 and 14044 (ISO, 2006). The main strengths of LCA lie in its ability to provide a holistic assessment of production processes, in terms of resource use and environmental impacts, as well as to consider multiple parameters (ISO, 2006).

The methodology also provides a framework to broadly identify effective approaches to reduce environmental burdens. Further, the approach is recognized for its capacity to evaluate the effect that changes within a production process may have on the overall life-cycle balance of environmental burdens. This enables the identification and exclusion of measures that simply shift environmental problems from one phase of the life cycle to another.

However, LCA also presents significant challenges. First, the data intensive nature of the method places limitations on the comprehensive assessment of complex, interconnected networks. Limited data availability can force the researcher to make simplifications, which can lead to losses of accuracy. A second difficulty lies in the fact that methodological choices and assumptions - such as system boundary delineation, functional units, and allocation techniques - may be subjective and affect the results. These complications call for a thorough sensitivity analysis.

II. VII Methods

To carry out a life cycle analysis requires that, the boundaries of the global system e.g. a set of subsystems must be defined precisely. The energy requirements for the hierarchy of alternatives are based upon the following global boundaries (Bisio and Xantos, 1994):

Input: One (1) kg of PET fraction in a waste stream that can be either source separated, sorted, landfilled or combusted. Additional energy as required for each option considered.

Output: Identical finish plastic parts.

MASS BALANCE OF THE PET BOTTLE PRODUCTION

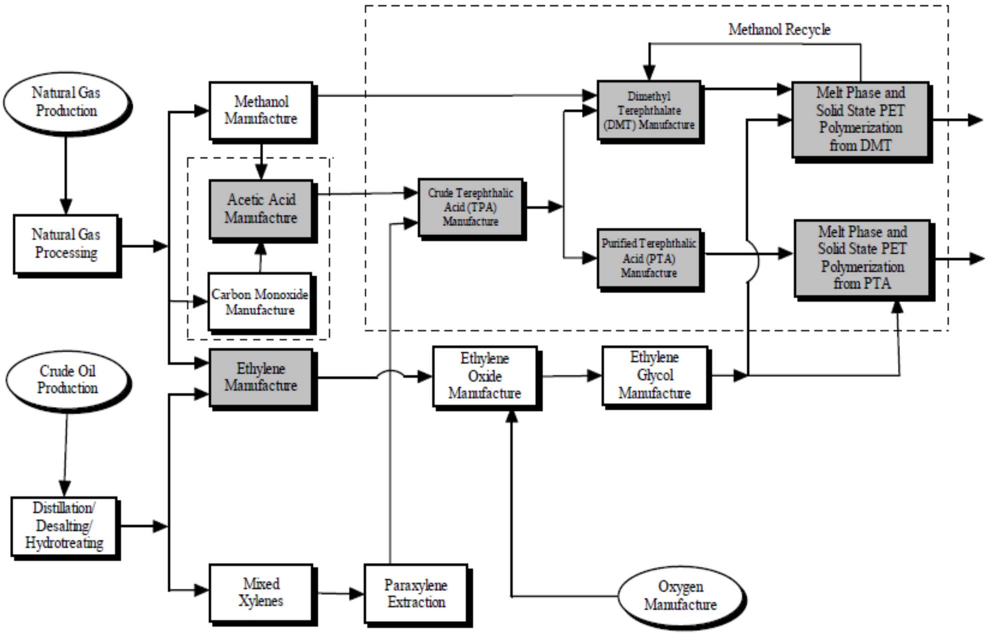


Figure 2.1. The simplified processing and manufacturing of PET

The amount of water and energy consumption which are used to calculate PET bottle production mass balance and raw materials required for producing PET bottles are as follows;

- ✓ 800 L production water is required for the production of 1 L crude oil. This production water is not calculated in the consumption of natural spring because of the fact that the production water is deep injected to underground again after the treatment (Nagy, 2002).
- ✓ Between 0.075 – 0.15 kWh electricity are consumed to desalting 1 tonne of crude oil. The water which is used in the crude oil desalting is the untreated water of other refinery processes or partly treated. Between 3-10% washing water is needed according to density of crude oil (European Commission, 2003).
- ✓ In the distillation of 1 tonne desalting crude oil 2-6 kWh electricity, 4 m^3 cooling water, 112-190 kWh energy are used (European Commission, 2003).
- ✓ In the refinery, approximately 8% light naphtha is produced, 8% heavy naphtha with desalting and distillation of 1 tonne crude oil. These product amounts are taken as approximate amounts because of the fact that these amounts change according to the quality of the oil and process (Tüpras,2001).

- ✓ In the process where naphtha is used as a raw material in the production of 1 tonne ethylene, approximately 3.2-3.4 tonnes of light naphtha, 44-54 kWh electricity, 370-470 m^3 cooling water are used.
- ✓ Approximately 0.6 tonnes ethylene, 0.6 tonnes oxygen, 468 kWh electricity, 314 m^3 cooling water are used for production of 1 tone ethylene glycol (DPT, 2001).
- ✓ 4.3 tonnes heavy naphtha, 31 kWh electricity, 258 m^3 water are used for production of 1 tonne p-xylene.
- ✓ 0.665 tonne p-xylene, 450 kWh electricity, 213 m3 cooling water are used for production of 1 tonne pure terephthalic acid (DPT, 2001).
- ✓ 0.32-0.355 tonnes ethylene glycol, 0.825-0.87 tonnes terephthalic acid, 5138 kWh electricity, 0.4-10 m^3 cooling water are used for production of 1 tonne PET.
- ✓ 251-264 kWh electricity, 0.2-15 m^3 water is used for solidification process of 1 tonne PET (Shyam Plastic, 2008).
- ✓ 28-30g PET granules to produce a pre-form needed to produce 1L PET bottle (European Commission, 2007).

III. LIFE CYCLE INVENTORY

III. I. Plastic Production

This section gives an overview of the complex and varied processes involved in making the PET bottle plastic. We also look at 'additives', which enhance the performance of plastic bottle or aid its processing. These chemicals often have a greater potential impact on the environment than the polymer itself. Finally, we consider information on the impact of making plastics on the environment and human health.

III.II Production Stage – Emissions and Energy Requirements for producing a 1L PET bottle

The production of different kinds of polymers has totally different energy requirements and the amount of emissions released. In this section, PET plastic bottle will be discussed in order to provide a clear result during the production stage.

Table 3.1. Environmental Profile for PET – PET Production Stage

Raw material	Oil & natural gas	**Main Product**	1kg PET is produced
Energy	83.8 MJ/kg	**Solid waste**	0.045130 kg/kg
Transport	0.2 MJ/kg	**Emissions**	CO_2 2330 g/kg SO_x 25 g/kg NO_x 20.2 g/kg CO 18 g/kg HCs 40 g/kg

III. III. Use of PET bottle

This section looks at the main sector that uses PET plastic bottle: packaging. During this stage, there are no energy and emissions released involved. Therefore, no data can be used to indicate the effect of PET plastic bottle during the use stage to the entire life cycle of plastic bottle.

III. IV. Transport of PET bottle

In this section, the produced PET bottle will be transported to consumers and eventually to recycling centers and disposal sites once it reaches the end of life of its services. Meaning to say, consumers dump the bottles into their dustbins after the plastic product becomes useless. We assumed the maximum of transport distance to consumers, recycling centers and disposal sites to be 200 km. The energy required for transportation was 0.01 MJ/kg/km according to (Albu,1997). We assumed no emissions released during transportation stage because the emissions released are most like to be insignificant.

III. IV. I. Transportation Stage – Emissions and Energy Requirements for a 1Kg PET bottle

Environmental Profile – Transportation Stage of PET

Transport=0.01*200=2MJ/Kg

III. V. Disposal of PET plastic bottle Waste

Plastic waste can be disposed-off using different kinds of methods. Recycling was also one of the improvement methods to be considered in this study. The idea being that recycling activities will reduce the waste generated to the earth and eventually lessens the risks of environmental burdens caused by the PET bottle.

III. V. I. PET Waste Recycle – Emissions and Energy Requirements

Where reuse is not the most environmentally sound way of extracting value from plastic bottle wastes, an alternative is to recycle them into feedstock or into energy recovery so that their intrinsic value is not lost. These two technological methods of plastic waste recovery have been developed in the industrialized countries on a large scale, mechanical recycling and incineration with energy recovery. Once the recyclates have been cleaned and shredded, the process is much the same as for the production of the PET plastic bottles from feedstock. Most plastics are recycled mechanically, but chemical recycling is at a developmental stage. Plastic bottles are the main type of plastics collected and recycled from household waste. During the process of recycling, energy is required and emissions are released to environment.

III. V. I. I. Waste Recycled – Emissions and Energy Requirements for a 1 Kg PET bottle

Table 3.2. Environmental Profile for PET – Waste Recycled

Raw material	-	**Main Product**	1 kg new PET bottle is produced
Energy	27.07 MJ/kg	**Solid waste**	-
Transport	0.2 MJ/kg	**Emissions**	CO_2 163 g/kg SO_x 0 g/kg NO_x 0.081 g/kg CO 0.205 g/kg HCs 0.016 g/kg VOCs 6.95 g/kg

III. V. I. II. Waste to Landfill – Emissions and Energy Requirements for a 1Kg PET bottle

Table 3.3. Environmental Profile for PET – Waste to Landfill

Energy	60.007 MJ/kg	**Solid waste**	-
Transport	0.2 MJ/kg	**Emissions**	CO_2 94.597 g/kg SO_x 0.848 g/kg NO_x 1.728 g/kg HCs 2080.609 g/kg

III. V. I. III. Waste Incinerated – Emissions and Energy Requirements for a 1Kg PET bottle

Table 3.4. Environmental Profile for PET – Waste Incinerated

Energy	32.5MJ/kg	**Solid waste**	-
Transport	0.2 MJ/kg	**Emissions**	CO_2 2016 g/kg SO_x 0.609 g/kg NO_x 2.436 g/kg CO 0.609 g/kg

III. VI. Summary – Emissions and Energy Requirements for a 1Kg PET bottle

In this section, we summed up and summarized the emissions released and energy requirements during the entire life cycle of a PET bottle. Table 4.14 summarizes the total energy required in MJ and total emissions released for the entire life cycle of 1 kg of the PET bottle for the different methods of waste disposal.

Table 3.5. Energy consumed and emissions released for entire life cycle of 1kg PET bottle

	Waste Recycled	**Waste to Landfill**	**Waste Incinerated**
Total Energy (MJ)	113.27	144.2	118.7
Total Emissions (g)	2603.45	4610.98	4452.85

IV. LIFE CYCLE IMPACT ASSESSMENT

IV. I. Introduction

In this section we used the results from the life cycle inventory to assess the potential impacts of PET bottle treated with different disposal methods. The best way of making a comparison of the PET bottle waste disposal method from an environmental point of view was to compare and analyze the energy involved and waste emissions released in the entire life cycle of the PET bottle. Next step was to assign the air emissions to the impact of global warming.

IV. II. Energy Use

Results for the total energy used are shown in Table 3.5 for PET with different treatment methods of disposal. The energy required to recycle 1Kg PET bottle is relatively lower than the energy consumed by the other two options. This is because it takes less energy to make recycled products due to its greatest environmental benefit provided that the recycled product is used to substitute virgin polymers. Besides, recycling is advantageous because every time that the material is reused, it is not produced again and, therefore, only half the waste remains in the soil than if virgin resin is used. The more times a material is recycled, the less the amount that remains in the soil and this will subsequently reduce the environmental load in the waste stream. According to Table 3.5, landfilling option required much more energy for the whole cycle of a kg PET bottle maybe due to vehicle fuel consumption on transportation, maintenance and the continuous monitoring on the landfill area. On the other hand, incineration is also one of the options to manage the PET bottle waste. Incinerator will burn all waste in ovens and the energy recovered is equivalent in amount to the heat of combustion of the different components.

IV. III. Global Warming

Table 4.1 presents the environmental impact for a 1kg PET bottle treated with different waste disposal methods. Global warming is the rising of the global temperature due to emissions of greenhouse gases. The only greenhouse gas emissions of any significance in the manufacture and disposal stages of the PET bottle are carbon dioxide and methane. Based on the results in Table 4.1, the order of preference is that recycling is better than incineration and landfilling in terms of energy and emissions. The emissions contributing to global warming for incineration of PET bottle is rather similar to the emission for landfilling. This is because all the fossil carbon is released during incineration, as well as during landfilling.

PET can also be co-incinerated with other combustible products from the waste stream which will give even greater contributions to the reduction of greenhouse gases by the prevention of the emission of methane gas from landfills. Methane has a global warming potential of 30 times that of CO_2 (McDougall et. al., 2001). This is why the prevention of waste going to landfill is a key measure to reduce the greenhouse gas emissions.

Table 4.1. Environmental impact for different treatment methods of the PET bottle

Environmental Impact	**Waste Recycled**	**Waste to Landfill**	**Waste Incinerated**
Global Warming (kg CO_2-eq)	3.33	47	4.3

IV. III. I. Example of Calculation for Global Warming Value

Process X releases 2.495 kg CO_2 and 0.040016 kg CH_4

The equivalency factors are the 100-year Global Warming Potentials (GWPs):

Q global warming-CO_2 = GWPCO_2 = 1 g CO_2

Q global warming-CH_4 = GWPCH_4 = 21 g CO_2/ g CH_4. The potential contribution to global warming of methane is:

Q global warming-CH_4 x gCH_4 = 21 g CO_2/ g CH_4 x 40 g = 840 g CO_2-Eq.

The total contribution of Process X to global warming is:

Total global warming = (2,495 + 840) g CO_2 = **3, 33 g CO_2-Eq.**

V. LIFE CYCLE INTERPRETATION

V. I. Introduction

The use of plastics can make a significant contribution to conserving natural resources, reducing energy consumption and minimizing the generation of wastes. Many applications of plastics have long useful lives and end-of-life plastics can often be recycled into second life applications. Nevertheless, the production, processing and use of plastics do generate wastes. It is essential that these wastes are properly and safely managed to protect human health and the environment.

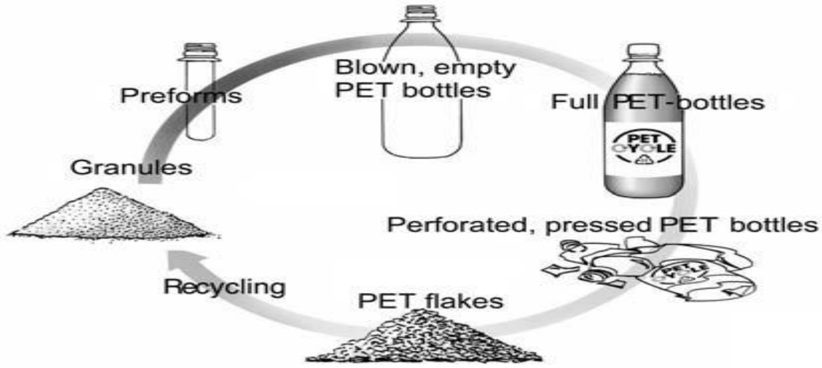
The final disposal of PET bottle plastic wastes is a matter of concern in Tomsk, as it is for any waste. If plastic wastes cannot be recycled, they can be disposed of as landfill or incinerated under certain conditions. The incineration of plastics, with or without energy recovery, at high temperatures and with appropriate scrubbing techniques for flue-gases, can be carried out under environmentally sound conditions. Incineration under environmentally sound conditions with energy recovery should be the preferred option as opposed to disposal into landfill or incineration without energy recovery.

Since the landfill method has created a great adverse impact to the environment, the continual growth of PET plastic bottle waste buried in landfill is unacceptable in the long term. The environmental effects of plastic waste, as well as the global warming due to landfill's emissions as a means of disposal, are leading to an increased need to designing processes with minimal environmental impact.

V. II. Process Improvement

Process improvement include the minimization of treating the PET plastic bottle wastes with landfilling method for reducing the amount of carbon dioxide and methane gases released to the atmosphere. The incineration of plastics, with or without energy recovery, at high temperatures and with appropriate scrubbing techniques for flue-gases, can be carried out under environmentally sound conditions. Incineration under environmentally sound conditions with energy recovery should be the preferred option as opposed to dispose into landfill or incineration without energy recovery. Another efficient method is recovering the energy required to process the new origin PET plastic by recycling method.

V. II. I. Recycling



Nowadays, people often wonder why we need to recycle. Some may feel that it's not their job to do so, and some may feel that it's a waste of time and money. Often people never realize about the advantages of recycling. So, it is suggested that the level of awareness among citizens in Tomsk, has not reached the level that we can be proud of. There are still plenty of loop holes here and there and it is important to educate the citizens of the advantages of recycling practices.

Rare materials, such as gold and silver, are recycled because acquiring new supplies is expensive. Other materials may not be as expensive to replace e.g. PET bottles, but they are recycled to conserve energy, reduce pollution, conserve land, and to save money. Several advantages of recycling can be highlighted here. This includes resource conservation, energy conservation, pollution reduction, land conservation and economic savings.

Recycling conserves natural resources by reducing the need for new material. Some natural resources are renewable, meaning they can be replaced, and some are not. Plastic products come from nonrenewable oil and natural gas. This oil can be conserved once raw material for making plastic is not required when new plastic can be produced from used plastic.

Recycling saves energy by reducing the need to process new material, which usually requires more energy than the recycling process. Recycling reduces pollution because recycling a product creates less pollution than producing a new one.

Recycling saves valuable landfill space, land that must be set aside for dumping trash, construction debris, and yard waste. Landfills fill up quickly and acceptable sites for new ones are difficult to find because of objections from neighbors to noise and smells, and the hazard of leaks into underground water supplies. The two major ways to reduce the need for new landfills are to generate less initial waste and to recycle products that would normally be considered waste.

Recycling in the short term is not always economically profitable or a break-even financial operation. Most experts contend, however, that the economic consequences of recycling are positive in the long term. Recycling will save money if potential landfill sites are used for more productive purposes and by reducing the number of pollution-related illnesses.

If we recycled all our recyclable waste materials, think of what a difference we could make in our lives, environment, and our natural resources. In practice though, recycling can be troublesome and expensive. If a company takes the time to think carefully and plan accordingly, then over time, the process and efficiency of recycling will improve and the payback will be enormous.

V. II. I. I. Emission Reduction

The recycling method proved to release lesser emissions into the atmosphere. From the studies that we had conducted, it showed that the emissions discharged were the least in comparison to other PET waste disposal methods. In addition to energy recovery, there is also a corresponding saving relevant to CO_2 and CH_4 emissions released into the atmosphere, since waste replaces other fossil fuels producing greater CO_2 and CH_4 levels.

Besides, PET bottle plastics can also be co-incinerated with other combustible products from the waste stream which will give even greater contributions to the reduction of greenhouse gases by the prevention of the emission of methane gas from landfills. Methane has a global warming potential of 30 times that of CO_2. This is why the prevention of waste going to landfill is a key measure to reduce the greenhouse gas emissions.

V. II. I. II. Energy Potential for Plastic Waste

Energy recovery from plastic waste can make a major contribution to energy production. If all of Europe's plastic waste which is not feasible to recycle were turned to energy, it would be equivalent to at least 17 million tons of coal. Energy from waste directly saves fossil fuels and makes an important contribution to the reduction of a country's dependency on fossil fuels. Such a contribution is crucial, particularly with the growing dependency on oil and gas, estimated to reach 65 per cent by 2015 in a business-as-usual scenario.

V. II. I. III. Reduction of Global Warming Potential and Improvement of Energy Efficiency from Energy from Waste

Energy from plastic waste reduces overall greenhouse gas emissions by more than 20% when compared with the use of coal which it can replace.

Last but not least, in order to tackle the volume of plastic bottle waste that requires disposal, close attention must be paid to reduce waste at every stage in a product's life; from cradle to grave. The waste management hierarchy prioritizes different measures and techniques for dealing with waste according to their environmental impact.

VI. CONCLUSIONS AND RECOMMENDATIONS

VI. I. Conclusions

The aim of the study was to use a life cycle assessment approach to determine which waste disposal options that will substantially reduce the energy consumption posed by the PET bottle. Several important observations can now be made.

1) Recycling of PET bottle waste can significantly reduce the energy required across the life cycle because the high energy inputs needed to process the requisite virgin materials greatly exceeds the energy needs of the recycling process steps.
2) Greenhouse gases can be reduced by opting for recycling instead of landfilling and incineration.
3) Quantity of waste emissions released from different disposal options was identified.
4) Recycling is the environmentally preferable disposal method for the PET bottle.

VI. II. Recommendations

PET bottle plastics make a valuable contribution to the way we live, but as a society we need to find ways of using these plastics more wisely. The way we make, use and dispose of PET plastic bottles should have a minimal impact on the environment. Some of the methods to reduce the impacts on the environment are:

1) A greener plastics industry

The manufacture of plastic materials is one of the major industries with potential for serious pollution to the surrounding environment. Different types of plastics manufacturing processes and disposal methods will contribute to different effects on the environment. Therefore, government agency must ensure that industry operates in a way that minimises adverse effects on people and the environment, and contributes to the achievement of sustainable development.

2) The potential impact of chemicals leaching from PET plastic bottles on human health and the environment

The use of PET plastic bottles in beverages and packaging increases the risk of exposure. Risk assessments have been carried out for some, but not all chemicals used in plastics. Where information exists, it suggests that the quantities released during the manufacture and disposal stages of the life cycle of plastics are much greater than those lost during the use phase, when humans are likely to be most exposed. This information gap needs to be addressed.

3) Reducing the waste generation

As a society, we are generating an increasing amount of waste. As with other materials, more must be done to reduce the amount of PET plastic bottle waste we produce. There has been a shift towards a ‘disposable’ culture, and the lower cost of plastics may have contributed to this and the associated growth in waste.

4) Practicing recycling habit

The attitude of the public in recycling practices should be improved. The public should be well informed of the importance to recycle. Environmental influences appear particularly effective among members of the public who have a “strong belief in personal responsibility and influence, as well as the power of self-determination”. The public would recycle more if they had a greater understanding of the environmental benefits of recycling.

5) Charging for waste

Although this practice is still not common in most countries, but several recycling centers in Russia are already implementing this concept, as a way to encourage more people to recycle. This concept is mainly targeting specifically at those who don’t recycle, and in turn supports those who do. By charging for the waste sent to the recycling centers, this can help to encourage more recycling practices among the public.

6) Introducing more recyclable products

By replacing the PET plastic bottles for packaging beverages, with recyclable and biodegradable ones; this can initially encourage more people to recycle. By displaying the international standard *‘Recycling Logo’* on recyclable products, the consumer will be fully informed whether the items can be recycled or not. When the consumer is aware that the items can be recycled, they will automatically categorize the items as recyclable products and will not dump them together with non-recyclable wastes. With such measures, it is hoped that the public will be more aware of the recyclable items available in the market.

1. G. Eason, B. Noble, and I. N. Sneddon, “On certain integrals of Lipschitz-Hankel type involving products of Bessel functions,” Phil. Trans. Roy. Soc. London, vol. A247, pp. 529–551, April 1955. (references)
2. J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68–73.
3. I. S. Jacobs and C. P. Bean, “Fine particles, thin films and exchange anisotropy,” in Magnetism, vol. III, G. T. Rado and H. Suhl, Eds. New York: Academic, 1963, pp. 271–350.
4. K. Elissa, “Title of paper if known,” unpublished.
5. R. Nicole, “Title of paper with only first word capitalized,” J. Name Stand. Abbrev., in press.
6. Y. Yorozu, M. Hirano, K. Oka, and Y. Tagawa, “Electron spectroscopy studies on magneto-optical media and plastic substrate interface,” IEEE Transl. J. Magn. Japan, vol. 2, pp. 740–741, August 1987 [Digests 9th Annual Conf. Magnetics Japan, p. 301, 1982].
7. M. Young, The Technical Writer's Handbook. Mill Valley, CA: University Science, 1989.

DIGITAL SPECTROMETRIC SYSTEM FOR MATERIAL STUDYING BY POSITRON ANNIHILATION TECHNIQUES

Yu.S. Bordulev, R.S. Laptev
Scientific Supervisor: PhD. A.M. Lider
Linguistic Advisor: PhD, Associate Professor A.S. Parnyugin
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: bordulev@mail.ru

Abstract.

Positron annihilation spectroscopy techniques are sensitive laboratory methods of in-depth study of the material structure and processes occurring in it. The digital spectrometric system described in this paper is designed to study the defect structure of materials by positron annihilation spectroscopy techniques. This system combines the methods of positron annihilation lifetime spectroscopy and Dopler broadening spectroscopy. These two techniques can be implemented either in one complex or individually. Application of these experimental techniques simultaneously provides a temporal and energy distribution of annihilation gamma-quanta, i.e. the most comprehensive qualitative and quantitative information of the electronic structure of the substance can be obtained. Using the coincidence γ-γ measurements in the Dopler broadening spectroscopy technique also allows observing the high-momentum part of the spectrum of the annihilation of positrons with deep shell electrons. The analysis of this part of spectrum enables to obtain the information about the chemical composition of the material. In comparison with the traditional analog systems, this system is being developed using modern digital components to ensure the ease of setup and operation of the equipment, as well as enabling the development of the system in order to improve its characteristics.

Keywords-positron; annihilation; lifetime; spectrometer; Doppler broadening.

I. INTRODUCTION

Nowadays the construction materials are demanded to be more reliable and durable. Whether it be materials of reactor vessels, plate solar panels of spacecraft or aircraft engine blades, they all operate in extreme conditions, corrosive environments at high temperatures. Therefore, in order to improve the performance of structural materials, it is necessary to carry out laboratory tests to study changes in the structure and properties of these materials under the influence of factors similar to the real operating conditions. Methods of positron annihilation spectroscopy (PAS) are sensitive laboratory techniques for the in-depth study of the material structure and research of the processes occurring in it.

Positron annihilation spectroscopy techniques are based on the effect of the positron interaction with the investigated material – positron annihilation. Annihilation photons which are born as a result of annihilation of positrons with electrons carry information about the electron structure of the material, i.e. the electron structure of the outer electron shells of atoms in a solid, which defines its basic properties, or the type of defects and their concentration in the crystal.

II. POSITRON ANNIHILATION SPECTROSCOPY TECHNIQUES

In the process of studying the materials by PAS techniques, the radioactive materials are often used as a positrons source. It is placed directly into the investigated material. The emitted positrons penetrate into the material, thermalize and then annihilate with surrounding electrons, as a result forming two gamma-quanta, the study of the characteristics of which provides information on the electron structure of the material.

Depending on the purpose of the research, three main methods of positron annihilation techniques are used [1]:

1. positron annihilation lifetime spectroscopy (PALS);
2. Doppler broadening spectroscopy (DBS);
3. angular correlation of annihilation radiation (ACAR).

The principles of these techniques are illustrated in Figure 1.

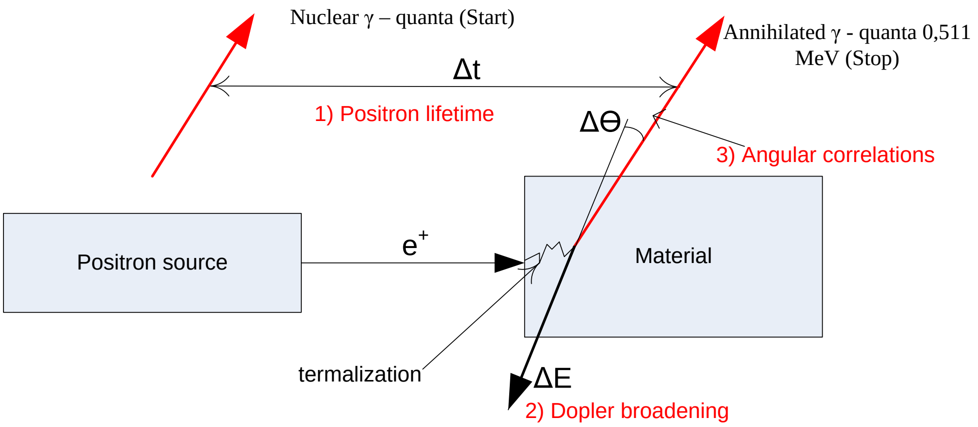


Fig. 2 Principles of three main techniques in positron annhilation spectroscopy: 1) Positron annihilation lifetime spectroscopy, 2) Doppler broadening spectrscopy and 3) Angular correlations measurements.

PALS technology is measuring the time interval between the nuclear gamma-quantum produced by the radioactive source almost simultaneously with the birth of a positron and one of the annihilation gamma-quanta. The collected time spectrum consists of contributions from components with different lifetime and corresponding intensities. When analyzed, the resulting spectrum can be approximated mathematically by several Gaussians corresponding to different lifetimes. The analysis of these components and their intensities carries information about the volume defects in solids and their concentrations [2, 3, 4].

ACAR and DBS methods are used to obtain the momentum or energy distribution of annihilation photons. In DBS measurements the precise measurements of the energy shift (Doppler broadening) of the annihilation gamma-quanta relative to the nominal value of 0,511 MeV are performed. This shift is produced as a result of nonzero momentum of the annihilating electron-positron pair and used to study the pulse and energy distribution of the electron structure of the investigated material [5].

Also, in addition to the energy shift due to the nonzero momentum of the annihilating pair, the deviation of the annihilation gamma-quanta opening angle from the angle of 180° is observed. This deviation can be explored with the γ-γ coincidence ACAR measurements in one or two dimensions. However, to obtain the required resolution in such experiments the detectors should be located at a distance of several meters from each other, which is not always acceptable [1].

The DBS and ACAR techniques provide additional information when interpreting the results of the temporal distribution of annihilation photons.

The application of the coincidence Doppler broadening spectroscopy (CDBS) with two detectors can significantly reduce the background by approximately three orders of magnitude [6]. It also allows watching the high-pulse part of the spectrum from the annihilation of positrons with the electrons of deep shells. The analysis of high-pulsed part of the spectrum allows determining the chemical composition of the elements around the location of positron annihilation [7].

Therefore, the coincidence Doppler broadening spectroscopy is widely used to identify defects in a variety of alloys, as well as to characterize a small number of inclusions [8, 9].

Thus, the association in one system of the CDBS and PALS techniques allows obtaining the most comprehensive qualitative and quantitative information on the electron structure of the materials. However, creating such a system, using analog spectrometric modules is difficult because of the complexity of adjustment, operation and the limited capabilities of such system.

III. DIGITAL POSITRON ANNHILATION SPECTROMETRIC SYSTEM

The digital spectrometric system combines the methods of coincidence Doppler broadening spectroscopy and positron lifetime spectroscopy. These methods can be implemented simultaneously, in a single experiment, on one sample, as well as separately.

The radioactive isotope ^{44}Ti ($\beta+,\gamma$) is used as a positron source. Radioisotope source based on ^{44}Ti is well suitable both for studies by DBS and for the PALS measurements, as almost simultaneously with the positron a nuclear gamma-quantum with energy of 1,157 MeV, which is the starting signal, is emitted. The source of positrons is located between two samples of material, forming the so-called "sandwich geometry". The main advantage of this geometry is that the positrons emitted by the source directly penetrate into the sample, which allows measurements in air.

The developed spectrometric system differs from the traditional ones by the presence of advanced digital components to ensure the ease of the setup process and operation of the equipment, as well as the increase in the productivity and accuracy of the experiments. The scheme of this system is shown in Fig. 2.

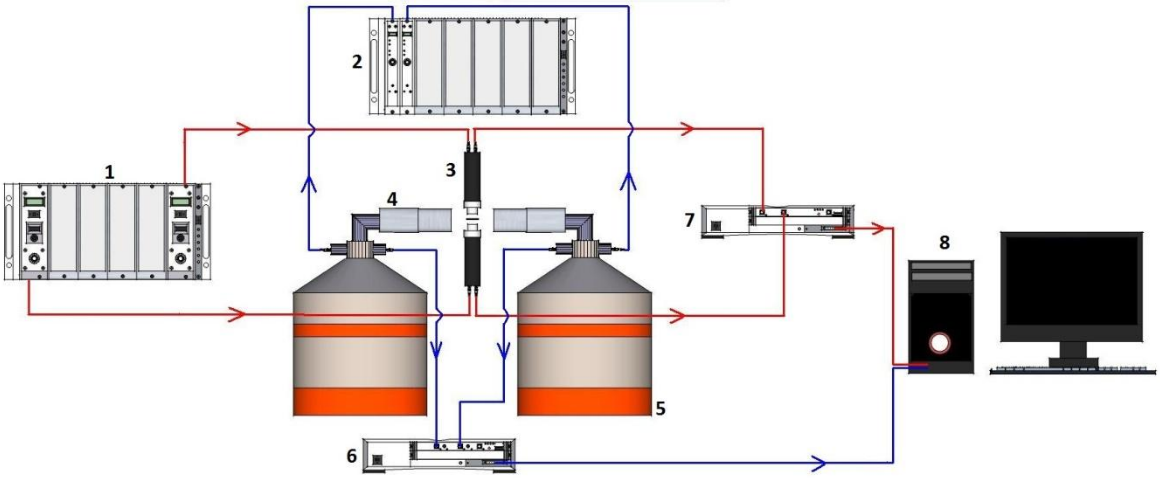


Figure 1. Developing spectrometric system for positron annihilation spectroscopy: 1 – High-momentum power supplies for scintillation detectors, 2 – High-momentum power supplies for Ge detectors, 3 – Scintillation detectors with photomultipliers (PMT), 4 – Ge detectors, 5 – Low-background vertical cryostat, 6 - High-speed digitizer for PALS measurements, 7 – High-speed digitizer for CDBS measurements, 8 – Personal computer with high computing power.

The system consists of two functional modules that implement two different techniques of positron annihilation spectroscopy.

Within the lifetime module, the scheme of delayed coincidences is used. The registration of gamma-quanta is implemented by the detectors, based on scintillators and photomultipliers (PMT).

As a scintillator crystals barium fluoride BaF_2 cylinders with a diameter of Ø30 mm and thickness 25 mm are used. Scintillators are combined with Hamamatsu, model H3378-50 fast photomultiplier tubes. The main advantage of BaF_2 is that this relatively heavy crystal can provide the same temporal resolution as a plastic scintillator, or even better. Therefore, to date, barium fluoride is the main scintillation material used in the positron annihilation lifetime spectroscopy due to the optimal balance of features such as temporal and energy resolutions [10]. PMT H3378-50 has a built-in divider and aluminum case with magnetic protection. The power to the detectors is provided by two high-voltage power supplies.

The signal from the detector is sent directly to the high-speed multichannel data conversion system, the main component of which is the high speed digitizer.

The detection unit for CDBS module is a system combining a semiconductor detector (*Ge*) and a charge-sensitive preamplifier. The efficiency of such a detection unit is 30%, and the resolution of the peaks 122 and 1332 keV is 0,8 and 1,8 keV, respectively. The power for the detectors is provided by two high-voltage power supplies 3106D by Canberra Industries, Inc.

The system consisting of two *Ge* detectors is used to implement the coincidence Doppler broadening spectroscopy modes. The cooling of the detectors is carried out with liquid nitrogen from two low-background vertical cryostats.

In other respects the system components are identical to those used in the data collection system for the analysis of temporal distribution of positron annihilation.

The software for managing this research system and data processing is developed in the Charles University in Prague, and in the Positron Annihilation laboratory at Martin-Luther-University Halle in the context of the EPOS Project and is distributed free of charge [11].

The developed system makes it possible to implement the following modes of materials research by positron annihilation techniques:

positron annihilation lifetime spectroscopy (PALS);
Doppler broadening spectroscopy (DBS);
coincidence Doppler broadening spectroscopy (CDBS);
combined PALS+DBC;
combined PALS+CDBS;
age momentum correlation (AMOC) measurements.

IV. CONCLUSION

The digital spectrometric system developed in this work is intended for the study of materials by methods of PAS and allows obtaining qualitative and quantitative information about the electron structure of the material. The system is developed on the basis of the following papers [9, 12].

The construction of the spectrometer on the basis of advanced digital components enables the development of this system in order to improve its characteristics, which distinguishes it from the previously established analog systems.

The system implements two powerful PAS methods allowing a comprehensive approach to the investigation of materials and providing information about the concentration and type of defects and the chemical composition of the material.

The developed system can be widely used in laboratories and research centers engaged in research of material structure and requiring precision studies.

1. Bosnar D., Friščić I., Jerbić-Zorc G., Makek M., Bosnar S. (2009, 4-8 May) Applications of Positron Annihilation Spectroscopy. Proceedings of International Topical Meeting on Nuclear Research Applications and Utilization of Accelerators, Vienna;
2. Dupasquier A., Mills A. P., (1995) Jr. (Ed.), Positron Spectroscopy of Solids. IOS Press, Amsterdam;
3. Saarinen K., Hautojarvi P., Corbel C. (1998) in: M. Stavola (Ed.), Identification of Defects in Semiconductors. Academic Press, New York;
4. Krause-Rehberg R., Leipner H. S. (1999) Positron Annihilation in Semiconductors. Springer, Heidelberg;
5. Grafutin V.I., Prokop'ev E. P. (2002) Positron annihilation spectroscopy in materials structure studies. Phys. Usp. 45 59–74;
6. MacDonald J. R., Lynn K. G., Boie R. A. and Robbins M. F., Nucl. Instr. Meth ., 153, 189(1977);
7. Asoka-Kumar P., Alatalo M., Ghosh V. J., Kruseman A. C., Nielsen B. and Lynn K. G., Phys Rev. Lett., 77, 2097, (1996);
8. Nagai Y., Hasegawa M., Tang Z., Hempel A., Yubuta K., Shimamura T., Kawazoe Y., Kawai A., Kano F., Phys. Rev. B 61 (2000) 6574;
9. ˇCı´zˇek J., Melikhova O., Procha´zka I., Kuriplach J., Stulı´kova´ I., Vostry´ P., Faltus J., Phys.Rev.B71 (2005)064106;
10. Laval M; Moszyński M.; Allemand R.; Cormoreche E.; Guinet P.; Odru R.; Vacher J. (1983) "Barium fluoride – Inorganic scintillator for subnanosecond timing". Nuclear Instruments and Methods in Physics Research 206: 169;
11. EPOS Software: Main Page, [Electronic source].- Access mode: http://positron.physik.uni-halle.de/EPOS/Software/;
12. Krille A., Krause-Rehberg R., Jungmann M., Becˇvar rˇ F., Brauer G., Digital positron lifetime spectroscopy at EPOS, Applied Surface Science 255 (2008) 93–95;

ENERGY OF THE FUTURE. ITER PROJECT.

E.V. Bulimenko

Linguistic Advisor: PhD, Senior teacher Yu. V. Falkovich

Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050

E-mail: bulimenko.ev@gmail.com

Abstract

Today humanity is satisfies its energy needs, mostly by burning oil, gas and coal. It is easy to available and cheap but their stocks limited to: taking into account the growth in energy consumption can be largely exhausted in the foreseeable future. but of oil and gas - is not only fuel, but also a valuable raw material for some chemical products Comrade, the production of protein and other vital substances. Search for alternative sources of energy scientists are engaged in many industrialized countries. The international ITER project is an important step in solving energy problems of mankind. And this article talks about the importance, development and prospects of the project.

I. INTRODUCTION

As the population of the Earth and improve quality of life in its various regions, growing energy consumption. According to forecasts, it is expected that the population Earth by the middle of the XXI century will increase from the current 6 billion to 9-10 billion. Estimates show that by this time the world energy consumption will increase by several times. This increase in energy consumption in the world need to provide sources of energy commodities, and the solution of this problem, start now, since the widespread introduction of new technologies in energy production takes more than one decade. Therefore humanity must discover alternative sources of energy that will be very effective and at the same time be safe.

II.

What to replace fossil fuels? Solar, wind and hydro power is not can provide basic human needs of energy and play only auxiliary role. Solar energy is too "dissipated" and not all available. Hydroenergetics almost fully engaged in the world and also have an adverse impact on the environment. Today, only the energy from nuclear reactions can be considered as long-term vision of humanity. Energy from nuclear fission of heavy elements (uranium) already provides about 20% of electricity generation in the world, and its role will grow. The problem for nuclear power are based on the division of recycling and disposal of radioactive waste that may affect the economic and environmental performance of energy. Nature has given to humanity, and other potential - nuclear fusion (fusion) of light elements with the release of enormous energy. Fusion reactions are a source of solar energy, which gives life to all living things on Earth. In the depths of the solar fusion reactions occur at temperature of about 20 million degrees. More than half a century ago, scientists have put task to implement the nuclear fusion reaction in terrestrial conditions, the release of energy for practical use. In unmanaged form, this process has been implemented in the mid-twentieth century, the explosion of water hydrogen bombs. The problem of mastering the nuclear fusion energy for peaceful purposes is called controlled thermonuclear fusion (CTF). [1]

The most affordable (feasible) is the reaction of nuclear fusion of hydrogen isotopes - deuterium (D) and tritium (T). Energetically favorable for the fusion reaction D-T mixture in the laboratory should be heated up to 100 million degrees (five times larger less than in the solar interior). In this case D-T-gas becomes fully ionized plasma consisting of positively charged nuclei and electrons. At this temperature, the rate of deuterium and tritium is that it is sufficient to overcome the Coulomb force repulsion and merge to form a neutron and helium nuclei (α-particles) with energy release at 17.6 MeV per reaction event.

The energy in the 17.6 MeV is realized in the form of kinetic energy of the neutron (80%) and α-particles (20%). The neutron, leaving the plasma falls into the coolant, the surrounding plasma, and its kinetic energy is converted into heat and energy of the nuclei of the helium atom (α-particles) can be used to maintain the temperature of the plasma in the required range. Deuterium contained in ordinary water, and the technology to get out of the water is well established. Tritium is virtually non-existent on earth, but his can be obtained if the neutron interacts with the lithium (Li), introduced into the coolant blanket (special shell surrounding the plasma).Thus, the fuel for fusion reactors are deuterium and lithium.

Therefore we can say that fusion energy is a very promising solution to the problem of power supply. Its advantages are:

* An abundance of fuel: supplies of deuterium in the water of the oceans are inexhaustible, the lithium content in the earth's crust is 200 times more than uranium.

* Radiation biohazard fusion reactor by about a thousand times lower than fission reactors.

* Lack of CO2 makes it possible to place the reactor in any

* The absence of "heavy" of radioactive waste that could be used to make "dirty" bombs.

* The physical impossibility of acceleration (the "explosion") of the reactor.

Energetically favorable flow conditions for the thermonuclear reaction

* Temperature of fuel (plasma of deuterium and tritium), about 100 million degrees.

* The density and the "lifetime" of hot plasma must be sufficiently large that the collision had happened deuterium and tritium nuclei and their merger.

There is a problem how to keep the matter in this extreme condition. In 1950, academics, AD Sakharov and IE Tamm suggested the use of a magnetic field for plasma confinement. The general idea of magnetic confinement has generated a lot of concrete solutions. Outstanding Russian scientists under the leadership of L. Artsimovich developed and implemented the concept of Tokamak fusion (toroidal magnetic chamber coil).

In 1968 at the International Conference on Plasma Physics, scientists from IAE. I. Kurchatov reported getting on the "Tokamak-3" consistently confined plasma with a temperature of about 5 million degrees. This is far superior to anything that has been achieved in the world in other areas of research. The world was built about 300 units of type tokamak. The largest of them were built in Europe, Japan, USA and Russia.

In the last generation plants tokamaks (TFTR, JET, JT-60) achieved a plasma temperature and density close to the required for a fusion reactor, and performed pulse-controlled thermonuclear reaction with respect to low power. Completed a fundamental stage in the development of new energy - carried out a scientific demonstration of controlled thermonuclear fusion reaction in the laboratory.

Next was the need to demonstrate a controlled thermonuclear fusion reaction with a few hundred megawatts of capacity and development of technology of its practical use. To implement this step, Russia, Europe, USA and Japan have decided to combine their scientific, technical and financial efforts to jointly develop the technical design world's first experimental fusion reactor, called ITER - International Thermonuclear Experimental Reactor. Work on the project sketch of the reactor began in 1988, and in 1992 signed an international agreement to develop the technical design of the ITER reactor, and an international team of experts went to work. Chairman of the governing body of the International project - the ITER Council, was elected Academician EP Velikhov. As a result of participation in the project, Russia has a complete documentation of the ITER project.[2]

The main objectives of the ITER project are:

- Demonstrate the scientific and technical feasibility of fusion energy for peaceful industrial scale
- The achievement of controlled thermonuclear ignition of the reaction with a tenfold excess of fusion power on the power expended in the creation and heating of the plasma
- Demonstration of long-term mode of burning plasma
- Development of systems and technologies needed to power nuclear fusion reactor, and tested in an integrated way

Engineering design of the ITER reactor completed in 2001. As part of the federal target program "International Thermonuclear Experimental Reactor ITER," Russia took part in the development, manufacture prototypes and test key elements of the reactor.

The scheme of the ITER basically repeats the classic Russian tokamak, created in the 60 years of the twentieth century. Significant technical differences from the first divertor tokamak is the introduction - a device to clean the plasma from the "impurity", an elongated vertical cross-section of the plasma and the use of superconductors to create magnetic fields in the reactor. The last principle, as a future power reactor is futile to do with the agents of copper.

Provision of two-stage reactor ITER. In the first stage reactor will operate in a pulsed mode at a power of 400-500 MW of fusion reactions, and a pulse duration of ~ 400 s.

The second stage will be practiced continuous operation of the reactor, as well as the tritium breeding system. In continuous operation of the reactor for one year from the fusion power of 500 MW, the consumption of tritium from external sources is 20 pounds.

construction Preparation of the site in Cadarache in southern France began in January 2007. This is an important first step in a long ten-year construction process, which is divided into two main phases: Preparation of the physical space subsequent construction of buildings ITER. [edit] Preparing the site ITER construction will house a total of 180 hectares of land of the commune of Saint-Paul-les-Durance (Provence-Alpes-Cote d'Azur, the region of southern France), which has become home to the French nuclear research center CEA (Commissariat à l'énergie atomique, the Commissariat of Atomic energy). The most important part of ITER - the tokamak itself and all the office space - will be located at the site of a kilometer long and 400 meters wide. Construction is expected to last until 2017. The main work in this step is performed under the direction of the French Agency of ITER, and the essence of CEA. In general, building ITER will be a 60-foot colossus weighing 23 tons. [3]

Very important to say about the security of the development. ITER is much safer nuclear reactor radiation on. First of all, the amount present in the body of radioactive material is relatively small. The energy that can be released as a result of an accident, too small, and can not lead to the destruction of the reactor. At the same time, the reactor design has few natural barriers to the spread of radioactive substances. For example, a vacuum chamber and cryostat shell must be sealed, otherwise the reactor will simply be unable to work.

Nevertheless, the design of ITER has been paid much attention to radiation safety, as in normal operation and during a possible accident. In order to prevent the spread of tritium and dust when they come out of the vacuum chamber and the cryostat, a special ventilation system will support the building of the reactor pressure is reduced. Therefore, the building will not leak air, except through the filter ventilation. During the construction of the reactor, where possible, materials will be used, already tested in the nuclear power industry. Because of this, the induced radioactivity is relatively small. In particular, even in the event of failure of cooling systems, natural convection will be enough to cool the vacuum chamber, and other design elements. ITER project meets the following requirements security of any accident level of environmental impact does not require evacuation. [4]

III. RESULTS

This project will be the first large scale attempt to use for electricity generation fusion reaction that takes place in the sun - hydrogen fusion reaction, which, if successful, will humanity truly inexhaustible source of energy. The main advantage of nuclear fusion reactor in comparison with nuclear - its considerable safety in terms of radiation. And, of course, the amount of electricity produced from nuclear fusion reactor must be many times more than its nuclear reactors. It is planned that nuclear fusion will be carried out in the ITER reactor in 2026, and the first experiments in this direction will be conducted as early as 2019. The experimental part will end in 2037, and after 2040 the reactor will produce electricity.

Summing up the report on this project, we can say that this design is a grand step in the development of modern power engineering. People need a new powerful and safe energy sources due to the growing problem of energy supply. Other sources of energy are irreplaceable or ecologically dangerous resources. And the a thermonuclear reactor is an effective solution to these problems. Other sources of energy are irreplaceable resources or ecologically dangerous. And a thermonuclear reactor is an effective solution to these problems. Starting the reactor will give humanity an inexhaustible, environmental and economically-effective energy source.

1. Garry McCracken, Peter Stott (2005). Fusion: The Energy of the Universe (Complementary Science Series)
2. Weston M. Stacey (1984). Fusion: An Introduction to the Physics and Technology of Magnetic Confinement Fusion
3. M. N. Rosenbluth (1994). New Ideas in Tokamak Confinement (Research Trends in Physics)
4.World Spaceflight News (2006). 21st Century Complete Guide to Nuclear Fusion, Fusion Energy and Power Plant Reactor Research, with Encyclopedic Coverage of Facilities and Labs

THE USE OF EDDY CURRENT METHOD FOR THE ANALYSIS OF LAYERED HYDROGEN CONTANT IN TITANIUM

A. A. Deriglazov

Scientific Supervisor: Dr., Prof. V. V. Larionov

Linguistic Advisor: Teacher A. A. Kuznetsova

Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050

E-mail: daa424@yandex.ru

Abstract.

This scientific work is about a new method of titanium diagnosis: «Eddy current method for the analysis of layered hydrogen content in titanium». This work was designed for the AVISMA concern – one of the largest producers of titanium. This method is cheaper than traditional. And it is more mobile. In addition, with the help of this method, we can analyze hydrogen content in certain layer of titanium sample. Our method can be used in oil, chemical, atomic and other branches of industry where titanium is used a lot.

I. INTRODUCTION

Metals. It is the main constructive material. But there is a real menace of hydrogen corrosion.

In a hydrogen atmosphere metal can absorb hydrogen molecules, which may lead to the destruction of metal structure[1]. It is an important fact, which can make huge damage in oil, chemical, atomic industry. To prevent it we should diagnosed our materials in time[2-4].

In this science work I want to present you new method of titanium diagnostic: “Eddy current method for the analysis of layered hydrogen content in titanium”, which is more chipper and mobile than traditional.

II.ANALYTIC SECTION

Studies of hydrogen has long history and it is actually today. Our problem solved with the help of the layered model. We should divided our sample into many layers which of them has it’s personal value of conductivity, resistance and current.

When we pass eddy current through our sample it penetrates on some depth. To calculate this depth we should recall Maxwell’s equations (1,2)[5-9]:

$$rot\ \vec{H} = \vec{j}\ (1)$$

$$rot\,\vec{E} = -\mu\mu_0 \frac{d\vec{H}}{dt}\ (2)$$

Some others equations, which can helped us in calculating (3-5).

$$\vec{j} = \sigma\vec{E}\ (3)$$

$$div\ \vec{H} = 0\ (4)$$

$$div\,\vec{E} = 0\ (5)$$

After calculating we can get this equation (1-5), which we can used in determinations of depth (6):

$$a = \sqrt{\frac{1}{\pi\ f\mu\mu_0\sigma}}\ (6)$$

How we can see, value of conductivity is unknown, to calculate it we should:

1) Measure resistance on our frequency
2) Calculate conductivity with known values of size of our sample.

$$R = \frac{l}{\sigma ab}$$

$$\sigma = \frac{l}{Rab}$$

After combining of this equations, we get final equations (7-9):

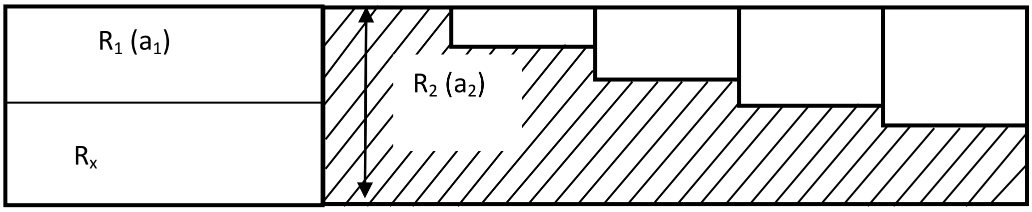
$$a = \frac{bR}{\pi\mu\mu_0 lf} \quad (7)$$

$$f = \frac{1}{\pi a^2 \mu\mu_0 \sigma} \quad (8)$$

$$\sigma = \frac{l^2 \pi\mu\mu_0 f}{b^2 R^2} \quad (9)$$

III. EXPERIMENTAL SECTION AND RESULTS

In practice we should have some references samples of titanium (to compare our samples with it). This problem can be solved by this model:



Pic.1. «Layered model»

We absorbed each layer of titanium sample, than we should measure current of it with the help of our device, cut of this layer, melt it and collect hydrogen, which stands out from titanium. All of this values and value of the depth which we calculated in past we should get into table, which followed next.

Sample №13 "Pure"					Sample №11 "With hydrogen"				
F	**Re(I)**	**Im(I)**	**|I|**	**a**	**f**	**Re(I)**	**Im(I)**	**|I|**	**a**
2,5	-0,006	0,013	0,014318	6,52	2,5	-0,006	0,013	0,014318	6,52
5	-0,006	0,014	0,015232	4,61	5	-0,006	0,014	0,015232	4,61
10	-0,006	0,016	0,017088	3,26	10	-0,006	0,015	0,016155	3,26
20	-0,017	0,022	0,027803	2,3	20	-0,015	0,02	0,025	2,3
40	-0,051	-0,002	0,051039	1,63	40	-0,043	0,003	0,043105	1,63
50	-0,063	-0,023	0,067067	1,46	50	-0,056	-0,015	0,057974	1,46
60	-0,072	-0,05	0,087658	1,33	60	-0,065	-0,038	0,075293	1,33
70	-0,075	-0,082	0,111126	1,23	70	-0,07	-0,066	0,096208	1,23
80	-0,097	-0,129	0,1614	1,153	80	-0,068	-0,1	0,12093	1,153
82	-0,095	-0,138	0,167538	1,139	82	-0,088	-0,112	0,142436	1,139

85	-0,091	-0,151	0,176301	1,12	85	-0,085	-0,124	0,150336	1,12
90	-0,083	-0,172	0,190979	1,087	90	-0,079	-0,143	0,163371	1,087
100	-0,041	-0,186	0,190465	1,03	100	-0,06	-0,182	0,191635	1,03
110	**-0,022**	**-0,131**	**0,132834**	**0,983**	**110**	**-0,024**	**-0,113**	**0,115521**	**0,983**
120	**-0,036**	**0,07**	**0,078715**	**0,94**	120	0	-0,209	0,209	0,94
130	0,046	-0,267	0,270934	0,904	130	0,032	-0,235	0,237169	0,904
140	0,087	-0,283	0,296071	0,872	140	0,069	-0,251	0,260311	0,872
150	0,129	-0,294	0,321056	0,842	150	0,106	-0,262	0,282631	0,842
160	**0,183**	**-0,33**	**0,377345**	**0,815**	160	0,144	-0,266	0,302476	0,815
170	0,215	-0,296	0,365843	0,79	170	0,183	-0,266	0,32287	0,79
180	0,258	-0,288	0,386663	0,769	180	0,221	-0,26	0,341235	0,769
190	0,3	-0,274	0,406295	0,748	190	0,259	-0,25	0,359974	0,748
200	0,34	-0,255	0,425	0,729	200	0,303	-0,226	0,378001	0,729
210	0,378	-0,23	0,442475	0,712	210	0,329	-0,215	0,393022	0,712
220	0,413	-0,201	0,459315	0,695	220	0,361	-0,19	0,407947	0,695
230	0,444	-0,167	0,474368	0,68	230	0,39	-0,163	0,422693	0,68
240	0,471	-0,129	0,488346	0,666	240	0,416	-0,132	0,43644	0,666
250	0,494	-0,088	0,501777	0,652	250	0,439	-0,099	0,450024	0,652
260	0,513	-0,046	0,515058	0,64	260	0,458	-0,064	0,46245	0,64
270	0,528	-0,003	0,528009	0,628	270	0,474	-0,026	0,474713	0,628
280	0,539	0,04	0,540482	0,616	280	0,486	0,012	0,486148	0,616
290	0,547	0,083	0,553261	0,605	290	0,495	0,052	0,497724	0,605
300	0,552	0,125	0,565976	0,595	300	0,501	0,091	0,509197	0,595
310	0,554	0,167	0,578623	0,585	310	0,504	0,131	0,520747	0,585
320	0,553	0,207	0,590473	0,576	320	0,504	0,169	0,53158	0,576
330	0,548	0,247	0,601093	0,568	330	0,502	0,206	0,542623	0,568
340	0,541	0,285	0,611479	0,559	340	0,496	0,242	0,551888	0,559
350	0,531	0,322	0,621003	0,551	350	0,488	0,277	0,561135	0,551
360	0,518	0,358	0,629673	0,543	360	0,478	0,311	0,570267	0,543

Table 1-1. «Some measured values of different titanium samples»

Sample №4 "With hydrogen"					Sample №2 "With hydrogen"				
F	**Re(I)**	**Im(I)**	**|I|**	**a**	**f**	**Re(I)**	**Im(I)**	**|I|**	**a**
2,5	-0,006	0,013	0,014318	6,52	2,5	-0,006	0,013	0,014318	6,52
5	-0,006	0,014	0,015232	4,61	5	-0,006	0,013	0,014318	4,61
10	-0,006	0,015	0,016155	3,26	10	-0,006	0,015	0,016155	3,26
20	-0,011	0,022	0,024597	2,3	20	-0,011	0,021	0,023707	2,3
40	-0,052	0,015	0,05412	1,63	40	-0,048	0,013	0,049729	1,63
50	-0,075	-0,007	0,075326	1,46	50	-0,068	-0,007	0,068359	1,46
60	-0,09	-0,04	0,098489	1,33	60	-0,082	-0,037	0,089961	1,33
70	-0,097	-0,079	0,1251	1,23	**70**	**0,088**	**-0,072**	**0,113701**	**1,23**
80	-0,093	-0,121	0,152611	1,153	80	-0,085	-0,11	0,139014	1,153
82	-0,091	-0,136	0,163637	1,139	82	-0,083	-0,118	0,144267	1,139
85	-0,088	-0,142	0,167057	1,12	85	-0,08	-0,13	0,152643	1,12
90	-0,08	-0,163	0,181574	1,087	90	-0,073	-0,148	0,165024	1,087
100	-0,057	-0,202	0,209888	1,03	100	-0,052	-0,184	0,191207	1,03
110	**-0,036**	**-0,149**	**0,153287**	**0,983**	**110**	**-0,026**	**-0,125**	**0,127675**	**0,983**
120	0	-0,258	0,258	0,94	120	0	-0,234	0,234	0,94
130	0,04	-0,286	0,288784	0,904	130	0,036	-0,262	0,264462	0,904
140	0,084	-0,303	0,314428	0,872	140	0,077	-0,277	0,287503	0,872
150	0,128	-0,313	0,338161	0,842	150	0,118	-0,287	0,310311	0,842
160	0,173	-0,317	0,361134	0,815	160	0,16	-0,29	0,33121	0,815
170	0,219	-0,315	0,383648	0,79	170	0,201	-0,288	0,351205	0,79
180	0,263	-0,306	0,403491	0,769	180	0,242	-0,28	0,370086	0,769
190	0,307	-0,291	0,423001	0,748	190	0,282	-0,268	0,389035	0,748
200	0,347	-0,272	0,4409	0,729	200	0,32	-0,249	0,405464	0,729
210	0,386	-0,246	0,457725	0,712	210	0,356	-0,227	0,422214	0,712
220	0,422	-0,216	0,474068	0,695	220	0,389	-0,199	0,436946	0,695
230	0,454	-0,181	0,48875	0,68	**230**	**0,419**	**-0,419**	**0,592555**	**0,68**
240	0,483	-0,147	0,504874	0,666	240	0,446	-0,134	0,465695	0,666
250	0,508	-0,106	0,518941	0,652	250	0,468	-0,096	0,477745	0,652
260	0,529	-0,063	0,532738	0,64	260	0,488	-0,057	0,491318	0,64
270	0,546	-0,019	0,54633	0,628	270	0,503	-0,016	0,503254	0,628
280	0,561	0,022	0,561431	0,616	280	0,515	0,026	0,515656	0,616
290	0,571	0,066	0,574802	0,605	290	0,524	0,067	0,528266	0,605
300	0,578	0,111	0,588562	0,595	300	0,529	0,108	0,539912	0,595
310	0,581	0,154	0,601063	0,585	310	0,532	0,148	0,552203	0,585
320	0,581	0,197	0,61349	0,576	320	0,531	0,187	0,562965	0,576
330	0,579	0,238	0,626007	0,568	330	0,528	0,225	0,573942	0,568
340	0,573	0,278	0,636878	0,559	340	0,521	0,262	0,583168	0,559
350	**0,564**	**0,647**	**0,858315**	**0,551**	350	0,512	0,297	0,591906	0,551
360	**0,552**	**0,656**	**0,857345**	**0,543**	360	0,5	0,332	0,600187	0,543

Table 1-2. «Some measured values of different titanium samples»

Next we build diagrams, which show dependence current of frequency:

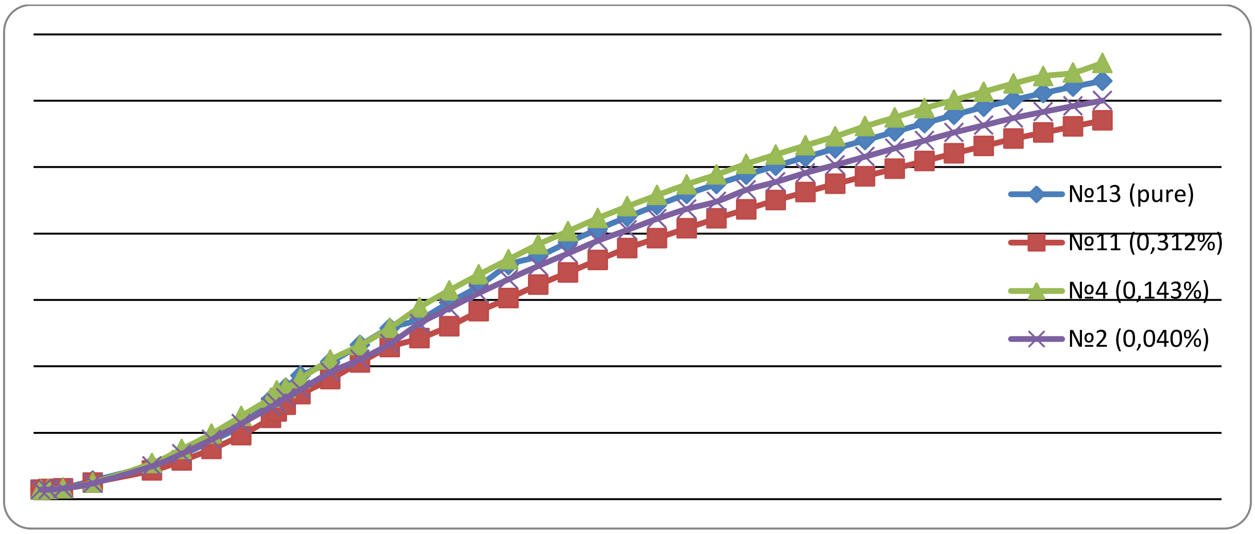


Fig 2. «Comparative diagrams»

Now we can measure value of current and resistance of investigated sample on some frequency, compare it's with this diagram and make a conclusion about hydrogen content of our investigated sample.

IV. CONCLUSION

If we increased level of hydrogen in titanium sample, we can observe formation of hydrogen connections [10]. This process followed by increasing of resistance on 50 – 10 MHz frequency and 0.2 – 0.24 concentration. After that we can see decreasing of resistance and increasing of current.

We show that our method can be used in practice; in addition with the help of this method we can measure hydrogen content in different layers of titanium sample. It is very useful in all industry .

1. Arefjev, K. P., Boev, O. V., Imas, O. N. (2003) Positron annihilation in hydrogen-saturated titanium. Solid State Physics, 1.

2. Chernov, I. P., Rusetsky, A. S., Krasnov, D. N., Larionov, V. V., Sigfusson, T. I., Tyurin, J. I. (2011) Journal of Engineering Thermophysics, 4, 360-379.

3. Chernov, I. P., Leader, A. M., Cherdantsev, J. P. (2000) Defects in titanium initiated by hydrogen. Physical mesomechanics, 6, 97-100.

4. Chernov, I. P., Larionov, V. V., Krasnov, D. N., Lisichko, E. V., Chistyakov, N. V. (2011) The targets for high-energy deuterons. Journal of Applied Physics, 6, 28-31.

5. Lammeraner, I., Shtafl, M. Eddy currents. Translated from Czech. (ML, Energy, 1967), p.208

6. Eddy currents. Great Soviet Encyclopedia. Retrieved 23 May 2012 from http://dic.academic.ru/dic.nsf/bse/74876/%D0%92%D0%B8%D1%85%D1%80%D0%B5%D0%B2%D1%8B%D0%B5.

7. Eddy currents. Electrical engineering. Retrieved 23 May 2012 from http://electrono.ru/elektromagnetizm-i-elektromagnitnaya-indukciya/22-vixrevye-toki

8. Grey, I. E., (2007) Titanium vacancy defects in sol-gel prepared J. Solid State Chem, 2, 670-678.

9. Cui, J., (2008) Escape of molecular hydrogen in Titan's thermosphere J. Geophys, 10, 479-487.

10. Kalinin, N. P., Ostapenko, V. D.(1983) Journal of Flaw detection, 5, 15-21.

RESEARCH OF ALF$_3$ PRODUCTION PROCESS USING HEXAFLUOROSILICIC ACID

S.I.Efremov, E.B. Asanov, N.A.Nikiteeva
Scientific supervisor: Assistant I.V.Petlin
Language consultant: Senior teacher N. V. Daneikina
Tomsk Polytechnic University, 634050, Russia, Tomsk, Lenina, 30
E-mail:nadianik77@gmail.com

Abstract.

This article is devoted to researching of production process of aluminum fluoride. The literature review includes description of existing methods of aluminum fluoride manufacture. The experimental part of this research work consists of a description of experimental device, experimental technique and results.

I. INTRODUCTION.

Aluminum fluoride (chemical formula AlF_3) is an inorganic binary compound of aluminum and fluorine.

The largest consumer of aluminum fluoride is the aluminum industry. Aluminum fluoride is used as an electrolyte element in electrolysis aluminum production process. For 1 ton aluminum about 30 kg aluminum fluoride is necessary [1]. The annual volume of output of aluminum in Russia makes about 4 million ton, for these purposes more than 100 thousand ton aluminum fluoride is required.

Besides, fluoride of aluminum is a part of gumboils, enamels, glasses, glazes, ceramics, coverings of welding electrodes; and also is the catalyst in organic synthesis.

The world volume of consumption of fluoride of aluminum makes about 1,3 million tons a year. World requirement for aluminum as a metal increases every year, that’s why also demand for aluminum fluoride will inevitably lead to an increase in volume of its consumption.

There is a deficiency of fluoric salts in Russia. According statistics I can say that fluoride of the aluminum blocked by the Russian sources only on 60 %. The rest of fluoride of aluminum necessary for manufacturing aluminum, is bought from foreign suppliers, mainly China.

The current situation can lead to dependence of the Russian manufactures of aluminum on importers, which undermines the whole economics of the aluminum industry of Russia.

There are two basic methods of obtaining aluminum fluoride, based on the use of gaseous fluoric hydrogen or hydrofluoric acid. Both methods have found the application in the industry and are used for manufacture of fluoride of aluminum at the domestic and foreign enterprises.

II. THE MAIN PART

II.I. The process of aluminum fluoride production from gaseous fluoric hydrogen.

The process of aluminum fluoride production from gaseous fluoric hydrogen is the worldwide dominating process, counting for approximately 65% of total AlF3 production. The main raw materials are fluorspar (CaF_2), aluminum hydroxide ($Al(OH)_3$) and Sulfuric acid (H_2SO_4). The two main steps of the process are:

1) the generation of gaseous HF from fluorspar and sulfuric acid
2) the production of AlF3 from gaseous HF and Al(OH)3

Dried fluorspar and Sulfuric acid are preheated to 120-150ºC and fed into a rotary kiln reactor, the pre-conversion is usually 30-50%. The reaction is completed in a directly or indirectly heated kiln where the temperature of the reactants is raised to 200-300ºC at the outlet end of the kiln. The overall reaction can be described by the following equation:

$CaF_2 + H_2SO_4 = CaSO_4 + 2\ HF$

Gypsum (synthetic anhydrite) is removed from the rotary kiln outlet end as a by- product and either transported to a landfill as waste or reused as construction material. The anhydrite is then cooled down and traces of Sulfuric acid are neutralized with lime before the product is ground to the required size for commercial purposes. Synthetic anhydrite from AlF3 plants is used mainly for the construction of self-leveling floors, as an additive to cement production and in the fertilizer industry.

The effluent gas from the rotary kiln after separation/concentration contains 40-100% HF and it is passed through scrubbers to remove dust, elemental sulfur and the impurities before it is used in the AlF3 manufacture step.

$Al(OH)_3$ is transformed to Al_2O_3 by heating it up to approximately 400ºC, and Al_2O_3 is fed into a fluidized bed reactor where the reaction with gaseous HF takes place according to the following overall equation:

$Al_2O_3 + 6\ HF = 2\ AlF_3 + 3\ H_2O$

This reaction takes place in a single or multi- fluidized bed reactor. Depending on the HF recovery system, a yield of 94-98% based on HF entering the aluminum fluoride reactor is achieved.

Gaseous effluent from the production of AlF_3 is cleaned by passing the gas through one or several wet scrubbers for the removal of HF, sulfur compounds and dust before being emitted to the atmosphere [2].

II.II The process of aluminum fluoride production from hydrofluoric acid.

The process of aluminum fluoride production from hydrofluoric acid comprises mixing and reacting hydrated aluminum oxide and aqueous hydrofluoric acid. The concentration of hydrofluoric acid is maintained in the reaction mixture of at least 50 percent. The reaction product is solidified on a moving bed of solid granules of aluminum fluoride having a particle size between 10 and 30 mm. The temperature is maintained at a greater than about 50° C. The moving bed containing sufficient granules of aluminum fluoride to prevent incrustation on the walls of the reactor[3].

This invention pertains to the manufacture of aluminum fluoride from hydrated aluminum oxides and hydrofluoric acid. The aluminum fluoride may be readily produced on a continuous basis and in a hydrate form where in it may be either dehydrated or mixed with sodium fluoride for reaction to form cryolite.

In processes known to the articles for manufacture of aluminum fluoride from aluminum hydroxide a number of disadvantages have become apparent. For example, it is known that reaction between the aqueous hydrogen fluoride and hydrated aluminum oxides starting materials at a somewhat elevated temperature on a batch basis, the components reacting with formation of a liquid product which, after a relatively long period, hardens to a solid aluminum fluoride hydrate. Such a process is often carried out in flat caldrons or rotating reaction drums. When flat caldrons are used, the hot liquid mass is discharged, after the reaction, into flat containers in which it is allowed to solidify[4]. To be removed from the containers the product uses drastic mechanical means, for example, drilling with a compressed-air hammer.

When the procedure is carried out in a rotating reaction drum, slurry of hydrated aluminum oxides and aqueous hydrofluoric acid of average concentration are run into the rotating drum and, upon completing the reaction, the liquid mass is allowed to remain in the drum, which continues to rotate, until it hardens. This second procedure, although it avoids blasting out the solidified masses from within the containers, also has the disadvantage that the walls of the reaction drums must be mechanically cleansed of baked-on aluminum fluoride.

To avoid the production of a hardened end product, it has been proposed to prepare aluminum fluoride by treating hydrated aluminum oxides in a fluidized bed with gaseous hydrogen fluoride. Such a process requires the use of anhydrous hydrogen fluoride, a much more expensive reagent than the aqueous fluoride solutions used in other processes. Also, the resulting aluminum fluoride has a higher alumina content than desirable and is in the form of fine powder which leads to a dust problem. Also, the anhydrous aluminum fluoride obtained cannot be converted to cryolite by simple addition of sodium fluoride[5].

In this invention, hydrated aluminum oxides and aqueous hydrogen fluoride are reacted and the liquid reaction mixture is contacted with a moving bed of warm solid aluminum fluoride granules. The granules may comprise aluminum fluoride and/or aluminum fluoride hydrate. These granules are usually maintained at a temperature of at least about 50° C, preferably about 100-150° C, and generally are provided in the amount of about 50-300% by weight of the liquid reaction mixture.

A suitable procedure is to continuously react, in a mixing device, aqueous hydrofluoric acid having a concentration of about 50-80%, preferably about 60-65%, with a hydrate of aluminum oxide in a molar ratio of about 1:3, plus a slight excess of HF of about 1-20%, preferably of about 1-10%, based on the stoichiometric amount necessary for the formation of $A1F_3$.

The term hydrated aluminum oxide comprises aluminum trihydrate [$Al(OH)_3$] as well as lower hydrated forms of aluminum oxides, such as AlO(OH) in its various and reactive modifications. Those hydrated aluminum oxides are preferred which react very promptly with HF. Therefore, for example $A1_20_3$ corundum or the crystal modification of diaspore which do not react with water to form aluminum trihydrate, are not suitable as starting materials per se. Generally spoken, all aluminum oxides and lower hydroxides can be used, which react in a short time with water to form $AI(OH)_3$. Preferably the trihydrate itself in the dry form is employed. It is, however, not necessary to apply the anhydrous form, as the reaction medium contains an appreciable amount of water by the hydrofluoric acid used. Therefore, also $A10(OH).nH_20$, $Al(OH)_3.nH_20$ and mixtures can be used. It is also possible to start with aqueous slurries of hydrated aluminum oxides. In this case, however, higher concentrated hydrofluoric acids must be applied to maintain a HF-concentration of at least 50% in the reaction medium. However, the diluted hydrofluoric acids of a concentration of about 60-65% are preferred, together with dry $Al(OH)_3$, as this performance of the process avoids the liberation of heat of dilution in the reaction apparatus thereby preventing the evaporation of gaseous HF.

The contact of the liquid reaction mixture with solid aluminum fluoride granules advantageously may take place in a heated rotating drum, partially filled with the solid product granules. The granules are present in an amount sufficient to prevent incrustation of the drum walls. The size of the granules may be controlled within certain limits by the temperature prevailing inside the reaction drum and the solidification time, as well as by the quantity of products admitted and withdrawn in a given unit of time. The alumina fluoride hydrate that has hardened may be continuously withdrawn from the rotating drum, for example, through an overflow connection. The solid product, which still contains some water of hydration, may then be calcined in a drying oven.

The solid aluminum fluoride granules used during the reaction have a diameter of about between 10 and 30 mm. Generally the feed rate of the aluminum fluoride granules and of the starting materials is so adjusted that the granules diameter of the resulting end product is of the same value as given above. It is, however, possible to produce also larger granules.

The hydrated aluminum oxide and the hydrogen fluoride may be reacted previous to contact with the solid granules or may be continuously fed individually to the moving bed of granules for reaction and solidification in situ. The hydrated aluminum oxide and hydrofluoric acid, in a molar ratio of about 1:3 may be continuously fed into a mixing vessel wherein they react with formation of a viscous mass. This viscous mass is then transferred, for example, by means of a conveyor, into the heated rotating drum[6].

The process of this invention also may be performed by continuously introducing the hydrofluoric acid and hydrated aluminum oxide separately into the rotating g drum and allowing the reaction to proceed along with almost instantaneous solidification onto the aluminum fluoride granules present therein. Also, in this case, no incrustation of the walls of the drum takes place. This modification of the process has the advantage that the Q heat given off during the exothermic reaction between the hydrofluoric acid and the hydrated aluminum oxide, is exploited during the granulation which takes place simultaneously, so that the external heat which needs to be applied to the rotating drum can be substantially lower. In carrying out this continuous process, it is recommended to operate with a slightly higher mixing proportion of liquid phase reactants to solid reaction product. This proportion depends on the size of the device serving as a reaction and mixing drum.

It is also possible to have the reaction product solidified by causing the liquid reaction mass to fall in drops onto a large quantity of cold aluminum fluoride. However, this procedure is less economical since it requires, on the one hand, the use of a considerable excess of previously formed reaction product, and therefore correspondingly larger dimensions of the mixing devices and, on the other hand, the use of much longer solidification periods.

The process which has been described above has the following advantages over known processes of this type.

The resulting material can be reacted with sodium fluoride to form cryolite. The aluminum fluoride hydrate prepared according to this invention is practically free of alumina so as to furnish, by a subsequent calcination, a 95-97% aluminum fluoride [7].

II.III. The process of aluminum fluoride production from hexafluorosilicic acid.

In a typical process for producing AlF_3 from FSA, hydrated alumina from a feed bin is weighted into a set of batch reaction tanks[8]. The hexafluorosilicic acid solution is pumped from storage tanks through a heat exchanger to the batch reaction tanks. In the reaction tanks, hexafluorosilicic acid reacts with hydrated alumina to form a metastable, soluble form of aluminum fluoride trihydrate (alpha-form) and silica according to the following reaction :

Al_20_3 (s) + H_2SiF_6 (aq) + 5 H_20 = 2 AlF_3*$3H_2O$ (aq) + SiO_2 (s)

In conventional processes, the moist aluminum fluoride trihydrate filter cake is then fed to a flash dryer which removes free moisture and water of hydration resulting in converting at least a portion of the aluminum fluoride trihydrate to aluminum fluoride hemihydrate according to the following sequence:

$AlF_3*3H_20(s)$ heat = $AlF_3*0.5\ H_2O$ (s)

$AlF_3*0.5H_2O(s)$ heat = AlF_3 (s)

The flash dryer operation may, in some applications, utilize waste heat from the calcining operation. The flash dryer product is then conveyed to a calciner and cooler where the mixture of aluminum fluoride further dehydrated by calcination to anhydrous aluminum fluoride per sequence above, and then cooled. The cooled AlF_3 product is then conveyed to an AlF_3 storage bin. From here it is loaded out by gravity to rail cars or trucks[9].

III. CONCLUSION

In summary, in the foregoing commercial process, aluminum fluoride is produced by the reaction of hexafluorosilicic acid and hydrated alumina; aluminum fluoride trihydrate is crystallized from the solution; and, following separation from spent liquor, aluminum fluoride trihydrate crystals are dried and calcined to yield anhydrous aluminum fluoride. It has been found in practice, however, that the aluminum fluoride trihydrate crystals have a tendency to breakdown during drying, calcination and handling. The final aluminum fluoride product thus contains a relatively high concentration of dust and fines of less than 325 mesh material that is considered an expensive nuisance during handling and processing of the material [10].

1. Rakov E.G. Chemistry and technology of inorganic fluorides. – M.: MSTI, 1990. – 162 c.
2. Aldaco, R. Luis, P and Irabien, A. Fluidized Bed Reactor for Fluoride Removal. Chemical Engineering Journal, 107, 1-3, 2005 pp. 113-117.
3. Broja G., Gradinger H. Patent. Aluminum fluoride manufacture with a moving aluminum fluoride bed. 1964.
4. Rodin V., Kosynkin V. Fluoride production from phosphate raw material treatment in Russia. – IFA technical sub-committee and committee meeting, 1999, Novgorod, Russia
5. .Korevaar, G. Sustainable Chemical Process and Products. PhD Thesis, Technische Universiteit Delft, 2004, Netherlands.
6. Turaev, N.S, Zherin I.I. Uranium chemistry and technology. The manual for high school/ N.S Turaev,., I.I Zherin.- M.: Publishing House "Ore and Metals", 2006. – 396 p.
7. Toxicological Profile for Fluorides, Hydrogen Fluoride, and Fluorine //U. S. Department of health and human services.2003.—383p.
8. Hydrofluoric Acid// Backgrownd report/U.S. Environmental Protection Agency.33p.
9. K. Bechel, H. Moretto,P. Woditsch, Industrial Inorganic Chemistry
10. Ming-Yan Ma, Ying-Jie Zhu, Liang Li and Shao-Wen Cao. // J. Mater. Chem. – 2008. - Vol. 18 - P. 2722-2727.

HYDROGEN SORPTION BY CARBON NANOSTRUCTURES MATERIAL

L.V. Gulidova, V. N. Kudiyarov
Scientific advisor: Associate professor, PhD. Physics A.M. Lider
Language advisor: Associate professor PhD, Associate Professor A.S. Parnyugin
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
l_gulidova@sibmail.com

Abstract.

The carbon nanotubes can be used as reservoirs for hydrogen storage. Hydrogen concentration in the sample of carbon material grows with cycles of sorption. Hydrogen concentration at room temperature is more than four times less than at low temperature. The maximum hydrogen sorption capacity of carbon materials is 4 wt% more at high pressure and low temperature.

I. INTRODUCTION

As a result of energy resources depletion and problems of environmental pollution, hydrogen has been recognized as an ideal fuel because it has specific properties. As high-performance and ecological energy carrier it has big perspectives for general using in power engineering, particularly as fuel for transports. The using of hydrogen economy is based on three important aspects of using hydrogen as a fuel for our energy needs, namely production, storage and transportation. One of the general problems is the lack of effective methods of storage and transportation of hydrogen. At this time no one method of storage meets the demands of the storage system [1]. Recently carbon materials, in particular, carbon nanotubes, have been regarded as reservoirs for hydrogen storage. In the recent decade these materials have been very popular and different laboratories have published experimental results about sorption capacity [2, 3, and 4]. The studying of all peculiarities of sorption and desorption of hydrogen by carbon nanotubes is important for science.

II. EXPERIMENTAL PROCEDURES

The superfine carbon material synthesis method was created in the Institute of Physics and Technology of Tomsk Polytechnic University [5]. The peculiarity of this method is combination of metal catalysts and the influence of microwave field on the catalysts and methane. Scientists used the flow reactor of the waveguide type. Metals Ni, Fe, Mo, Ti are used as catalysts. The flow reactor consists of a catalytic chamber and an arc chamber. The first chamber is a metal cylinder with a catalyst-filled quartz tube. The microwave charge is formed in the arc chamber. The agglomerator and a system of filters are used for reaction product collection. Figure 1 shows the flow reactor of the waveguide type.

The material produced by conversion of natural gas has different modifications of carbon as nanotubes, nanofibers, onion-particles, microcrystals of graphite and amorphous carbon. The content of nanotubes in the final product is not more than 70%. The received material was chemically treated against impurities (other modifications of carbon such as nanofibers, onion-particles, microcrystals of graphite and amorphous carbon) and metallic catalysts.

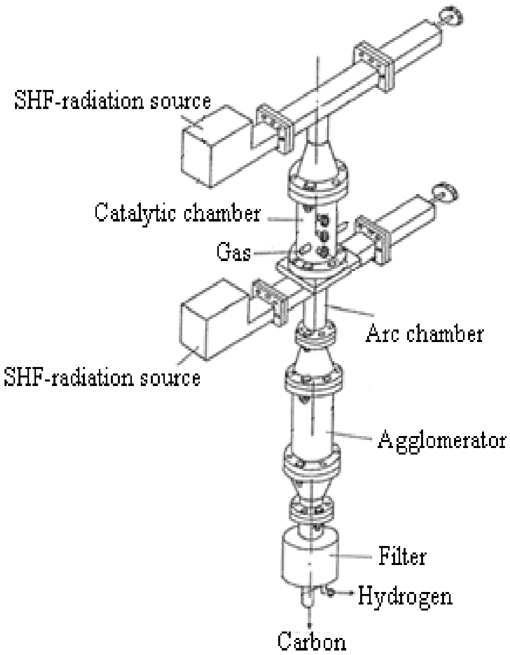


Figure 1. The flow reactor of waveguide type

The samples of carbon material were researched with the help of scanning electron microscopy and transmission electron microscopy. Scanning electron microscopy is a powerful tool for the investigation of surfaces. The major feature of this technique is the ability to resolve electronic and structural features with nanometer spatial resolution. Scanning electron microscopy guarantees the spatial resolution necessary to measure the structural modifications of the carbon nanotubes after the functionalization process [6-7]. Figure 2 shows the micrographs of carbon material which contains a large quantity of carbon nanotubes with different diameters. The diameters reach 150 nm.

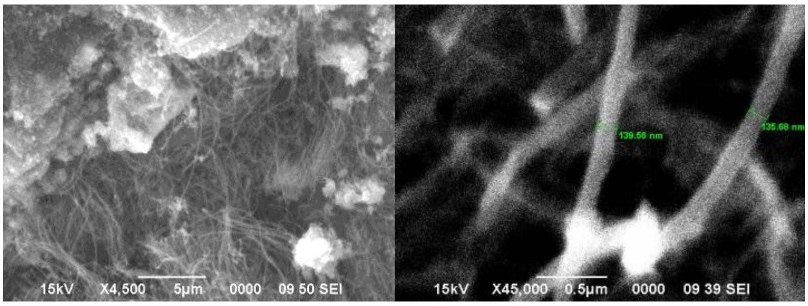


Figure 2. Micrographs of carbon material: 1- general view, 2 – diameters of carbon nanotubes.

The transmission electron microscope is realized on the electron microscopes which examine the thin-film object with the accelerated beam with energy 50 – 200 keV.

For making the microscopic investigations the sample of the superfine carbon material was mixed with acetone and dispersed in the ultrasonic bath. The resulting suspension was applied on the electron microscope copper mesh with carbon film. The microstructure of nanocomposites was investigated with a transmission electron microscope with high resolution [7-8].

Figure 3 b shows a micrograph of the carbon material, which clearly distinguishes single-walled carbon nanotubes with an inner diameter of 20 nm and wall thickness of about 20 nm.

The Gas Reaction Controller automatic system by Advanced Materials Corporation [9] was used for measuring the sorption of hydrogen by carbon materials [10].

The Gas Reaction Controller Low Pressure 100 automated complex (Figure 4) has a computer with special software, control system, oven and chambers for samples. Gas sorption or desorption can be studied with the help of this complex. And samples can be saturated with hydrogen in this equipment. The data about hydrogen sorption in the sample are automatically saved by the computer.

The theory of operation of the Gas Reaction Controller is based on the measuring and comparing the amount of gas before and after the reaction. First the unit's control system admits the reaction gas to the chamber of known volume (reservoir). From precise measurement of temperature and pressure, it determines the amount of gas. It then sends the gas into the reaction chamber, where the gas gets absorbed by the sample. The temperature, pressure and reaction speed may be controlled and measured. At any given point of reaction, the unit keeps track of the amount of gas. Any missing amount is attributed to absorption. By this method, the unit is also capable of measuring desorption characteristics because any desorption from the sample results as an additional amount of gas.

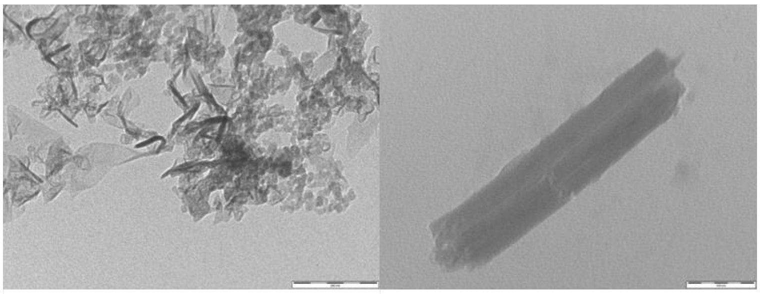


Figure 3. Micrographs of carbon material: a - general view,b – a single-wall carbon nanotube.

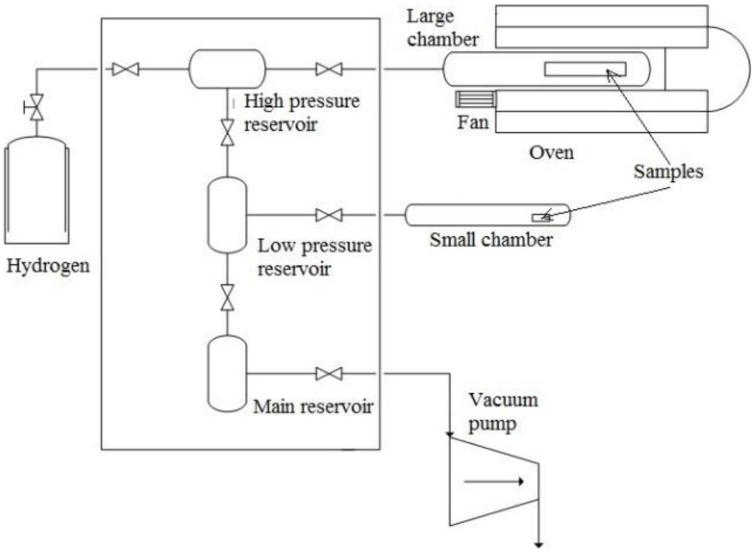


Figure 4. Scheme of the Gas Reaction Controller automated complex

There are two methods of hydrogen saturation in the Gas Reaction Controller. The first method is «soak». In this method the process of absorption runs in one step and the amount of hydrogen (which was sorbed by the sample) is determined as a difference between the initial and final pressure in the chamber. The process is stopped when the specified time period passes. The second method is «PCI absorption». In this method the process of absorption runs in many steps and each step ends when the pressure equilibrium is reached. The process is stopped when the specified value of the settled pressure exceeds.

The samples were used in the compressed state. The samples were hydrogen saturated at the temperatures of 243K and 300 К at the «Soak» method and the pressure of the hydrogen 0-8 atm using the «PCI absorption» method.

High purity hydrogen (99,9999%) was used for the investigation of the sorption capacity of carbon material. The hydrogen was produced by HyGen 200 generator by Claind. It allows evading of anomalously high sorption capacity and problems of results reproducibility.

III. RESULTS AND DISCUSSIONS

In Figure 5 a concentration-time sorption diagram at room temperature is presented. In this experiment the sample was saturated with hydrogen with the help of «soak» method in three steps, one following one another. In the Figure 5 the first step is 1, the second step is 2 and the third step is 3. With increasing the number of saturation cycles, the hydrogen concentration increases and the maximum concentration is 0.9 mass percent. The graph shows that the sample absorbs more hydrogen in the first seconds any of the saturation cycles.

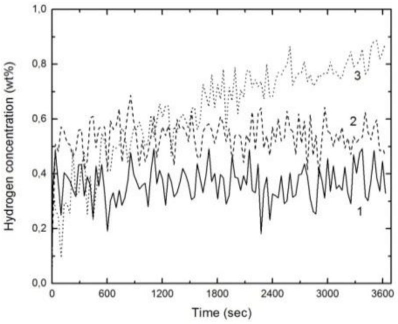


Figure 5. Concentration-time sorption diagram at room temperature

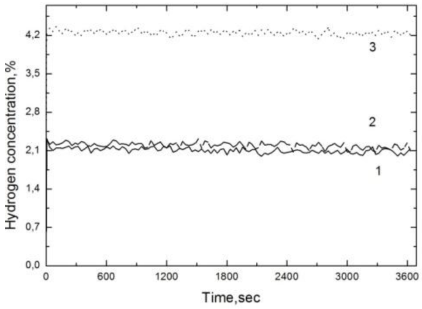


Figure 6. Concentration-time sorption diagram at low temperature

Figure 6 shows a concentration-time sorption diagram at a low temperature. In this experiment the sample also was saturated with hydrogen with the help of the «soak» method in three cycles, one following one another. With increasing the number of saturation cycles, the hydrogen concentration increases and the maximum concentration is 4.2 mass percent. It is 4.6 times more than the hydrogen concentration which was achieved at room temperature. The diagram shows that the time of each cycle can be shortened, because the amount of adsorbed hydrogen does not change with increasing the sorption time.

Figure 7 shows a concentration-pressure sorption diagram at a room temperature. In this experiment the sample was saturated with hydrogen with the help of «PCI absorption».

Figure 8 shows a concentration-pressure sorption diagram at a low temperature. In this experiment sample was saturated with hydrogen with the help of «PCI absorption». The difference between the diagrams at a room temperature and low temperature is that hydrogen molecules don't have enough energy for leaving the carbon nanotubes at a room temperature. The diagram at the low temperature shows the equilibrium state of system.

The big advantages of the physisorption for hydrogen storage are the low operating pressure, the relatively low cost of the materials involved, and the simple design of the storage system [11].

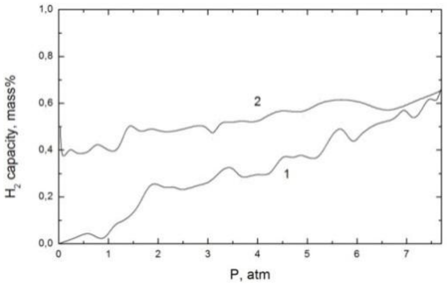


Figure 7. Concentration-pressure sorption diagram at room temperature

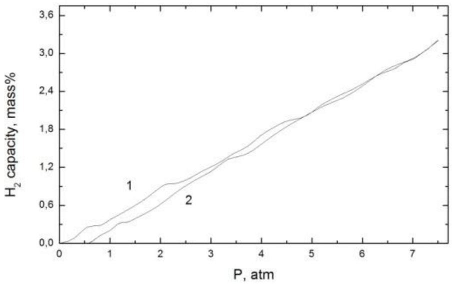


Figure 8. Concentration-pressure sorption diagram at low temperature

IV. CONCLUSIONS

Hydrogen concentration grows with cycles of sorption. Hydrogen concentration at room temperature is more than four times less than at low temperature. The maximum hydrogen sorption capacity of carbon materials is 4 wt% more at high pressure and low temperature. All these results prove the high efficiency of using the carbon material produced by conversion of natural gas as hydrogen sorbent.

1. Eleckiy A.V. (1997). Uglerodnie nanotrubki. Physics-Uspekhi , 167, 9.
2. Yuda Yurum, Alpay Taralp, T. Nejat Veziroglu. (2009). Storage of hydrogen in nanostructured carbon materials // International journal of hydrogen energy, 34, 15.
3. Chang Liu, Hui-Ming Cheng. (2005). Carbon nanotubes for clean energy application. Journal of Applied physics, 38, 22.
4. Tarasov B.P., Goldshleger N.F. (2002). Hydrogen sorption by carbon nanostructures // International Scientific Journal for Alternative Energy and Ecology, 3, 20-38.
5. Zherlicyn A.G., Shiian V.P., Medvedev Yu.V., Galanov S.I., Sidorova O.I. (2007). Poluchenie uglerodnogo nanomateriala I vodoroda iz prirodnogo gaza pod vliyaniem sverh-vysokochastotnogo izlucheniya. Russian Physics Journal, 10, 280-284.
6. Nacci, C.(2005). Scanning tunneling microscopy investigation of functionalized carbon nanotubes. Anno Accademico..
7. Rivera, W. (1995). Scanning tunneling microscopy current-voltage characteristics of carbon nanotubes., American Vacuum Society.
8. Vorobieva A.N. (2010). Apparatus and methods for the study of carbon nanotubes. Physics-Uspekhi.
9. AMC’s WWW user survey. (n.d.). Retrieved September, 2010, from www.advanced-material.com
10. Varin, R. A., Wronsky, Z. S., Czujko, T. (2009). Nanomaterials for Solid State Hydrogen Storage. ISBN 978-0-387-77711-5.
11. Züttel,.(2004). Hydrogen storage methods. Naturwissenschaften, 91, 157–172.

ACCUMULATION OF HYDROGEN IN TECHNICALLY PURE TITANIUM AT ELECTROLYTIC SATURATION AND AT SATURATION FROM GAS ATMOSPHERE

V.N. Kudiyarov
Scientific supervisor: PhD, Associate professor A.M. Lider
Language supervisor: PhD, Associate professor A.S. Parnyugin
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
victor31479@mail.ru

Abstract.

Methods of hydrogen saturation (electrochemical saturation and saturation from gas atmosphere) are described in this work. The results of the study of hydrogen accumulation and distribution in commercially pure titanium are shown.

I. INTRODUCTION

Titanium and its alloys are materials of great technological interest due to the combination of the two mechanical properties of resistance to corrosion and hardness. Hydrogen in metals and alloys is known to cause embrittlement. For titanium and titanium alloys the presence of hydrogen and titanium hydride enhances the fracture by localized plastic deformation and brittle fracture respectively [1].

II.

There is significant problem of hydrogen embrittlement for structural materials in aggressive environments such as blades of aircraft engines. Also, at the rolling of titanium sheets (in the factories that manufacture components for aircraft) hydrogen penetrates into them and reduces the quality of finished products. It is important to study hydrogen effect on the properties of materials to develop methods of protecting structural materials from the harmful effects of hydrogen and to develop methods for removing hydrogen from materials.

Sample preparation is an important step in studying the influence of hydrogen on the properties of metals. At the preparation of the samples it is important to know how hydrogen is distributed in the samples because it influences the accuracy of the experiments very much.

The aim of the study is the investigation of the hydrogen accumulation and distribution in the technically pure titanium after electrochemical saturation and saturation from gas atmosphere at high pressures and temperatures.

III. EXPERIMENTAL PROCEDURE

Rectangular plates (24 x 80 x 1 mm) of technically pure titanium (Table 1) were prepared for studying of hydrogen distribution on the sample surface. The plates were previously mechanically polished and annealed.

Table 1. Chemical compound of technically pure titanium in mass percent.

Fe	*C*	*Si*	*N*	*Ti*	*O*	*H*	Impurities
0,18	0,07	0,1	0,04	98,61-99,7	0,18	0,12	0,3

The saturation of the first plate was carried out by electrolytic method for 72 hours at current density 0,05 A/cm^2. Aqueous solution of sulfuric acid was used in the electrolysis. The plate (cathode) was placed in the center of the beaker and platinum (anode) was fixed at circle at the top of the beaker.

Hydrogen penetrates into the metal in atomic form during electrolysis. Then it associates to form molecules in the pores and in the defect structures. Hydrogen enters chemical reactions with titanium, nonmetallic inclusions and impurities and forms hydrides and other chemical compounds. Part of hydrogen remains in the free state in the range of solubility [1]. The formation of the hydride layer on the titanium surface is a result of electrochemical saturation [2-3].

The saturation of the second plate was carried out in Gas Reaction Controller automated complex by Advanced Materials Corporation [4]. Its principle of working is based on the Sieverts method when hydrogen saturation runs from gas atmosphere at high pressures and temperatures [5]. The complex consists of a computer with special software, a controller to manage the experiment, a horizontal furnace for heating the sample and the sample chambers. There is a cooling fan between the furnace and the controller to prevent damaging of connecting wires from heating.

The scheme of the *Gas Reaction Controller* automated complex is shown in the Picture 1.

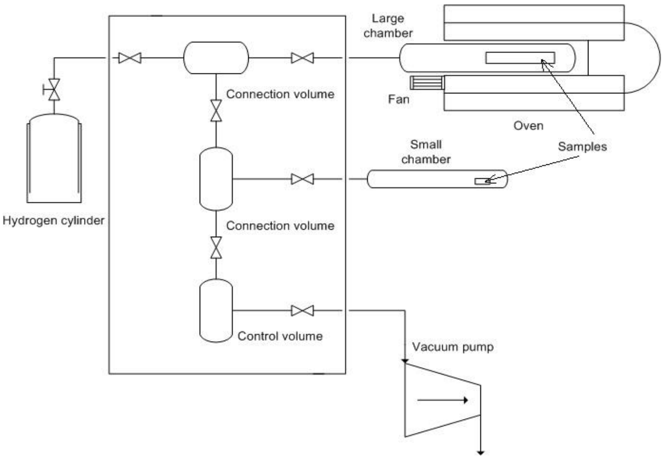


Fig1. The scheme of the Gas Reaction Controller automated complex.

The principle of operation of the Gas Reaction Controller is as follows: the connection volume (Picture 1) is filled with hydrogen and system determines its molar volume N_0 by using its pressure and temperature. Then the system opens the valve between the reservoir and the reaction chamber and the necessary amount of gas is supplied from the reservoir into the reaction chamber. After the finishing of hydrogen absorption by the sample the reaction is stopped and the system automatically calculates the total molar volume of gas N_g in the chamber. The molar volume of hydrogen which was absorbed by the sample N_s is calculated as follows:

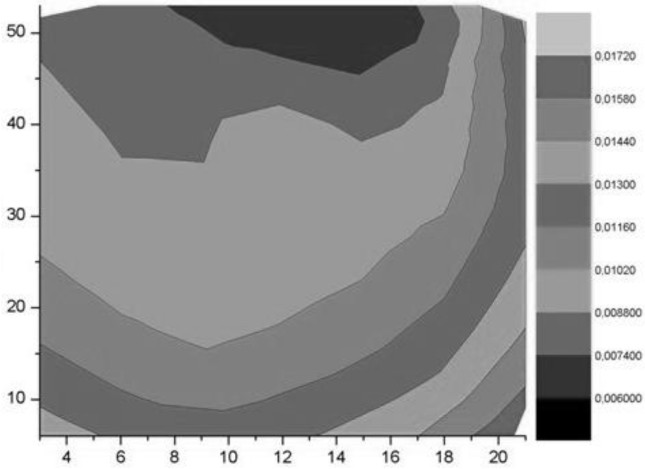
$$N_s = N_0 - N_g$$

During the experiment the plates were placed in the reaction chamber which was evacuated to a pressure of 10^{-6} atm. Then the sample heating was carried out to a temperature 650 °C. After the evacuation of the gases that are desorbed from the sample during heating the reaction chamber was quickly filled with hydrogen to a predetermined pressure. The initial hydrogen pressure was 0,7 atm., the time of exposure of the sample in the hydrogen atmosphere was 30 minutes. The dependence of the pressure in the reaction chamber on the time and the temperature was automatically recorded on the computer.

The hydrogen concentration in samples was measured within an hour after the end of hydrogen saturation with the help of hydrogen analyzer RHEN602 by LECO [6]. Distribution profiles of hydrogen in the bulk of the samples were obtained with the help of a GD-Profiler glow discharge optical emission spectrometer 2 by Horiba [7]. The depth of the craters was measured with the help of a Hommel-Etamic profilometer by Jenoptik Germany.

IV. RESULTS AND DISCUSSIONS

Figure 2 shows a diagram of the distribution of hydrogen concentration on the sample surface after the electrochemical saturation. With increasing of the depth in the electrolyte, the hydrogen concentration in the sample increases. This is due to the fact that the bottom corners of the sample were isolated and, therefore, the area of interaction between the electrolyte and the plate was greater at the bottom than of the top. The upper corners of the sample have not contributed to the hydrogen saturation because the electrolyte level was below their locations.

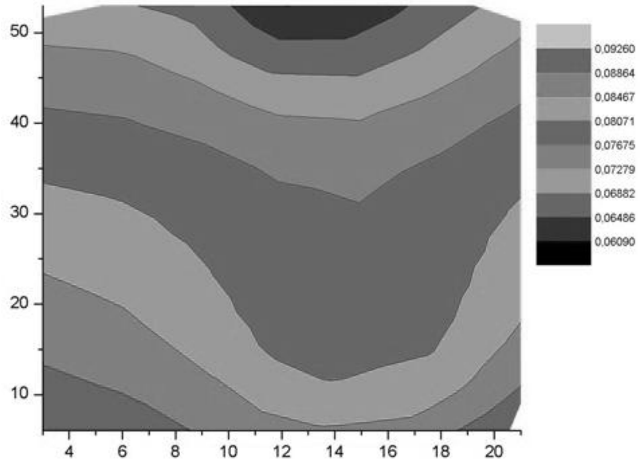


Picture 2. The hydrogen distribution on the sample surface after electrochemical saturation

The hydrogen distribution across the width of the sample is nonuniform, the hydrogen concentration at the edges is more than hydrogen concentration in the center. This is due to the penetration of hydrogen through the side faces of the sample. A larger amount of hydrogen is concentrated on the right side of the sample, it happened because in the electrolysis there was nonuniform distribution of the current density over the entire volume of electrolytic glass due to the geometrical shape of the anode.

Thus, after the electrochemical saturation hydrogen is distributed nonuniformly on the surface of the rectangular plate. Hydrogen concentration depends on the geometric characteristics of the plate (the presence of edges and corners), the location of the plate in the beaker during electrolysis and the location of the anode.

Figure 3 shows a diagram of the hydrogen concentration distribution on the sample surface after the saturation from gas atmosphere. At the saturation from gas atmosphere the hydrogen concentration in the sample is one order of magnitude greater than the hydrogen concentration in the sample obtained during the electrochemical saturation. The hydrogen distribution along the length of the sample is nonuniform, the highest concentration of hydrogen is at the bottom of the sample and the lowest is at the top. This is due to the location of the sample in the reaction chamber.



Picture 3. The hydrogen distribution on the sample surface after saturation from gas atmosphere

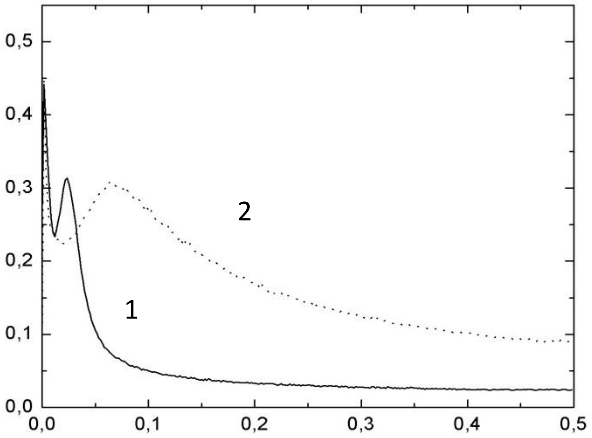
As well as for the electrochemical

saturation, the hydrogen distribution across the width of the sample is nonuniform: hydrogen concentration at the edges is more than in the center.

Thus, after hydrogen saturation from gas atmosphere at high temperature and high pressure the hydrogen concentration is distributed nonuniformly on the surface. Hydrogen concentration, as well as after the electrochemical saturation, depends on the geometric characteristics of the plate (the presence of edges and corners) and sample location in the reaction chamber during the saturation. The highest hydrogen concentration is in the part of plate which was located at the most remote place from the cooling system in the reaction chamber. Also there is more hydrogen concentration at the edges than in the center of the plate.

Figure 4 shows the distribution profiles of hydrogen concentration in the samples after the electrochemical saturation and after saturation from gas atmosphere at high temperature and high pressure.

During the electrochemical saturation hydrogen penetrates and is accumulated on the sample surface. Due to a low coefficient of hydrogen diffusion at room temperature hydrogen does not enter the bulk of the sample. As a result, a hydride layer is formed in the near-surface layer [8-9]. This hydride layer prevents further hydrogen penetration into the sample. This explains the low hydrogen concentration in the samples which were saturated with the help of the electrochemical method. The hydride layer is expressed as the peak intensity in the graph of hydrogen distribution in the depth of the sample. Next is a decrease in the hydrogen concentration in the sample.



Picture 4. Distribution profiles of hydrogen in the depth of samples: 1 – electrochemical saturation: 2 – saturation from gas atmosphere

During the hydrogen saturation from gas atmosphere at high temperatures and high pressures hydrogen penetrates into the metal in atomic form and diffuses into the sample bulk the depth which is more than depth of hydrogen penetration during electrolysis. As a result, hydrogen concentration in such samples is more than hydrogen concentration in samples after the electrochemical hydrogen saturation. The intensity peak of hydrogen which belongs to the hydride layer is not expressed as clearly as after electrochemical saturation. This is due to the fact that hydrogen has a very high speed of diffusion at the temperature at which the saturation takes place (550 °C). And hydrogen penetrates very fast to the bulk of the sample without forming the hydride layer. During cooling the samples after hydrogen saturation the hydride layer is formed ($\alpha + \gamma$ phase) [10], but less expressed than after the electrochemical saturation.

V. CONCLUSIONS

As a result of the performed work of studying the distribution of hydrogen in technically pure titanium after electrochemical saturation and saturation from gas atmosphere, the following conclusions has made:

1. Hydrogen distribution along the width of the plates is uniform. The hydrogen concentration at the edges is more than in the center due to the hydrogen penetration through the side faces of the plates. After the electrochemical saturation the hydrogen concentration is higher on the right side of the plate due to the nonuniform distribution of current density over the entire volume of the electrolyte glass, which happens because

of the shape of the anode. After hydrogen saturation from gas atmosphere the hydrogen concentration is one order of magnitude greater than hydrogen concentration achieves during electrochemical saturation. Hydrogen distribution along the length of the plate occurs uniformly, the highest hydrogen concentration at the bottom of the plate, the lowest – on the top. This is due to the nonuniform temperature distribution along the length of the chamber.

2. During the electrolysis, hydrogen, while penetrating, is accumulated on the surface of the metal. Due to the low coefficient of hydrogen diffusion at room temperature, it does not penetrate into the sample bulk. As a consequence, the hydrogen forms a hydride phase of titanium in the surface layer, and further penetration of hydrogen into the samples is complicated by the need to overcome the hydride layer. At the saturation from gas atmosphere by Sieverts method hydrogen penetrates into the sample in atomic form and diffuses into the depth, which exceeds the depth of hydrogen penetration in the electrochemical saturation. As a consequence, the absolute amount of hydrogen in these samples is higher than in the electrochemical saturated samples.

Thus, after the hydrogen saturation of technically pure titanium hydrogen is distributed nonuniformly, the concentration depends on the geometric characteristics (the presence of edges and corners) and the location of the samples during the saturation. The highest concentration of hydrogen is at the bottom of the sample and on the side which is located near the anode during the electrochemical saturation and in that part of the sample which is located in the chamber away from the cooling system during the saturation from gas atmosphere. Also, the hydrogen concentration is higher in the edges compared to the center of the plates. The absolute amount of hydrogen is one order of magnitude higher in the samples which are saturated from gas atmosphere than in the samples which are saturated with the help of electrochemical saturation.

The results of this work are used in the preparation of the samples for the development of methods of protecting construction materials from destructive hydrogen effects and in studying hydrogen influence on the properties of metals and alloys.

1. Cheng Z-H., MacKay G.R., Small D.A., Dunlap R.A. Phase development in titanium by mechanical alloying under hydrogen atmosphere // Journal of Applied Physics. – 1999. – 32. – P. 1934 – 1937
2. Okamoto H., Mizuno K., Kobayashi T., Fujiki F., Furuya Y., Hirano K. Evaluation of hydrogen diffusion in alpha-titanium by diffraction-enhanced X-ray imaging technique/ Proc/ 8th Int. Conf. X-ray Microscopy IPAP Conf. Series 7. – 2008. – P. 297 – 299
3. Lunarska Ellina, Chernyayeva O., Lisovytskiy D., Zachariasz R. Softening of α-Ti by electrochemically introduced hydrogen // Materials Science and Engineering C. – 2010. – 30. – P. 181 – 189
4. www.advanced-material.com
5. Robert A. Varin, Tomasz Czujko, Zbigniew S. Wronsky. Nanomaterials for Solid State Hydrogen Storage. ISBN 978-0-387-77711-5, 2009.
6. www.leco.com
7. Thomas Nelis, Jozsef Pallosi. Glow Discharge as a Tool for Surface and Interface Analysis. Applied Spectroscopy Reviews. – 2006. – 41. – P. 227 – 258
8. Elias R.J., Corso H.L., Gervasoni J.L. Fundamental aspects of the Ti-H system: theoretical and experimental behavior // International Journal of Hydrogen Energy. – 2002. – 27. – P. 91 – 97

9. Xu J.J., Cheung H.Y., Shi S.Q. Mechanical properties of titanium hydride // Journal of Alloys and Compounds. – 436. – 2007. – P. 82 – 85

10. Takasaki A., Furuya Y., Ojima K., Taneda Y. Hydride dissociation and hydrogen evolution behavior of electrochemically charged pure titanium // Journal of Alloys and Compounds. – 224. – 1995. – P. 269 – 273

MEASUREMENTS OF ELECTRONIC BEAM PARAMETERS IN BETATRON

Hans Michael Kröning[2], Maxim Rychkow[2], Roman Laas[1, 2]

[1]Institute of applied physics and engineering, National Research Tomsk Polytechnic University, Tomsk, Russia

[2]TOLMI, National Research Tomsk Polytechnic University, Tomsk, Russia

Linguistic Advisor: PhD, Senior teacher Y.V. Falkhovich

Roman.laas@gmail.com

Abstract

Nowadays betatrons are widespread and used in many branches of technics and engineering. They can be applied to build systems of material inspection. Screening systems with betatrons are cheaper than detectors with He-3 and allow quickly inspect wide objects, such as cars. To construct efficient and effective systems betatron must be well configured. Measurements of electronic beam are taken place mostly during injection or after ejection.

Deep analysis of measuring methods was made. Calorimetric, acoustic, collector and emission methods can not be applied because of their nontrasparency. Radiation methods are not effective enough because of their low sensibility. Ionization method was considered to be the most efficient. It is transparent and can be applied to measure not only current, but coordinates of electronic beam gravity center. The residual gas is ionized by the circulated electronic beam. The number of appeared secondary electrons grows proportionally with current. Signal electrodes are placed over and under beam direct in vacuum camera, the difference of potential is about 2 kV. Because of the electric field electrons move along the lines of magnetic field to collector and than through resistors go to the ground. Voltage on resistors goes in direct proportion with beam current. The principal idea and scheme of measurement tool is created. Applied to betatrons, it can help increase the efficiency of inspecting complexes.

Keywords-betatrons; electronic beams; parameters measurements, optical methods, ionisation methods.

I. INTRODUCTION

To set betatron up and in process of its exploitation it is necessary to have maximum data about beam behavior inside acceleration camera. The most interesting is to get information about the location of a beam. For circular accelerators this information is required to demand the location of an orbit and to provide the effective ejection of particles. One of the most important parameters is line profile of beam, which is current density-distribution function in a cross section. The maximal value of integral of this function is in proportion to beam current. Characteristics of density-distribution of current make it possible to identify beam fluctuation type and find out ways to stabilize it. The measurement of a beam charge is not a simple task, because there is no way to set direct measures of this value. A lot of methods using electrostatic electrodes, magnetic-induction measurers and hall-effects sensors that are widely used for synchrotrons can not be applied for betatrons: First of all, the beam in acceleration camera is not bunched, azimuth continuous during the whole acceleration time, there is no spaces, where no magnetic field is; second, the measuring process is affected by background noise made by injection schemes and bias circuits. Shielding of elements is impossible, because presence of ferromagnetic materials in acceleration camera will affect control magnetic field.

II. REQUIREMENTS

There are some very important requirements to measuring systems:

- The impact of measurer has to be minimal (transparency).
- The ability to get information about beam parameters constantly.
- High immunity, exploitation reliability.
- Radioresistance

According to the requirements next conclusions can be made:

Collector, emission, calorimetric and acoustic measurers are inappropriate, because of their non-transparency. Radiational methods are also inapplicable because of their low sensibility for betatrons. From all the rest, the most interesting are ionization and optical methods.

III. IONIZATION METHODS

Ionization method is transparent and can be applied to find the center of balance of a beam. It is based on phenomena of ionization of residual gas by electrons. Although there is vacuum in camera, number of gas molecules is enough. The ionizing ability of electrons is quite low, much lower than ability of protons, but still, it`s enough to set measures for betatrons, because circulated current is much bigger, than in proton accelerators. This method can be applied to measure both current value and beam profile. The suggested system includes sensors of intensity, location and density-diversity. The principal scheme of measures is showed on picture 1.

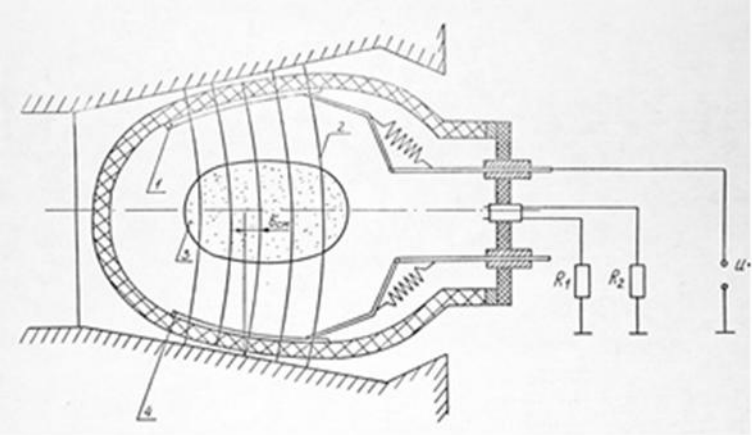


Fig. 1: Construction of ionization detector

The number of gas ions and secondary electrons is in direct proportion to current. When the current of circulated beam is 5A, the number of secondary electrons is about 10^{14} for each cm. The electrodes 1 and 4 are places above and under the beam 3 direct in acceleration camera. The negative electrode is under voltage U created by high-voltage generator. The positive collector-electrode 4 is divided into 10 parts, each part is ground through resistance R_n, where n is the number of collector section. Secondary electrons are moving along the magnetic lines(2) of control field and through the resistances flow to the ground. Voltage on each resistance is in proportion to current of accelerated electrons above each section. The sum of currents is in proportion to the whole beam current. As a guard electrode the conductive coating inside the acceleration camera is used.

The basic characteristic of this method is its sensibility, which can be defined as ionization current I_i, taken from collector divided through circuit current I_c of the whole beam.

$$S_I = \frac{I_k}{I_c} = klpB(E) \qquad (1)$$

Where k – coefficient of secondary electrons collection, l – length of a section of collector, p – residual gas pressure, B(E) – possibility of ionization, that is defined as the number of pairs of ions, created on 1 cm of path under the pressure 1 Mpa by 1 proton or electron.

$$\mathrm{B(E)} = \frac{(\frac{\mathrm{dE}}{\mathrm{dx}})_{\mathrm{ion}}}{\varepsilon \mathrm{p}_0} \qquad (2)$$

Where p_0 – atmosphere pressure, ε – average energy needed to create 1 pair of ions, $(\frac{dE}{dx})_{ion}$ – ionization loss – average quantity of energy lost by particle on ionization on 1 cm path.

The dependence of sensibility on accelerated particles energy is defined by B(E), and the behavior is defined with ionization loss. For electrons this loss can be defined as

$$-(\frac{dE}{dx})_{ion} = 4\pi e^4 N_a Z_a \sqrt{e/2}\,\frac{\ln(mv^2/2I)}{mv^2} \qquad (3)$$

and for relativistic particle

$$-(\frac{dE}{dx})_{ion} = 2\pi e^4 N_a Z_a \ln[\frac{(E^3/2mc^2I^2)+1/8}{mc^2}] \qquad (4)$$

where N_a - number of atoms in 1 cm^2, Z_a - atomic number of a substance, I – average ionization potential.

According to (3) and (4) ionization loss and sensibility of described method are in proportion to $1/\beta^2$ in area of low energies (β<<1, where β is relative speed of electrons). The minimum of function is when energy is $2{,}5m_0c^2$, than sensibility growth with lnE. Protons and electrons of the same velocity have quite similar losses of energy on ionization.

To measure the position of balance center, collector electrode is divided into 2 parts diagonally. Differential signal is measured. It is in proportion to radial displacement of a beam, but it also depends on the intensity of a beam. To avoid this dependence the total signal, that also depends on intensity of a beam is measured. Differential signal is divided through total.

$$I_c = Ql\beta c/2\pi r_0 \qquad (5)$$

where Q – total circulated charge, c – speed of sound, r_0 – radius beam orbit. Than

$$\Delta U = (I_1 - I_2)R = RQl\beta ckp\Delta rB(E)/2\pi r_0 m \qquad (6)$$

$$\Sigma U = (I_1 + I_2)R = RQl\beta ckp\Delta rB(E)/\pi r_0 m \qquad (7)$$

As we can see from (6) and (7) ΔU/ΣU does not depend on Q or B(E).

IV. OPTICAL METHODS

The possibility of applying optical methods exist because of 2 reasons:

- Synchrtron emission;
- Glowing of residual gas.

Synchrotron emission was studied particular in 1950s as a probable disturbance for accelerators work[4]. Now it is applied in many spheres of technic, where strong monochromatic gamma-rays are requiered, for example in medicine to cure cancer.

Direct method of measuring then number of accelerated electrons N is based on measuring the absolute intensity of electromagnetic radiation. Estimation of N can be made by measures of the whole specter. To do this nonselective detector of energy i.e. absolute black body has to be applied.

This method is inconvenient for many reasons. First of all, absolute black body is a model and it is impossible to provide full absorption of the whole specter, especially in areas of wide ultraviolet and soft x-ray, that leads to hardly estimating inaccuracy. Another problem is that detector has to be placed direct in acceleration camera, because it is impossible to eject the whole specter through the glass or plastic. Strong control magnetic field will affect the results of measurements. To estimate the number of electrons i.e. current the method, based of absolute measurement of intensity in small area of wavelength λ is applied. Δλ is typically chosen in visible part of specter in area of the biggest sensibility of the installation. If Δλ is narrow enough, than N can be defined as

$$N = P_\lambda / P_\lambda(\Delta\lambda) \qquad (8)$$

where $P_\lambda(\lambda)$ – capability of emission of1 electron along unit interval of wavelenght; P_λ – experimentally estimated capability of all the electrons.

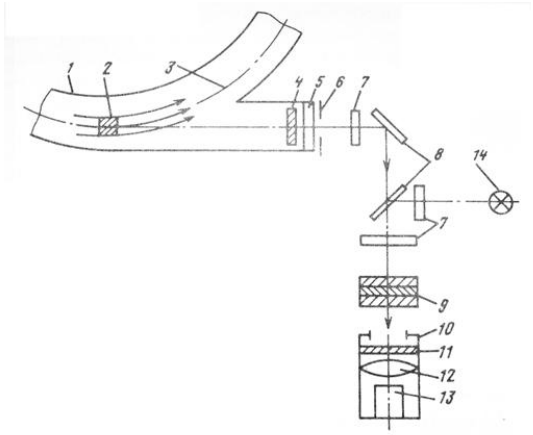


Fig. 3. Scheme of number of electrons measures

Light emission throug the window 5 is ejected from vacuum camera 1. Than emission through the mirror 8 and lens 12 comes to the electron multiplier phototube 13, which is placed in cover 10. Diaphragm 6 is required to change depth of focus and avoid defocussing. In intervals between measurements of light given by cyllindrical finite volume 2 window 5 is closed by curtain 4. Also the beams of electromagnetic radiation comes through the polarisation unit 7. Than the number N can be defined as:

$$N = \left(I_e - I_{syn}\right)\left(\frac{\rho_8}{\rho`_8}\right)\left(\frac{\tau_e}{\tau_{syn}}\right)\left(1/\tau_f\right) \qquad (9)$$

where I_e – intensity of emission, which comes to electron multiplier phototube , ρ_8 and $\rho`_8$ – coefficients of reflection of the mirror 8 for horizontal compotents of line polarized light, τ_e and τ_{syn} are coefficients of transparency for synchrotpon emission and lamp light, τ_f – coefficient of transparency for neutral filters, I_{syn} - estimated intensity of 1 electron emission.

Optical methods are very effective at studying fast moving processes in electrons accelerators. The presence of electromagnetic emission of electrons, strong enough in visible part of specter makes it possible to study density diversity in cross-section of a beam during the acceleration process using different methods:

- high-speed camera shooting,
- electro-optical transformation,
- mechanical scan and
- space and time transformation.

Optical methods are also applicable, when particles doesn`t emit themselves, but cause glowing of residual gas. We`ll consider photographic method more particular.

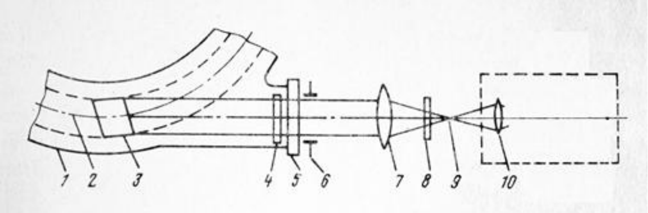


Fig. 2. Optical scheme of installation for high-speed shooting.

The high-speed photo shooting was applied as a method of studying synchrotron emission in 1948. Authors made shooting at speed 3000 shots/sec and showed possibility of deriving data. At present high-speed shooting is widely used to get information about beams profile and fluctuations of particles.

Principle of method is easy:

Electromagnetic rays emitted by accelerated electrons goes out of acceleration camera 1 through the glass of optical window 5 tangentially to beam 2. Using the condenser 7 light comes to the dot 9 on main optical axis, making transitory image. This image is taken by camera with lens 10. To shoot monochromatic light, filter 8 should be placed. Diaphragm 6 makes it possible to change depth of field. So that if the diaphragm is close enough the picture of a small cylindrical volume 3 will be taken.

Pictures of a bunch taken by high-speed camera are images of electrons diversity in a cross section average in time of exposition of one photograph. The diversity is explained by the facts, that beam is not collimated in acceleration camera and that during the exposition tome electrons can have lots of fluctuations. The taken picture will be reprocessed later on.

The highest resolution available depends on accelerator type and properties of synchrotron radiation. For single electron, that gyrates along an orbit with radius R_0 the angle of emission ν can be defined as

$$\nu = 2\sqrt[3]{\frac{3\lambda}{4\pi R_0}} = 1{,}24\sqrt[3]{\frac{\lambda}{R_0}} \qquad (10)$$

If there`s no chromatic aberrations in optical system on the output resolution will be characterized by value

$$2\sigma = \frac{\lambda}{\pi\nu} = 0{,}25\sqrt[3]{\lambda^2/R_0} \qquad (11)$$

Expression 9 defines marginally recognizable size in both radial and axial directions. However, the finite size of observed space applies additional restrictions on radial recognizable size. For optimal angular size

$$\nu'_{\mathrm{opt}} = 0{,}15\sqrt[3]{\lambda^2 \mathrm{R}_0} \tag{12}$$

of the diaphragm in plane of orbit

$$2\sigma_{rad} = 2\sqrt{2\sigma} \tag{13}$$

This results do not take into account the defocusing, which also appears because of finite size of observed zone. However the estimation of this factor showed, that effect of defocusing is negligible even when the size of input lens is big.

Identifying ν/ν` as k, define breaking azimuth resolution as

$$2\sigma_{az} = R_0\nu(1+k) = 1{,}25(1+k)\sqrt[3]{{R_0}^2\lambda} \tag{14}$$

For optimal value ν`:

$$2\sigma_{ax} = 0{,}25\sqrt[3]{\lambda^2/R_0} \tag{15}$$

$$2\sigma_{rad} = 0{,}35\sqrt[3]{\lambda^2/R_0} \tag{16}$$

$$2\sigma_{az} = 1{,}4\sqrt[3]{\lambda \quad /{R_0}^2} \tag{17}$$

V. CONCLUSION

Ionization and optical methods were considered to be the most convenient and efficient to be applied on betatrons. They both are transparent i.e. do not change the state and properties of electronic beam. Further research will be made to provide the biggest possible sensibility so that methods will be applicable not only for high-current betatrons, but for small mobile installations.

1. Moskalyov V.A., Sergeev G.I. // Measurements of parameters of charged particles beams, Moscow 1991, P.240
2. Moskalyov V.A. // Betatrons, Moskow, 1981
3. Sergeev G.I. // Measurements of electronic beam parameters in betatron applying ionization method.
4. Dressel R.W. // Phys. Rev. 144.1.1996. p 332
5. Elder F.R., Lanmuir R.V., Pollok H.C. // Phys. Rev. 1948. V. 74. N1. P.52-56
6. J.D. Lawson // The physics of charged-particle beams
7. Peter T. Kirstein, Gordon S. Kino, William E. Waters // Space – charge flow
8. L. Ondris,D. Krushinsky,E. Frolov,V. Gorchenko,A. Kirichenko, A. Kovalenko, B. Sveshnikov,V. Volkov // Charged Particle Beams Space Parameters measuring system for low intensity levels

9 B. Gaiduchenko, V. M. Rybin // Measurement of differential beam parameters of charged particle beams

10 Galatis, Andreas A. // Beam parameter estimation for beam parameters measurements

METHODOLOGY OF NUCLEAR RADIATION DOSIMETRY BASED ON POLYMER FILMS

I.A. Miloichikova
Scientific Supervisor: PhD, Senior teacher A.R. Wagner
Linguistic Advisor: Associate Professor R.I. Tolbanova
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: ircha1988@mail.ru

Abstract

In the research the possibility of using the GafChromic EBT film to define the parameters of the accelerated electron beam in the betatron, such as the spatial distribution of dose fields, necessary for planning intraoperative radiation therapy, is considered.

In the introduction the actuality of the research is discussed.

In the main part the bases of the intraoperative radiation therapy, the main parameters of radiochromic films are described. General principles of the GafChromic EBT film calibration are given. The calibration procedure of the GafChromic EBT film and the results of calibration on the X-ray beam, monochromatic gamma-radiation of radioactive Co^{60} *tracer and bremsstrahlung radiation electron accelerator of 6 MeV energy are demonstrated. The results of measuring the electron beam distribution in a betatron accelerator chamber are presented.*

In conclusion the main results are given. The prospects of research are considered as well.

Keywords: intraoperative radiation therapy, radiochromic film, optical density, calibration procedure, field distribution of irradiation.

Research field: nuclear physics, material-radiation interaction, dosimetry.

Related sciences: medical physics.

I. INTRODUCTION

Modern advances in the development of radiotherapy methods obtained in experimental and clinical radiobiology and oncology have increased the role and efficiency of radiotherapy. With this in mind, it is necessary to create a modern technical base at research institutions and clinics.

In carrying out diagnosis and radiation therapy special attention is given to the control of the parameters of ionizing radiation source. Therefore, today medical physicists focus on the creation of new methodologies, techniques and devices to control these parameters with the necessary accuracy.

The GafChromic EBT film has a higher sensitivity as compared to radiographic films and allows clinically relevant doses to be accurately determined, measures absolute doses with a low spectral sensitivity, provides an excellent image resolution, does not require chemical processing, and can be handled and prepared at room light. For these reasons, the GafChromic EBT film seems to be a promising candidate for high-quality dosimetry.

Research objective is development of nuclear radiation beam dosimetry method with the help of the GafChromic EBT film.

Research tasks:

- calibration of the film;

- approval of the film on the electron beam.

II. INTRAOPERATIVE RADIATION THERAPY

The technique of intraoperative radiotherapy (IORT) allows carrying out direct visualization of the region to be irradiated after the removal of the lesion as well as to protect healthy tissue. The IORT technique consists in the delivering of a single high dose of radiation to the target volume by shielding the healthy tissue, during the operation. [1]

Intraoperative radiation therapy can deliver an extra dose directly to the surgically exposed unresectable tumour or to the turnoutbed. The combination of IORT and external beam irradiation can increase the dose absorbed by the target area while sparing the surrounding normal tissue. [2]

For produce better treatment results in patients it is necessary to obtain the main radiation characteristics and three-dimensional dose information for each treatment plan. Consider the availability of the GafChromic EBT film for this purpose.

III. FILM DOSIMETRY

III.I. The GafChromic EBT film

The GafChromic EBT is a new model of sensitive radiochromic films.

The main advantage of the GafChromic EBT film:

- sensitivity to doses ranging from 0.1 Gy to 8 Gy;
- the energy of detected radiation is from 15 keV to 15 MeV;
- the film is suitable for use in water phantoms. [3, 4].

The EBT film consists of two active layers (total thickness 34 μm) separated by a surface layer (6 μm) coated onto a polyester base (194 μm).

The material composition of the film is 42,3%C, 39,7%H, 16,2%O, 1,1%N, 0,3%Li and 0,3%Cl. The effective atomic number Z_{eff} of the film material ranges from 6,0 to 7,0 that is close to the Z_{eff} of biological tissues (7,64 for muscle, 6,46 for fat), therefore providing an important advantage when performing measurements in water or water-alike phantoms. [5, 6]

III.II. Image formation of the GafChromic EBT films

A double-substituted diacetylene, organized into crystals, is used for film dosimeters. Upon exposure to irradiation, solid-state polymerization of the monomers occurs, resulting in the film adopting a progressively blue color.

The dose that films have received can be correlated to their change in optical density (*OD*).

Prior to irradiation, the dosimetric film presents an *OD* called fog density, OD_{fog} depending on its material and initial colour. The *OD* of a film originating from radiation exposure is defined as the net optical density OD_{net} : $OD_{net} = OD - OD_{fog}$. [5]

Digital image of the film is a data set consisting of the values of color intensity. The red color channel is the most suitable for dosimetric purposes.

The EBT model presents a versatile high-quality dosimetric tool appropriate for the dose range of interest in intraoperative radiation therapy.

IV. CALIBRATION PHASE

IV.I. The calibration procedure of the GafChromic EBT film

Irradiation of films was produced by the X-ray generator and by the gamma therapy unit «Teratron – Equinox».

Calibration on the X-ray beam is performed within the range from 0,1 Gy to 3 Gy. The dose received by the film during irradiation was fixed by the therapeutic dosimeter UNIDOS E [7] complete with a soft X-ray ionization chamber (volume 0,02 cm^3) № 23 342. [8]

Calibration on the gamma-ray beam is performed within the range from 0,57 Gy to 8 Gy. The dose received by the film during irradiation was fixed by the therapeutic dosimeter UNIDOS E [7] complete with a waterproof PTW farmer ionization chamber (volume 0,6 cm^3) № 30013. [9]

Picture 1 shows the calibration curve, the equation of the regression line expressed by the exponent.

Accuracy of measurement results is presented in picture 1 and the standard deviation is: horizontal 2% (the error of the scanner), vertical 5% (ion chamber).

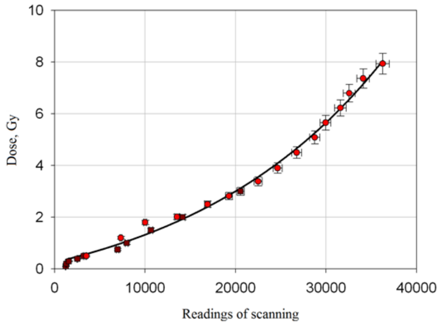


Fig. 1. The calibration curve of the GafChromic EBT film: ■ *- the experimental results were obtained on the X-ray beam;* ● *- the experimental results were obtained on the gamma-ray beam.*

The measurements of bremsstrahlung were performed on the microtron. Picture 2 shows a plot of the absorbed dose rate of bremsstrahlung at the distance. [10]

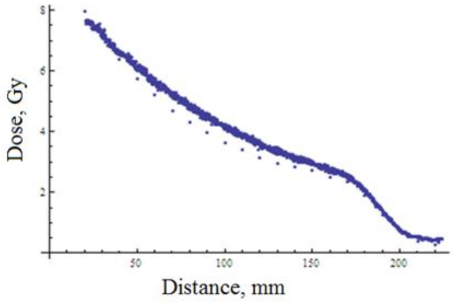


Fig. 2. Field distribution of the microtron bremsstrahlung:

● ● ● *- the experimental results were obtained by the therapeutic dosimeter UNIDOS E;*

▬ *- the experimental results were obtained by the GafChromic EBT film.*

The measurements performed on the microtron show that the qualitative results obtained with the help of the GafChromic EBT film and the therapeutic dosimeter UNIDOS E are in good agreement (better than 5%).

IV.II. MEASUREMENT OF THE ELECTRON BEAM DISTRIBUTION IN A BETATRON ACCELERATOR CHAMBER

Parameters of exposure:

- The exposure time 1 sec, 2 sec, 10 sec.
- Mode of operation of the betatron: without the reset of accelerated electrons on the target of generating bremsstrahlung, with the reset of accelerated electrons on the target of generating bremsstrahlung.

The films irradiated at the different parameters and the 3D distribution of the electron beam in a betatron accelerator chamber are shown in pictures 3 and 4.

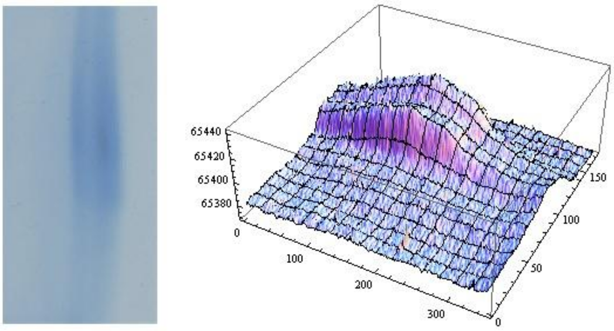


Fig. 3. An irradiated film (left) and 3D distribution of the electron beam in a betatron accelerator chamber (right): X-axis, Y-axis - the size of the film (mm); Z-axis - absorbed dose (Gy).

Parameters of exposure: the exposure time - 2 sec; mode of operation of the betatron - with the reset of accelerated electrons on the target of generating bremsstrahlung.

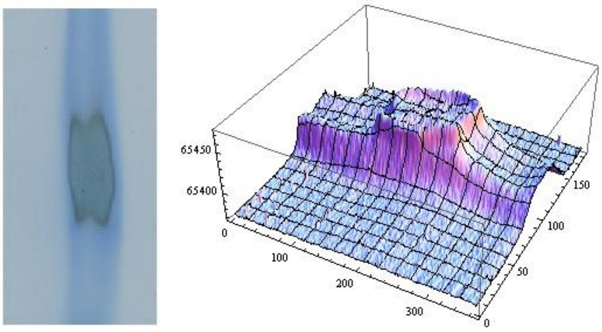


Fig .4. An irradiated film (left) and 3D distribution of the electron beam in a betatron accelerator chamber X-axis, Y-axis - the size of the film (mm); Z-axis - absorbed dose (Gy).

Parameters of exposure: the exposure time - 2 sec; mode of operation of the betatron - without the reset of accelerated electrons on the target of generating bremsstrahlung.

According to the fashioned 3D distributions of the electron beam in a betatron accelerator chamber can be concluded that this method is highly informative for providing experimental data which were obtained by the help of scanning device witch digitized the films. And the film illustrates the distribution of the electron beam in a betatron accelerator chamber to the best advantage. In this case, the prospect of the research is calibration of the GafChromic EBT film at the betatron extracted beam.

V. CONCLUSION

The results of the research suggest that the measurement technique of the radiation dose distribution of electron beam with the help of the GafChromic EBT film allows to meet the requirements for X-ray diagnostics and radiotherapy.

The prospects of the research are calibration of the GafChromic EBT film on the betatron extracted beam and on the photon beam.

Currently, there are some technological problems aligned with calibration on the betatron extracted beam:

- there is no stable beam extracted from the betatron at present;
- it is possible to calibrate at other electron accelerators. But this calibration can result in errors because of different electron energies and, consequently the cross sections of accelerated electrons interacting with the film are different as well. At this moment there are no works that would confirm or refute the linear / nonlinear dependence of the optical density change of the film by the energy of accelerated electrons, which are also invited to explore.

1. Lamanna E., Gallo A., Russo F., Brancaccio R., Soriani A., Strigari L. Intra-Operative Radiotherapy with Electron Beam, from http://cdn.intechopen.com/pdfs/34246/InTech-Intra_operative_radiotherapy_with_electron_beam.pdf
2. Matsutani M., Nakamura O., Nagashima T., Asai A., Fujimaki T., Tanaka H., Nakamura M., Ueki K., Tanaka Y., & Matsuda T. (1994) Intra-operative radiation therapy for malignant brain turnouts: rationale, method, and treatment results of cerebral glioblastomas, from http://www.springerlink.com/content/w2160l08v7020000/
3. Muench P.J, Meigooni A.S., Nath R., & McLaughlin W.L. Photon energy dependence of the sensitivity of radiochromic film and comparison with silver halide film and LiF TLDs used for brachytherapy dosimetry. Medical Physics, 1991 – 18 – 4 –P. 769–775.
4. Schumer W., Fernando W., Carolan M., Wong T., Wallace S., Quong G., & Geso M. Verification of brachytherapy dosimetry with radiochromic film. Medical Dosimetry, 1999 – 24 – 3 – P. 197–203.
5. GafChromic EBT film (2007, August), from http://online1.ispcorp.com/_layouts/Gafchromic/content/products/ebt/pdfs/EBTwhitepaper.pdf
6. Fuss M., Sturtewagen E., De Wagterand C., Georg D. Dosimetric characterization of GafChromic EBT film and its implication on film dosimetry quality assurance. Phys. Med. Biol.- 2007 - 52-P. 4211–4225.
7. UNIDOS E Universal Dosemeter, from http://www.ptw.de/unidos_e_dosemeter_ad0.html
8. Soft X-Ray Ionization Chambers 34013, 23342, 23344, from http://www.ptw.de/soft_x-ray_chambers0.html?&cId=7049
9. Waterproof PTW Farmer® Chamber, from http://www.ptw.de/waterproof_farmer_chamber0.html?&cId=7049
10. А.Р. Вагнер, Е.С. Куликова, Ю.А. Попов, Методика диагностики источников излучения с помощью пленочных дозиметров. Известия высших учебных заведений – Физика – 2010

CALCULATION OF CHARACTERISTICS OF RADIO-FREQUENCY FLARE PLASMATRON

I.A. Miskun
Scientific Supervisor: PhD. Associate Professor, Yu.Yu. Lutsenko
Linguistic Advisor: Teacher S.S. Budkova
Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050
E-mail: ivanmiskun@gmail.com

Abstract

This article provides an example of radio-frequency flare plasmatrons calculation. It focuses on determination formulas for the power of the Joule loss, the power, dissipating in the discharge channel of flare plasmatron, the wave resistance of a plasmatron. Moreover, some important conclusions of the optimal conditions of radio-frequency flare plasmatrons operation were made. The calculations were made for the kind of plasmatron that uses a metal vessel as a load-carrying part of the construction. This work was made by taking into account the presence of the reflected electromagnetic wave in a high-frequency flare discharge channel. The results of this work can be used for projecting of industrial plasmatrons, for subsequent works, for optimization and determination of flare plasmatrons characteristic.

I. INTRODUCTION

A high-frequency flare discharge (HFFD), burning under the atmospheric pressure, can be used in practice first of all as a source of dense plasma jets. For this purpose there have been made a number of constructions of radio-frequency (RF) flare plasmatrons with rather high efficiency and great resource of work.

One little requirement to the construction of RF flare plasmatron is its mechanical strength. Therefore, the majority of plasmatrons have a metal vessel, which is used as a load-carrying part of the construction. Sometimes, the vessel of the plasmatron is used as a discharge chamber.

In this case the plasmatron is a metal chamber in the form of cylinder, inside of which the central electrode is installed (Fig.1) [1].

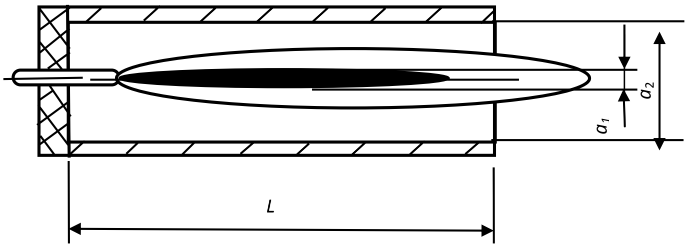


Fig.1.Scheme of flare plasmatron

In our research we shall calculate some characteristics of the plasmatron taking into account the presence of the reflected electromagnetic wave in the HFFD channel.

II. METHODS

To simplify the analysis, we shall assume that the length of the current-carrying part of the discharge coincides with the length of the discharge chamber of the plasmatron. In this case we believe that the reflection of the current wave at the end of the plasmatron is of cophased character.[2]

We shall notice that the cylindrical metal chamber, which is placed in alignment with the channel of the burning discharge, is a coaxial line, where the inner conductor is a discharge channel, and the outer conductor is a discharge chamber of the plasmatron.

Spatial field distribution for the coaxial line with the inner conductor of the radius a_1 and the outer cylinder of the radius a_2, and also taking into account the reflection at the end of the line will be as follows [3]:

$$E_{1r} = \frac{\omega\mu_1 h}{k_1^2} H_{1\varphi} \qquad E_{1z} = \frac{\omega\mu_1\lambda_1}{k_1^2} \frac{J_0(\lambda_1 r)}{J_1(\lambda_1 r)} H_{1\varphi} \qquad H_{1\varphi} = \frac{k_1^2}{2\pi a_1 \omega\mu_1\sigma_1} I \cdot \frac{J_1(\lambda_1 r)}{J_1(\lambda_1 a_1)}$$

$$E_{2r} = \frac{\omega\mu_2 h}{k_2^2} H_{2\varphi} \qquad E_{2z} = -\frac{\omega\mu_2 h}{jk_2^2} \frac{AJ_0(\lambda_2 r) + BN_0(\lambda_2 r)}{AJ_1(\lambda_2 r) + BN_1(\lambda_2 r)} H_{2\varphi} \qquad H_{2\varphi} = -\frac{jk_2^2}{\omega\mu_2\lambda_2}\left[AJ_1(\lambda_2 r) + BN_1(\lambda_2 r)\right] ch(L-z)\cdot h$$

$$E_{3r} = \frac{\omega\mu_3 h}{k_3^2} H_{3\varphi} \cdot \frac{1}{k_3^2} \cdot \frac{H_0^{(1)}(\lambda_3 r)}{H_1^{(1)}(\lambda_2 r)} \qquad E_{3z} = -\frac{\omega\mu_3\lambda_3}{k_3^2} H_{3\varphi} \qquad H_{3\varphi} = -\frac{jk_3^2}{\omega\mu_3\lambda_3} CH_1^{(1)}(\lambda_3 r) ch(L-z)\cdot h$$

Here E_{ir}, E_{iz}, $H_{i\varphi}$ are the radial and the longitudinal components of electric field and the axial component of magnetic field, respectively (indexes i = 1, 2, 3 refer to the range $r < a_1$, $a_1 < r < a_2$, $r > a_2$); ω is the angular frequency of the field; σ_i is the conductivity in these ranges; $J_0(\lambda_i r)$, $N_0(\lambda_i r)$, $N_0^{(1)}(\lambda_i r)$, $J_1(\lambda_i r)$, $N_1(\lambda_i r)$, $N_1^{(1)}(\lambda_i r)$ are zero- and first-order Bessel and Neumann functions and Hankel functions of the first kind.

Next step of our work was to determine the Joule loss in the walls of the chamber and therefore their contribution in the total energy balance of the plasmatron.

We can see clearly from above expressions that $|E_{r3}| \ll |E_{z3}|$. In this case the Joule loss in the walls of the discharge chamber of the plasmatron is determined in the following way:

$$W_{p.k.} = \int_V \sigma |E_{z3}|^2 dV = 2\pi \int_0^L dz \int_{a_3}^{a_3+\Delta} \sigma |E_{z3}|^2 rdr$$

where Δ is the thickness of the wall of discharge chamber.[4]

After some operations, we obtain the following expression for the Joule loss in the walls of the discharge chamber:

$$W_{p.k.} \approx 2\sqrt{2}(\sigma_3\mu_3\omega)^{3/2}\sigma_3 a_2 \frac{I_0^2}{(2\pi a_1\sigma_1)^2} \frac{(\sigma_1\mu_1\omega)^3}{|h|^2} \times$$

$$\times\left[1-e^{-\frac{2}{\sqrt{2}}\left(\sigma_3\mu_3\omega\right)^{1/2}\cdot\Delta}\right]\times\left[\frac{sh2\beta L}{2\beta}+\frac{1}{4\alpha}\sin\alpha L\cos\alpha L-\frac{L}{2}\right]$$

The power of the Joule loss in the discharge is determined in the following way:

$$W_p=2\pi\int_0^L dz\int_0^{a_1}\sigma_1\left|E_{z1}\right|^2 rdr\approx\frac{I_0^2}{\pi a_1^2\sigma_1}\int_0^L\left(ch2\beta z-\sin^2\alpha z\right)dz$$

After summarizing all above-mentioned we determine the relation of the Joule loss in the wall of the discharge chamber to the power, dissipating in the discharge channel:

$$\frac{W_{p.k.}}{W_p}\approx\frac{\sqrt{2}}{4\sigma_1}\sigma_3 a_2\left(\sigma_3\mu_3\omega\right)^{-3/2}\frac{\left(\sigma_1\mu_0\omega\right)^3}{\left|h\right|^2}\left[1-e^{-\frac{2}{\sqrt{2}}\left(\sigma_3\mu_3\omega\right)^{1/2}\cdot\Delta}\right]$$

We shall notice that the value of W_{pk}/W_p increases greatly at the increase of the conductivity of the discharge channel and the frequency of electromagnetic field. Due to this, the Joule loss in the discharge chamber becomes comparable to the discharge power if the conductivity of the discharge channel corresponds to the temperature in the discharge channel T > (4,5…5) · 10^3 К and the frequency of electromagnetic field is in the UHF or the microwave band.

Now we shall determine the wave resistance of a radio-frequency flare plasmatron. The wave resistance of the plasmatron will be determined by the ratio of the voltage between the wall of the discharge chamber and the discharge channel to the total current in the discharge:

$$\dot{z}_в=\frac{\dot{U}}{\dot{I}}\approx\left[\frac{\beta a_2^2}{4\pi\omega\sigma_1}+\frac{\alpha}{2\pi\omega\varepsilon_0}\ln\frac{a_2}{a_1}\right]-j\left[\frac{a_2^2\alpha}{4\pi a_1^2\sigma_1}-\frac{\beta}{2\pi\omega\varepsilon_0}\ln\frac{a_2}{a_1}\right]$$

The curve of dependence of the reactance on the frequency of electromagnetic field of the laboratory flare plasmatron in power 1-1,5 kW is shown in Fig. 2.

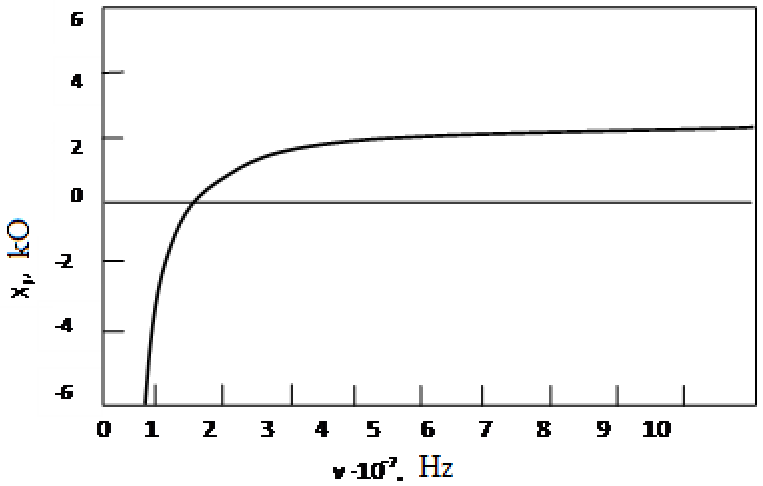


Fig.2. Dependence of the reactance on the frequency of electromagnetic field

III. RESULTS

As Fig.2 shows, the value of the reactance module does not exceed 2 kO at frequencies more than 12 MHz. We shall notice that for the HFFD burning this frequency is close to a threshold frequency. At the same time, the frequency is 22 MHz, which corresponds to the optimal plasmatron operation, is also comparatively close to the threshold frequency, which proves the data of previous works on greater efficiency of the HFFD burning at the frequencies close to the threshold one.

These results are very important for future researches. In our work we obtained main characteristics of the plasmatron. That's why different applications of radio-frequency (RF) flare plasmatrons will be of high efficiency. For example, one of the well-known applications is eco-friendly utilization of oil sludge. With the help of results of our work we can optimize not only this process but many others.

IV. CONCLUSION

Let's take a brief look at the results of our research work. In present research work the formulas for the power of the Joule loss and the power, dissipating in the discharge channel of flare plasmatron were obtained, the fact that the Joule loss in the discharge chamber is not significant was found and the wave resistance of a plasmatron was determined. After that the curve of dependence of the reactance on the frequency of electromagnetic field was built. It helps to make some important conclusions about optimal conditions of work of radio-frequency flare plasmatrons. All objectives were reached and the results of our work are adequate for subsequent application.

1. Truneček V. Unipolar high frequency torch discharges: Folia Fac. Sci. Nat. Univer. Purkyn. Brne. Vol. 12. - p. 3-13, 1971.
2. Janča J. "Transmission and energy exchange in unipolar h.f. discharges", Folia prirodoved. Fac. U.J.E.P.Brne, Bd. 9, №10, ss. 129-142, 1968
3. Nowakowska H., Zakrzewski Z., Moisan M. Propagation characteristics of electromagnetic waves along a dense plasma filament: Journal of Physics D: Applied Physics. Vol. 34, pp. 1474-1478, 2001.
4. Naidis G.V. On propagation characteristics of electromagnetic waves along a plasma filament: Journal of Physics D: Applied Physics, vol. 34, p. L103-L104, 2001.

5. Benilov M.S., Naidis G.V. Simulation of discharges in atmospheric-pressure air sustained by traveling electromagnetic waves: IEEE Transactions on Plasma Science. Vol. 31, no. 4, p. 488-494, 2003.
6. Tikhomirov I. A., Tikhomirov V. V. The Equipment and Methods of Researches of The high-frequency Discharge Plasmas, Tomsk, 1976.
7. Khal'yaste A.Ya. Proceedings of the 4th All-Union Conference on Physics of Gas Discharge, Makhachkala, 1988.
8. Kachanov A. V. Proceedings of the 8th All-Union Conference on Generators of Low-Temperature Plasmas, Novosibirsk, 1980.
9. Cobine J.D., Wilbur D.A. The electronic torch and related high frequency phenomena: Journal of Applied Physics, vol. 22, no. 6, 1951
10. Farský V. The power characteristic of a torch discharge and its dependence on electrode geometry: Czechoslovak Journal of Physics, vol. B17, 1967.

DEPOSITION THIN FILMS AL_2O_3 AND TIO_2 WITH DUAL MAGNETRON SPUTTERING SYSTEM

D.V. Sidelev

Scientific Supervisor: Head of laboratory, Y.N. Yurjev

Linguistic Advisor: Senior teacher, O.M. Stepanova

Tomsk Polytechnic University, Russia, Tomsk, Lenin str., 30, 634050

E-mail: Dimas167@tpu.ru

Abstract

The article is about plasma technologies. A review of problems of deposition process of dual magnetron sputtering is given. The special parameters such as current–voltage characteristics, hysteresis phenomena and deposition rate are discussed. As the main result, the optimal characteristics of deposition thin films are determined.

Keywords*: dual magnetron sputtering; deposition; thin films; current-voltage characteristic; hysteresis; deposition rate.*

I. INTRODUCTION

At present, Al_2O_3 and TiO_2 coatings are widely used in optical, semiconductor and medical branches of industry. Modern requirements to quality of these coatings generate the development and modification of various technologies of getting thin films. The Al_2O_3 and TiO_2 films are deposited using different chemical and physical methods. At the moment, magnetron sputtering system (MSS) is one of the most promising and widely used technologies of deposition. Magnetron sputtering has several advantages: a relatively high purity, a high deposition rate, a high adhesion. In addition, one of the main characteristics of magnetron sputtering is the ability to change and control parameters of the discharge plasma during in the process of deposition. However, magnetron sputtering has some technological problems, when oxide is deposited. The solution of this problem is to use a dual magnetron sputtering system (DMSS) [1,2]. In this regard, the purpose of this work is the development of technology of Al_2O_3 and TiO_2 thin film deposition with DMSS, which provides a high deposition rate, stability and reproducibility of electrical parameters.

For this purpose the following tasks are: to investigate the electrical characteristics of the discharge, hysteresis and to determine the deposition rate depending on the parameters of the system; to analyze the experimental data and to determine the modes of stable deposition of thin oxide films with maximum rates for the given experimental equipment.

II. THE EXPERIMENTAL EQUIPMENT

The deposition Al_2O_3 is occurred in the «PVR–1», TiO_2 – «YASHMA–5». The DMSS is alternately set in both plasma setups. The investigation deposition rate is conducted with the quartz thickness measuring instrument «MICRON–5».

III. THE OPTIMUM OPERATING PARAMETERS OF THE DEPOSITION OF OXIDES OF ALUMINUM AND TITANIUM

The investigation of sputtering modes is important to identify the effective technological characteristics. The most important characteristics of deposition are a current-voltage characteristic, hysteresis and deposition rate. The analysis of these parameters will determine processes in the discharge and identify the most appropriate characteristics of magnetron sputtering for the given conditions [3,4].

III.I. The current–voltage characteristic (CVC)

The current-voltage characteristic is a function of current on voltage discharge, when the gas flow is a constant. The shape of current-voltage characteristic is determined by different processes in discharge, which define properties of the films [5–7]. The experiments are conducted for Al_2O_3 for three cases: the sputtering in pure argon, the sputtering in pure oxygen, the sputtering in the mixture of argon and oxygen (20% – oxygen, 80% – argon at a constant total flow of gas – 40 cm^3/min). The maximum discharge power is limited at 5 kW.

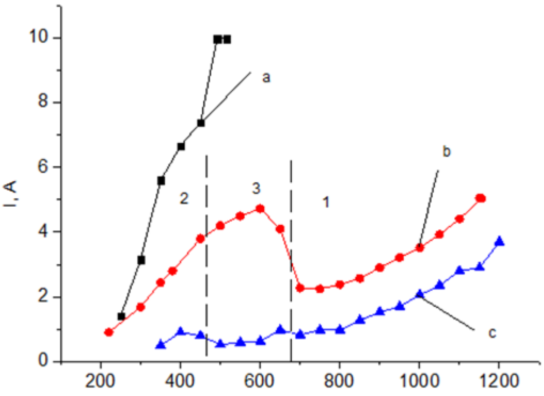


Fig. 1. The CVC of deposition Al in oxygen (a), the gas mixture (b) and argon (c): 1 – the spraying pure metal, 2 – the sputtering oxide, 3 – the transition area.

The current–voltage characteristics in pure oxygen (a) and pure argon (c) have a classic monotonic dependence (fig. 1). However, the curve «a» is shifted to the higher currents. This fact is explained by the sputtering in the mode of oxidated target. The coefficient of electron emission from Al_2O_3 is higher than from Al. So, the current of «a» rises, when level of oxidation of the target increases. The dependence «b» is non-linear. This CVC is N-shaped and it can be divided into three modes of reactive sputtering. The first one is the area of high voltage (700–1200V), where the partial pressure of reactive gas is not enough to oxidation of the target. Thus, the metal sputtering is occurred. The second one is the area of low voltage (200–400V). The target surface mostly covers chemical compound. The discharge power is low, also the deposition rate is low. The transition of target from metal to oxide is described in the third area. The high power discharge and high deposition rate are reached. Also the possibility of changing level of target oxidation allows to control the mode of sputtering. Finally, the third is the optimal area.

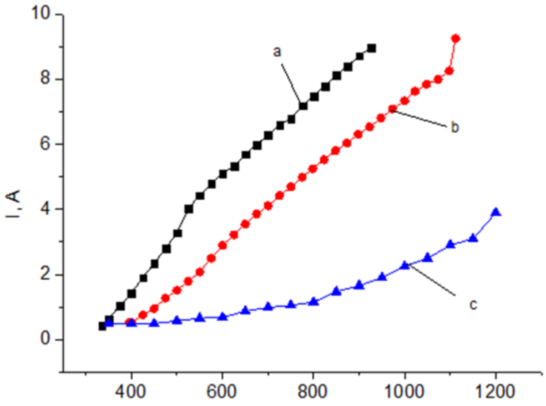


Fig. 2. The CVC of deposition Ti in oxygen (a), the gas mixture (b) and argon (c).

The experiments are conducted for TiO_2 for three cases: the sputtering in pure argon, the sputtering in pure oxygen, the sputtering in the mixture of argon and oxygen (20% – oxygen, 80% – argon at a constant total flow of gas – 52 cm^3/min). The maximum discharge power is limited at 5 kW. All of the obtained current-voltage characteristics have a classic monotonic dependence (fig. 2). However, curves «a» and «b» are shifted to higher currents comparatively with the curve «c». This is explained by the fact that the reactive gas (O_2) is easier to ionize than the inert gas (Ar). Therefore, the degree of ionization rises with increasing partial pressure in the vacuum chamber. So, there is relation between currents in different cases: $I_a > I_b > I_c$. Consequently, the optimal area of deposition of TiO_2 is high currents (7.5–10A).

III.II. The Hysteresis

The stability is one of the main parameter of technological process of thin film deposition. The reactive sputtering has some negative features, one of which is forming the chemical compound on the surfaces of the target, anode, walls of vacuum chamber. As a result, the deposition rate is reduced and the electrical breakdown at the surface occurs. Subsequently, changes in discharge plasma lead to its instability. So, the aim of the investigation of hysteresis is to determine the working parameters, which process of sputtering is stable [8,9].

The experiments of hysteresis phenomena are conducted for Al_2O_3 under the following conditions: the maximum of discharge power is equal to 3 kW, the maximum voltage is 800V, the total constant flow of gas into the chamber is 40 cm^3/min, the range of changing concentration is 0…45%. The view of the hysteresis loops for a planar and the DMSS is significantly different (fig. 3). The square of the hysteresis loop «a» is large. It is explained by the instability of sputtering process. When the modes are transformed (metal to oxide and back), the sharp of the curves changes. These phenomena are observed at 5% and 30% oxygen concentration in the flow. The impossibility of using a planar magnetron for oxide deposition can be explained by the hysteresis.

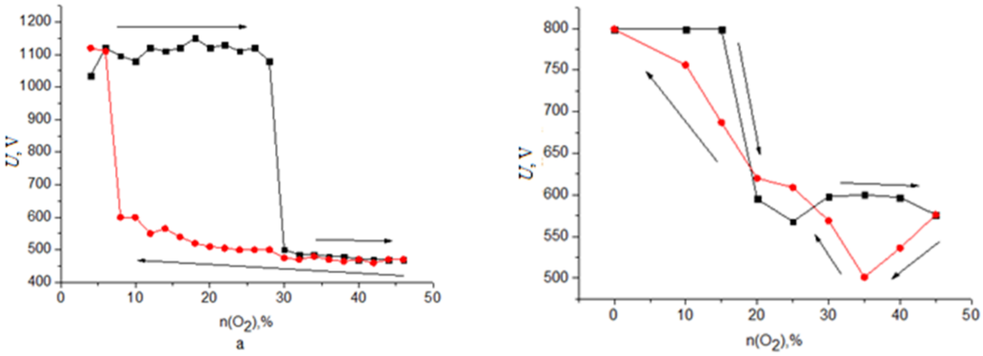


Fig. 3. The hysteresis of voltage in the planar magnetron (a) and the dual magnetron (b) for Al target.

The sputtering by means of the dual magnetron is stable. It is confirmed by the fewer square of the hysteresis loop («b») than for the planar magnetron. The change of mode occurs at equal values of concentration (about 20%). But, in case of the DMSS, the sputtering can be controlled by the composition of the total gas flow. The discharge power has a maximum in the transition area (15–25%).

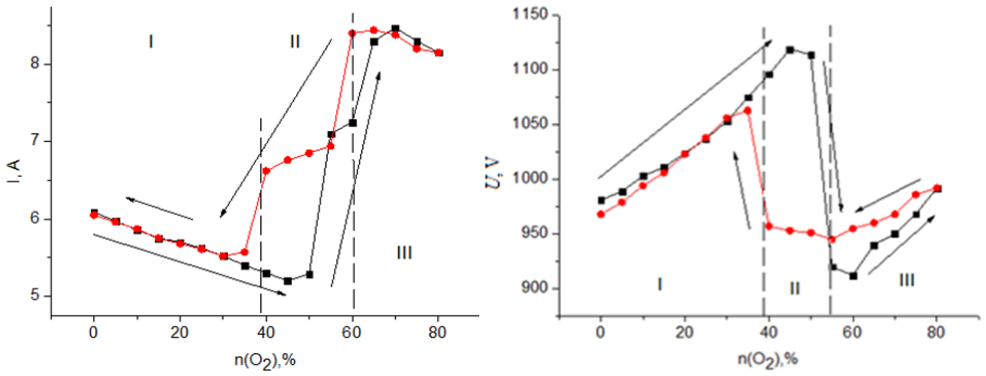


Fig. 4. The hysteresis of current (a) and voltage (b) in reactive magnetron sputtering of Ti target: I - the pure target, II – the transition area, III – the partly oxidized target.

The experiments of hysteresis phenomena are conducted for TiO_2 under the following conditions (fig. 4): the maximum of discharge power is equal to 5 kW, the maximum voltage is 1200V, the total constant flow of gas into the chamber is 52 cm^3/min, the range of changing concentration is 0…80%. The first area is described by the slight oxidation target. The film grows and so absorbs oxygen. It leads to decreasing the partial pressure of oxygen in the vacuum chamber. As a result, the falling current is observed. The change modes of sputtering the target is occurred in the second area (metal to oxide). The area between the second and third is described by the achievement of special operating point, where the deposition is occurred with the excess oxygen. The third area is characterized by rising current and falling voltage of the discharge. It can be interpreted by the complete oxidation of the target (the coefficient of electron emission from TiO_2 is less than from pure Ti). So, the preferable working parameters for sputtering are in 2 and 3 ranges. Totally, the optimal area is the range between the second and third areas, when conditions of sputtering satisfy to the requirements of the stoichiometry and maximum of the power.

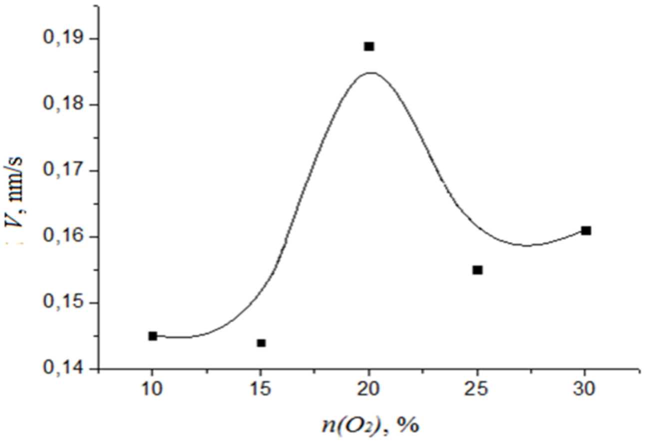


Fig. 5. The dependence of the deposition rate of Al_2O_3 films on the concentration of O_2 in the total gas

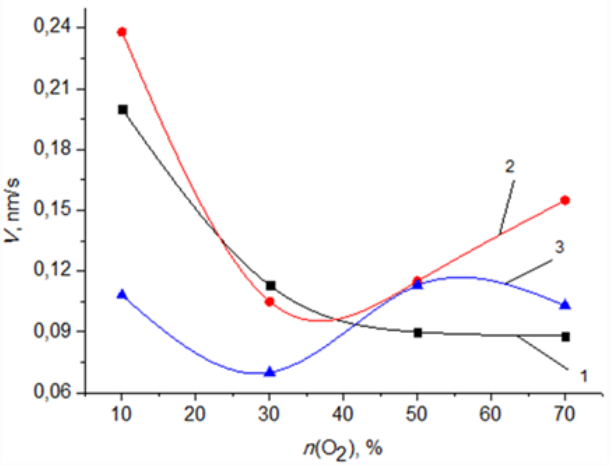


Fig. 6. The dependence of the deposition the rate of TiO_2 films on the concentration of O_2. The total pressure in the vacuum chamber is: 1 – 0.12 Pa, 2 – 0.17 Pa, 3 – 0.3 Pa.

III.III. The Deposition Rate

The maximum deposition rate is required for technological process of deposition of thin films in the given conditions. The discharge power and the composition of gas mixture have a significant impact on the deposition rate. The dependence of the deposition rate on the discharge power is linear [10]. So, the main interest of investigation of the deposition rate concerns the different ratio $n(Ar)/n(O_2)$ in the total gas flow.

The dependence between the concentration of oxygen in the gas mixture and deposition rate of Al_2O_3 is investigated, when oxide aluminum is deposited. Duration of deposition is 5 minutes, the maximum discharge power is 6.5 kW. Modes of deposition are stable. And the total gas flow is a constant. The deposition rate is defined as the ratio of film thickness to the duration of deposition. The dependence between the deposition rate of Al_2O_3 films and the concentration of O_2 in the total gas flow is non-linear (fig. 5). The oxidation of the target occurs at the initial stage (10–15%). So, the gas mixture is consumed to the formation film on the surface of target and the deposition rate falls. Then, the dependence has a maximum, which is described by changing the emission coefficient (it also increases). This maximum is equal to 0.189 nm/s, when the concentration of oxygen is 20%. This result is concluded in section 2.2. The slight fall of the deposition rate is described by the deposition of atoms on the walls of the vacuum chamber. When the oxygen concentration is 30% and more, the deposition rate is almost constant. That is caused by the hysteresis loop for the DMSS (section 2.2, fig. 3).

The dependence of the deposition the rate of TiO_2 films on the concentration of O_2 in the gas mixture is investigated. The technological process of deposition includes 20 passes into magnetron discharge (one pass lasts 20 second). The maximum discharge power is 5 kW. The process of obtain thin films occurs at the stable modes and at constant total gas flow into the chamber (52 cm^3/min). The deposition rate is defined as the dependence of film thickness on the duration of deposition. The dependence between the rate of TiO_2 deposition and the fraction O_2 in the total gas flow is non-linear (fig. 6). The level of target oxidation is small at low concentrations, so the metallic phase is predominantly sputtered. The increasing concentration of oxygen results in decreasing the deposition rate for $n(O_2)$ of 10–40%. This fact is explained by the fewer coefficient of electron emission from the oxidated surface than from a pure target. The minimum of deposition rate is observed in the area of 25–40% concentration reactive gas in the total flow. The increase in deposition rate after 40% concentration oxygen in gas flow is described by rising partial pressure of reactive gas in the vacuum chamber. The rate of deposition of TiO_2 increases, when the fraction O_2 is equal to 45–70%. It is caused by changing mode of sputtering. The partial pressure of oxygen in the vacuum chamber is enough to deposition with excess O_2.

The requirement of experiment is deposition of thin film with the stoichiometry of dioxide. So, the optimal conditions for TiO_2 deposition are observed at 45–70%. This conclusion is agreed with results of section 2.2.

IV. CONCLUSION

The technological parameters for deposition of Al_2O_3 and TiO_2 are identified. These characteristics provide a high deposition rate, stability of electrical parameters and reproducibility of the films. The optimal range of the electrical characteristics is in the transition area of the discharge in case deposition Al_2O_3, where deposition process can be controlled. The dependence current from voltage on the discharge is linear in the case of TiO_2. So the optimal range is the area of high currents (about 7.5-10 A).

The research of hysteresis phenomena has shown that the processes of deposition of Al_2O_3 and TiO_2 are stable. The fluctuations electrical characteristics is caused by the changing modes of deposition (metal to oxide). So, in case of Al_2O_3, sharp of CVC changes, when the concentration of oxygen in flow is equal to 20%. The hysteresis loop has a complicated form for the TiO_2. The changes of deposition parameters of discharge occur, when the oxygen fraction in total gas flow is equal to 45–60%. The stability of deposition oxides of Al and Ti causes the good reproducibility of the process and the quality of the films.

The dependence of deposition rates on the concentration oxygen is non-linear. The maximum of deposition rate of thin films aluminum oxide is 0.189 nm/s, when the proportion oxygen in the flow is equal to 20%. The highest deposition rate of thin films TiO_2 is equal to 0.1–0.155 nm/s, when the concentration O_2 is 45–70%. The thin films have a high stoichiometry in this case.

1. Struempfel J., Beister G., Erbkamm W., Rehn S. (2002). Patent USA №:6,361,668 B1, MPK C23C 14/34.

Spruttering installation with two longitudinally placed magnetrons. Published March 26, 2002.

2. Krivobokov V.P., Sochygov N.S., Soloviev A.A. Plasmennie pokritiya: ychebnoe pocobie, Plasma Coatings: Study book (TPU, Tomsk, 2008), p. 104.
3. Panfilov Y. Nanecenie tonkix plenok. Texnologii v electronnoi promishlennosti. Deposition thin films. Technologies in electronic industry (2007), 3, 76–80.
4. Cheng Y.H. (2004). Influence of O2 flow rate on the structural properties of MgO films deposited by dual magnetron sputtering. Surface and Coating Technology, 177, 784–788.
5. Dyxoplelnikov D. Magnetronnie raspilitelnie cictemi. Magnetron sputtering systems (MGTU, Moscow, 2009), p.54.
6. Danilin B., Sirchin V.Magnetronnie raspilitelnie cictemi. Magnetron sputtering systems (Moscow, 1982), p.73.
7. Yurjeva A.V., Yurjev Y.N., Yanin S.N., Krivobokov V.P. Nanecenie plenok dioxoda titana s pomochiy dyalnogo magnetrona. Izv. Vyzov. Phizika. Deposition films dioxide titanium with dual magnetron. News of high schools. Physics (2007), 9, 483–487.
8. Lou L., MacDonough G., Walde H., Roche R., School R. (1999). Closed loop controlled reactive dual magnetron sputtering. Retrieved December 1, 2011, from http://www.advanced-energy.com.
9. Sproul W.D, Christie D.J and Garter D.C. (2005). Control of reactive sputtering processes. Thin Solid Films, 491, 1–17.
10. Strumpfel J., Beister G., Schulze D. (1997). Reactive dual magnetron sputtering of oxides for large area production of optical multilayer. Presentation on the 40th Annual Technical Conference of the Society of Vacuum Coaters (New Orleans), p. 10.

RESEARCH OF PROCESS OF RECEPTION Nd - CONTAINING ALLOYS BY ELECTROLISIS METHOD OF WATER SOLUTIONS.

Tatarenko A. L., Panasenko A. I., Arsentev M. V.
Research supervisor: PhD, Associate Professor Vodjankin A.J.
Tomsk Polytechnic University, 634050, Russia, Tomsk, Lenin's avenue, 30
E-mail:tarnum@sibmail.com

Abstract

Now the great value is given to manufacturing of high power magnets in which the Nd with Fe alloy is widely used. The basic method of reception metallic Nd is metallothermy and electrolysis of salts liquid. Both methods are carried out at high temperature that leads to the big power inputs. [1]

I. INTRODUCTION

The purpose of the given work is studying of possibility of reception of Nd – Fe alloy by method of electrolysis of water solutions at low temperatures. Introduction of this method in manufacture will allow us considerably lower the product cost price.[2]

II. DETERMINATION OF OPTIMUM OF VOLTAGE VALUE.

For determination of optimum value of voltage the current-voltage characteristic of the solution is received, which is presented in figure 1.

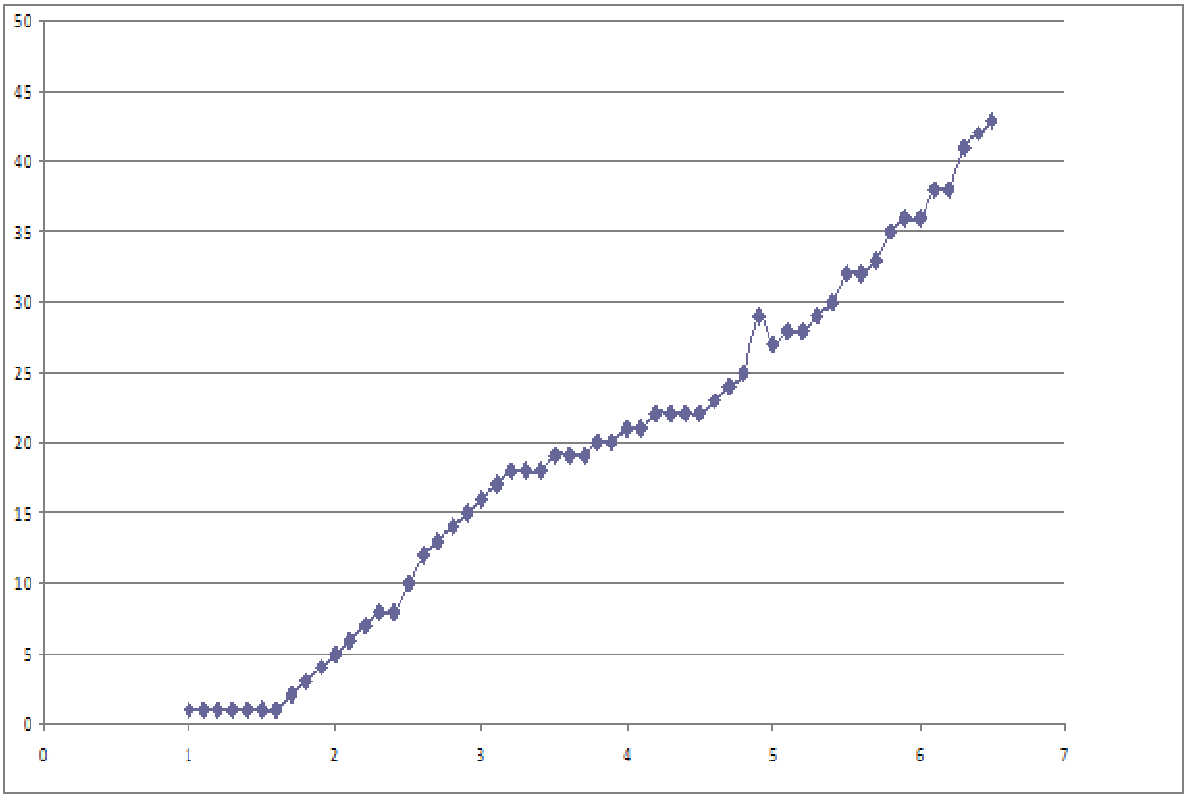


Fig. 1. The current-voltage characteristic of a solution

Given results show that process begins at voltage of 1,7 volts that corresponds to potential of emission of iron. And after voltage increase above 4,5 volt sharp growth of a current strength is observed that is accompanied by emission of hydrogen and output decrease of current. Hence optimum value of voltage for process carrying out makes 4,5 volts.

III. AN ELECTRODE CHOICE.

It is necessary to study influence of cathode material on alloy structure. Results of the conducted researches are showed in table 1.

Material	Graphite	Fe	Al	Zr	Cu
C (Nd, % of weights)	12	25	17	15	13

Table 1. An electrode choice

According to the data resulted in the table follows that the greatest content of Nd has been received by the iron cathode use.

IV. STUDYING OF ELEMENTAL COMPOSITION, BY METHOD OF THE ROENTGEN FLUORESCENT ANALYSIS.

The analysis of an alloy is conducted by RFla method or the purpose of detection of metals relation between Nd and iron. The analysis is conducted of K – series for iron and L - series for neodymium, since K – series of Nd requires analysis carrying out at big energies.[3]

Lines of characteristic radiation for iron and Nd:

$Fe_{k\,\alpha}$ – 6.40 keV,

$Fe_{k\,\alpha}$ – 7.05 keV,

$Nd_{L\,\alpha}$ – 5.24 keV,

$Nd_{L\,\beta}$ – 5.73 keV.

According to results of the analysis the alloy contains 25 % Nd and 75 % of iron.

The spectrum of the received alloy is shown in figure 2.

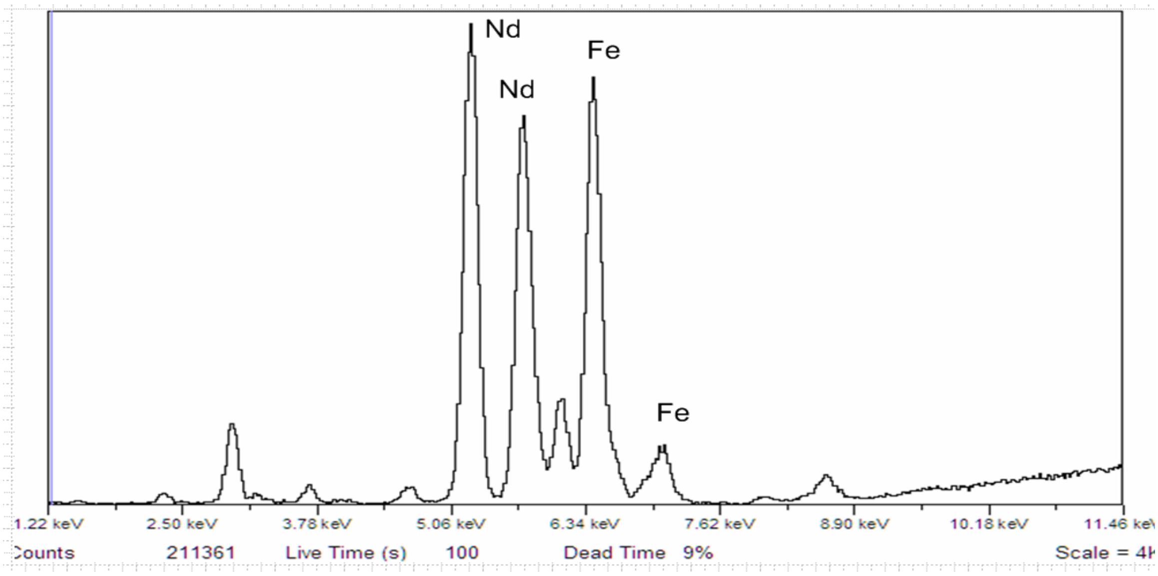


Fig. 2. Roentgen fluorescent alloy spectrum.

The given analysis has allowed to make sure of Nd and Fe in alloy and to give qualitative evaluation of their structure.[4]

Also at studying of phase composition of the alloy, the analysis has shown that the alloy has amorphous structure.

V. THE PROOF OF PRESENCE OF A METAL PHASE.

For the proof of presence of a metal phase a number of experiments on dissolution of a ready product in hydrochloric acid and measurement of volume of hydrogen received at reaction.[5] Experiments are conducted on laboratory installation which is intended for detection of a part of a metallic phase in a product by means of measurement of volume of the emitted gas.[6] The given laboratory installation is shown in figure 3**.**

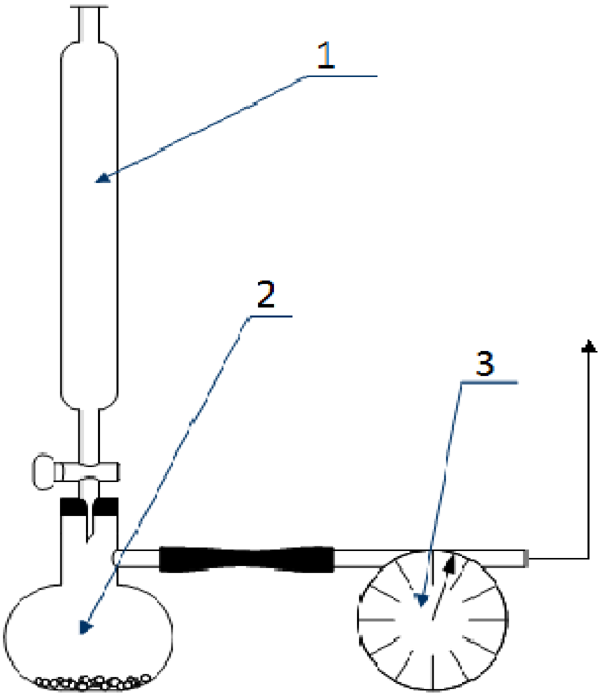


Fig. 3. The scheme of laboratory installation

1 – separating funnel, 2 – Vurz flask, 3 – gas clock.

Results of experiments are presented in table 2.

№	M_{sp} (g)	V_t (ml)	V_p (ml)	C_{met} (%)
1	0,112	67,0	64,0	94,3
2	0,113	67,8	65,0	96,1
3	0,112	67,0	63,0	94,0

Table 2. Alloy dissolution in hydrochloric acid

According to the received results the presence of a metal phase has made from 94 to 96 percent. [7]

VI. PROCESS OF AN ALLOY RECEPTION.

During the work the technological sequence of reception of the alloy, has been offered including the following stages:

1. Dissolution of iron and neodymium oxide, in sulfuric acid.[8]

2. Electrolysis of the received solution (at temperature of 25 degrees of Celsius and pH=4). Electrolyzer represents the device of periodic action, which soldered from vinyl plastic. In it two graphite anodes are used and one cathode made of steel of st. 2 kp. mark.

3. A filtration of the mechanical impurities formed as a result of dissolution of graphite electrodes, with return of a filtrate to a storage capacity.[9]

VII. THE CONCLUSION

The received results allow to judge possibility of reception of alloys, by method of electrolysis of water solutions. Rough economic calculation allows to say that the cost price of a ready product is equal 900 rubles for 1 kg, and the payback period has made less than 2 years.

1. Strashko A.N., Blinov A.E, Tshe of M.V. Hydrometallurgical processing of section wastes magnetic manufacturing.//«Modern technics and technologies CTT 2008»:Tomsk, 2008. – s.120-121.
2. Vyacheslavov P.M. Electrolytic sedimentation of alloys. – L., 1986. – 112 s.
3. Gschneidner, K. A.; Eyring, L. (1978). Handbook on the Physics and Chemistry of Rare Earths. Amsterdam: North Holland
4. Y. Wei et al. "The Effect of Neodymium (Nd3+) on Some Physiological Activities in Oilseed Rape during Calcium (Ca2+) Starvation" 10th International Rapeseed
5. Swain, Frank (March 6, 2009). "How to remove a finger with two super magnets". Seed Media Group LLC. Retrieved 2009-06-28.
6. Charles Bray (2001). Dictionary of glass: materials and techniques. University of Pennsylvania Press. p. 102.
7. "Rare-Earth Metal Long Term Air Exposure Test". Retrieved 2009-08-08.
8. Neodymium Based Ziegler Catalysts - Fundamental Chemistry (Advances in Polymer Science) by Oskar Nuyken (Nov 14, 2006)
9. High-temperature heat contents and entropies of sesquioxides of europium, gadolinium, neodymium, samarium, and yttrium by L. B. Pankratz (Jan 1, 1962)

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ИЗДАТЕЛЬСТВО ТПУ. 634050, г. Томск, пр. Ленина, 30
Тел./факс: 8(3822)56-35-35, www.tpu.ru