STAND AT THE MARIA RESEARCH REACTOR FOR THE STUDIES OF TRANSMUTATION OF FISSION PRODUCTS AND INCINERATION OF MINOR ACTINIDES

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Reduction of the radioactive wastes by transmutation of radioactive long-lived fission products such as ^{99}Tc, ^{129}I and ^{135}Cs and by incineration of minor actinides is a very large field of study requiring significant experimental and financial support.

We propose to replace the accelerator spallation source with the neutron source obtained by converting the thermal neutrons from the horizontal channel of the research reactor MARIA into fast neutrons. Taking into account the large flux of thermal neutrons in the horizontal channel, it is possible to use a fission converter i.e. an arrangement containing ^{235}U placed in the axis of the horizontal beam. Thermal neutrons cause the fission reactions producing fast neutrons needed.

A natural metallic uranium blanket covering several fuel rods of EK-10 type constitutes the converter to be placed on the moderator support (Fig. 1). The space between the EK-10 type fuel rods will be filled with lead which does not moderate the fission fast neutrons. A polyethylene blanket covering the fuel rods has been also considered.

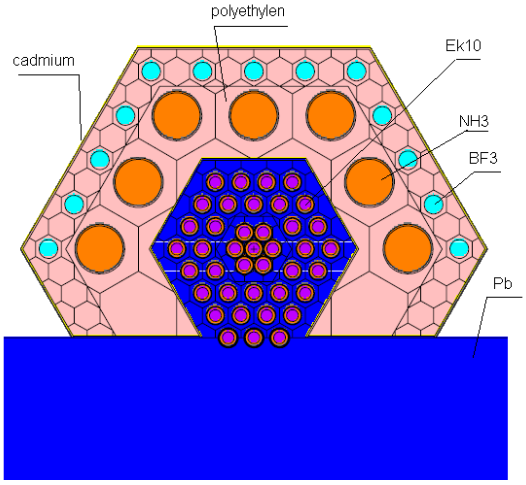

Fig. 1. The simplified converter geometry of the stand.

The converter (Fig. 1) consists of two zones: first the fast neutrons zone consisting of EK-10 type fuel rods placed in the lead block and the second, thermal neutron zone consisting of metallic natural uranium rods (NH3) placed inside the polyethylene block. The natural uranium rods of 30 cm length, 2.72 cm diameter and 2.8735 kg weight are hermetically sealed in an aluminium cladding.

The sub-critical calculations for the stand at the horizontal channel of the MARIA research reactor have been performed using Monte Carlo N-Particle methodology of version MCN PX. The calculations were normalized to one external neutron source. The axial distribution of total neutron flux in the experimental channels of the lead support were calculated (Fig. 2).

For the thermal neutron flux of 3 – $5 \cdot 10^9$ cm^{-2}s^{-1} at horizontal channel we obtained the total neutron flux in the first channel (d=15 cm) equal to ~$5 \cdot 10^{6}$ cm^{-2} ·s^{-1} and for the fifth (d=115 cm) ~10^3 cm^{-2} ·s^{-1}.

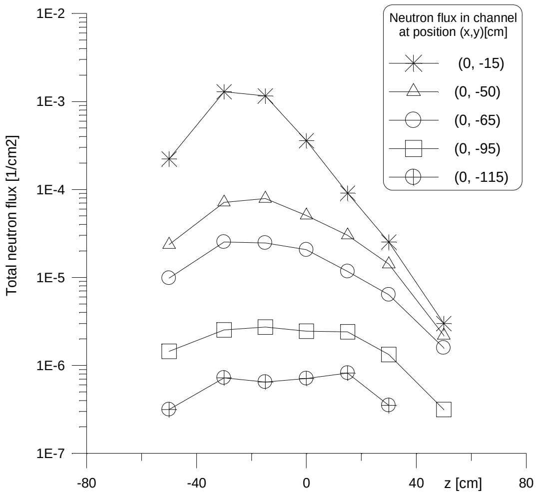

Fig. 2. Axial distribution of total neutron flux in the experimental channels of the Pb support.

The system can be used to study the application of thorium fuel in the sub-critical assembly of the ADS.

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RESULTS OF Y-89 IRRADIATION ON U/Pb-ASSEMBLY USING 1.6 GeV DEUTERON BEAM FROM THE JINR NUCLOTRON

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The neutron field inside the U/Pb assembly of the JINR Dubna experimental set-up ‘Energy plus Transmutation’ (EpT) was investigated with the Y-89 activation detectors. In the experiment the 1.6 GeV deuteron beam impinged on the cylindrical lead target surrounded by uranium blanket shielded by polyethylene container [1,2]. The neutron field was determined with thirty five pure Yttrium 89 (99.9% Y-89) samples placed in specified positions inside the U/Pb assembly. Neutron capture in Y-89 yields various (n,xnyp), reactions, where ‘x’ and ‘y’ are integer numbers. Isotopes created in these reactions are unstable and gamma active. After the 5.8×10^{13} beam deuterons were collected the gamma activity was measured with HPGe spectrometer. Taking into account necessary corrections we have determined isotope production per one gram of the sample and per one beam deuteron at specified positions inside the EpT facility. The spatial distribution of the Y-88 isotope production was determined (Fig. 1). The presence of the Y-87 and Y-86 was also revealed.

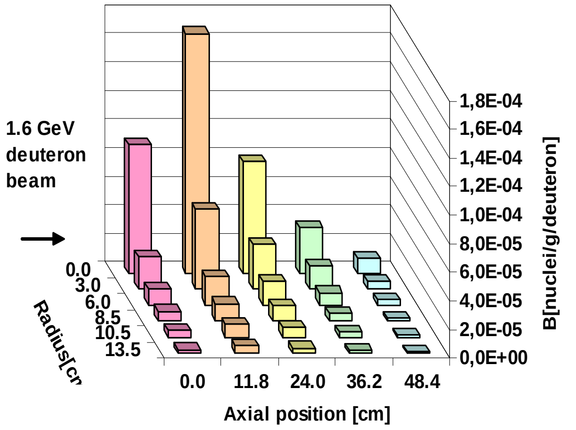

Fig. 1. Spatial distribution of Y-88 produced by spallation neutrons in Y89(n, 2n) reaction.

The spatial distribution of the Y-88 isotope (Fig. 1) is a superposition of two processes – beam deuteron interaction with the samples and spallation neutron interaction. During the deuteron interaction with yttrium nuclei neutron stripping (d,dn) takes place in the central axis region. Beside the central region, at $R \geq 3$ cm, the yttrium samples indicate only the spallation neutrons. We found that isotope production attain a maximum of axial distribution in the second plane, 11.8 cm from the front of the EpT facility (Fig. 2).

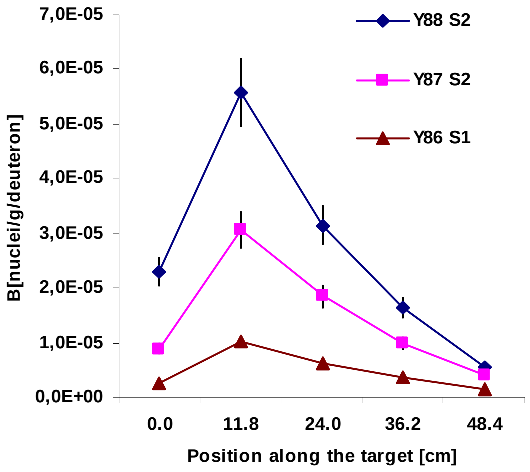

Fig. 2. Axial distribution of isotopes produced at radial distance 3 cm from the 1.6 GeV deuteron beam axis by spallation neutrons in Y89(n,xn) reactions.

The Y-88, Y-87, and Y86 production reactions are the threshold reactions with the threshold energy 11.5, 20.8, and 32.7 MeV, respectively. Hence, the isotope production ratio (e.g. Y87/Y88) depends on neutron energy spectrum and can serve as a spectral index. The region of constant spectral index (SI) was found in the middle of the EpT assembly (Fig. 3).

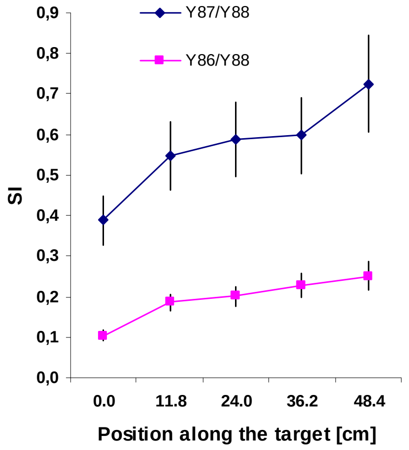

Fig. 3. Axial distribution of the spectral index at radial distance 3 cm from the 1.6 GeV deuteron beam axis.

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UO_2 GRAIN SUBDIVISION FOR VERY DEEP BURN-UP AND RELATIVELY LOW TEMPERATURE AND ITS IMPACT ON FISSION GAS RELEASE

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The beginning of the grain subdivision process in the nuclear fuel is observed at burn-up from ~60 MWd/kgU to 75 MWd/kgU [1] at the temperatures less than 1200 ^{o}C. The peripheral region of the high burn-up UO_2 fuel rod with a particular nano-structure is known as the “rim region”. The nano-structure changes start when the average burn-up exceeds ~40 MWd/kgU. The marked decrease in the grain size is accompanied by an increase in porosity and a decrease in the signal for fission xenon [2].

It was established [1] that the local xenon concentration in the UO_2 matrix attains a maximum as a function of the local burn-up. Coincident with the local xenon concentration decrease is the local grain subdivision in the rim area of the pellet. With increasing grain size, rim structure development rate is suppressed, and the Xe depressions for the large-grained pellets are about half of the value for the standard grain size pellet.

Although the physical details of the process are not fully understood, an attempt has been made to describe these processes by a simple model [3]. It is assumed that beside the modification of the properties of the “athermal” rim surface layer of the UO_2 fuel pellet by neutron irradiation, the total surface area increases when the local xenon concentration decreases. Further on we assume that the fission gas release from the UO_2 fuel during low temperature irradiation depends on the knock-out process of the defect trap model and is proportional to the total surface area. The knock-out process occurs also in the fuel transformed by grain subdivision.

We assume that above a limiting value of fission fluency a more intensive process of irradiation induced chemical interaction occurs. Significant part of fission gas products are chemically bound in the matrix of UO_2. It seems to be natural that the chemically bound fission gas atoms can form weak facets. At certain saturation conditions subdivision of the grains can occur and the increase in fission gas products release may be expected.

In the defect trap model the fission gas release (R) is described:

$$R = g_2 f M_{tr} S r / V \qquad (1)$$

where S – total surface area, f - fission rate, r– average fission fragment range, V – volume of the subdivided fuel, g_2 – constant.

When $S\,r$ attains V then total surface area stops to increase and the process of poligonization is accomplished.

Assuming that r = 6 μm we obtain that total surface is equal to about 1.6 10^3 cm^2/cm^3. Relative density of the fuel for this total surface area is equal to about 89 % and the porosity is ~11 %. This value is comparable with the experimental porosity data (15 %). Thus we obtain the total surface area of ~9 10^3 cm^2/cm^3 for 85 % relative density, which we call the limiting total surface area (S_l).

Our analysis let us postulate that the total surface area of the fuel in the rim region depends on the burn-up b in simple way

$$S = S_{bp} + (S_l - S_{bp})(1 - e^{-cb}) \,, \qquad (2)$$

with S_{bp} – total surface area before the process, S_l – limiting total surface area and c - a constant dependent on the grain size.

From the solution of the defect trap model equations for the high burn-up we obtain that the release rate is equal to the birth rate

$$g_2 f M_{tr} = \beta_i \, f \qquad (3)$$

where M_{tr} is the concentration of gas atoms in the bubbles, and β_i is formation yield of the intermediate gas of the i-th isotope.

In conclusion, the increase of gas concentration in function of burn-up is explained by defect trap model and the gas concentration at high burn-up (>120 GWd/tU) does not change. Nevertheless, the behavior of gas concentration in the intermediate burn-up range of 60 – 120 GWd/tU requires further study.

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ADVANCES IN THE SUB-CRITICAL MC CALCULATIONS FOR THE YALINA THERMAL FACILITY

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YALINA-Thermal benchmark [1,2] is a part of the IAEA Coordinated Research Projects *Analytical and Experimental Analysis of Accelerator Driven Systems* and *Low Enriched Uranium Fuel Utilization in Accelerator Driven Sub-Critical Assembly Systems.* The YALINA thermal facility is designed to study the ADS physics and to investigate the transmutation of MA and LLFP using an ADS. The main objective is to compare the results of different calculations, performed by different research institutes, and experimental data.

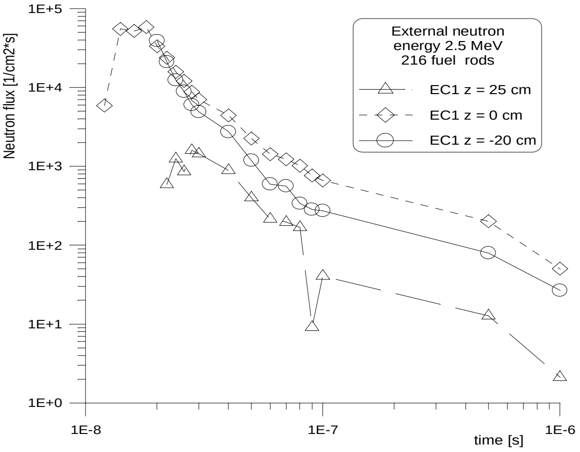
In this work we present preliminary results of calculation using MCNP4 [3] and MCNP5 [4] codes. The geometry is based on the specification of the YALINA-Thermal assembly [2].

Yalina-Thermal assembly uses EK-10 type fuel rods and external neutron sources based on the fusion reactions D-D (2.5MeV) and D-T (14MeV). Calculations [5] were performed for six different arrangements of fuel rods and external neutron sources (Table 1).

Table 1. Experimental arrangements studied.

Number of EK-10 fuel rods	Mass of ^{235}U [kg]	Energy of external neutron source [MeV]
280	2.16	14.0
280	2.16	2.5
245	1.99	14.0
245	1.89	2.5
216	1.67	14.0
216	1.67	2.5

The time dependence of the spatial distribution of neutron flux and energy in the experimental channels (EC1 – EC7) was calculated (Fig. 1). The effective multiplication factor (k_{eff}) (Fig. 2), multiplication source factor (k_s) and average prompt removal lifetime were calculated.



Fig, 1. Total neutron flux (per one external neutron) time dependence in the experimental channel EC1 at three different position z = 0, +25 cm and -20 cm, 216 EK-10 elements and 2.5 MeV external source.

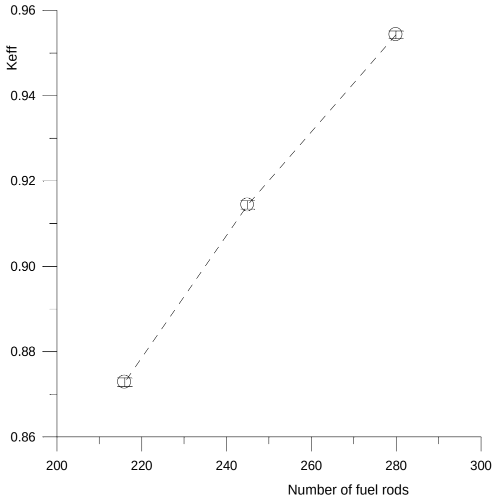


Fig. 2.Calculation results of k_{eff} as a function of number of fuel rods.

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PRESENT STATUS OF IV-GENERATION LEAD-COOLED FAST REACTORS DEVELOPMENT

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International Committees GIF and INPRO have set a number of technology goals for Generation IV nuclear energy systems. They should provide sustainable energy generation, promote long-term availability of systems, effectively utilize the fuel, minimize the amount of nuclear waste and reduce the long term fission products, be proliferation resistant, excellent in safety and reliability, have a very low likelihood and degree of reactor core damage, eliminate the need for external emergency actions, have an overall cost advantage over other energy sources and have a level of financial risk comparable to other energy sources. The Lead-cooled Fast Reactor (LFR) is one of the six IV-Generation nuclear systems selected by GIF and INPRO.

The first in the world reactors using lead-bismuth eutectic – LBE (55 wt% Bi-45wt% Pb) as a primary coolant were Soviet propulsion reactors used in alpha-class submarines (1972-1983).

LFR, as fast reactor, turns ^{238}U into feasible isotopes of plutonium so it can breed fuel. Fast Breeder Reactors can utilize uranium at least 60 times more efficiently than thermal spectrum reactor.

In contrast to sodium-cooled reactor the lead- and lead-bismuth eutectic-cooled reactors are safer due to the properties of the coolant. Lead and lead-bismuth eutectic do not react vigorously with water or steam and do not burn when exposed to air. This chemical inertness enables elimination of intermediate loop in the heat transport circuits with corresponding cost savings. Lead and lead alloys exhibit low neutron absorption and low neutron slowing down power (this is important in fast reactors) and are also effective as neutron reflectors, which enables reduction of fuel enrichment. Heavy metal is an excellent gamma ray shield. Both coolants have relatively low melting temperature – 327°C for lead and 123.5°C for LBE (98°C for sodium), extremely high boiling temperature at atmospheric pressure – 1750°C for lead and 1670°C for LBE – and high heat of vaporization as well low vapour pressure at operating temperature. These properties enable using an ambient pressure primary system and high pressure cooling circuit. The feasibility of primary coolant pump elimination has been confirmed. Most of LFR designs have no separate steam generators. The working steam is generated by direct contact of feed-water and liquid metal in reactor vessel and then is sent to the turbine. For the steam Rankine cycle subcritical and supercritical options are considered. The presence of light fluid above the core drives natural circulation of the coolant. The simplification of heat transport system allows remote deployment of lead-cooled systems.

The experience with lead-cooled reactors is rather scarce and requires research and development. The main issue is the incompatibility of the coolant with the structural and cladding materials. Cladding material must be also suitable for high-exposure of fast neutrons. Structural material corrosion, coolant activation and chemistry, filtration of impurities are investigated in several research centers all over the world. The major issue, associated with direct heat transfer from liquid metal to water, is entrainment and carry over of primary coolant vapour and Polonium (^{210}Po is produced by ^{209}Bi activation) into the energy conversion system. Four fuel types are being considered: mixed-nitride (UN-PuN), metallic (U-Pu-Zr), oxide (UO_2-PuO_2) and carbide (UPuC).

Currently achieved core coolant outlet temperature is limited by material properties to 550–600°C, but in the future it can be extended into the 750–800°C range, which is suitable for hydrogen production. In addition the Pb-alloy cooled reactors are capable of burning actinides and long-life fission products contained in the spent fuel of LWRs.

Sizes of the lead-alloy-cooled reactors designs are broad in scope: from small plants of 6 to 100 MWe – Angstrem (6 MWe), ENHS (50 MWe), LSPR (53 MWe), SSTAR (10÷100 MWe), SVBR-75 (75 MWe), through medium – BREST-300 (300 MWe), to large – BREST-1200 (1200MWe).

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NUCLEAR POWER COMPONENT IN FORESIGHT ON ENERGY IN POLAND

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The first technology foresight study on future developments in the energy sector in Poland was completed by the end of 2007 [1]. Looking ahead to 2030, the study aimed to identify energy-related technologies, scenarios, a mix of energy sources and infrastructure developments for Poland. One of the key requirements was seen as a re-assessment of the future role of nuclear power in Poland to ensure security of power supply and diversity, and avoid dominance by coal for reduction of CO_2 emissions.

The paper [2] provides a short description of the methodology applied as well as main results and findings of the foresight study referring to the perspective of nuclear power option in Poland. The study can be broadly divided into two phases: Delphy survey with two rounds of expert judgment on anticipated technological development and creation of Road Maps.

A large majority of the Delphi survey participants expect the introduction of nuclear components in a mix of electricity sources in Poland just after 2020. However, almost 17% of the respondents do not believe it will ever occur. Delphi respondents generally agree that the positive perception of nuclear fission in the public mind will be improved.

Roughly half of the experts believe that at some point after 2030 high-temperature gas-cooled reactors will be in practical use for thermo-chemical processes. However, there are no chances for the commercialization of this technology before 2030.

The second important task of the project consisted in systematic creation of Road Maps for variant scenarios of nuclear power development in Poland up to 2030 (Fig. 1).

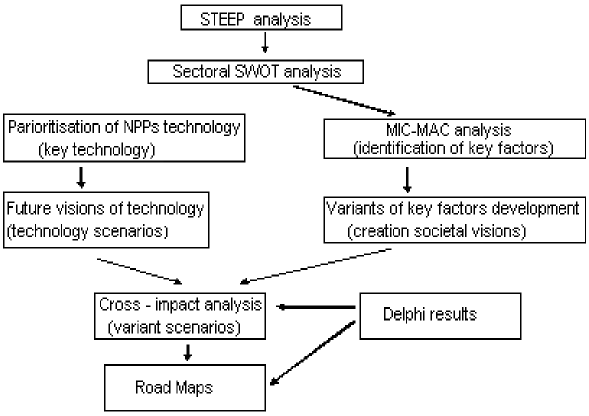

Fig. 1. Research phases of the study to create Road Maps for nu clear option development.

The process was launched with STEEP and SWOT analysis aimed at isolating the main drivers of Polish future energy system. These analyses were useful to establish the preliminary list of possible variables related to future energy demand and supply as well as economical, political and social fields, which are likely to have an important influence on the future development of nuclear option.

The Road Maps with detailed time frame for each implementation phase of the individual technology within three scenarios have been developed (Fig. 2). Similar to those R&D Road Maps have been designed with specification of the required actions.

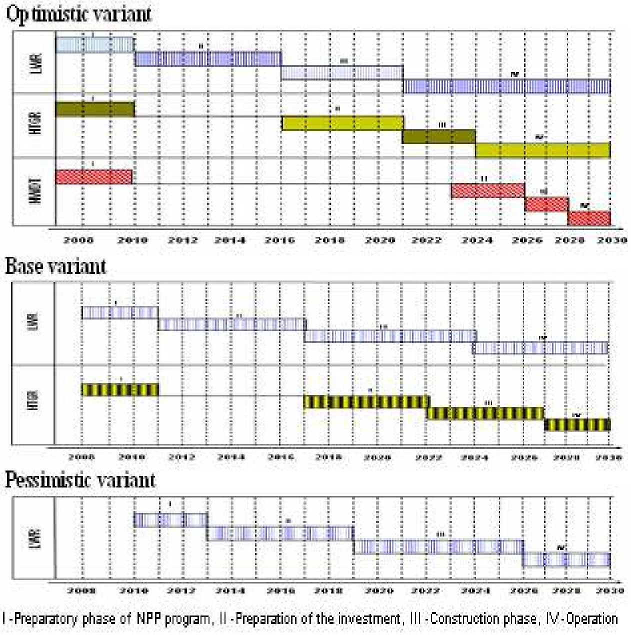

Fig. 2. Road Maps on NPP technology implementation for individual scenarios.

The knowledge gathered gives insight into the possible future constellations of nuclear power sector and on the actions necessary to increase the likelihood of the successful implementation nuclear technology in Poland. The ultimate objective of the project was to provide advice on energy R&D policy which should be useful for the decision makers.

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CORRELATION BETWEEN MULTIPLICITY, RAPIDITY AND IMPACT PARAMETER IN PION-XENON INTERACTIONS AT GeV ENERGIES

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The impact parameter (IP) is the basic characteristic determining the initial geometry of the interaction of hadrons and nuclei with nuclei at intermediate and high energies. It enters in the appropriate theoretical formalism and, in particular, in the widely used Glauber model. However, in experiments measured are only such quantities as multiplicity (M) of produced particles of definite sorts, their energies, momenta and emission angles. Using these observables constructed are such characteristics as various and numerous scaling variables, longitudinal rapidity (LR), four-velocity transfer and centrality enabling categorization of experimental data. But the classification of this kind is by its nature of statistical meaning and always the question remains concerning the reliability and ambiguity of this procedure.

In the present work we study the correlation between the IP, M and LR of neutral and charged pions, protons and neutrons produced/emitted in the interactions of charged pions with xenon nuclei at momenta of 2.34, 3.5, 9 and 30 GeV/c. The correlation is investigated using JAM modeling code [1] whereas the above-listed reactions have been chosen because just in this case the corresponding experimental information is available, especially on neutral pions, registered within 4π geometry and practically without limitation on their energy [2], except to the case of the reaction at 30 GeV/c which is selected to follow the energy behavior of the investigated correlation only. Simple analytic parameterizations of investigated correlations have been obtained, too. As an example of our results we present here the dependence on IP of the average multiplicity and average rapidity of neutral pions produced in the reaction of πXe at 3.5 GeV/c calculated with the JAM code (Fig. 1).

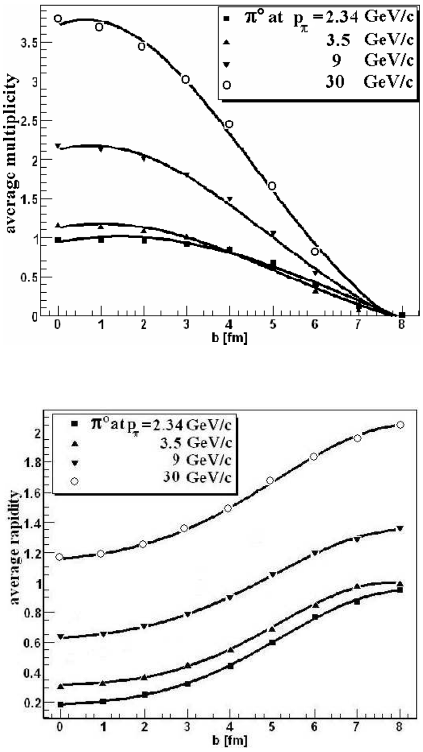

Fig. 1. Average multiplicity of neutral pions vs. impact parameter (left) and average rapidity vs. impact parameter (right) calculated using the JAM code [1] for the reaction of charged pions with xenon nuclei at four incident momenta: 2.34, 3.5, 9 and 30 GeV/c.

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PARAMETRIZATION OF FLUCTUATION OF ENERGY LOSS IN ELECTROMAGNETIC CASCADES AT INTERMEDIATE ENERGIES

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Our present knowledge on the fluctuation of energy loss in electromagnetic cascades (EC) induced by gamma quanta of high enough energy in dense amorphous materials comes to integral characteristics of the phenomenon [1,2]. But it is the major contributor of uncertainties of energy and direction of gammas registered in electromagnetic detectors (for example, [1]). The influence of this fluctuation is meaningful especially in the range of intermediate energies, i.e. from about 100 MeV to several GeV when in EC participate not so much produced particles.

In the work we continued to study longitudinal fluctuation of energy losses (LEL) in EC created in liquid xenon by gamma quanta of energy E_γ= 200, 550, 2375 and 3375 MeV at four different cut-off energies $E_{c.o.}$ = 0.6, 1.25, 2.0 and 3.0 MeV, and two values of threshold A= 0.5 and 0.7. The investigation was done using the EGS modeling code [3]. Modeled are in total 48000 events of cascades. The obtained distributions of E_γ and $E_{c.o.}$ dependence of the fluctuation defined as r.m.s. of LEL have been satisfactorily parametrized by the generalized gamma function:

$$P(t_A)=\alpha\cdot t_A^{\beta}\exp(-t_A^{\delta}/\gamma). \qquad (1)$$

Our results show that all parameters attain their asymptotic regimes at E_γ ~ 600 MeV. The behavior is demonstrated in the parameter γ distributions vs E_γ for various $E_{c.o}$ (Fig. 1). The calculations were performed for two values, 0.5 and 0.7, of the threshold A, i.e. the part A at the EC depths at which released is, on the average, 0.5 and 0.7 of the total EC energy loss, correspondingly. Analogous distributions have been obtained for β and δ parameters. The conclusion is that near the 600 MeV the description of LEL fluctuation in the form (1) turns out to be universal.

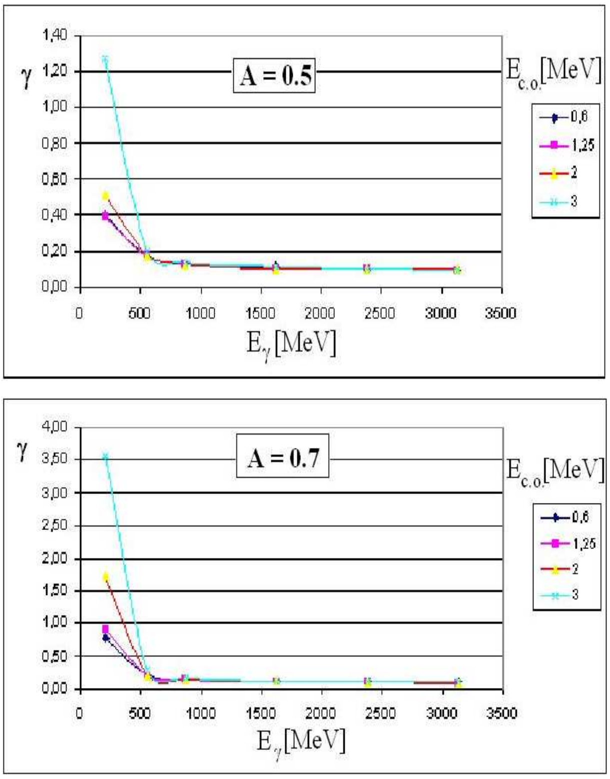

Fig. 1. Distributions on gamma quanta energy E_γ of the parameter γ for two threshold values A at which the part A=0.5 and A=0.7 of EC energy is released on average. The cascades are initiated in liquid xenon by gamma quanta of energy E_γ at the cut-off energy $E_{c.o.}$ = 0.6, 1.25, 2.0 and 3.0 MeV.

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SEARCH FOR THE UNIVERSAL PARAMETERIZATION OF ELECTROMAGNETIC PROFILES IN HEAVY AMORPHOUS MEDIA

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It is commonly agreed that the average longitudinal profile of electromagnetic cascades (EMC) initiated by high energy gamma quanta in uniform amorphous media may be satisfactorily parameterized by a gamma-type function:

$$f_t(t) = a_t \cdot t^{b_t} \cdot \exp(-t/c_t),$$

where the parameters a_t, b_t and c_t are to be determined by fitting to experimental data for some materials being of interest (e.g. [1]). Among these parameters mainly c_t depends both on the cut-off energy $E_{c.o.}$ of cascade particles and material characteristics. Somewhat more ambiguous is the description of radial EMC profiles but from the viewpoint of simplicity one can admit that the relevant distribution is of the form of the weighted sum of two exponents

$$f_r(r) = a_r \cdot \exp(-r/b_r) + c_r \cdot \exp(-r/d_r)$$

where the parameters a_r, b_r, c_r and d_r containing information about the initial and cut-off energies, and on a medium, should be calculated as the best fit to the relevant experimental results [1].

In the work the simulation of EMC developing in the six most frequently used materials: $Bi_4Ge_3O_{12}$ (BGO), $CdWO_4$ (CWO), liquid Xe, W, $PbWO_4$ (PWO) and Si has been performed for three values of primary energy E_γ: 500, 1500 and 3000 MeV (i.e., covering the characteristic transition region) and two values of $E_{c.o.}$: 0.6 and 1.25 MeV (i.e., as typical for most experiments). For each set of parameters (i.e. material, E_γ and $E_{c.o.}$) 5000 histories were traced using the EGS code [2] and all parameters determining both longitudinal and radial EMC profiles have been estimated. The dependence of the slope parameter c_t on the medium characteristics $\rho Z/A$, where ρ is the medium density, Z and A are its electric charge and atomic number (or corresponding average values for compounds) have been determined (Fig.1). Moreover, it has been found, that the above mentioned parameterization functions correspond with our modeled data reasonably well.

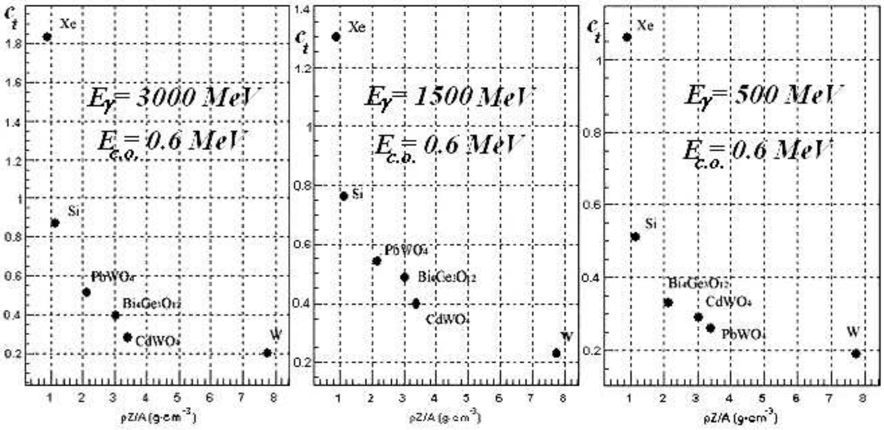

Fig.1. The example of the slope parameter values estimated from simulations of EMC for different incident gamma quantum energy and different materials.

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ANALYSIS OF PROSPECTS OF WIND ENERGY IN POLAND

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In view of the large subsidies to wind power and plans of its fast development there is a new discussion on whether it is necessary do develop nuclear power, if the renewable energy sources can be made available. The example of Denmark is quoted as the case of a country which is very successful in developing wind power. On the other hand, Both European Parliament and governments of such countries as France and UK see the necessity of nuclear power as a stable and cheap source of energy. The review of facts concerning wind power is therefore needed.

The changeability of wind is proverbial. An example of daily changes of electricity demand and of wind output in a chosen week in summer 2002 in Denmark shows that there are days when the wind system simply does NOT produce any energy.

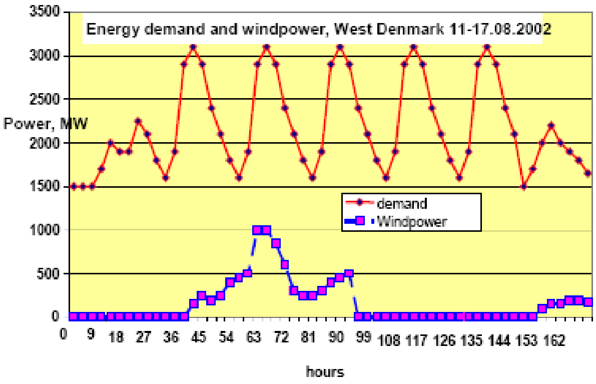

Fig. 1. Loss of wind power in Denmark in a week in August 2002 [1].

The changes can occur very rapidly. When there is no wind, it is necessary to have reserve power plants ready to step in and take up the load. This means that for each wind power plant we must build another of nearly the same power, which will be just waiting idle until the wind.

This is a heavy investment load. Moreover, the nominal power of a wind turbine is misleading – in practice the wind power is much less than the maximum rated value, so e.g. in Germany the average annual load factors for wind turbines range from 16 to 20%.

Fast changes of wind power can not be compensated by coal fired power plants. Gas can partly help, but the real answer lies in hydropower, which can be easily regulated. Denmark is fortunately situated close to the large hydropower system of Scandinavia, which produces 178 TWh/a and can accommodate both sudden increases and decreases of wind power. But Denmark has to pay for it – it must send most of its energy abroad at dumping price, and so loses annually one billion Danish crowns [2].

Capital costs for wind power are very high. A comparison of an NPP with the load factor of 0.88, which is less than the actual average value in the world, and wind power plants with load factors of 0.,34 on land and 0.45 offshore [3] – which is very high for wind turbines - shows that the capital costs per unit of energy generated over the lifetime are much higher for wind than for nuclear power plants [1].

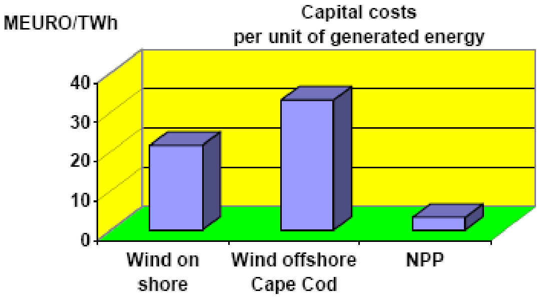

Fig. 2. Unit investment per unit of electricity produced over the lifetime is higher for wind than for nuclear power [1].

In Poland the average annual wind velocity in the best locations is within the range of 4 to 5 m/s., which is much less than 7÷11 m/s considered as good conditions for wind power.

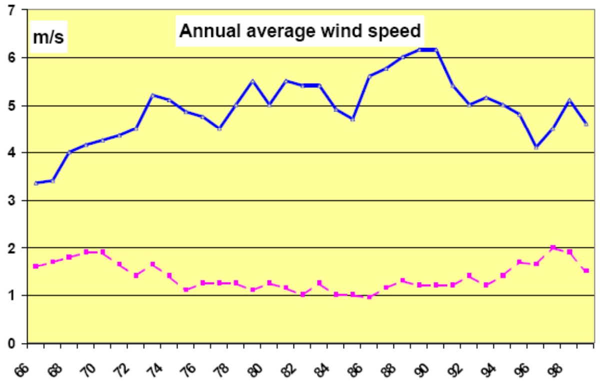

Fig. 3. Wind velocity in Poland at the seaside (blue line) and in south regions (dashed red line) [1].

Moreover, the power of the hydropower is small in Poland which makes problems of compensation of wind changes very difficult. Thus although wind power is renewable, and so should be used in Poland, related costs will be high.

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FACTORS IMPLYING THE IMPLEMENTATION OF NUCLEAR POWER IN POLAND

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In Poland above 94% of electricity is produced from coal fired power plants. In the European Union the dominating electricity source is nuclear power, which in 2004 provi8ded about 32% of overall needs. Coal provided 29.7% of electricity needed in the EU, and gas 18% [1].

Nuclear power offers Poland advantages in three respects:

- Security of supply, important in view of the limitations of possibilities of use of coal.
- Economical profits, as nuclear power is presently the lowest cost stable energy Skurce.
- Health and environmental protection, as nuclear power means clean air, water and soil around the NPPs.

CO_2 emission permits introduced by the European Commission which add to the price of coal about 22 euro/ton CO_2, and even more the emission permits which limit Polish emissions much below actual use, are very strong incentives to stop building coal fired power plants. Nuclear power is economically competitive even without consideration of emission permits [1]. Nuclear industry has made great progress on the road of reduction of capital costs and improvement of operational parameters and is presently the lowest cost energy source (Fig. 1).

The operational resources of organic energy source in Poland will be exhausted within some 40 years after which it will be necessary to build much deeper coal mines and produce coal at much higher costs.

Polish economy develops and is expected to continue this trend so that in 2025 the electricity needed in Poland will be 220 TWh. An analysis of existing and potential energy sources has shown, that without nuclear power the energy needs cannot be satisfied.

Coal production is slowly decreasing year after year. Gas contribution should not be assumed, because in near future the availability o gas will go down, and its goes up. Thus, if we assume that in 2025 coal and gas will keep their present production quotas (143 TWh/a), it will be an optimistic view.

Renewable energy sources in Poland are quite limited and much more expensive than coal or nuclear power. The potential of hydroenergy is presently about 4 TWh/a, and till 2025 further 3 TWH can be developed, biomass can provide up to 6 TWh, biogas (from all resources) up to 14 TWH and wind 8 TWh.

Together this yields 174 TWh. We are short by 46 TWh – and this is the equivalent of 2 NPPs with 2 units of 1600 MWe power each.

Besides being necessary and cheap, nuclear power is also clean The technical studies in the EU [2] and in Poland [1] are in full agreement: the question for Poland is not whether to build NPPs or not, but rather how soon it is technically possible.

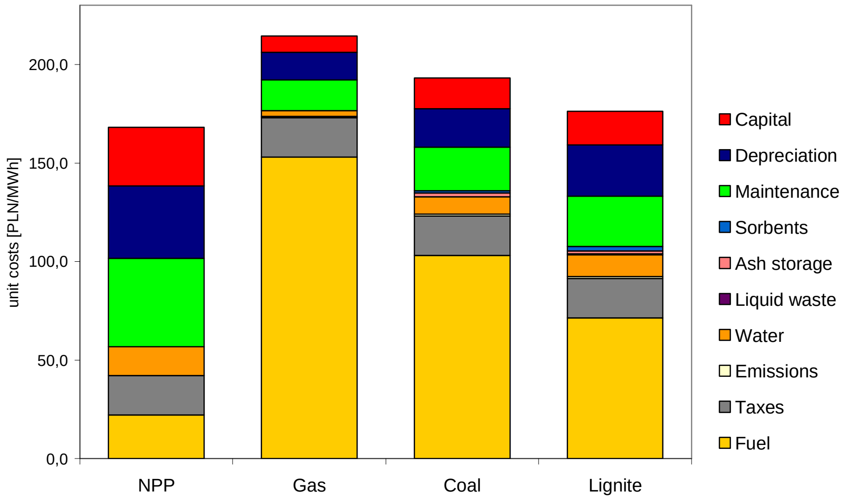

Fig. 1 Electricity generating costs in Poland according to the study of Energoprojekt Warsaw [1].

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