IX. NUCLEAR ISSUES

NUCLEAR ENERGY AND PUBLIC AWARENESS

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ABSTRACT

The Hungarian government signed an intergovernmental agreement with Russia in 2014 on the construction of two new units at the site of the currently-four-unit Paks Nuclear Power Plant. This decision – based on the National Energy Strategy adopted in 2011 – maintains the capacity of the Hungarian nuclear based electricity production for the next decades. Public acceptance of a new nuclear construction, which is determined by the public awareness, is a key point of the success of the project. It is essential to educate environmentally and socially conscious youth, but also to provide them with the necessary technical knowledge to ensure that the next generation can have a well-based judgement of energy-related issues instead of an emotional approach. The presentation gives an overview about the Paks 2 project and the possible methods of information and education of the next generation concerning the energy policy including the new nuclear units.

INTRODUCTION

The Paks Nuclear Power Plant (Paks NPP) has an inevitable role in the Hungarian electricity system: it has a share of more than 50% in the domestic electricity generation, and a 36% share in the electricity supply of Hungary. There are four Russian designed nuclear units operating at the Paks site with a total electric output of 2000 MW. The units started commercial operation in the '80s, so they are reaching their originally planned 30-years lifetime in this decade. After a comprehensive preparatory program, the units are now in the lifetime extension licensing process, as a result of which they would be able to operate for a further 20 years (having their lifetime extended from 30 to 50 years). However, even after the lifetime extension the units will be shut down between 2032 and 2037, so there is an urgent need to ensure their replacement capacities.

The idea of constructing new units at the Paks site has been on the agenda since the '80s. The site itself is suitable for hosting two further units and has the necessary infrastructure for the construction; moreover, it is the most explored and best-known potential site in Hungary. In addition, the surrounding population supports the project, recognizing the positive economic effects of the construction on the region.

Following several years of preparatory work of the project, the Hungarian government signed an intergovernmental agreement with Russia on 14 January, 2014. The intergovernmental agreement (IGA) includes the construction of two pressurized water reactors with a capacity of at least 1000 MW each at the Paks site. Regarding the financing of the project, the IGA lays down that the Hungarian state would get an interstate loan from Russia.

After the announcement of the IGA, intensive negotiations started between the parties about the exact technical, legal and financial details of the cooperation. As a result of these negotiations, three contracts (the so-called Implementation Agreements) were signed by the Hungarian Paks 2 Development Ltd. – the future licensee of the new units – and the Russian JSC NIAEP company on 9 December, 2014. The Implementation Agreements covered the engineering, procurement and construction details (EPC contract), the operation and maintenance support and the nuclear fuel supply. The basis of these agreements is a set of a significant number of safety-related, technical and legal requirements defined by the Hungarian party. These requirements ensure that a state-of-the-art, Generation 3+ nuclear power plant will be built at Paks, with the reasonably highest possible safety level.

ELECTRICITY – DEMAND AND SUPPLY

One of the most important challenges to be solved by our society is the secure energy supply. We can read different expert statements and analyses about the ideal energy sources. However, it is obvious, that there are some misunderstandings and misinterpretations of natural and technical facts among laypeople in the subject of electricity supply.

Electricity is one of the most important products in our life. Unfortunately, unlike other everyday goods, electricity cannot be stored in industrial scales. Of course, there are several solutions for the small-scale electricity storage – e.g. batteries – but the possibilities are very limited in large dimensions. Among the exceptions the pumped-storage hydroelectricity shall be mentioned, which is a high-efficiency, proven method for a short term electricity storage.

The most important feature of the electricity system is the consequence of restricted storage possibilities, which means that the balance of the generated and consumed electricity shall be maintained in each moment for the whole electricity system. The quality of this special product (i.e. the electric energy) in the electricity grid can be described by the frequency. It is 50 Hz in Europe, and the system operators and even the power plants have to keep this 50 Hz frequency very precisely to maintain not only the quality, but the stability, or even functionality of the whole system. If the frequency increases or drops beyond certain limits, the electricity system will collapse, causing a severe supply problem as well. Keeping the electricity system between the required frequency limits needs lot of efforts. So-called primary, secondary and tertiary reserves – i.e. dedicated power plants – shall be ensured for the electricity system to cope with the unforeseen demand or generation fluctuations. The different reserve types are responsible for the different levels of electricity grid control.

If the electricity production and consumption get unbalanced, the frequency of the system deviates from the nominal value. For example if a power unit gets shut down because of technical reasons or if the increase of the electricity consumption (e.g. in the morning hours) cannot be fully covered by operating power plants the frequency decreases. Immediately after the decrease of the frequency the primary reserves are necessary: these power plants are running and parallelized with the 50 Hz system, so if there is a load increase, these primary reserves can be started or their power can be increased to supply the necessary electricity to the grid (immediate intervention). The secondary reserves can interact with the system within few minutes – these are shut down power plants (or ones operating at low power), which are able to get started very quickly after the frequency change. The tertiary reserves are usually shut down power plants, used for the mid-term balancing of the electricity grid. To keep the system operating, very precise planning and high availability of the power plants is necessary.

Having a look at the daily change of the electricity demand (this is the so-called load curve, see Fig.1.), different daily load curves can be observed, depending on the season, on workdays / holidays, or on special weather conditions. Even an important and very popular sport event or TV program can influence the load curve. Their common feature is that there is a minimum in the electricity consumption in the pre-dawn hours, when the electricity demand is only about 60-70% of the peak load. The value of the daily peak load in Hungary is about 4000-6300 MW – larger in winter season and on workdays, lower at summer weekends. However, with the increasing deployment of air-conditioning, the summer electricity load is approaching or even exceeding the winter demand peaks, as it is well-known for example in the USA.

The shape of the load curve depends on the value and time point of the peak load, which can occur during working hours or in the evening. In some cases, even two peaks with very similar height can be observed. We can make a difference between the typical load curve with the help of two animals: the load curve with one load peak is similar to the back of an elephant, whereas the two-peak curve is similar to a two-humped camel.

The knowledge of the shape and values of the load curve is essential for the planning of the generating capacities. The constant part of the demand (i.e. below the minimal demand) can be supplied with cheap, continuously operating power plants, these are the so-called baseload power plants – typically the nuclear power plants are in this category. Baseload plants are necessary for the secure, inexpensive electricity supply. The load-following power plants are responsible for the supply of the foreseeably fluctuating part of the load – these are typically the flexible fossil-fuel-fired power plants, mostly gas-, but recently often coal-fired power plants. In the short, high-electricity-demand periods, peaking power plants are used, which can be started very quickly, but usually with high generating prices – these are typically gas turbines.

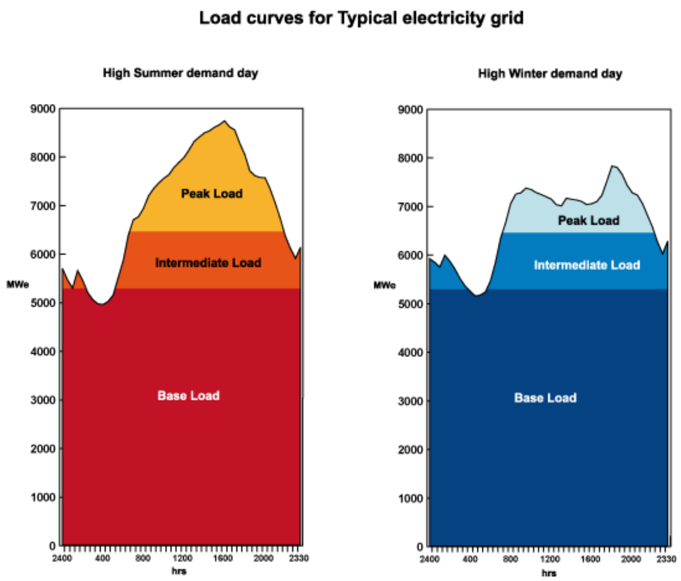

Fig.1. Typical daily load curves (Source: World Nuclear Association) [1]

ROLE OF RENEWABLE ENERGY SOURCES IN ELECTRICITY GRID STABILITY

Considering the renewable energy sources, a difference shall be made between the weather-dependent and the continuously operating power plants. Plants with continuous operation (as large hydroelectric power plants or biomass-fueled plants) can act as part of the baseload generation. The pumped-storage hydroelectric plant is a typical peak-load plant – the upper water reservoir can be filled up in the demand valley time period with cheap electricity coming from baseload power plants, and the energy can be recovered in peak-load periods.

However, the situation is totally different in case of the weather-dependent renewable sources, as wind power or solar power. The forecast of the electricity generation from these sources is very complicated, causing difficulties in the electrical grid control.

Germany, on the road of its energy transition to the clean renewable sources is a good example for the difficulties caused by the weather-dependent energy sources. (The German energy policy aims the total phase-out of nuclear power plants until 2022 and sets out a target for 80% share of renewable sources in the German electricity consumption by 2050.). The daily peak load in Germany nowadays is about 60-70 000 MW. There is an installed wind based production capacity of more than 40 000 MW and solar (photovoltaic, PV) capacity of roughly 38 000 MW – so these renewables would be able in theory to cover the demand by themselves. However, the real feed-in from the renewables is much smaller; the PV panels can generate only daytime, and the wind power plants are not able to generate continuously either. Additional to that we have to mention that the wind feed-in never reaches 100% of wind production capacity.

In Fig.2, the electricity production in Germany is shown in January of 2014. It can be clearly seen, that the baseload power generation comes from large hydro, biomass, nuclear and lignite-fueled power plants. The generation from the wind power plants is uncontrollable and weather-dependent, so the necessary production-side control takes place with coal-fired and natural gas fueled power plants.

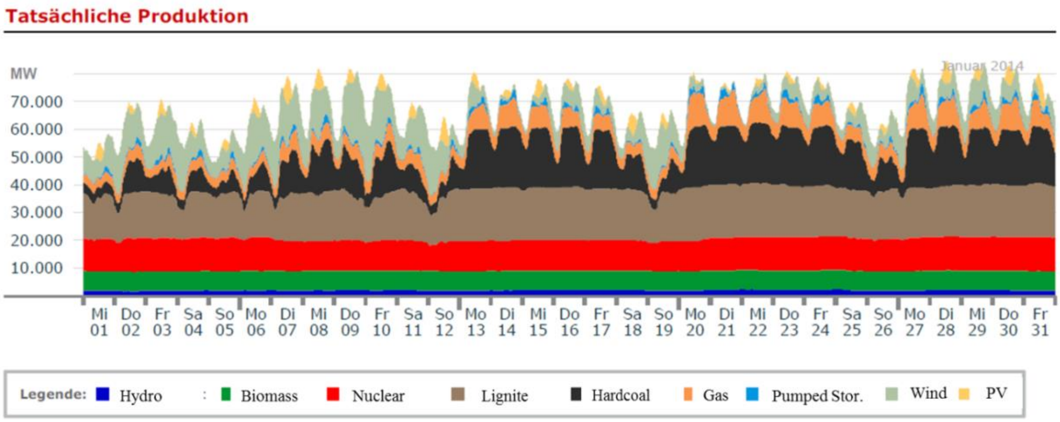

Fig.2. Electricity generation in Germany in January 2014 [2]

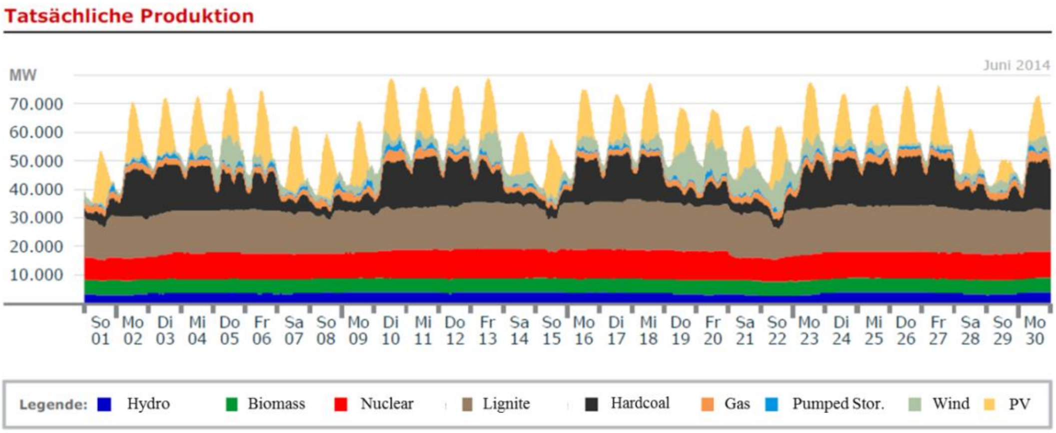

Fig.3. Electricity generation in Germany in June 2014 [2]

Fig.3. shows the electricity generation for another month, for June of 2014. In summer, daytime feed-in from solar panels is much higher than it was in winter, as it can be observed

in the figure – combined with a very low but fluctuating wind generation. The role of the natural gas was almost negligible in the electricity generation in that month, however gas played important role in short-term balancing.

The result of the large renewable production can be observed in Fig.4, which shows the data for a selected week in August 2014. The grey sector is the electricity generated by the conventional (i.e. nuclear plus fossil-fired) power plants. The green part shows the wind production, and the yellow humps represent the solar generation. There are some periods, when the feed-in from wind is over 20 000 MW, but there are long hours when the feed-in from wind is negligible. The sudden changes of the wind production can cause serious grid control problems – the necessity of keeping the frequency stable is the main rule, so the high rate of wind power requires large capacity of reserve power plants, which makes system operation even more expensive and technically more complicated.

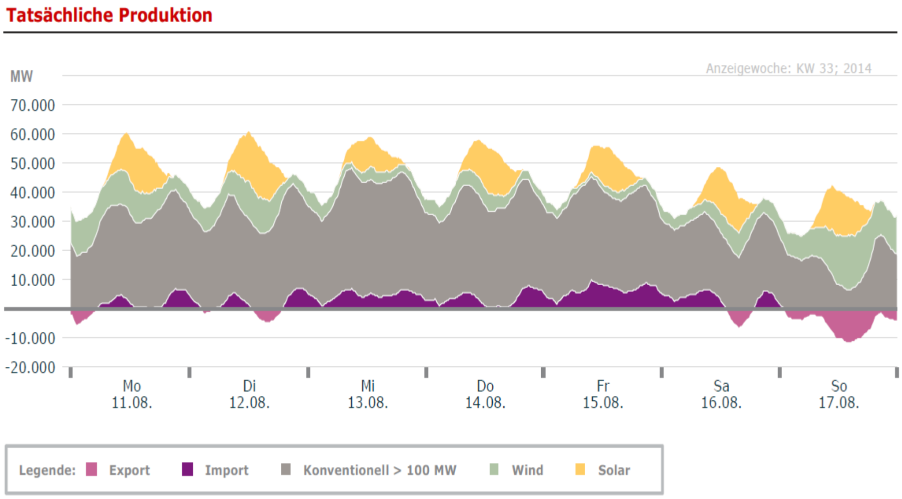

Fig.4. Electricity production in Germany from renewable sources, August 11-17, 2014 [2]

According to the figure, the daily peak production of conventional power plants varies from 30 000 to 50 000 MW, and the export-import balance varies from -10 000 MW (export) to +5000 MW (import). The large changes in the generation can cause forced (not planned and not contracted) export to the neighboring countries, causing grid instability in these countries as well. An extreme consequence of the unforeseeable production changes is the presence of negative electricity prices as it happened at the end of August 2014: in some cases of sudden renewable overproduction – combined with a drop in grid loads – the operators of the baseload power-plants cannot shutdown their units for few hours therefore they had to pay for taking over the electricity generated by them. In the events on the weekend of August 17th 2014 between 12:00 and 16:00 the spot price of electricity has been climbing down to minus (!) 60 EUR per MWh. These are definitely symptoms of a distorted market which is characterized by high subsidies of renewables. This distortion materializes in a market environment where electricity markets are not giving real, long-term price signals and seriously endanger the future investment in dispatchable power plants that ensure electricity supply security. This development, namely the lack of new investment in dispatchable power plants, a worsening future supply security is clearly against the most important energy policy objective of Europe.

It is unclear at this moment how these issues can be resolved. However this is evident that stable, controllable power plants are henceforward necessary to ensure reliable electricity system operation, security of supply and system safety. Large capacity of power plants is inevitable which are independent from weather conditions and are available in all seasons. By the selection of future energy mix we have to consider many different factors including economics and targets for combating climate change.

ROLE OF NUCLEAR POWER PLANTS IN THE ELECTRICITY SYSTEM

Now, at the beginning of 2016, there are 442 nuclear power reactors in operation worldwide, with a total net installed capacity of 383 GW, covering about 11-12% of the annual global electricity production. After the Fukushima accident (2011) some countries decided to phase out nuclear power plants – for example Germany, as mentioned earlier. However, at the moment 66 nuclear units are under construction, and many countries are planning to maintain or expand their nuclear generation capacity.

According to the forecast of the International Energy Agency (IEA, see Fig.5), after the post-Fukushima stagnation of the nuclear industry, the total installed capacity of the nuclear power plants will increase in the next decades, mainly because of the fast nuclear expansion in China and other developing countries. However, in the EU the sustainment of the nuclear capacities is forecasted until 2040 (see Fig.5).

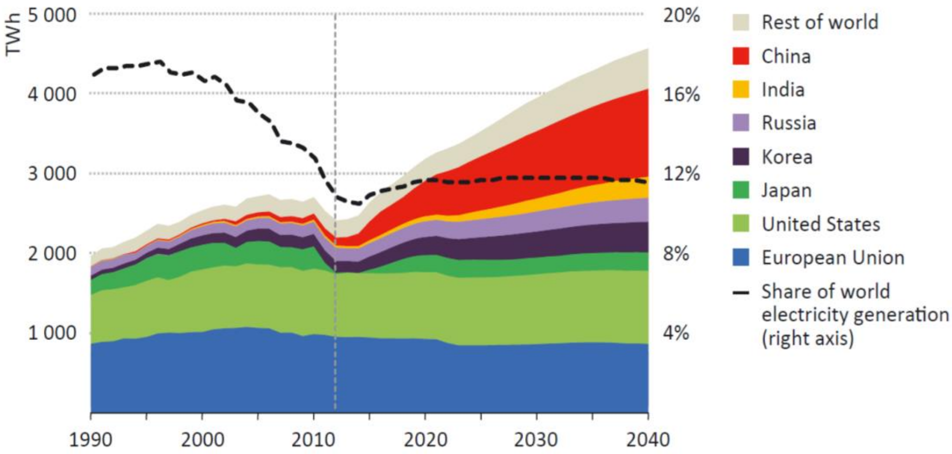

Fig.5. Installed capacity of nuclear power plants until 2040 according the World Energy Outlook [3]

The member states of the European Union have the right to choose their own energy mix, including the mix of primary energy sources in their electricity production (the combination of the applied electricity generation methods), as far as they are consistent with the energy policy goals of the EU. These goals – to increase the competitiveness, to ensure affordable electricity prices, to enhance supply security of the Union and to help the battle against the climate change – can be met with the use of nuclear energy as a part of the energy mix. Nuclear power plants can operate without emitting carbon-dioxide, and also their CO2-emmission during the whole life-cycle (per kWh) is in the order of the emission of renewable sources (wind, PV). The security of the energy supply can be improved as well, because fresh (unused) nuclear fuel assemblies are easy to handle and to stockpile reserves, even for years. The uranium, the raw material for the fuel is available from different, politically stable countries. By given technical and commercial conditions the fuel assemblies can be procured from different fuel vendors. For the transportation of the fresh fuel alternative means e.g. rail and air transport are available, which is much more flexible than gas import through pipeline or electricity import by transborder power-lines.

A special feature of nuclear power plants is the relatively high investment cost, together with low operation-maintenance and fuel costs. As a result, if appropriate financing is available, electricity generated in nuclear reactors is especially competitive with other electricity generation technologies (see Fig.6). Because of the favorable financial conditions of the new Paks units, the levelised cost of electricity of the new units will be even lower than the values of the IEA forecast for Europe.

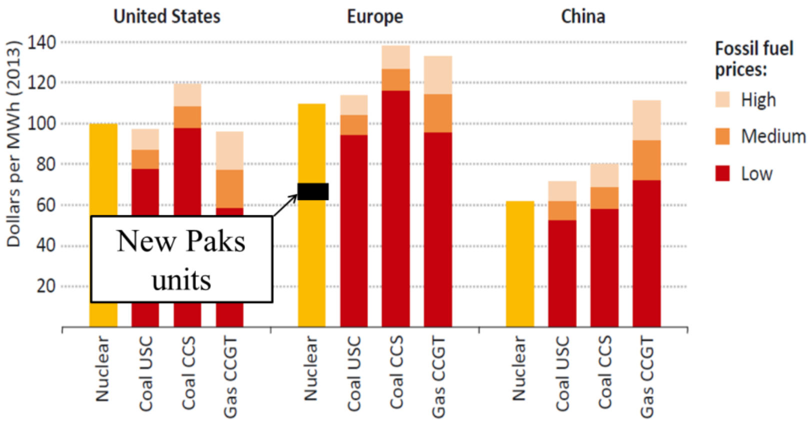

Fig.6. Cost of electricity generation for different sources according the World Energy Outlook [3]

NEW UNITS AT THE PAKS NUCLEAR POWER PLANT

The annual total gross electricity consumption of Hungary is about 44 TWh (2015: 43,75 TWh, see data of MAVIR) with a peak load of about 6500 MW, while the installed capacity in the Hungarian power plants is only 9000 MW and is decreasing. In the next decades, the annual total gross electricity consumption, together with the peak load is expected to increase with a rate of about 1% / year. Combined with the shutdown of old Hungarian power plants, these developments result in a need of about 7300 MW new generating capacity to be built until 2030. The Hungarian energy policy aims to increase the security of electricity supply that makes the construction of new nuclear reactors necessary.

The Hungarian parliament approved the preparation of new NPP construction on March 30, 2009. After this decision in principle of the parliament, the Hungarian electricity utility MVM established the Lévai-project with the task of performing the further preparatory works. In July 2012, the Paks II NPP Developing Company has been established, which is now responsible for the pre-construction and construction works.

On 14 January, 2014 the Hungarian government signed an intergovernmental agreement with Russia on the cooperation in the peaceful use of nuclear energy, including the construction of two new units at the site Paks Nuclear Power Plant. The choice of the Russian supplier can be explained with the very favorable loan conditions and the long experience of the Hungarian institutions in the application of Russian nuclear technologies.

The offered reactor design is the VVER-1200/V491, which is a state-of-the-art pressurized water reactor (PWR) type with 1200 MW gross electric output – the same design has been selected for the Finnish Hanhikivi project. The design can be classified as a Generation III+ reactor, i.e. with improved safety and economic performance compared with the actually operating Generation II reactors. The Generation II and Generation III/III+ reactors use low enriched uranium, which is unsuitable either in fresh or in spent fuel form for production of nuclear weapons. These type of units are designed to fulfill wide range of nuclear safety, nuclear security and also non-proliferation requirements.

For the commissioning of the units altogether about 6000 different permissions are necessary (see Fig.7). The licensing process has already started; recently the site licensing and the environmental licensing processes are underway. Concerning the environmental licensing, the EIA (Environmental Impact Assessment) report was submitted to the competent authority on 19

December 2014. During the spring of 2015, 41 presentations were given during a public information roadshow in the settlements around the site, and a public hearing was also organized in the town of Paks. In the frame of the preliminary international consultation process (began in 2012), the preliminary consultation document (PCD) was sent to 30 countries, among which, 11 countries have been registered to take part in the environmental licensing process according to the Espoo Convention, the biggest part of which took place in 2015. Expert consultations and public consultations were organized in 7 countries by the Ministry of Agriculture; another 4 countries requested written consultations. The EIA – published on the internet – described the expected environmental effects of the construction, operation and decommissioning of the new units. The results showed that the largest impact on the environment would be the heat release from the power plant into the river Danube during the operation; however, this heat load is still tolerable for the flora and the fauna living in the vicinity of the plant. In the international section of the licensing process, the potential consequences of severe nuclear accidents were demonstrated as well.

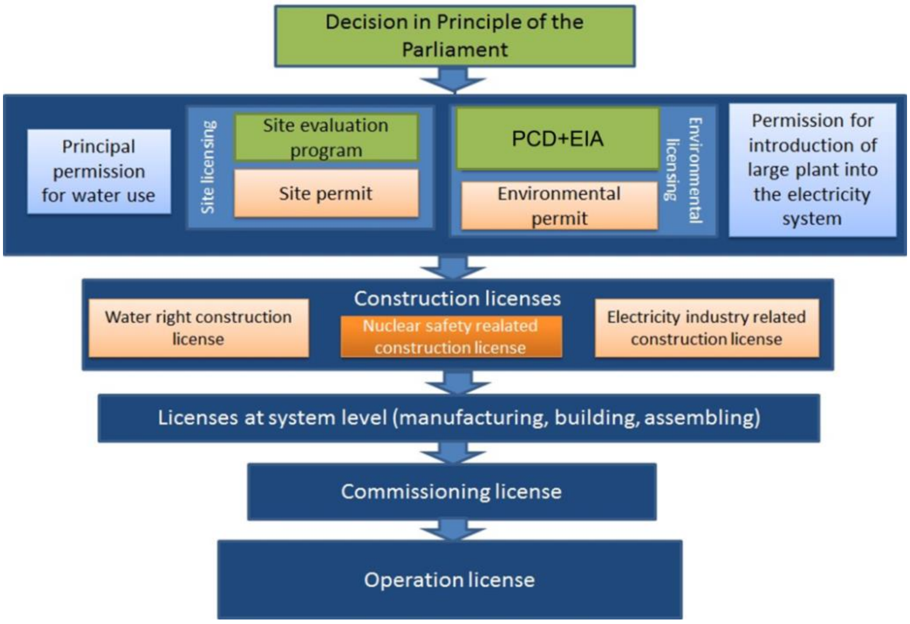

Fig.7. Licensing process for the new units

Concerning the site licensing, the site investigation and assessment program has been already accepted by the Hungarian nuclear safety authority. Based on this program, 3D seismic measurements were performed in August-September 2014 as the first steps of the investigation. The Geological Research Program started in May 2015 with the first geological drilling. The Program includes on-site measurements and laboratory investigations as well with surface and underground research processes.

According to the schedule, the first new unit would start commercial operation in 2025. This requires the start of the construction in 2018. Until this date, the construction licenses should be obtained from the different authorities, requiring hard work in the upcoming years from the licensee and the regulatory bodies as well.

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PHYSICS TEACHERS ON TEACHING THE RADIOACTIVE DECAY LAW

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ABSTRACT

Teaching the law of radioactive decay is a mandatory task in Hungarian secondary schools. It is also one of the major problems in methodology. A survey was done among practicing teachers of physics in secondary schools in this topic. I am seeking to answer the questions below that were asked in the survey:

- *How do colleagues cope with this task?*
- *What aspects and motives can they rate high or name as the main insufficiencies?*
- *What methodological solutions are known? Which ones are in use? Which ones are liked?*

The survey aims to suggest what conditions and needs are to be met in the methodological solutions in order to support success in the teaching practice in the secondary school classrooms. I will also present a project which can give a new solution in didactics to the problem. It is planned based on the "hands-on, minds-on" approach.

INTRODUCTION

The law of radioactive decay is well known in two ways. The law can be put like this using the number of radioactive nuclei:

$$N(t)= N(0)\cdot 2^{-t/T} \tag{1}$$

The law of radioactive decay is also known using the concept of activity:

$$A(t)=A(0)\cdot 2^{-t/T} \tag{2}$$

In both formulae the concept of half-life is essential. As we can see from the formulae above, this law is a representative of the exponential laws in science. Teaching the law of radioactive decay is one of the most problematic issues in physics didactics.

In Hungary the radioactive decay law is in the syllabus of the compulsory physics course for all high school students. According to the national syllabus, the law is to be studied in grade 11, at the age of 17-18.

In a survey a number of active high school physics teachers were asked to report on how they can cope with the task in their everyday practice.

COLLECTING THE DATA

In Hungary there is an annual meeting for physics teacher organized by the Roland Eötvös Physical Society. The one organized in 2015 was held at Hévíz (Fig.1.) from 27th to 30th of March.

The attendance of the event was about 160 people, from which the estimated number of high school teachers present was 65-70. We estimate the number of practicing high school physics teachers at 2500+ in Hungary. Others at the conference were lecturers, experts from companies or universities, colleagues who work in primary schools or others who are interested in physics teaching.

Fig.1. Hévíz, the Hungarian spa

We left the survey sheets at the registration desk, but only five colleagues took one with themselves to support our work. Personal contacts are very important, so based upon this, 47 accepted the sheet, and 35 of them returned it filled.

THE SAMPLE OF COLLEAGUES

First, we need to see who are represented in the survey. The first task was to circle the type of high school the respondent has practice in. Some of the colleagues had practice in several types of schools. We counted each answer as a separate one, so we had 39 checkmarks. Table 1 shows what background of experience we can get information from.

Table 1. Number of teachers who gained experience in the given type of school

type of high school	top third	medium third	bottom third	number of checkmarks
secondary grammar	7	10	4	21
secondary technical	5	7	3	15
vocational	3			3

MONITORING REALITY

The survey was anonymous, because in our country following the syllabus is a compulsory task for the teacher. We chose this since we wanted to find out as reliably as possible how or whether teaching this law really happens in the Hungarian classrooms.

The second task in the survey was to provide information at what extent teaching the law happens in practice. Many of our colleagues made a note saying “depending on the class”, so we considered each mark as separate answers. We gained 46 answers this way. The results the respondents gave are shown in Fig.2. In Fig.2.a) you can see the full scale, whereas in Fig.2.b) we specify the answers of those who need to face problems in their practice.

We can conclude that one third of our colleagues are not satisfied with the work they can perform in their practice. It is definitely an issue we need to pay attention to.

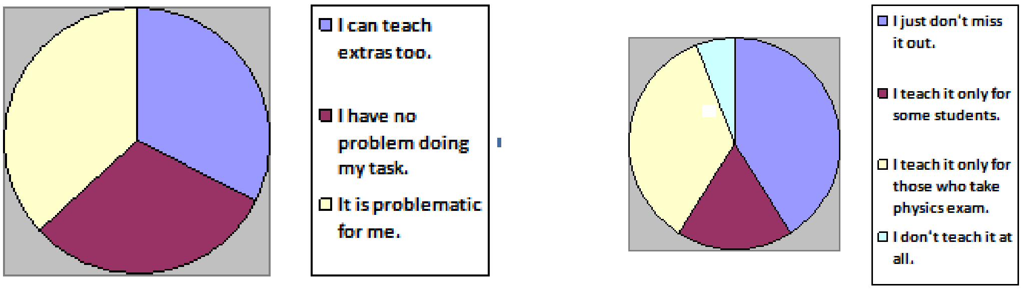

Fig.2. a) Can you teach it? b) Do you mention it at all?

A SURVEY OF THE MOST OUTSTANDING PROBLEMS IN TEACHING THE LAW

We asked the teachers to grade 10 statements. To match the Hungarian evaluation system as much as possible, the grades were 1-5. (1 showing that the statement does not have a great influence on the problems, 5 meaning it is a very important factor.) The statements were put into 3 sets according to the potential causes. Table 2 shows the sets of statements.

Table 2. Types of statements

questions	sets of influence
A1, A2, A3, A4	the students' attitude as a factor of the problems
M1,M2, M3	mathematical skills as causes of the problems
S1, S2, S3	monitoring some scientific issues

Monitoring the students' attitude

We mentioned four aspects in this set (Fig.3. shows the grades for the "A" statements):

A1 Physics among our students is not popular: they don't like, understand, or study this subject.

A2 The attitude of our students is negative to nuclear physics.

A3 They already have fact-fragments in this topic from the media.

A4 This topic is in the last year of the secondary physics course, and it is not a compulsory subject in the High School Leaving Exam (érettségi).

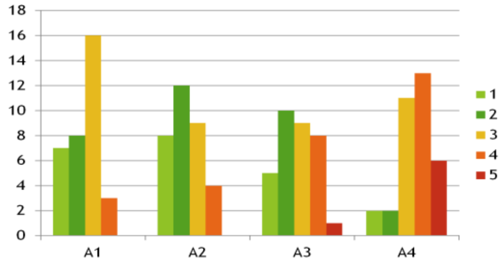

Fig.3. "A" statements graded

Monitoring the students' poor mathematical skills

We mentioned 3 aspects of mathematical skills (Fig.4. shows the grades for the "M" statements):

M1 The law is one of the exponential formulae. The students don't know the exponential functions properly.

M2 The effect of the low mathematical competence of the students is that they are not able to apply their knowledge.

M3 In mathematics classes there are not enough exercises for using mathematics in real problems and applications.

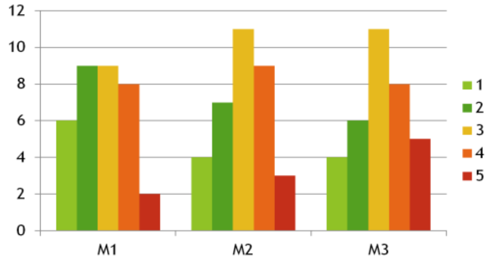

Fig.4. “M” statements graded

Monitoring scientific issues

On the sheet the respondents found 3 statements. They had to grade them just like the previous ones (Fig.5. shows the grades for the “S” statements):

S1 There is no possibility to carry out experiments.

S2 The scientific model students should use is too abstract for them.

S3 There is a lack of knowledge in the model they should also study it in chemistry.

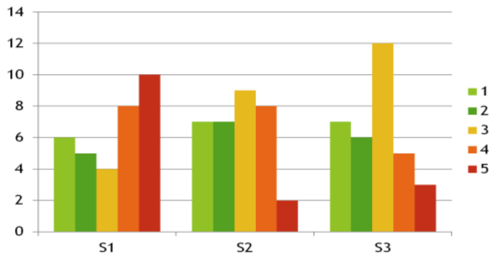

Fig.5. “S” statements graded

Analysing the data

The mean values of the grades for the statements are given in Table 3.

Table 3. The mean values of the grades

	Attitude				Mathematics			Scientific issues		
means (statement)	2.44	2.27	2.70	3.56	2.74	3.00	3.12	3.33	2.73	2.73
means (set)	2.75				2.95			2.93		

So the main problems that were highlighted by the teachers are as follows:

1) 3.56 (A4) This topic is in the last year of the secondary physics course, and it is not a compulsory subject in the High School Leaving Exam (érettségi).
2) 3.33 (S1) There is no possibility to carry out experiments.
3) 3.12 (M3) In mathematics classes there are not enough exercises for using mathematics in real problems and applications.

When studying the answers, two remarks arose. These are really worth mentioning.

* We can envy some colleagues: they graded each but one problem to 1 (2 for S1). It might mean that they don’t find teaching this law a problematic task.

* International surveys show a bad attitude. Hungarian colleagues don’t experience it, they think about it as a result rather than as a cause, or just don’t rate it high as a problem.

Further causes

In the survey we gave opportunity to share further causes and remarks to the mentioned topic for those who gave their opinion. It was an open ended question. The remarks we got are all listed. Our remarks are in brackets.

- “Many have misconceptions; they can’t differentiate it from the distorted esoteric knowledge.”
- “Hungarian physicists’ activity in the last century.” (We can’t see clearly what is meant by this remark. But we do not have a chance to figure it out.)
- “They study no other exponential law, they have nothing to bind to.” (A very important point was highlighted.)
- “In mathematics the statistical nature of the phenomenon, the incidental events are difficult to comprehend. But some students can get fired up just because of this.” (We find it a very important comment from a colleague.)
- “I didn’t rate anything to 5, because my highest mark goes to *Severe Literacy Problems*.” (It is a problem far beyond the physics methodology.)

INTERPRETATION OF DIDACTICAL SOLUTIONS

The evaluation system

We also studied what methodological or didactical solutions are liked, known and used in the teaching practice among our colleagues. We provided a list of didactical solutions they had to grade from two perspectives:

in column 1	in column 2
A – “I know and like the mentioned solution.”	A – “Mostly this is used in my classes.”
B – “I am familiar with the method.”	B – “I have experience with the method.”
C – “I don’t know that method.”	C – “I have no experience with it.”

Evaluating the didactical solutions

Table 4 shows the listed didactical solutions and the results of the evaluation.

Table 4. Evaluation of the didactical solutions

didactical solution	Known? A — B — C			Used? A — B — C		
Presentation & interpretation by the teacher.	22	9	0	30	3	0
Presenting on an educational film.	11	18	3	8	16	7
Processing literature (alone or in a group).	5	20	7	2	9	23
Project or drama pedagogy.	1	13	19	0	3	31
Home essay or student’s presentation.	13	16	1	8	16	8
Computer simulation.	18	9	4	13	15	6
Simulation game.	7	9	15	2	7	20
Data-processing, simulation game, in-situ measurement project, “hands-on, minds-on” way.	4	10	17	0	10	23

We found that our teachers present and interpret the law for their students, and a third of them adds spice to it with a computer simulation or in some other way. A number of methods are known, referring to the fact that our colleagues are open to widen their palette.

Notes, remarks

As an open ended question we asked those who answered to share their further comments in this topic with us.

We can gain ideas from the comments (our notes are added):

- “I am not familiar with the hands-on, minds-on method, though I’d expect I’d like it.”

- "I organize a presentation of measurement for the entire school every year. I warmly recommend it to others!" (Great idea, really!)
- "Keep in contact with companies, and visit a factory." (Great, but not exceptional.)
- "Measuring activity with a Geiger-Muller tube, the sample is prepared with vacuum-cleaner and gauze." (A great idea from the "Physics Teachers in the CERN Program".)
- "Modelling the decay with beer-foam." (This process hasn't an exponential nexus.)

CONCLUSIONS OF THE SURVEY

- The respondents are not a representative group of active physics teachers in Hungary.
- One third of the respondents has problems with teaching the law of radioactive decay.
- Most teachers alter the methods they use to best suit the classes.
- In the opinion of the colleagues mathematical and scientific issues are more influential problems than the students' attitude.
- In the respondents' opinion the most outstanding problems are respectively: no compulsory test in physics, no experiments, not enough applications in maths classes.
- Teachers' presentation and interpretation spiced with computer simulation are the methods used in the Hungarian classrooms.
- These colleagues know other methods as well and might be persuaded to try them.

"PROBLEMS CANNOT BE SOLVED BY THE SAME MIND SET THAT CREATED THEM"

The quote mentioned above is attributed to Albert Einstein [1]. The fact that there are more wordings in the original English suggests that it is a paraphrase of what we can read from him published in the New York Times on 25th May 1946 or 23rd June 1946.

Didactical research had been in progress since the autumn of 2012. Four classes in a Technical High School were divided into eight groups. Four were taught using the "hands-on, mind-on" method. These were tested against the other four groups as reference groups.

As an introductory part of the project, a topic titled "The wonderful world of measurements" gave a base to in-situ measuring project in classical physics. Having experience with the method, special attention was drawn to the exponential laws. First, the "Newton's law of cooling" project represented these tasks: sensing + measuring + data processing. Then, the project titled "Discharging a capacitor" provided measuring + data processing tasks to the students.

In a period lasting from February to April in 2015 the students investigated half-life by data processing. They studied the decay with a simulation game relying on their active participation. Finally, they estimated the number of nuclei in a sample based on "in-situ" measurements and commented on the reliability of the outcome.

This method is appropriate to teaching and also meets the needs and suggestions of experienced colleagues.

ACKNOWLEDGEMENTS

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NEUTRON CAPTURE NUCLEOSYNTHESIS

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ABSTRACT

Heavy elements (beyond iron) are formed in neutron capture nucleosynthesis processes. A simple unified model is proposed to investigate the neutron capture nucleosynthesis in arbitrary neutron density environment. Neutron density required to reproduce the measured abundance of nuclei assuming equilibrium processes is investigated as well. Medium neutron density was found to play a particularly important role in neutron capture nucleosynthesis. Using these findings most of the nuclei can be formed in a medium neutron capture density environment e.g. in certain AGB stars. Besides these observations the proposed model suits educational purposes as well.

INTRODUCTION

Nearly sixty years after BBFH [1], it is possible and necessary to review and rethink our knowledge about the neutron capture nucleosynthesis. The result of the formation of the nuclei is shown in the various abundances. It is important to mention that the unstable nuclei decayed into stable nuclei and we are only able to observe the abundance of the remaining stable nuclei. "The success of any theory of nucleosynthesis has to be measured by comparison with the abundance patterns observed in nature." – say Käppeler, Beer and Wisshak [2], that is, we need to create such model that gives back the observed abundances.

Since the formation of nuclei takes place in a variety of conditions, the experienced abundance is a result of several processes. Therefore, more models are necessary for different conditions. According to the conditions of the models the nuclei are classified into categories as s-nuclei, r-nuclei etc.

It seems that the reverse approach is also useful: the observed abundances preserve the conditions of the formation of the nuclei. Instead of investigating whether the theoretical model fits the observed abundance, we look for the circumstances when the observed abundance is known. To do this, we need suitable data: the half-life of unstable nuclei and the neutron capture cross section of nuclei. These data are not always constant. For certain nuclei the half-life depends on the temperature [2], [3] and [4]. Fortunately, the reaction rate per particle pair $<\sigma v>$ is constant between 10 and 100 keV because of the energy dependence of σ [2], [3]. So we can use the σ values at 30 keV [5]. The possible resonances only improve the capture capabilities.

OVERVIEW

Many nuclei are known (Fig.1.). Processes that are used to describe the formation of nuclei of elements heavier than iron were defined by Burbidge, Burbidge, Fowler and Hoyle (B2FH) in 1957 [1]. In sixty years the model was refined such that element abundances in the Solar System are reproduced with less than one percent error. Such accurate quantitative description leads to the general and unquestioned acceptance of two main processes that describe neutron capture nucleosynthesis in the literature: the s-process (slow process) in low neutron density environments such as helium- and carbon-oxygen-burning asymptotic giant branch stars and the r-process (rapid process) in high neutron density environments, typically supernova explosions. This separation relies on the fact that an unstable nucleus can either decay or first capture another neutron. Assuming individual nuclei and s-process a neutron capture is expected every ten years. Nuclei having a half-life less than a year almost certainly decay. Formation of elements occurs along a path (s-path) in the nuclear valley of stability, from the light towards the heavy elements. Only nuclei having a lifetime longer than ten years must be considered if the strictly classical approach is followed. So the question arises: Does the neutron take part in the neutron capture process during its full fifteen-minute lifetime at all?

Obviously, the classical approach needs refinement if the neutron capture time and decay time are of the same order. The notion of branching was introduced for such cases in the s-process [2] and even the latest literature relies on this view [5], [6]. The r- and s-nuclei are important observation evidences of the two processes. According to the classical model, s-nuclei can only form in s-processes and r-nuclei can only form in r-processes.

In the classical model nucleosynthesis by the s-process occurs in a path along the valley of beta stability and it is generally accepted that the s-process nucleosynthesis terminates at bismuth by the fast alpha decay of polonium [7]. Only with the r-process is it possible to go further from the valley of beta stability to the neutron rich region of nuclei, towards the neutron drip line. And only by the r-process is it possible bypass the trap of polonium.

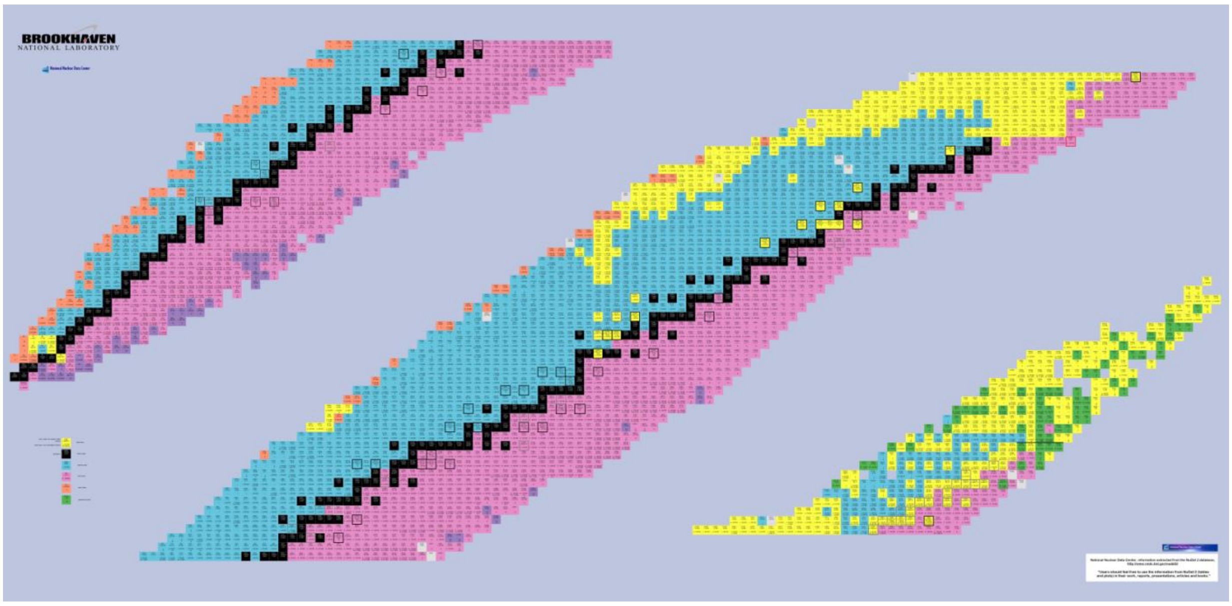


Fig.1. The Chart of Nuclei [8]

THE NUCLEOSYNTHESIS BASED ON OUR MODEL

A computer simulation program was created in order to make a graphical representation of nucleosynthesis by neutron capture [9-12]. The illustrative presentation made the formation and abundance of nuclei visible. Previously unknown details of nucleosynthesis became observable. In the differential equations that provide the basis of our model, the nuclei are distinguished by both atomic and neutron number. The possible values of the neutron density were not limited. The formation of elements is determined by the half-life, the neutron capture cross section, the neutron density and the amount of their parent's nuclei (overstep threshold). The model allows to investigate the role of the individual parameters in the formation of nuclei as well.

Our model requires specific nuclear data for each individual nucleus. Some of these (such as half-life, decay mode and branching ratio) can be found in the literature, but neutron capture cross sections were missing in some cases, mostly for those nuclei that are not used in the classical s- or r-processes. Due to the lack of these data we have investigated both measured and calculated neutron capture cross sections at 30 keV from different sources. Studying published values of Maxwellian averaged neutron capture cross sections we found that those obeyed simple phenomenological rules as a function of proton and neutron number. We found some simple rules for the location of the highest capture cross section on the Z-N plane (Ridge of neutron capture cross sections) and also its maximum value. We used these rules to make predictions for cross sections of neutron capture on nuclei with proton number above 83, where very few MACS data is available and needed for our model [13].

Exploiting the capabilities of our model we have investigated the formation of the elements using various assumptions. We have established that that nucleosynthesis of heavy elements occurs along a wide band near the valley of the beta stability. Our model, named band-process, is based on simple physical assumptions [9-12]. The width of the band and the isotope with the maxima amount in the band depend on the neutron density. The initial amount of nuclei is also important and it depends on the mass and metallicity of the star.

If we use a long time for step and a small amount initial iron nuclei, then we exclude the most of the nuclei from formation. Using a short time interval (one second or shorter) and sufficient amount of initial iron, we can see the true nature of the processes, the band formation of nuclei during the nucleosynthesis by neutron capture. The neutron capture process at low neutron density ($n_{\mathrm{n}} \sim 10^{7} - 10^{8}\,\mathrm{cm}^{-3}$) is called s-process and the neutron capture process at high neutron density ($n_{\mathrm{n}} \sim 10^{20} - 10^{25}\,\mathrm{cm}^{-3}$) is called r-process. Based on our model we can see what these concepts mean during nucleosynthesis and how the bands evolve in the different cases.

We have found that the processes that occur at moderate, $n_{\mathrm{n}} \sim 10^{10} - 10^{14}\,\mathrm{cm}^{-3}$ neutron density (m-process) are very important. They typically take place during the TP state of AGB stars [14], [15].

The nucleosynthesis in stars with moderate mass and low neutron density occurs in a band along the valley of beta stability and is terminated at Z=83 by the alpha decay of the polonium. If the neutron density exceeds $n_n = 10^{12} cm^{-3}$, the evolution does not terminate at bismuth. In AGB stars during a thermal pulse the neutron density significantly exceeds this value so the valley may proceed to fermium. The simulated abundance approximates well the observations, only the abundance of lead is higher than the expected value. Our program indicates the production of r-nuclei at low neutron density and s-nuclei at high neutron density. The r-nuclei found in SiC meteorite grains demonstrate the possibility of their formation in slow or moderate processes [5].

The band of nucleosynthesis reaches the adjacent r-nuclei even at low neutron density, although the amount of these nuclei is negligible. At moderate neutron density the amount of these nuclei increases to the empirical abundance found in the Solar System. However, the experienced abundance can be reproduced with nuclei produced at processes with low, intermediate and high neutron density.

In the case of high neutron density, if the neutron density does not significantly exceed the $n_n = 10^{20} cm^{-3}$ value then some s-only nuclei are also produced with some exceptions (${}^{176}_{72}Hf_{104}$ and ${}^{192}_{78}Pt_{114}$) [9].

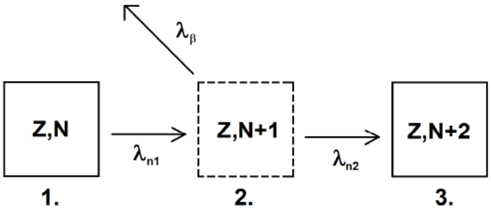
We found that neutron capture process in the AGB TP phase at intermediate neutron density forms elements heavier than bismuth, the formation of nuclei can evolve even to fermium [9]. Although "sweep-out" obscures this situation, there is an empirical argument that confirms the predictions of our model. This argument is the anomaly of the isotopic abundance of tellurium, namely the two most abundant tellurium isotopes are r-nuclei with thirty-thirty percent abundance. This anomaly is unique; there are no other elements with such a strange isotopes anomaly. It seems that there are two arguments: 1. the formation band which includes these two nuclei, 2. fermium that forms in the AGB TP phase goes through spontaneous fission and results in unstable tin isotopes. The unstable tin isotopes decay into ${}^{128}_{52}Te_{76}$ and ${}^{130}_{52}Te_{78}$, and that is the other way part of these two abundant isotopes come into existence [9]. We can reproduce the distribution of tellurium isotopes with a linear combination of isotope distributions obtained with slow, moderate and rapid processes. According to our model the most important places of element formation are AGB stars. This is in agreement with the recent results in the literature [6], [15]. The observation of radio nuclei ${}^{26}Al$ and ${}^{60}Fe$ in the Milky Way and the discovery of the daughter isotopes in the pre-solar grains provide further confirmation of the conclusions of our model [5], [16].

VERIFICATION

Currently, verification of a model almost completely relies on one criterion: the abundances of elements in the Solar System [17] should be correctly reproduced. However, observed abundances include the aggregate effects of multiple processes that take place during nucleosynthesis. It seems reasonable to assume the existence of an intermediate neutron density nucleosynthesis to bridge the gap between the s- and r-processes. Anomalous isotopic ratios observed in early meteorites substantiate such assumptions [5]. Intermediate processes take place in AGB stars.

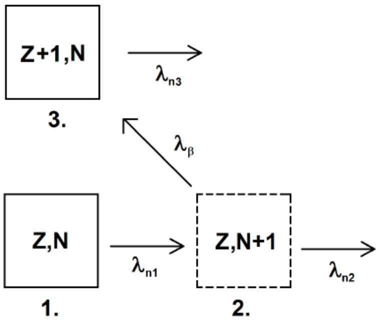
There are several ways to verify the model. Besides the ratio of r- and s-nuclei, mainly the accurate reproduction of the abundances measures the goodness of the model. The latter however, depends on many other parameters, because the elements form in stars of different states under different conditions. The abundance of isotopes is very important for verification as well. Discovery of radiogenic nuclei with long half-life in the Milky Way or elsewhere in the universe could be an important evidence, too.

An independent way of verification is the rate analysis [18]. Abundances of elements can be classified as elemental abundance, isotopic abundance, and abundance of nuclei. In our works the nuclei are identified by (Z,N), which allows reading out new information from the measured abundances. We are interested in the neutron density required to reproduce the measured abundance of nuclei assuming equilibrium processes. This is only possible when two stable nuclei are separated by an unstable nucleus. At these places we investigated the neutron density required for equilibrium nucleosynthesis both isotopically (Fig.2.) and isotonically (Fig.3.) at temperatures of AGB interpulse and thermal pulse phases. We obtained an estimate for equilibrium nucleosynthesis neutron density in most of the cases. Next we investigated the possibility of partial formation of nuclei. We analyzed the meaning of the branching factor. We found a mathematical definition for the unified interpretation of a branching point closed at isotonic case and open at isotopic case. We introduced a more expressive variant of branching ratio called partial formation rate. With these we were capable of determining the characteristic neutron density values. We found that all experienced isotope ratios can be obtained both at $10^8 K$ temperature and at $3 \cdot 10^8 K$ temperature and at intermediate neutron density ($\leq 2 \cdot 10^{12} cm^{-3}$).



$$n_n = \frac{\lambda_\beta}{v\left(\sigma_1 \frac{N_1\sigma_2}{N_3\sigma_3} - \sigma_2\right)}$$

Fig.2. The isotopic case and its equilibrium neutron density



$$n_n = \frac{\frac{N_1}{N_3}\frac{\sigma_1}{\sigma_3} - 1}{\sigma_2}\,\frac{\lambda_\beta}{v}$$

Fig.3. The isotonic case and its equilibrium neutron density

EDUCATIONAL USAGE

The origin of heavy elements beyond iron is an important and interesting problem; therefore, it is worth discussing it in the classroom. Recently these questions are presented in the final exam of high schools [19].

Traditionally we speak only about fusion and decays, but it also is an interesting question how the elements heavier than iron are formed. The primary purpose of our investigation was educational. With the model the processes can be followed and demonstrated easily and can be integrated into education.

Our model is capable of demonstrating the decay processes, the decay trees from arbitrary initial nucleus (i.e. isotope) as well. So we can follow the change of the amount of seed isotopes and the daughter isotopes as well.

CONCLUSIONS

The neutron capture formation of nuclei occurs in a band. There are no r-nuclei (in exclusive meaning). Most s-nuclei can form in r-process. The bypass of bismuth is possible at medium neutron density. All experienced isotope ratios can be obtained both at $10^8\,K$ temperature and at $3\cdot10^8\,K$ temperature at intermediate neutron density (10^{12}-$10^{14}\,cm^{-3}$), so the m-process and the AGB stars are probably one of the main places of nucleosynthesis. It seems that the so-called r-nuclei can form in intermediate processes as well.

Our model is also capable of visualizing the processes of neutron capture nucleosynthesis and the decay processes as well.

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VISIT TO THE MAINTENANCE AND TRAINING CENTER AT PAKS NUCLEAR POWER PLANT

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ABSTRACT

The last official program of the Teaching Physics Innovatively (TPI-15) conference was a visit to Paks Nuclear Power Plant (NPP) in particular to the Maintenance and Training Center (MTC), with approximately 30 participants. The scope of MTC is the preservation of staff competence and training for any new activities in a non-radioactive environment. Besides this work, the MTC offers for the public guided tours for the better understanding of the basic nuclear processes and operational techniques of a modern NPP.

1. HISTORY AND IMPORTANCE OF PAKS NPP

Paks is a small town located in the middle of Hungary on the shore of the river Danube. Here is the Paks Nuclear Power Plant (NPP) [1] located, which operates 4 nuclear units from the 1980's. The type of the units is VVER440-213 [2] which denotes a Russian-designed Pressurized Water Reactor (PWR). The first unit produces electricity since 1982 and the youngest unit is in operation since 1987. The nominal electric power of the reactors was 440 MW, however, through the years the reactor powers have risen to 500 MW. The planned operation time of the units was 30 years, but thanks to the operation lifetime extension programs this period will be expanded by another 20 years [3]. The total power of the four units is 2000 MW, which covers approximately 50% [4] of the Hungarian electricity production and approximately 40% of the electricity consumption. Thus Paks NPP plays a very important and unique role in the Hungarian electricity market.

But why is it so unique? In our world the global warming and the reduction of the emission of greenhouse gases has become a major and urgent global problem. To solve this problem the use of renewable energy sources together with the nuclear power [5] could be the key, since the greenhouse gas emission during the normal operation of these technologies is zero. Modern countries around the world, for example the counties of EU agree that the greenhouse emission should be decreased step by step in the future. The use of nuclear power totally satisfies this modern demand.

To understand this claim we should explain the principles of operation of a NPP. In a NPP the energy is released from a nuclear fission reaction, in the particular case of Paks NPP, where enriched UO_2 is the material of the fuel, the following reaction releases the energy:

$$n + {}^{235}U \rightarrow 2 \text{ fission fragments} + \text{new neutrons} + \text{radiation} + \text{kinetic energy} \quad (1)$$

The average energy that is released in one fission reaction is about 200 MeV. This energy is distributed as the photon energy and kinetic energy between the released particles. The kinetic energy of the β particles and the fission fragments will be dissipated in the vicinity of the fission event (in the UO_2 matrix) while neutrons and γ radiation can very easily leave the fission fuel. After the thermalization of the new neutrons they can close the loop causing new fission events. This loop is also called nuclear chain reaction.

The Paks NPP is a PWR reactor which contains a huge amount of water. The water in this system has a double purpose: it is used as a moderator or neutron slowing material and water is also used as a coolant.

The moderator material is essential because only relatively slow neutrons, so-called thermal neutrons can cause easily nuclear fission in the ^{235}U, but the neutrons born in the chain reaction are with relatively high energies (~2 MeV).

As mentioned above, the fission fuel will absorb a great fraction of the released energy, thus it will be heated up, and it will transfer its heat to the coolant, the water. The water is circulated in a closed circuit through the reactor core (so-called primary circuit), where the typical temperatures are around 270 ^{o}C and 300 ^{o}C in the inlet and outlet points, respectively. For these high temperatures an increased water pressure is also needed to prevent the boiling of the water in the reactor core. The typical pressure in the reactor core is about 120 bar. The primary circuit can transfer its heat to another closed circuit called secondary circuit via a heat exchanger, so-called steam generator.

The pressure in the secondary circuit is much smaller, therefore a huge amount of hot steam will be generated, absorbing the heat transferred from the primary circuit. The steam drives the turbines and the turbines drive electric generators.

After the foregoing it is clear that NPPs do not produce greenhouse gases, and the clouds which are released from their cooling towers contain only evaporated water. In Paks the cooling towers are missing since the cooling of the closed secondary circuit is solved with fresh water from the Danube.

2. THE ROLE AND MISSION OF THE MAINTENANCE AND TRAINING CENTER

The Maintenance and Training Center (MTC) [6] is located at the Paks NPP site. The MTC is a unique place where the workers of the NPP can be trained and prepared for any kind of work in a non-radioactive environment since 1997. The spectrum of these trainings is very wide, from the occupational safety and health (OSH) trainings to the specialized maintenance works everything takes place here. But the MTC fortunately offers even more, there is the possibility for visitor groups to participate in guided tours. These tours introduce every aspect of the work on a real nuclear unit from the clothing and proper use of work protection techniques to the detailed working scheme of motors, pumps, armatures. Moreover, from the point of view of a visitor the MTC provides a unique opportunity to see and touch (or even crawl inside) a full-scale (original) steam generator and a reactor core. The reactor core contains every part of a real reactor except the nuclear fuel assemblies so the reactor tank, reactor shaft, control rod drives etc. These original reactor equipment were transported to Paks from a built but never used nuclear unit in Poland. During the guided tours the visitor can listen short presentations and they can ask questions according to their field of interest. While this is a non-radioactive facility of the NPP, it is ideal for visitors, where they can really see and learn how large and complex an NPP is. For a layman the visit of the MTC is advised after the visit of the Visitors Center.

3. THE ADVANTAGE OF A VISIT AT MTC IN PHYSICS EDUCATION

The traditional way of teaching nuclear physics or nuclear techniques in Hungary is mainly based on strong theoretical education or hands-on trainings with small isotope sources, but there is no chance for real application-oriented training, or to experience the real industrial scale of modern nuclear facilities. This is also the situation in high school even during the higher educational training (except for a few specializations). However, Hungary is in a special situation because there are 6 nuclear reactors in operation: 4 NPP units at Paks and two smaller reactors at Budapest. There is an Experimental Reactor at the Hungarian Academy of Sciences (HAS), Centre for Energy Research (EK) and the Training Reactor at the Budapest University of Technology and Economics (BME).

For nuclear physics and technology education the training on the two units at Budapest is essential, however, these facilities cannot introduce the industrial scale applications to the students. Therefore, even for university students it is a great opportunity to visit the MTC and experience the real industrial environment for their own. This type of visit is periodically organized for mechanical engineers and physicists, where Hungarian students and also students from abroad (Slovakia, Brazil, Vietnam) can participate.

For high school students the visit of the MTC can be even more beneficial. Many physical education topics are related to NPP and the electricity production process, for example mechanics, thermodynamics, nuclear physics, electrodynamics, etc. During a visit it is easy to demonstrate how physics is working in real life applications from all of the above mentioned topics.

4. DESCRIPTION OF A VISIT

For the visit a prior appointment is necessary, which can be done through the Information and Visitors Center of the NPP. It is recommended to devote at least 2-3 hours or more for a visit if a visit to the Information and Visitors Center or to the Museum of Nuclear Energy is also included. Visiting groups over 16 year of age can visit the power plant’s operational area as well, then a longer time is needed. The standard maximum size of a visiting group is 40 people, this group size is ideal for a secondary school class. Catering can be organized at the NPP’s canteen.

During a visit in the MTC the visitors can look at some 1:1 scale original primary and secondary circuit components, the same types that are in use at the Paks NPP: The visit includes a hands-on experience with the steam generator and the reactor vessel. The guides who are active trainers at the maintenance center kindly answer any kind of NPP- or MTC-related questions. During the tour teaching aids, nameplates of components and even film screening helps the better understanding of the ongoing physical and operational processes of the NPP. The attendance is free of charge.

5. SAFETY ISSUES TO EXPERIENCE

The safety issues used in a nuclear power plant have significantly high importance during the operation. This is one of the keys to the operation without accidents, incidents or malfunctions. Nuclear power plants use the concept of defense in depth, which means every system is redundantly installed and the reactors are inherently safe. To understand this concept visitors can see every safety barrier to prevent the release of radioactive materials to the environment. The first barrier is the fuel ceramics matrix, which retains fission products in the fuel itself. The second barrier is the fuel cladding, which encloses the fuel in zirconium-alloy tubes. The third barrier is the primary circuit itself, and the last barrier is the airtight reactor building called box or containment. To experience these safety concepts is useful even if the students won't choose a related profession in the future, because generation of fear and rumors increasingly appear in the media.

SUMMARY

During the last day of the TPI-15 conference a visit to Paks NPP, in particular to the Maintenance and Training Center took place, where the participants could experience the advantages of such a training center in physics teaching on their own. During a few hours of guided tour several physics area are brought up in the explanation of the basic operational processes of the NPP which can be extremely fruitful for secondary school students. This type of visit is ideal to experience the complexity of an industrial facility but keeping always in foreground the underlying physical processes and the most important aspects of nuclear safety.

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6. Kiss. I.:, The maintenance training center of the paks nuclear power plant – past, present and future, VGB PowerTech **81**, 101-104, 2001.

An areial view of the Paks NPP with river Danube in the background (source: [1])

The main buildings of the Paks NPP (source: [1])

Vessels in the NPP that the visitors can touch or even crawl inside (source: [1])