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THE PAKS NUCLEAR POWER PLANT

SCIENTIFIC INVENTIONS - PRACTICAL APPLICATIONS

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A fair question may be what lessons and messages a presentation of a nuclear power plant that was conceptualized in the sixties-seventies and commissioned in the eighties tan provide. Energy consumption by populations causes global problems so the development and safety of nuclear energy has a high priority in our global world.

Modern civilization and development cannot be imagined without electric power and from this point of view Paks Nuclear Power Plant is a positive example, because it is one of the most successfully operated nuclear power plants in the world. In our opinion, solving global environmental and climatic problems is inconceivable without using nuclear energy. But our main reason is to present Paks Nuclear Power Plant due to scientific invention and technical development, as not a technical acquisition of a declined atomic age, but as a clean source of electric power that meets current modern requirements and that tan be operated safely for many years to come.

The main parameters and operating characteristics of Paks Nuclear Power Plant (figures on p. 189) clearly demonstrate the outstanding technical level of the plant. We analyse why and how this technical level has been reached, what preparations preceded the domestic usage of nuclear energy, what innovation process was initiated from the very start until now in order to increase safety and availability of the nuclear power plant. This presentation is a technical-historical overview that also provides lessons for future and other technical-scientific areas.

Features of the Nuclear Power Plant

The four units of the Paks Nuclear Power Plant are operated with water moderated, water cooled reactors of the VVER-440/V213 type. This type was developed in the seventies in the former Soviet Union. The development reflected the possibilities and restrictions of Soviet industry: the quality of mechanical engineering, and the relative underdevelopment of electronics and computer technology. This type is not characterized by technical solutions that determine the actual safety of the units, optimized from an investment point of view, but by oversized solutions. On the one hand the VVER-440/V213 type is characterized by a robust reactor core, which is small in the neutron-physical sense with a low, stable power distribution that tan be easily controlled. On the other hand it is also characterized by large coolant mass, smooth, stretched out transient behavior and decay heat removal less sensitive to operator errors. The design solution of the containment and pressure suppression system is quite unusual, and different from the technique widely accepted in western designing practices of that time. In 1983, during his visit to the nuclear power plant, *Eugene P. Wigner* said with some wonder: *"There is too much steel and concrete for this low capacity"*. Some disadvantages of this type are already known. This type was not designed for resisting outside environmental effects (for example: earthquakes) and its protection against inside danger sources (for example: high energy pipeline breaks) is not adequate, the former qualification of the installation did not follow western practices.

The Paks nuclear power units were connected to the grid between 1982 and 1987. As a result of some improvements the actual power of the units is above that designed: Annual electric power generation is around 14000 GWh, which is about 40% of the total electric power generation of the country. This type of electric power generation is the cheapest in the country. The complete lifetime load factors of the units are 83.7-87.4%, which means, that according to operability and load factors two of our units are among the top ten but alt the units are among the best 25 nuclear power units on the world.

Successful operation is verified not only by the performance indicators, but also by the safety statistics. The number of reactor scrams per year for a unit is less than 1. Events occurring during the operation of the units are inconsiderable or irrelevant with respect to the internationally accepted event rating scale and safety.

The nuclear power plant is extremely clean and ecological beneficial. The amount of radioactivity released is below the authority limit, e.g. the amount of gases with respect to radioactive noble gases is about 5% of the authority limit, in other cases it does not exceed 1% of the limit. But the most important aspect is that due to its operation carbon dioxide emissions in Hungary is smaller by 24%, i.e. 14 million tons a year due to the Nuclear Power Plant.

Technology Transfer on the Borderline of the East and West

Among the pioneers and inventors of nuclear energy utilization Hungarian scientists played an important role in this century. At the entrance of the Nuclear Power Plant, the busts of *George de Hevesy*, *Leo Szilard*, *Eugene P. Wigner*, *Edward Teller* and *John von Neumann* welcome the visitors (photos on centerfold). For historical reasons and geopolitical conditions, Hungary imported the nuclear power plant from the former Soviet Union as ready-made technology. Now it is absolutely clear that the transfer of nuclear technology from the Soviet Union was successful in those cases where the recipient country, on the basis of its degree of technical-scientific development and erudition, was able to criticize the imported technology and was prepared to creatively use the scientific and technical results and safety requirements of the western world for Soviet designed nuclear power plants.

The Top Twenty-five *Source: Nuclear Engineering International*

Lifetime World Power Reactor Performance to June 30, 1998, among 375 reactors over 150 MWe

Rank	Country	Year of First Power	Capacity Factor %
1	Germany	1988	92.0
2	Germany	1989	90.5
3	Germany	1984	89.3
4	Finland	1980	87.5
5	Germany	1984	87.3
6	Finland	1978	87.0
7	Belgium	1985	86.9
8	Finland	1980	86.3
9	Switzerland	1971	86.3
10	Hungary	1986	86.1
11	Hungary	1987	85.9
12	Switzerland	1979	85.5
13	Hungary	1984	85.1
14	Spain	1984	85.0
15	Belgium	1982	84.7
16	Japan	1992	84.4
17	Germany	1988	84.2
18	U.S.	1989	84.2
19	Germany	1981	84.1
20	Belgium	1982	84.1
21	Spain	1985	84.0
22	Finland	1977	84.0
23	Hungary	1982	83.8
24	Spain	1983	83.7
25	Canada	1982	83.7

$$\text{Capacity Factor} = \frac{\text{actual electricity generation}}{\text{perfect electricity generation}}$$

In Hungary at the end of the fifties, by constructing a research reactor near Budapest, the establishment of a domestic, independent, technical-scientific base was started. Engineers and physicists graduated from Hungarian universities, and specialists who had obtained special qualifications in Soviet universities were ready to use the new technology and nuclear energy (considered as the gift of the atomic age in Hungary as well). Under the then political conditions research-development work was performed mainly in co-ordination with the then socialist block. In the scope of this co-operation Hungarian researchers and research bases (critical systems at the Central Physics Research Institute ZR6 and the thermohydraulic testing equipment at NVH) played a more and more important role, which partially can be explained by the respective openness of the country, as Hungarian research acted as a bridge between the East and West from the sixties. In this way Hungarian technical-scientific capacity developed under a twofold effect. Launching education in nuclear engineering in Hungary and the construction of the training reactor at the Budapest Technical University joined with the vision of a growing, very prospective branch of industry. In fact the country accepted the decision about construction of the nuclear power plant favorably. Young and talented technical specialists started to work in the electrical industry with great ambition. Probably only a few nuclear power plants in the world have been established and are operated by such a qualified, even in a certain sense overqualified, personnel as the Paks Nuclear Power Plant. The Paks Nuclear Power Plant uses the services of Hungarian institutions and international companies, it has in-house technical support capacity, which is able to solve problems independently in each area. There is also technical support capacity integrated into operation and maintenance, which is able to solve problems from simple troubleshooting to processing complex problems. It is a fact that the over-qualification and large technical support capacity in this industry, but especially at the operating company, is not usual, but even in most countries with developed technical infrastructure it is not necessary. We are sure, however, that the safety and availability of the Paks Nuclear Power Plant has needed and will continue to need extraordinary human resources in the future.

The twofold, eastern and western effect showed clearly during the discussions about the technical documentation of the nuclear power plant, where the Hungarian party knowing western safety requirements and development achievements - was able to modify the original plan in several points or could obtain confirmation of the design with suitable analyses. In Hungary analyzing the facts and experiences obtained from the TMI accident gave significant cause for discussion with the designer. Quality assurance used during the establishment and the rigorous control functions of the prospective operating organization contributed greatly to the quality of construction, so that the quality deficiencies of the industry at that time were eliminated during construction, assembling and commissioning the units. The first significant achievements of the critical and innovative approach were already born during the construction of the plant: in Units 3 and 4 Hungarian measuring devices and data acquisition systems were installed. They have been followed by a Hungarian in-core data acquisition and analysis system, which - by better monitoring of the core condition - has allowed the exploitation of the thermal capacity of the unit while meeting the given authority limits.

The nuclear power plant not only affected the innovation directly linked to the operation, but also gave inspiration to nuclear research activities and was the mentor of several R&D topics and educational projects. As an example, Vocational School for Energetics in Paks can be mentioned, which was established and maintained by the Paks Nuclear Power Plant. However, the nuclear power plant has devoted the most to supporting domestic research and development work for the evaluation and upgrading of nuclear safety. Thanks to this, in Hungary expertise, analysis techniques, software and methods are available and are developing continuously, which is necessary for the adequate and accepted evaluation of safety by the western developed countries. It is partially a follow up research; results can prove constructive use of the scientific achievements accumulated in the world, highgrade creativity in the field of safety evaluations and accident stimulation. In some cases the applicability of western methods was justified experimentally. Complex evaluation of safety made it necessary to develop disciplines that were not widely practiced in the country before, such as seismic engineering, and modern engineering techniques, such as the support of the application of finite-element strength and dynamic analyses methods.

This creative, technical-scientific activity was affected by some great names in nuclear engineering visiting Paks, such as *Eugene P. Wigner, Alvin Weinberg* and *Edward Teller*, as well as by critical reviews of the International Atomic Energy Agency (IAEA) and other international organizations, which were carried out in Hungary first among the countries with soviet designed units.

For the Safe and Clean Generation of Energy

The mistrust followed the TMI accident and then the complete discredit of the Chernobyl accident inspired Hungary to make attempts for verifying the safety of the nuclear power plant, which plays important role in respect of electric power generation and even of the national economy. Preparation and the first safety evaluation was performed in the eighties in the frame of the Hungarian research and development programs supported by the nuclear power plant. Hungarian attempts well fitted to the safety review work coordinated by the IAEA (Vienna) and gave a positive example to other VVER operators. While in other Central and Eastern European countries the change of the political regime, in Hungary a logical internal development caused the critical safety evaluation of the VVER-440/V213 units at the Paks NPP. In 1994 a complex safety evaluation - the criteria and techniques of which met the requirements of developed countries - was financed and supported technically by the Paks Nuclear Power Plant. When Soviet technology was shocked by the Chernobyl catastrophe, the institutions and suppliers, which were negatively affected by the political changes, were not able to provide practically any support to this review. This self-criticism gave legitimacy to the Paks Nuclear Power Plant in the eyes of the Hungarian and international professional and non-expert public opinion. Re-evaluation of the safety included system analyses, deterministic incident and accident simulations, probabilistic safety analysis (PSA) and severe accident analysis. These analyses covered internal events, human error, and - in the frame of an independent project - protection against inside and outside environmental effects, such as earthquakes, aircraft-crashes, highenergy pipeline breaks. It was confirmed that with respect to internal events or risk sources the core damage frequency of the units is several times 10^{-4}/year. This value is similar to the average safety level, which was considered to be acceptable even during the early eighties. It was also shown that by performing some important technical measures and safety upgrading modifications the core damage frequency could be reduced by one order of magnitude with respect to the internal risk sources. As a result of this analysis the nuclear power plant started a safety-upgrading program, which essentially improved the protection and operability of heat transfer from the reactor. The safety upgrading modifications and measures that have been carried out so far have already reduced the core damage frequency by nearly one order of magnitude. As a result of the re-evaluation of the site seismic hazard a comprehensive program has started to review and improve the seismic safety of the plant.

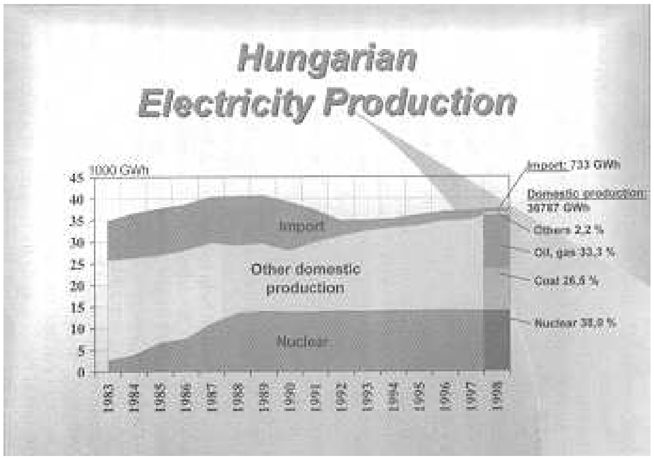
Between 1996-98 after the complex safety evaluation of the plant, the re-evaluation of the site's seismic risk and the start of the safety improvement program, the Paks NPP - first among the former socialist countries - performed the periodic safety review of Units 1 and 2, which not only considered the designed status, but also the ageing of the equipment. The method and criteria of the periodic safety review met the international practices set by the International Atomic Energy Agency. The review confirmed, ranked and scheduled the safety improvement measures. The new Act on Atomic Energy, accepted in 1996, and the governmental decrees and nuclear safety regulations issued together with this act determined the frame of the implementation of this program. The shutdown probability safety analysis, fire and flooding probability safety analysis, which have been carried out since that time, and their measures complete the safety improvement program of the nuclear power plant.

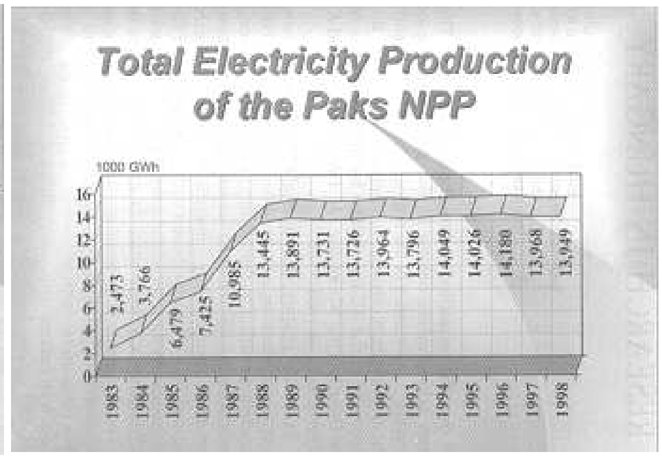
On the Edge of the New Millennium

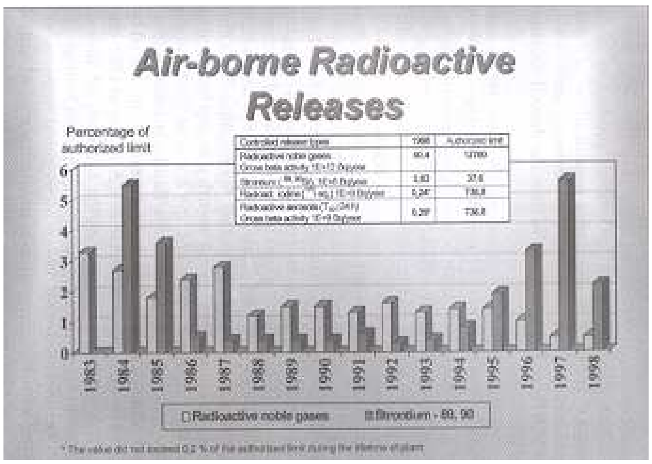
The aim of the Paks Nuclear Power Plant is to complete the safety improvement program by the end of 2002, so that the total core damage frequency is reduced to 10^{-5}/year in respect of the inside risk sources and earthquakes. On this basis at this safety level the further operation of the plant is ensured. However, our conception of safety of the nuclear power Plant is not static: new scientific knowledge, operating experiences may discover new aspects of safety and we have to be prepared to solve new problems in the new millennium.

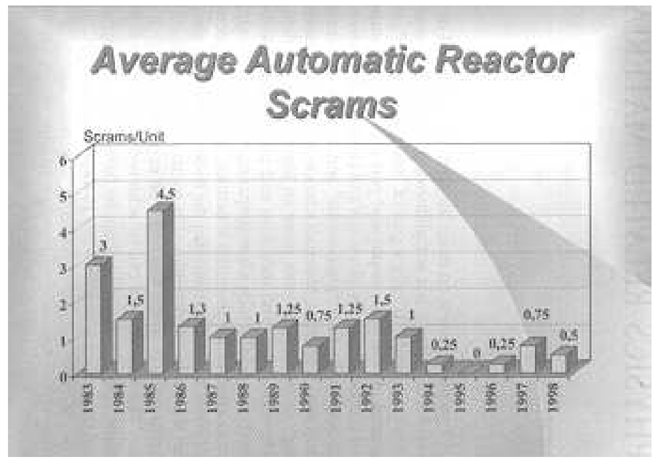
Today we think that the new technical-scientific challenges will be connected to the extension of the nuclear power plant's lifetime and making provisions for possibilities of the expanded lifetime. An important question will be the reasonable scheduling of the reconstruction, but mainly the determination of the lifetime of the non-replaceable equipment, components and their limit of safe operability. The latter requires the development of not only typical nuclear engineering disciplines, but also new achievements in material sciences for determining the radiation damage of the reactor vessel material or ageing of other, non-replaceable components. By the new millennium the Paks Nuclear Power Plant first among the eastern VVER nuclear power plants will have a modern, freely programmable reactor protection system, which is one of the first examples of the safety-related reconstruction. Another complex reconstruction is the replacement of the water condensers. The new condensers with stainless steel tubing make the application of secondary water chemistry with a high pH value possible, which saves the lifetime of the steam generators. The power Plant has just started the comprehensive lifetime management program that is to analyse the problems of ageing and safety, safety and lifetime, and to elaborate adequate strategies in this field.

In the new millennium a new challenge is, however, not only to operate the existing units with such a high safety that is acceptable to the public, bit to establish new reactor units. In our opinion the site of the Paks Nuclear Power Plant is predestined by the established infrastructure and professional culture to have new nuclear power units constructed on it in the future, especially when decommissioning of the existing four units becomes due. The population of the region accepts high-tech nuclear facilities. Operating experiences of the four units at the Paks Nuclear Power Plant prove completely that in the hands of conscientious, well-prepared operating personnel, who are committed to safety, the nuclear power Plant is the cleanest source of electric power. Rigorous monitoring of environmental effects and the condition of the environment is one of our most important tasks, by which we establish not only the acceptance of the existing four units by the public, but environmental protection and public conditions for construction of the prospective units. We are sure, that we can provide the best alternative from both ecological and economical aspects for future generations.


Hungarian
Electricity Production
1000 GWh
Import: 733 GWh
Domestic production: 36767 GWh
Others 2,2 %
Oil, gas 33,3 %
Coal 26,5 %
Nuclear 38,0 %
Import
Other domestic production
Nuclear
1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998


Total Electricity Production
of the Paks NPP
1000 GWh
2,473
3,766
6,479
7,425
10,985
13,445
13,891
13,731
13,726
13,964
13,796
14,049
14,026
14,180
13,968
13,949
1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998


Air-borne Radioactive
Releases
Percentage of authorized limit
1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998
Radioactive noble gases
Strontium - 89, 90


Average Automatic Reactor
Scrams
Scrams/Unit
3
1,5
4,5
1,3
1
1
1,25
0,75
1,25
1,5
1
0,25
0
0,25
0,75
0,5
1983 1984 1985 1986 1987 1988 1989 1990 1991 1992 1993 1994 1995 1996 1997 1998