JOURNAL OF SCIENCE OF THE MILITARY ACADEMY OF LAND FORCES

Volume 49 Number 3 (185) 2017

DOI: 10.5604/01.3001.0010.5127

THE USE OF NUCLEAR ENERGY FOR MILITARY AND CIVILIAN PURPOSES SAFETY IN THE NUCLEAR POWER INDUSTRY

Roman JÓŹWIK*

* *Military Institute of Armament Technology – Zielonka*
e-mail: jozwikr@witu.mil.pl

Received on 2nd March ; accepted after revision May 2017

Abstract:

The purpose of the article was to gather the basic information about the mechanism behind nuclear energy formation and the types of reactors, already built worldwide or potentially planned for construction in the near future, and to present the history of the beginnings of nuclear power in Poland. The issues of the safety of reactors, independent safety assurance systems and systems for emergency shutdown of a reactor are discussed in more detail. The problem of responsibility for the safety of nuclear equipment is also examined, including the relevant authority and method for such safety inspection. The initiatives taken in Poland in connection with the programme for the nuclear power industry are also described.

Keywords:

Nuclear energy, chain reaction, nuclear reactor, safety systems, programme for the nuclear power industry

INTRODUCTION

The phenomenon of nuclear fission was discovered by Otto Hahn and Fritz Strassmann in 1938. In 1939, Lise Meitner with her nephew, Robert Frisch, published the research results (Nature, 143, 239-240), which showed that from among heavy elements only two can be split using low energy neutrons, the so-called thermal neutrons. These are:

$$^{235}_{92}\mathrm{U} + n \rightarrow {}^{93}_{36}\mathrm{Kr} + {}^{140}_{56}\mathrm{Ba} + 3\,n + 2\mathrm{x}10^{8}\mathrm{eV}^{*}$$

$$^{239}_{94}\,\mathrm{Pu} + n \rightarrow {}^{140}_{56}\mathrm{Ba} + {}^{94}_{38}\mathrm{Sr} + 2n + 2\mathrm{x}10^{8}\mathrm{eV}$$

$$^{239}_{94}\,\mathrm{Pu} + n \rightarrow {}^{130}_{51}\mathrm{Sb} + {}^{107}_{43}\mathrm{Tc} + 3n + 2\mathrm{x}10^{8}\mathrm{eV}$$

These reactions are accompanied by gamma radiation (having the energy of a few MeV), whereas the kinetic energy of the fission products amounts to approx. 200 MeV. The above energy is released during the disintegration of one nucleus. The disintegration of all nuclei in one kilogram of uranium would release the energy of approx. 80 TJ, which is equivalent to the explosion of 20,000 tons of trinitrotoluene.

As illustrated by the reactions presented hereinabove – in the process of fission of both uranium and plutonium more than one neutron can be emitted. Owing to this a chain reaction can occur. Two or three emitted neutrons can split one, two or three atoms of U (Pu).

Thus, the chain reaction may develop in a geometric progression. The condition for the occurrence of such reaction is the appropriate volume (critical mass) of the fissionable material, enabling the generated neutrons to find subsequent uranium nuclei, which prevents them from escaping outside the reaction area.

*An electron volt (eV) is a unit of energy used in nuclear physics. One electron volt is the energy gained, or lost, by an electron, which moved in the electric field with a potential difference of one volt.

$$1\ eV = 1e \times 1V = 1{,}602 \times 10^{-19}\ J$$

Where does this huge amount of energy come from? To explain briefly the mechanism of its formation the comparison between chemical and thermonuclear synthesis reactions can be used. The combustion of hydrogen may serve as an example of chemical synthesis. The reaction occurs at the level of the electron shell of an atom.

The ENERGY released during the combustion of hydrogen is the ENERGY OF THE BOND of the newly formed water molecule. It means that the necessary condition for disintegrating the molecule into oxygen and hydrogen is the provision of the same amount of energy.

$$2H_2 + O_2 \rightarrow 2H_2O + \text{approx. } 2eV/\text{molecule}$$

2eV – energy of a water molecule bond

The nuclear synthesis or nuclear fusion is the phenomenon, which consists in fusing two lighter nuclei to form one heavier nucleus.

$${}_{1}^{2}H + {}_{1}^{3}H \rightarrow {}_{2}^{4}He + 1n + 2x10^{7}\ eV$$

As a result a helium nucleus and a neutron are formed and the energy of the bond of this nucleus is also emitted.

Why is the energy of a nucleon-nucleon bond in the atomic nucleus more than a dozen million times greater than the energy of the bond in the chemical molecule?

Atomic nuclei are composed of protons and neutrons. Protons have a positive electric charge and therefore they repel each other. In order to join them they have to be close enough to each other to make the nuclear forces act and overcome electrostatic repulsion forces. Nuclear forces have to be significantly greater than the electrostatic repulsive forces and they act over distances of the order of the size of nucleons, i.e. 10^{-15} m.

Nuclear forces belong to strong interactions and they are the fourth type of interactions known in physics. They are more than a dozen million times greater than the forces of the so-called weak interactions, e.g. electrostatic interactions. Thence, the energy of the bond released during the thermonuclear reaction is more than a dozen million times greater than the energy of the bond released during the chemical reaction.

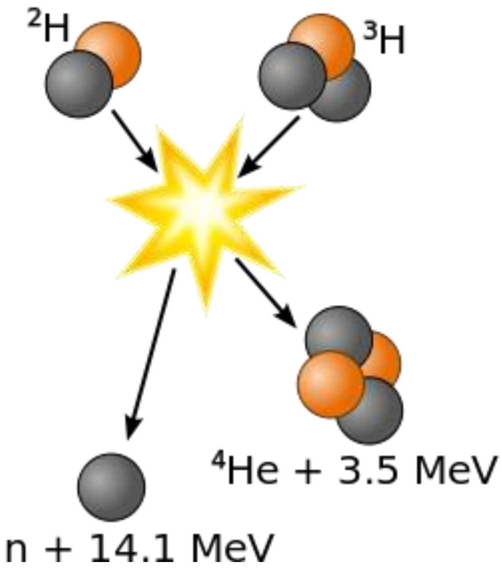


Fig. 1. Thermonuclear synthesis of hydrogen isotopes

Source: [17]

1. PRACTICAL APPLICATIONS OF NUCLEAR ENERGY

1.1. Nuclear reactor

A nuclear reactor is a device used to carry out a controlled chain reaction, i.e. the continuous acquisition of energy from the fission of U^{235} or Pu^{239} nuclei. The operation of the reactor is based on the controlled fission reaction (chain reaction). For the reaction of splitting uranium nuclei to continue (and, thence, for the operation of a reactor) it is necessary to slow down the accelerated neutrons released with the energy of 14 MeV from the uranium nuclei during the fission.

A typical nuclear reactor consists of a core, neutron reflector and biological shields. The core itself comprises fuel rods, control rods, safety rods, moderator, cooling channels and test channels.

1.2. First objective – nuclear bomb

In April 1939, in Germany, the Nazis started to work secretly to this aim. Although the German scientists were pioneers in nuclear research by 1941, later they were left far behind by the Americans and the British and even by the Russians. It can be attributed to the fact that many outstanding physicists and chemists escaped to the U.S. to avoid persecution in the Third Reich (it should be remembered that many of them were of Jewish origin, e.g. Albert Einstein or Lise Meitner).

In 1942, in the U.S., the Manhattan project started, the objective of which was to produce a nuclear bomb – before it was accomplished by Nazi Germany. The secret research centre was located in Los Alamos in the Nevada Desert. Robert Oppenheimer was the manager of the project and Lise Meitner was his right hand. The other participants of the project included also Niels Bohr, Arthur Compton, Enrico Fermi, Otto Frisch and Klaus Fuchs (who was later proved to be a spy for the Soviet Union). As many as 26 then present and future Nobel Prize laureates were involved in the project.

In the middle of July 1945, the above-mentioned group conducted the first test explosion of a nuclear bomb. The scientists were 100% positive about its design and the probability of an explosion. Similar bombs were dropped on Hiroshima and Nagasaki (6 and 9 August 1945).

1.3. First reactor

Already at the end of 1942, under the grandstand of the squash courts at the University of Chicago, the world's first model of an experimental nuclear reactor was built. Prof. Enrico Fermi carried out the first controlled chain nuclear reaction using this reactor. As this first model was not equipped with any cooling system or shields, its first activation was discontinued after 28 min using a cadmium rod.

EBR-I (Experimental Breeder Reactor), using fast neutrons, was the first nuclear reactor which was not designed for military purposes. Its construction was started near Idaho Falls in May 1949. EBR-I was intended mainly for research, among others, to determine the possibility of breeding of nuclear fuel. EBR-I was in operation till 1966, and since June 1975, it has been turned into a museum.

1.4. First nuclear power plants

The world's first experimental reactor, which supplied electrical energy was a research reactor with plutonium fuel, cooled with liquid metal, built near Idaho, the U.S. (1952). In 1953, also in Idaho, two reactor prototypes were activated which are the most often operated types of reactors till today, i.e. pressurised water reactors (PWR) and boiling water reactors (BWR). This type of reactor was installed in 1957, in the Shippingport power plant near Pittsburgh (the State of Pennsylvania), that is on the 15th anniversary of activating the world's first nuclear reactor by Enrico Fermi in Chicago.

At the same time in Obninsk in Russia a commercial 10 MW reactor moderated with graphite was built. In 1954, the reactor started to operate for commercial purposes and it was a precursor to RBMK reactors. The reactor was in operation till 29 April 2002. The power plant in Obninsk is considered to be the world's first commercial, though small in size, nuclear power plant.

The following years witnessed the momentous development of the nuclear power industry, which was halted after the accidents in Three Mile Island (1979) and Chernobyl (1986). At present, because of the exhaustion of energy resources and substantial technological advancement in the area of safety of nuclear facilities, the nuclear power industry is enjoying its renaissance. The countries which have already had nuclear power plants are building the new ones and in some countries which earlier abandoned this form of generating energy nuclear power is coming back to favour. Also the countries, which have never had any nuclear power plants, e.g. Poland, are making use of this solution.

The author is convinced that the competitiveness of nuclear power in relation to other energy sources and its practically negligible harmfulness to the environment guarantee that it will continue to develop dynamically in the following years.

The history of the first nuclear power plant in Poland started in August 1971, when the decision was taken to begin the construction of a power plant equipped with four reactors with the total power of 1,600 MW. Kartoszyno, a village at Jezioro Żarnowieckie (Żarnowiec Lake) was chosen as the target site for the construction of the power plant.

The works proceeded quickly and efficiently. According to the official statistics 50 companies and more than 6.5 thousand people were involved in the construction works. The neighbouring cities were extended to receive subsequent workers. It was planned to activate the first reactor in 1991, however, the construction works were discontinued in 1990.

The decision to abandon the project was influenced by the disaster in Chernobyl, which gave rise to violent protests of ecologists, joined by well-known people, including, among others, Lech Wałęsa.

Fig. 2. Building site of the Żarnowiec Nuclear Power Plant

Source: [16]

The official position was different. Tadeusz Syryjczyk, Minister of Industry in the government of Tadeusz Mazowiecki, stated that the Żarnowiec Nuclear Power Plant is a dispensable project for the Polish power system in the following 20 years. On 4 September 1990, the Council of Ministers decided to discontinue the construction of the Żarnowiec Nuclear Power Plant. After closing the construction site two reactors were scrapped, one was bought by Finland, where it operates without any breakdown till today, and the fourth one was transferred to a Hungarian training centre. At the site of the would-be power plant there remains a huge, covering several hundred hectares, unfinished construction site. (Fig. 2).

2. TYPES OF REACTORS USED IN NUCLEAR POWER PLANTS

2.1 Pressurized water reactor (PWR) (65% of reactors worldwide)

The PWR consists of two main cooling systems: reactor coolant system (primary) and secondary coolant system. The reactor coolant system is a loop in which the coolant, water in this case, is heated to a high temperature at a high pressure and circulates in a closed circuit between the core and the steam generator – marked in red in Fig 3. In the steam generator the energy is transferred to the secondary coolant system, where

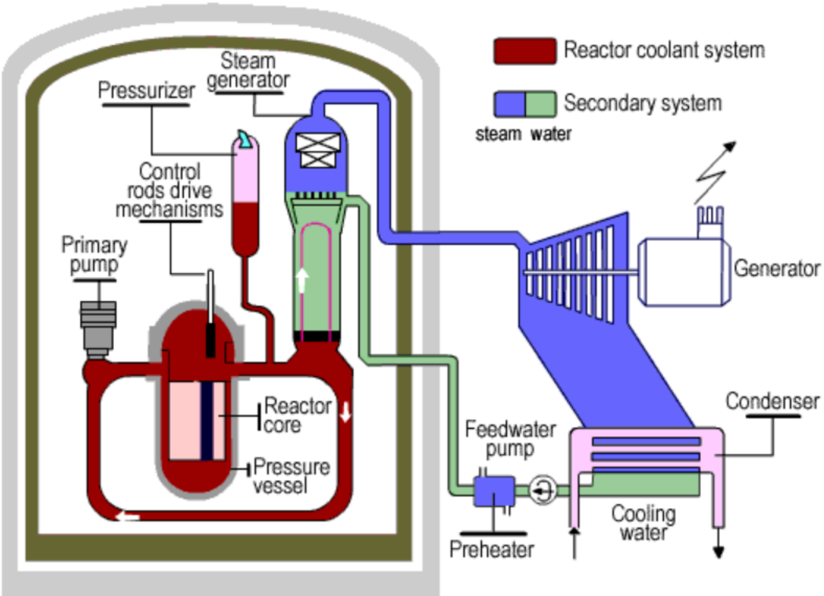


Fig. 3. Pressurized Water Reactor (PWR)

Source: [16]

water is converted into steam at a lower pressure – marked in green and blue in Fig 3. Steam from the secondary system is transferred to the turbine, where it expands and puts the turbine blades in motion. The turbine is connected via a shaft to the electric generator and thus electric energy is produced (generation of approx. 5,000.- ton of steam/hour in a 1,000 MW reactor).

2.2. Boiling water reactor (BWR) (approx. 25% of reactors worldwide)

In the reactor of the BWR type water is heated in the core by collecting heat from the fuel rods to the level where it starts to boil and, then, to vaporise. The produced steam and water mixture is directed to the stream dryers and via the steamline to the turbine (Fig. 4).

In comparison with the reactor of the PWR type the design of the BWR is simplified, as there are no separate steam generators or pipes of the reactor coolant system (primary). There is also no need to prevent water from boiling.

Unfortunately, the disadvantage of the single loop reactor of the BWR type is the fact that steam and water flowing through all elements of the power plant become slightly activated and contaminated with radioactive isotopes. Therefore, all equipment and parts of the nuclear power unit have to be provided with additional shields.

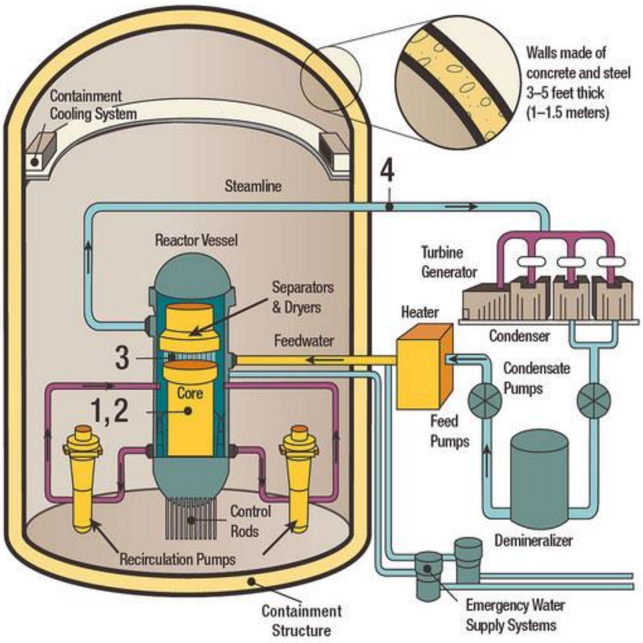


Fig. 4. Boiling Water Reactor (BWR)

Source: [16]

2.3. Specific design applications

Table 1. Comparison of reactors

parameter	**EPR**	**ABWR**	**ESBWR**	**AP-1000**
type	**PWR**	**BWR**	**BWR**	**PWR**
coolant	light water	light water	light water	light water
moderator	light water	light water	light water	light water
electric power, MWe	1,750	1,370	1,520	1,117 (net)
average temperature at the core	312.6˚C	288°C (steam temperature)	281.6˚C	303.39°C
pressure	15.5 MPa	7.17 MPa	7.17 MPa	15.513 MPa
licence	France Great Britain	4 in operation Hitachi; Toshiba	licence the U.S.,	Licence the U.S., China. at the stage of licensing in the UK

parameter	EPR	ABWR	ESBWR	AP-1000
type	PWR	BWR	BWR	PWR
status (under construction/planned)	4 under construction/ 1 planned	4 under construction/ 8 planned	only planned	Under construction, the U.S. and China

Source: own elaboration

Table 2. Comparison of reactors

	EC6	APR-1400	WWER-1200
type	PHWR	PWR	PWR
coolant	heavy water	light water	light water
moderator	heavy water	light water	light water
electric power, MWe	740 MWe	1,400 MWe	1,170 MWe
average temperature at the core	288.15°C	307.2°C	313.5˚C
pressure	10.09 MPa	15.5MPa	16.2 MPa
licensing status	pre-licensing assessment completed by the Canadian supervision authority, but it is not licensed or constructed in any country	the U.S. – licence + initial safety assessment – report- 09.2018) Korea – construction, start-up and operation the UAE – licence for the construction	Licence of Russia and Finland
status (under construction/planned	none	Shin Kori 3 in operation, 3 – Korea 3 – the UAE	8 under construction, 11 planned

Source: own elaboration

EPR – European Pressurized Reactor - The EPR has been designed by the French company AREVA and it represents the continuation of French and German designs of PWR type reactors. The EPR has four active safety systems.

ABWR – Advanced Boiling Water Reactor - The reactor has been developed by the Japanese corporations Hitachi and Toshiba on the basis of the boiling water reactor design created by the American corporation General Electric. At present, this reactor is offered by both GE Hitachi Nuclear Power and Toshiba.

ESBWR – Economic Simplified Boiling Water Reactor – successor of ABWR - The ESBWR has been designed by the American and Japanese consortium GE – Hitachi and represents the continuation of boiling water reactors made by this company.

AP-1000 – Advanced Passive - AP-1000 is a reactor designed by the American company Westinghouse, currently owned by Toshiba. The number '1000' in its name refers to the electric power of the reactor. The name itself comes from the heat exchanger – PRHR (Passive Residual Heat Removal).

EC6 – Enhanced CANDU 6 - EC6 has been designed by the Canadian company Atomic Energy of Canada Limited and it is a reactor of the PHWR (Pressurized Heavy Water Reactor) type. Canadian CANDU (Canada Deuterium Uranium) reactors represent the vast majority of reactors of the PHWR type operated worldwide.

APR-1400 – Advanced Power Reactor - The APR has been designed by Korea Electric Power Corporation (KEPCO) – a company cooperating with Samsung, Hyundai and Doosan. The design is based on the U.S. System 80+ solution (certified in the U.S.).

VVER-1200 – Vodo-Vodyanoi Energetichesky Reaktor (WWER – Water-Water Energetic Reactor) - The VVER is a power reactor cooled and moderated with water. The design has been developed as a result of cooperation between several Russian outstanding designing offices and scientific institutes. The whole is coordinated by the Russian company ROSATOM. VVER-1200 forms the continuation of standard VVER-440 and VVER-1000 designs, which once were very popular in the countries influenced by the USSR.

As at 31 December 2015, worldwide, 439 nuclear power units were in operation with the total power of 382.5 GW and 66 nuclear power units were under construction with the total design power of 70.3 GW.

In 2015, the production of electric energy in nuclear power plants amounted to 2,500 TWh, which accounted for 15-17% of the world's total electric energy production. Lithuania – 80%; France – 70%, Belgium – 60%; Bulgaria, Hungary, the Czech Republic, Slovakia, Sweden – approx. 40% [17].

2.4. Nuclear power industry in Poland

The issues related to the use of nuclear power for the country's social and economic purposes fall within the competence of the minister responsible for energy affairs, pursuant to Art.7 a.2.2 of the Act on Branches of Government Administration of 4 September 1997.

On 13 January 2009, the Council of Ministers adopted a resolution on commencing the works on the Programme for the Polish Nuclear Power Industry and appointing the Government Representative for the Polish Nuclear Power Industry. The purpose of the Programme is to put into operation the first nuclear power plant in 2020. It is planned that PGE Polska Grupa Energetyczna S.A. will be the main investor.

In July 2009, the Ministry of Economy published the *Framework Action Plan for the Nuclear Power Industry*.

The Council of Ministers adopted a resolution on the Programme for the Polish Nuclear Power Industry (PPEJ), prepared by the Minister of Economy. The Programme comprises the scope of activities to be undertaken to use nuclear power in Poland in a safe manner.

The Programme includes actions to be carried out in five stages:

- Stage I – till 31.12.2013: establishing the institutional and programme bases for the development of the nuclear power industry; passing and enacting the legislation indispensable for the development and operation of the nuclear power industry;
- Stage II – 1.01.2014 – 31.12.2016: identifying the location and concluding an agreement for the technology selected for the first nuclear power plant;
- Stage III – 1.01.2017 – 31.12.2018: drawing up the technical design and obtaining all approvals and opinions required by law;
- Stage IV – 1.01.2019 – 31.12.2024: building permit, construction and connection to the grid of the first unit of the first nuclear power plant, commencing the construction of subsequent units/nuclear power plants;
- Stage V – 1.01.2025 – 31.12.2030: continuing and commencing the construction of subsequent units/nuclear power plants. Finishing the construction of the first nuclear power plant. It was planned that the second nuclear power plant should be completed in 2035.

The previous Government (the Ministry of Economy and the National Atomic Energy Agency (PAA)) in principle completed the first stage. The Act of 2000, the Atomic Law, was amended and the relevant Regulations were issued regarding the execution of the further stages of the Programme. During the second stage only the requirements regarding the location of the power plant were established.

Pursuant to the decision taken by the Prime Minister, Ms. Hanna Trojanowska concluded her work as the Government Representative for the Polish Nuclear Power Industry. At present, the fulfilment of these tasks is the responsibility of the Minister of Energy, who so far (together with the Minister of Environment) dismissed the President of the PAA, Mr Janusz WŁODARSKI, and appointed Mr Andrzej PRZYBYCIN (a geologist by education) to this position.

2.5. Accidents

In the history of operation of nuclear power plants worldwide, lasting 60 years, there occurred more than a dozen accidents. Apart from the two most dangerous ones, none of them led to the loss of health or life. The two most dangerous ones include Chernobyl and Fukushima. (In Chernobyl the power increased 1,000 times.)

Errors made by the operators during the cooling of one of the units of the Nuclear Power Plant in Chernobyl caused one of the biggest nuclear disasters in the world. It occurred on 26 April 1986. The explosion and meltdown of the reactor fuel rods caused the death of 31 people and necessitated the evacuation of 300,000 inhabitants. The radioactive cloud was drifting all over Europe. It cost 6.7 billion USD to only partially remediate the effects. (The RBMK reactor was moderated with graphite and not with water.)

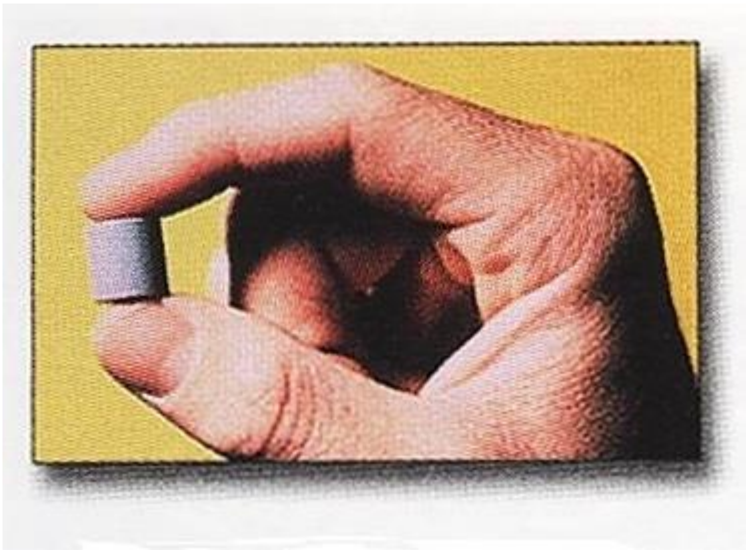
As a result of an earthquake, tsunami and failure of the cooling systems in the nuclear power plant Fukushima I as well as problems in the other nuclear facilities, on 11 March 2011, a nuclear emergency situation was declared in Japan. One hundred and forty thousand people residing within the 20 km radius of the power plant were evacuated.

3. SAFETY IN THE NUCLEAR POWER INDUSTRY

3.1. Sources of hazards

The source of potential hazard in the nuclear power industry is the possibility of releasing the radioactive substances and the impossibility of removing residual heat, causing the destruction of fuel rods and all the resulting consequences.

Radioactive substances in the core and coolant of the PWR-1000 reactor (Fig. 5):



- fuel pellet (UO_2);
- fuel pellets in the casing (cladding);
- filled with helium, for better;
- heat exchange, form fuel rods;
- several dozen fuel rods;
- in the casing form;
- a fuel assembly;
- the coolant and moderator flow around the fuel rods;
- (this is water in the majority of reactors).

Fig. 5. Nuclear fuel

Source: [13]

- Core: $3.7 \cdot 10^{20}$ Bq (1.1×10^{10} Ci), where over 200 nuclides are formed. These are the fission products, (mainly) transuranic elements, such as Kr, Xe, J, Br, Cs, Rb, Sr, Ba and Se;
- Water in the reactor coolant system (primary): 1.1×10^{15} Bq (3×10^{4} Ci), containing gaseous fission products (Kr, Xe, J).

It should be emphasised that releasing to the atmosphere even as little as 10^3 Ci, at adverse weather conditions, may result in the occurrence of maximum allowable doses at a distance of 1 km from the nuclear power plant. Not to mention the radioactivity present in the core, which is ten million times higher.

3.2. Basic principles and means of ensuring safety in the nuclear power industry

3.2.1. Structural elements of the reactor – safety barriers

All structures that are in operation employ the so-called in-depth defence strategy. Several subsequent defence (safety) levels act according to the principle that if one of them fails, another one takes over. It is like in the medieval castle: ditch, moat, traps, moat and high defence walls. The first level of ensuring safety is formed by a system of subsequent protection barriers. The nuclear reactor is designed in the way ensuring that the fission products are gathered in the so-called core of the reactor (fuel pellets). The core of the reactor is separated from the environment with a system of four protection elements (Fig. 6):

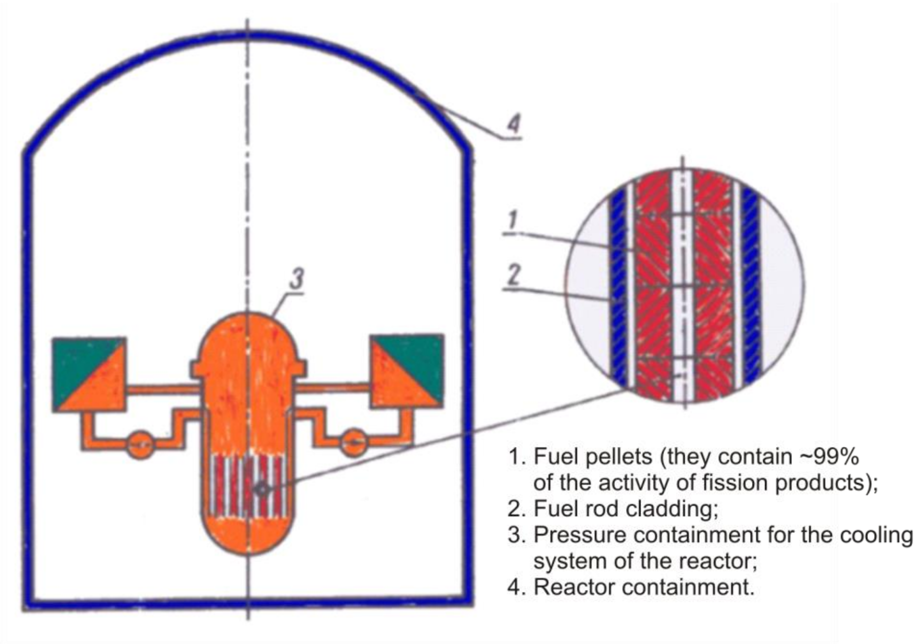


Fig. 6. System of safety barriers – isolating radioactive substances from the environment

Source: [12]

It should be emphasised that the reactor containment, apart from fulfilling the function of isolating the radioactive substances from the environment, protects the reactor from the effects of external events, such as a plane crash or chemical explosion. The structure of the containment, even several metres thick, has to withstand the high emergency pressure. It is usually made of prestressed reinforced concrete with steel lining, consisting of one or several layers.

The system for spraying the containment reduces the pressure inside the containment and accelerates the sweeping of radioactive aerosols (mainly iodine). It is supplied by an emergency generator.

3.2.2. Engineering controls – stability and self-control of the reactor

The reactor has to incorporate negative feedback mechanisms that safely restrict any significant increase in reactivity, and thence, in power generated by the reactor. These mechanisms make the reactor pass immediately to a subcritical state. (Reactivity is a physical parameter, which determines the balance of neutrons in the reactor). A sudden increase in power causes the insertion or drop of safety rods (e.g. cadmium, boron), which effectively absorb thermal neutrons and, thus, decrease reactivity, which results in reducing the reactor's power, including its shutdown. Water pumps (emergency pumps) have to guarantee the reliable and fast removal of residual heat. (It should be emphasised that the removal of the moderator – water converted into steam – interrupts the operation of the nuclear power plant.)

An important role is performed by the emergency core cooling system (ECCS). The system supplies water (mainly boron water) and floods the core in the case of a possible failure (e.g. loss of coolant in the primary circuit), thus ensuring the effective removal of residual heat. These systems are supplied by emergency generators or batteries.

The next level of protection systems of the reactor comprises an automatic power reduction or emergency shutdown of the reactor. The logic circuit generates several automatic protection signals initiating the insertion or drop of control or safety rods to the core – resulting in the shutdown of the reactor.

The system for monitoring, mixing and removing hydrogen from the reactor containment is designed to prevent any uncontrolled combustion or detonation of hydrogen.

Each reactor has to be equipped with reliable emergency power supply (power grid, power generator and batteries).

It is also significant to observe strictly the requirements for the reactor design and equipment, ensuring the reliability of elements critical for the safety of a nuclear power plant. Quality assurance is given priority at all stages of design, construction, start-up and operation.

3.2.3. Organisational means

The diagram (Fig. 7) presents the institutions, which are or will be connected with the Programme for the Nuclear Power Industry in Poland. Similarly to other countries, also in Poland the institutions involved with the construction, operation and promotion are clearly separated from the supervising institutions. The President of the PAA is the state regulatory and control body, and acting as a "nuclear supervision" has to be independent of the owners of nuclear facilities subject to supervision. The President of the PAA has been granted the relevant powers, qualified personnel and financial and technical resources appropriate for the current scope of activity.

All nuclear facilities have to be strictly supervised and inspected by the state agencies. The system includes permits, certification of companies, certification of their employees, commissioning procedures and inspections conducted in such companies. The whole system has to comply with the provisions of the Atomic Law and the regulations issued by the Council of Ministers and the President of the PAA.

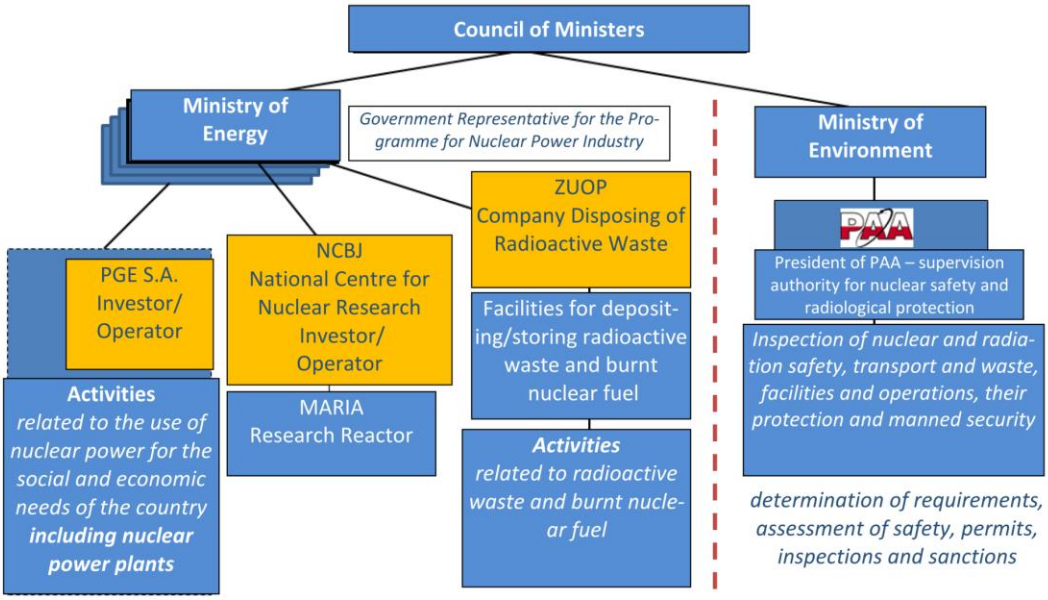


Fig. 7. Place of nuclear inspection in the government administration; Structure of responsibility for safety

Source: [13]

Furthermore, the safety criteria and requirements of the International Atomic Energy Agency have to be met, including the ten principles for protecting people and the environment from the harmful operation of ionising radiation, i.e.: 1) responsibility for safety, 2) role of the government, 3) management for ensuring safety, 4) justification for the facilities and operations related to exposure to radiation, 5) optimisation of protection, 6) limitation of risk to people, 7) protection of the present and future generations, 8) prevention of failures, 9) preparedness and counteracting failures, 10) protection activities aimed at reducing radiological hazards.

The holders of permits for conducting operations in nuclear facilities, i.e. the owners of these facilities, are absolutely and wholly responsible for ensuring their safety**.** After the failure of the nuclear power plant in Chernobyl, the World Association of Nuclear Operators (WANO) was established, whose task is to enhance the safety and reliability of operation of nuclear power plants to the maximum possible extent. The Association coordinates the exchange of information between power plant operators, implements programmes for inspecting power plants by independent experts and organises courses, workshops and seminars.

The adoption of two international conventions was also of fundamental importance: one regarding the early warning system and the other concerning mutual assistance in the case of a nuclear failure. As part of the first convention the member states have undertaken to notify the Agency of any nuclear accidents. The other convention ensures prompt assistance provided on request from the member states to limit to the minimum any radiological effects of a failure and to protect human life, social goods and the environment.

4. RISK RELATED TO THE NUCLEAR POWER INDUSTRY IN COMPARISON WITH OTHER HAZARDS

As shown by the American data (Rasmussen's Report) and the data of the OECD , the risk related to the operation of power plants equipped with the second generation reactors is several orders of magnitude lower than the risk posed by failures of traditional power plants and the risk related to other threats.

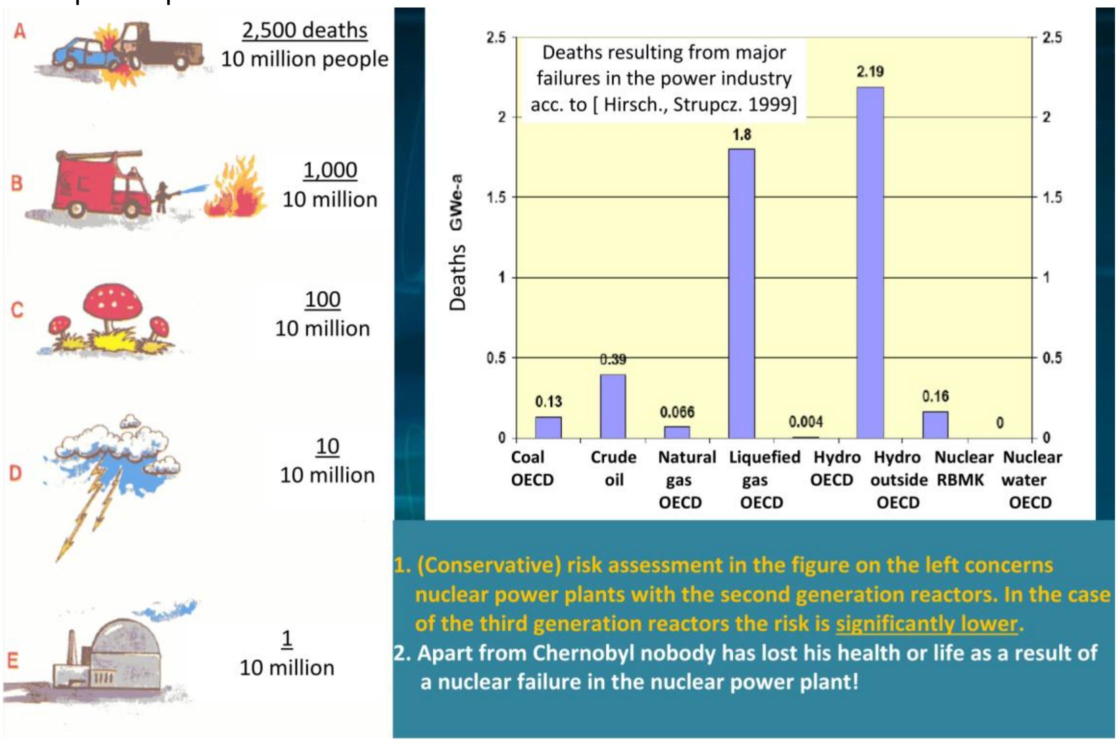
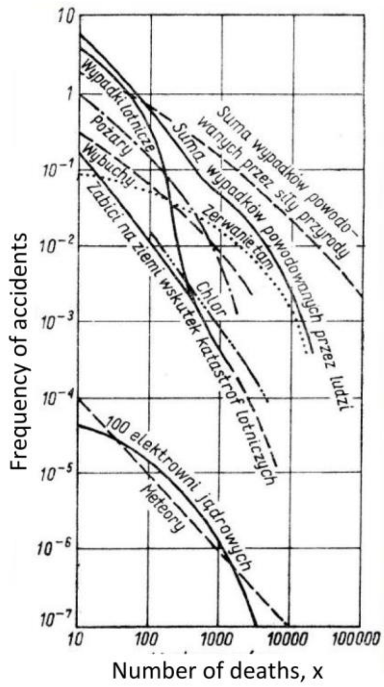


Fig. 8. Risk related to the nuclear power industry in comparison with other hazards

Source: [12]

Apart from Chernobyl and partly Fukushima nobody has lost his health or life as a result of a failure of reactors in the nuclear power plants. It should be emphasised that the risk related to the operation of currently built reactors, i.e. the third generation reactors, is about 100 times lower than the risk related to the operation of the second generation reactors.



Reason for an accident	Number of deaths in the U.S. per year	Individual's probability of death per year
Cars	55 791	1:4 000
Falls	17 827	1:10 000
Fire	7 451	1:25 000
Drowning	6 181	1:30 000
Guns	2 309	1:100 000
Going by plane	1 778	1:100 000
Falling objects	1 271	1:160 000
Electric current	1 148	1:160 000
Lightning	160	1:2 000 000
Cyclone	91	1:2 500 000
Hurricane	93	1:2 500 000
Total number of accidents	111 992	1:1 600
Failures per 100 reactors	–	1:5 000 000 000

Very conservative risk assessment for nuclear power plants with the second generation reactors – Rasmussen's Report

Reactor Safety Study: An Assessment of Accident Risks in U.S. Commercial Nuclear Power Plants. Report WASH-1400 (NUREG-75/014). U.S. Nuclear Regulatory Commission, 1975

FOR THE THIRD GENERATION REACTORS THE RISK IS ABOUT 100 TIMES LOWER THAN FOR THEIR SECOND GENERATION

Key:

- Meteorites
- 100 nuclear power plants
- Killed on the ground as a result of a plane crash
- Chlorine
- Explosion
- Fires
- Dam failure
- Plane crashes
- Total number of accidents caused by people
- Total number of accidents caused by the forces of nature

Fig. 9. Risk related to the nuclear power industry in comparison with other hazards

Source: [12]

CONCLUSION

Like on the Polish political scene, in the case of using nuclear energy in the national economy the community concerned is divided into two groups: supporters and opponents of the construction of nuclear power plants in Poland. The paper attempts to show that modern nuclear reactors are the safest and most ecological way of producing energy. Taking into consideration the fact that natural resources, such as crude oil, gas and coal, are limited, a continuous increase in the number of supporters of this project can be observed. In Poland there are no earthquakes or tsunamis and the reactors that were damaged in Japan were about 30 years old. The third generation reactors pose a risk that is 100 times lower than the risk attributed to the second-generation reactors, e.g. those in Fukushima.

The author hopes that the article convinces, at least in part, the participants of the conference to support this project.

REFERENCES

1. Czerwiński A. „*Energia jądrowa i promieniotwórczość*”, OW Krzysztof Pazdro 1998.
2. Grzegorz Jezierski, „*Energetyka jądrowa wczoraj i dziś*”, Wydawnictwo Naukowo-Techniczne, Warszawa 2005.
3. Jaśkowski J. „*Fakty i mity energii atomowej*” (Book 1987).
4. IAEA Country Nuclear Power Profiles.
5. International Atomic Energy Agency, Nuclear Security Series No. 7, Implementing Guide, Vienna, 2008.
6. Mielczarek M., 2000, *Kultura bezpieczeństwa w przedsiębiorstwie*, „*Bezpieczeństwo Pracy*”, no. 10, CIOP-IB, Warszawa.
7. Encyklopedia multimedialna WIEM – 2003.
8. Opracowanie zespołowe „*Stan i tendencje rozwojowe energetyki jądrowej na świecie w 1995*”.
9. Pidgeon N., O’Leary M., 2000, Man-made disasters: why technology and organizations (sometimes) fail, “Safety Science”, Vol.34.
10. Pidgeon N., 1997, The limits to safety? Culture, politics, learning and man-made Disasters, “*Journal of contingencies and crisis management*”, vol.5, no.1.
11. PN-EN 61513:2013-11E, Elektrownie jądrowe - oprzyrządowanie i systemy kontroli ważne dla bezpieczeństwa - wymagania ogólne dla systemów.
12. Podstawy bezpieczeństwa energetyki jądrowej. Szkoła Energetyki Jądrowej. Gdańsk,20 października 2010r. mgr inż. Władysław Kiełbasa.
13. Rola dozoru jądrowego w bezpieczeństwie elektrowni jądrowej; Maciej J. Jurkowski „*Energetyka Jądrowa dla Polski*”; Międzynarodowe Energetyczne Targi Bielskie, Bielsko Biała 11-14 września 2012 r.
14. Umowa Europejska ADR – stan prawny 1.07.2001 r. Wydawnictwo ONZ
15. U.S. Department of Energy, Office of Nuclear Energy, Science and Technology „*The History of Nuclear Energy*”, Washington, D.C.
16. EJ Żarnowiec – atom.edu.pl.
17. Energetyka Jądrowa – Wikipedia.

BIOGRAPHICAL NOTE

Roman JÓŹWIK - Ph.D., Eng. Roman Jóźwik graduated from the Military University of Technology in Warsaw in 1967, completing the master’s degree course and receiving his M.Sc. (Eng.) degree in technical physics, majoring in nuclear physics. In 1977, he obtained his Ph.D. degree in science. His whole professional career (56 years of service for the Polish Armed Forces) has been strictly connected with research and development projects, focusing mainly on the defence against weapons of mass destruction. Roman Jóźwik worked for 25 years for the Military Institute of Chemistry and Radiometry, including five years as its Director. In the years 1989-1999, he worked for the Foreign Affairs Department of the Ministry of National Defence. He participated actively in the negotiations on the "Chemical Weapons Convention" and the "Comprehensive Nuclear-Test-Ban Treaty". In 1993, he was the leader of the group of Military Observers of the Polish Military Contingent in the UN peace mission in Cambodia. Roman Jóźwik finished his military service in 1999, at the position of Deputy Director of the Military Foreign Affairs Department of the Ministry of Foreign Defence.

In the years 2012-2016, he was a member of the PAA President's Nuclear Safety and Radiological Protection Council. Currently, he is employed with WITU – Zielonka at the position of Director's Advisor.

HOW TO CITE THIS PAPER

JÓŻWIK R., (2017)., The use of nuclear energy for military and civilian purposes safety in the nuclear power industry*. Zeszyty Naukowe Wyższa Szkoła Oficerska Wojsk Lądowych im. gen. Tadeusza Kościuszki Journal of Science of the gen. Tadeusz Kosciuszko Military Academy of Land Forces,* 49 (3), p. 106-123, DOI: 10.5604/01.3001.0010.5127