Safety Reassessment of Research Reactors in the Light of the Lessons Learned from the Fukushima-PAA point of view. Selected Issues.

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Abstract

The MARIA multipurpose high flux research reactor is at present the only operating nuclear reactor in Poland. In case of the MARIA research reactor, the safety assessment recommended by the IAEA in the SRS-80 report after the Fukushima accident was re-evaluated. Most of the safety analysis already exists and was appropriate, however, there are additional safety analyzes needed. Therefore, appropriate PAA and operator actions will continue in the near future. This report contains description of activities performed by PAA and Maria research reactor operator. The study also includes information on some changes in the Polish Atomic Law.

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The MARIA research reactor

The MARIA multipurpose research reactor is at present the only operating nuclear reactor in Poland which recently has been given a new 10-year license for operation (the other reactors, operated in the past, had been either permanently shut down or decommissioned : EWA, AGATA, ANNA and MARYLA). It is a high-neutron flux pool-type reactor, water cooled and water and beryllium moderated reactor, with design nominal thermal power of 30 MWt. The MARIA reactor has been in operation since December 1974 at the Institute for Nuclear Research, then, since 1983 at the Institute of Atomic Energy in Świerk. In years 1985-1993 the reactor operation was stopped for its essential modernization. Since 2011 the reactor has been operated by the National Centre for Nuclear Research. From April 1999 to June 2002 the reactor core was converted from highly enriched uranium (80%) to highly enriched uranium fuel (36%). In the years 2012-2014 the reactor core was further converted to low- enriched fuel LEU (concentration of 19,75% of U235). Each fuel element is placed in a pressurized tube and is allowed to operate at maximum thermal power 1.8 MWt and neutron flux of $3x10^{14}$ n/cm^2s. The fuel channels are placed in a beryllium metal matrix and are cooled with water. The primary cooling system consists of two independent circuits: the fuel channel cooling (FCC) one and the circuit designed for reactor pool cooling (PCC). FCC is the pressurized (maximum 1.7 MPa) close loop system containing ca. 20 tons of water. The fuel channels are connected in parallel to the headers, situated in the reactor pool above the core. The open reactor pool, containing ca. 250 tons of water, constitutes a part of the pool cooling circuit. PCC removes heat generated in beryllium and graphite matrices and all other core internals, including some 500 kW transferred to the pool by the hot outlet piping of the fuel channel. Additional technological pool, adjacent to the reactor pool, serves as a spent fuel storage and it contains 250 tons of water. Both primary cooling systems remove heat to common secondary cooling circuit which gives it off to the atmosphere through the cooling tower (ultimate heat sink from the reactor and spent fuel storage). MARIA has been designed with a high degree of flexibility to provide possibilities of production of radioisotopes, of physical experiments and material testing. The MARIA reactor is used for irradiation of Uranium targets necessary for the production of radioisotopes for medical purposes, for conducting research with the use of horizontal channels, for irradiation of crystals, for example with the use of neutron activation analysis, and finally for training purposes.

MARIA reactor pool (PAA official website)

Regulatory body

The President of the National Atomic Energy Agency (PAA) constitutes the central organ of the governmental administration, competent for nuclear safety and radiological protection. The activities of the President of National Atomic Energy Agency are regulated on the basis on the Act of Parliament on the Atomic Law and its secondary legislation. The President of the National Atomic Energy Agency is independent in taking decisions with regard to tasks entrusted to him on the basis of the Atomic Law Act. Since 1 January 2002 the supervision over the PAA President has been exercised by the Minister competent for the environmental matters on the basis of Article 28, Section 3 of the Act of Parliament on Governmental Administration Departments of 4 September 1997 and article 109 section 4 of the Atomic Law. The Agency's President is nominated and recalled by the Prime Minister. The scope of activities of the Agency's President includes the tasks that involve ensuring national nuclear safety and radiological protection, in particular:

a. issuing licenses and other decisions in issues related to the nuclear safety and radiological protection, according to the principles and methods established by the Act;
b. conducting inspections in nuclear facilities and organizational units which possess nuclear materials, ionizing radiation sources, radioactive waste and spent nuclear fuel,
c. performing the tasks involving the assessment of national radiation situation in normal conditions and in radiation emergency situations, and the transmission of relevant information to appropriate authorities and to the general public,
d. developing the drafts of legal acts on the issues covered by this Act and conducting the process of establishing their final form, according to the procedures established in the working rules for the Council of Ministers.

The reassessment of the MARIA reactor.

The reassessment of the MARIA reactor safety recommended by the IAEA in the SRS-80 report after the Fukushima accident was included in the updated MARIA Safety Analysis Report (ERBM2015). The assessment can be divided into two parts. The first deals with updating of environmental data, with particular reference to demographic data, geological data (containing the seismic characteristics of the Świerk Nuclear Center), meteorological and hydrological data. Land use data has also been updated within 3 km of the reactor. This information is provided in ERBM2015 (Chapter 3). The second parts is related directly to the safety assessment of the MARIA reactor, taking into account the possible impact of external events. Based on the data collected in Chapter 3 of the ERBM2015 report, the possibility of their occurrence and the resulting design events has been assessed. Among the events described in the SRS-80 failure of the power supply system (coincidence of external power failure and failure of diesel generators), earthquake effects on reactor reactivity and the possibility of its safe shutdown and external flood has been selected and analyzed. In addition, the effects of internal flooding and internal fire has been analyzed. Event analysis that does not have to be directly related to external events, but potentially dangerous for the reactor, has also been performed. These include loss of core cooling capacity (both primary and secondary), reactivity disturbances in the reactor core, and behavior of stored fresh and spent fuel. These analysis is included in Chapter 16 of the ERBM2015. Safety analysis show that in the case of severe accident, the following two serious consequences can occur:

1) Flooding of battery compartments, which are an important components to ensure safe cooling of the reactor after it has been shut down.
2) Damage of nuclear fuel, as a result of which it may be necessary to evacuate personnel from the reactor control room.

Therefore, the MARIA Reactor Emergency Plan and the NCBJ Emergency Response Plan were analyzed and the following actions were taken:

1. the procedure was developed to cover actions to be taken in case of battery compartment flooding and incorporated it into the MARIA Emergency Response Plan;
2. to organize the emergency control room, from which it will be possible to supervise the emergency situation in the reactor in the event of evacuation of personnel from the control room. The creation of this control room primarily requires the introduction of several key technological signals from the reactor rooms. It is also necessary to develop a procedure for the necessity of leaving the reactor control room by the reactor operators.

The measures, with regard to the above mentioned modernization of infrastructure, are underway. The expected date of their completion is at the end of 2017. The re-evaluation of environmental factors that may affect the safety of MARIA reactor has been performed, including such natural external phenomena like earthquake, flooding, extreme weather conditions like rainfall, snowfall or gale.

Earthquake

The Mazovia region, where the MARIA reactor is located, belongs to the Trans European Suture Zone (TESZ), separating the mobile Phanerozoic terranes from the ancient Precambrian structure. In spite of it the reactor site can be considered as an aseismic or pen seismic (rare and weak earthquakes) area. The only historical earthquake jolted the region in 1680 and did not exceed the magnitude 5 on the Richter scale. For the MARIA site the PGA(peak ground acceleration) limit is <0.05g. The original design of the reactor did not take into account the risk of an earthquake. The reevaluation inspired by the Fukushima accident implies that the risk of an earthquake should be incorporated to the Safety Analysis of the MARIA reactor. The PGA for the Designed Basis Earthquake should be subsequently set at 0.1g.

External flooding

The MARIA reactor is situated at an elevation of 121 meters above the sea level and 16 meters above the water level in the nearest river Swider, distanced 920 meters away from the reactor building. The Swider river is the main hydrographic element of the area and on the whole has an infiltration character. Average flow rates of the river are within the range of 4.6 -4.9 m3/s. Typically, there are two freshets yearly, due to the spring thaw and the summer rainfall. In the past 50 years the flood waters never approached the site at a distance closer than 600 m. Thus, the Swider river does not determine a flooding hazard to the reactor site. Groundwater water level at the reactor site is in average at a depth of 5 m beneath the ground. MARIA site region underground water level is monitored by means of piezometers, built in the special tube wells. All the piezometers are benchmarked. In the reactor operation history there has been one incident, where the thawing water (after heavy snowfall) appeared in the basement of the reactor auxiliary building without affecting the safety important components. Among others the battery room, located at the level -3m below the ground level, was slightly inundated by a dozen or so centimeters of water.

Internal flooding

There are three considerable water reservoirs in the reactor building or nearest vicinity, namely the reactor and the temporary pools, containing ca. 250 tons of water each and the cooling tower tank with ca. 900 m3 capacity. The reactor has the rain-drain water sewage systems located in the region of the pumping station and the cooling tower where the water from cooling circuits can be discharged. Hypothetically, the unintentional release of water from the reactor pools or other water installations (e.g. water supply system) may lead to a flooding of basement premises of the reactor building. The analysis pointed out, that the most sensitive from the point of view of resistance of the reactor to the loss of power supply is the battery room. It’s location -3m below the ground level creates unfavorable conditions for protection against flooding of important onsite power supplies, namely the 220 V emergency power supply from two sets of batteries as well as 24 V and 48 V DC batteries. The rest of onsite power supply components i.e. the DC/AC invertors, diesel generators with their start-up batteries etc. are located on the ground level or above and cannot be affected by the local flooding.

Extreme weather conditions

Some extreme weather conditions such as heavy rainfalls or snowfall, gales or icing can affect the MARIA reactor site. Due to geographical reasons such phenomena like tropical cyclones and hurricanes or waterspouts do not appear in the region and are not considered. The region of Warsaw is characterized by relatively low quantities of rain falling over the short periods of time. The highest rainfall recorded in a single day never exceeded 100 mm and is distinctly lower than the highest value of 180 mm recorded in 1996 at Lesser Poland(Małopolska). One of the reactor roof loads considered in snow conditions. According to the civil codes of practice the reactor building withstands the overload of 0.7 kN/m^2 what is equivalent to some 70 cm of snow. At the Mazovia Lowland such level of snow cover however rare but happens. Once the snow layer exceeds 30 cm the intervention procedure is set up to remove snow from the roofs.

Dominating for Swierk are the west winds with the velocities (average 10 minutes values at the elevation of 10 m above the ground level, for the terrain roughness of 0-1) not exceeding of 4 m/s. Tornadoes pose a highest threat to the overhead supply lines. According to the recent governmental report3 on the territory of Poland occur 1-4 tornadoes per year (compared with ~1000 tornadoes per year for USA). Their magnitude does not exceed F3 in Fujita scale, what corresponds to the peak wind velocity within the range of 50-100 m/s. The strongest historical tornado, with the magnitude of F3-F4 hit the city Lublin in 1931. Also a heavy snowfall or icing can overload mechanically the off-site high voltage lines. The combination of snowfall or icing and wind can bring the lines into oscillations and cause their damage. In summer 1985 the combination of heavy wind (velocity reached 30 m/s) and intense rainfall did not affect the reactor installations but caused the collapse of 440 kV overhead lines pylons and loss of off-site power supply. The main power supply break lasted 2 weeks and the reactor and other plant systems were powered by the DGs.

Activities performed by the regulator

After events in Fukushima Daichii during planned inspections performed by PAA in research reactor MARIA issues concerning loss of off-site power have been highlighted. There were two major findings and conclusions:

1. The DGs room is situated on ground level without water-resistant door, when the entrance is located in the lowest point of surrounding area. That could possible cause flooding of start-up batteries for the DGs during heavy rainfall. The start-up batteries should be placed on higher level than floor level. Done.
2. On-site tests performed to verify the Safety Analysis Report proved that during off-site power blackout batteries could power two pumps and ventilation for 3 hours till the diesel generators will be turn-on. Done.

The PAA has verified the reassessment of the safety of the MARIA reactor recommended by the IAEA in the SRS-80 report. Documentation has been reviewed (ERBM2015 ,The MARIA Reactor Emergency Plan and The NCBJ Emergency Response Plan, procedures, instructions et cetera). A SRS-80 compliance assessment report was prepared and recommendations for follow-up were made. For example, issues related to PIE(Postulated Initiating Events):

List of postulated initiating events (review).

A – complete analysis ERBM-2015
B – partial analysis ERBM-2015
n.a. – Not applicable.

(1) Loss of electrical power supplies:		**(5) Erroneous handling or failure of equipment or components:**	
1. Loss of normal electrical power.	A	1. Failure of the cladding of a fuel element;	A
		2. Mechanical damage to core or fuel (e.g. mishandling of fuel, dropping of a transfer flask onto the fuel);	A
(2) Insertion of excess reactivity:		3. Failure of an emergency cooling system;	n.a.

1. Criticality during fuel handling (due to an error in fuel insertion);	B	4. Malfunction of the reactor power control;	A
2. Startup accident;	A	5. Criticality in fuel in storage;	A
3. Control rod failure or control rod follower failure;	A	6. Failure of means of confinement, including the ventilation system;	B
4. Control drive failure or system failure;	A	7. Loss of coolant to fuel during transfer or storage;	B
5. Failure of other reactivity control devices (such as a moderator or reflector);	B	8. Loss or reduction of proper shielding;	A
6. Unbalanced rod positions;	A	9. Failure of experimental apparatus or material (e.g. loop rupture);	A
7. Failure or collapse of structural components;	B	10. Exceeding of fuel ratings.	B
8. Insertion of cold water;	A	**(6) Special internal events:**	
9. Changes in the moderator (e.g. voids or leakage of D2O into H2O systems);	A	1. Internal fires or explosions;	A
10. Influence by experiments and experimental devices (e.g. flooding or voiding, temperature effects, insertion of fissile material or removal of absorber material);	A	2. Internal flooding;	B
11. Insufficient shutdown reactivity;	B	3. Loss of support systems;	n.a.
12. Inadvertent ejections of control rods;	B	4. Security related incidents;	n.a.
13. Maintenance errors with reactivity devices;	n.a.	5. Malfunctions in reactor experiments;	A
14. Spurious control system signals.	B	6. Improper access by persons to restricted areas;	B
(3) Loss of flow:		7. Fluid jets and pipe whip;	B
1. Primary pump failure;	A	8. Exothermic chemical reactions.	B
2. Reduction in flow of primary coolant (e.g. due to valve failure or a blockage in piping or a heat exchanger);	A	**(7) External events:**	
3. Influence of the failure or mishandling of an experiment;	n.a.	1. Earthquakes (including seismically induced faulting and landslides);	B
4. Rupture of the primary coolant boundary leading to a loss of flow;	A	2. Flooding (including failure of an upstream/downstream dam and blockage of a river and damage due to tsunami or high waves);	A
5. Fuel channel blockage;	A	3. Volcano eruption (including lava flow, ash deposition, toxic gas emission, etc.);	n.a.
6. Improper power distribution due, for example, to unbalanced rod positions in core experiments or fuel loading (power–flow mismatch);	n.a.	4. Tornadoes and tornado missiles;	A
7. Reduction in coolant flow due to bypassing of the core;	n.a.	5. Sandstorms;	n.a.
8. Deviation of system pressure from the specified limits;	B	6. Hurricanes, storms and lightning;	n.a.
9. Loss of heat sink (e.g. due to the failure of a valve or pump or a system rupture).	A	7. Tropical cyclones;	n.a.

(4) Loss of coolant:		8. Explosions;	B
1. Rupture of the primary coolant boundary;	B	9. Aircraft crashes;	B
2. Damaged pool;	B	10. Fires;	B
3. Pump-down of the pool;		11. Toxic spills;	B
4. Failure of beam tubes or other penetrations.	B	12. Accidents on transport routes (including collisions into the research reactor's building);	n.a.
		13. Effects from adjacent facilities (e.g. nuclear facilities, chemical facilities and waste management facilities);	n.a.
		14. Biological hazards, such as microbial corrosion, structural damage or damage to equipment by rodents or insects;	n.a.
		15. Extreme meteorological phenomena;	B
		16. Lightning strikes;	B
		17. Power or voltage surges on the external electrical supply line.	B
		(8) Human errors.	B

In the coming year the PAA will check the implementation of the conclusions and recommendations of the inspection in this issue. The MARIA reactor is constantly increasing its nuclear safety(new IAEA standards are being implemented). National and international requirements also are implemented to Polish Atomic Law.

Legislation changes

Many solutions which are now found as lessons learned from Fukushima Daiichi accident were already implemented in Atomic Law and the working version of Regulation on nuclear safety and radiological protection requirements which must be fulfilled by a nuclear facility design when the accident happened. Legal framework for the development and functioning of nuclear power has been established, and updated, in line with the relevant international standards, European Union regulations and best practices of leading nuclear countries. The key legislative developments in this area are as follows:

1. Amendment to the Atomic Law of 29 November 2000, in force as from July 2011 (with the aim to provide for establishment of a transparent and stable regulatory framework covering the entire investment process by the National Atomic Energy Agency).
2. Amendment to the Atomic Law of 29 November 2000, in force as from May 2014 (with the aim to implement the provisions of the Council Directive 2011/70/Euratom on the safe management of spent fuel and radioactive waste).

3. Secondary legislation to the Atomic Law of 29 November 2000, which consists of over forty regulations, mainly resolutions of the Council of Ministers, e.g.:
a. Regulation of the Council of Ministers of 31 August 2012 on the scope and method for the performance of safety analyses prior to the submission of an application requesting the issue of a license for the construction of a nuclear facility and the scope of the preliminary safety report for a nuclear facility.
b. Regulation of the Council of Ministers of 10 August 2012 on detailed scope of assessment with regard to land intended for the location of a nuclear facility, cases excluding land to be considered eligible for the location of a nuclear facility and on requirements concerning the location report for a nuclear facility.
c. Regulation of the Council of Ministers of 31 August 2012 on nuclear safety and radiological protection requirements which must be fulfilled by a nuclear facility design.
d. Regulation of the Council of Ministers of 11 February 2013 on requirements for the commissioning and operation of nuclear facilities.

Summary

The reassessment of the MARIA reactor safety recommended by the IAEA in the SRS-80 report after the Fukushima accident- process is in progress. New requirements, modernizations and organizational changes in the reactor is still facing new challenges both to regulator and operator. Through international cooperation we are constantly moving forward and achieving the goal of increasing nuclear safety.

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