Safety Reassessment of German Research Reactors in the Light of the Accident at the Fukushima Daiichi Nuclear Power Plant – Current Status of the Improvements focused on Emergency Preparedness

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Abstract. In the light of the accident at the Fukushima Daichii nuclear power plant, in summer 2011 the first comprehensive safety assessment was requested for all German research reactors with a continuous thermal power of more than 50 kW. The general approach for the safety assessment of research reactors was based on the stress test for nuclear power plants. The main goal was to verify the robustness of research reactors against severe conditions. The statement of the Reactor Safety Commission (RSK) identifying the robustness of the facilities and improvement measures was published on 3rd May 2012. In 2015, RSK performed a reassessment of research reactors verifying the implementation status of measures identified in the first assessment.

1. Introduction

The first actions following the accident at the Fukushima Daiichi Nuclear Power Plant on 11th March 2011 were taken in Germany already a few days later. On 14th March 2011 the federal government and the competent prime ministers of the federal states requested a comprehensive plant specific safety assessment - stress test - of nuclear power plants. On 7th of July 2011, just after the stress test for nuclear power plants has been conducted by the RSK, a similar comprehensive safety assessment was requested also for all German research reactors being in operation and having a continuous thermal power of more than 50 kW [1]. Specifically, this includes the Heinz Maier Leibnitz research neutron source (FRM II, 20 MW), the BER II experimental reactor in Berlin (10 MW) and the TRIGA Mark II research reactor in Mainz (FRMZ, 100 kW).

In an approach similar to that applied to German nuclear power plants, the installations robustness was reviewed with regard to:

- natural hazards (such as earthquakes, flooding),
- expanded postulated events (station blackouts and emergency power failures),
- precautionary measures,
- emergency control measures,
- man-made hazards (such as airplane crash, gas release).

Due to the comparable lower radioactivity inventory and the lower risk potential of research reactors, the assessments criteria were adjusted individually in a meaning of graded approach. The corresponding catalogue of requirements and the assessment of the robustness of research reactor facilities have been carried out by the Reactor Safety Commission (RSK). The main goal was the verification of the fundamental safety functions "control of reactivity", "cooling of fuel elements" and "confinement of radioactive material". Furthermore, also the robustness of the instrumentation for monitoring of reactor parameters and the radiological parameters was checked in order of its operability under severe conditions.

The statement of the RSK regarding the robustness of the facilities and identifying improvement measures was published on 3rd May 2012 [2]. In general the RSK confirmed the robustness of research reactors, which in details differs for individual facilities depending on the considered scenario. Nevertheless, a number of generic and facility specific recommendations were derived in order to improve the robustness even more. Most of the recommendations concerned the emergency preparedness. In particular, there was a need for (further) development of facility specific, preventive and mitigative emergency control measures, independently from the external disaster control measures. In 2015 upon request of the Federal Ministry for Environment, Nature Conservation, Building and Nuclear Safety (BMUB) the RSK started a safety reassessment aiming the implementation of recommendations identified in the first step of process in 2012. The corresponding report was published in March 2017 [3].

This paper focus on the emergency preparedness in German research reactors. In order to give a comprehensive description, it includes not only the recommendations of the RSK and the recently implemented measures, but presents entire concept of emergency preparedness in its current status.

2. Recommendations of the RSK for the emergency preparedness

There were a number of generic recommendations concerning preventive and mitigative emergency control measures in the RSK statement [2]. In general, the concept should be (further) developed correspondingly to the respective recommendations for nuclear power plants [4]. The emergency control measures should consider following aspects:

- establishment of emergency response team,
- aggravated boundary conditions, e.g. damaged infrastructure and communications equipment, increased dose rate and hydrogen generation,
- failure of the monitoring instrumentation, also these caused by the loss of power supply,
- loss of coolant, including supply alternatives and sealing of the reactor pool,
- limitation of activity release in case of core meltdown.

Though, the concept has to be facility specific and account for the risk potential of individual research reactors in a meaning of graded approach. For this, the RSK formulated more detailed, facility specific recommendations taking into account already existing emergency control measures and its adequacy for given research reactor.

3. Fulfilment of recommendations of the RSK for the emergency preparedness

The research reactor licensees evaluated and updated their facility specific concept for the emergency preparedness. This concept is described in the emergency manual (NHB), which is based on the guidance for nuclear power plants [4]. It includes preventive and mitigative on-site emergency control measures. The NHB gives a comprehensive description of the emergency response team, including functions and competences of individual team members as well as the technical and spatial equipment for the emergency response team. It describes cooperation of the emergency response team with external disaster control organisations. Furthermore, the communication-path to the competent authorities and provision of information to the public are specified. The NHB is together with the operational manual (BHB) a part of the required documentation in the control room. The transition from one to another manual is precisely defined. The NHB describes actions for: emergency water supply for the reactor pool, controlling the reactivity in case of malfunction of containment isolation and emergency power supply, including mobile emergency diesel generators. Also means for the radiological monitoring are specified. Detailed information on the specific emergency control measures, as included in the emergency manual in different research reactors are given below.

3.1 Emergency response team and initiation of emergency control measures

The research reactors have chosen individual approaches for establishing the emergency response team, which reflects the facility specific conditions. At some facilities only reactor staff is involved, while other refer to the entire research centre. Also support from external organisations, like e.g. a fire department is solved in different ways.

<u>FRM II</u>
The emergency response team consists of the reactor staff. However, the internal fire department and the press office of TUM (Technical University of Munich) may also be represented. The leadership of the emergency response team is the technical director of the reactor. The initiation of measures described in the NHB follows according to the criteria:

- beyond design basis accident is anticipating,
- criteria of pre-alarm/disaster alarm are reached or are anticipating.

<u>BER II</u>
The initiation of measures described in the NHB follows according to the criteria:

- emission of radioactive materials is increased and reach 1 % of alarm value,
- fundamental safety functions are endangered or injured,
- operational power supply and emergency power supply are lost.

The emergency preparedness of BER II has some particularities. It introduces a so called “Reflexphase” for severe scenarios, where the expected radiological consequences may be above intervention reference levels for protective measures. For such scenarios, the pre-alert will be suspended and the alert will be given promptly, allowing immediate initiation of necessary measures. Another particularity is that the NHB refers not only to BER II reactor but to the entire research site, the Helmholtz-Centre-Berlin (HZB). Correspondingly, the emergency response team consist of the reactor staff and the management of HZB. The head of the team is the safety officer of HZB. Nevertheless, the decisions concerning reactor safety, radiation protection and security of BER II belongs to the competent reactor staff, respectively.

As an emergency control centre of the HZB a bunkered room at the site is provided, which has a connection to the emergency power supply and is equipped with emergency communication systems as well as instrumentation to gather the environmental, weather and radiological data. Alternatively the rooms of the fire department of city Berlin can be used for the emergency control centre. The fire department of the research centre HZB and the local fire department of city Berlin are an inherent part of the emergency response team.

FRMZ
The FRMZ reactor has considerably lower risk potential. The activity inventory is at such level that even in case of very unlikely incident with a core damage the consequential radiation doses would be below intervention reference levels for the disaster control measures. The main difference compared to the two other facilities is that at FRMZ no preventive emergency control measures and no additional time for introducing given measures are necessary. The NHB focus on mitigative measures and is dedicated especially for extreme natural and man-made hazards, e.g. earthquake, aircraft crash, sabotage. It describes responsibilities of the entire emergency response team, including internal reactor staff and external management of the Johannes Gutenberg University. To fulfil all requirements to the emergency preparedness two new positions were created for strengthening the responsibilities for radiation protection, nuclear safety and security at the facility.

The concept for establishment of emergency response team and conditions for initiation of the emergency control measures is adequate to the risk potential of the individual research reactors and is consistent with the guidance for nuclear power plants [4]. However, its explanation of the organisation in the emergency manual is not in every case entirely clear. The RSK recommends further elaboration and more detailed description, where it is appropriate.

3.2 Emergency water supply

The facilities have adequate measures for the emergency water supply, which fulfils the requirements for the redundancy, diversity and physical separation. Available are various water reservoirs, especially for FRM II and BER II, e.g.: public water system, the storage tank, buffer tank of fire extinguisher system, small local stream or lake.

FRM II
Here, e.g. a system for back-feeding for “normal" operational leakage, a wall hydrant and mobile fire pumps are available. These may be connected to different water reservoirs.

BER II
Following water supply systems are available:

- system for back-feeding for “normal" operational leakage,
- dry standpipe of fire extinguisher system,
- direct feeding by pipe connection to the reactor pool,
- mobile fire pumps.

Their connection to different water reservoirs is possible.

FRMZ
Based on the design features of the reactor, the recriticality of the core in a consequence of a loss of coolant in the reactor pool may be practically excluded. The

divers cooling is guaranteed by the air. In order to mitigate possible radiological consequences, mobile fire pumps may be used for emergency core cooling.

Despite of this variety of possibilities for emergency core cooling, up to now none of the research reactors has foreseen a measure allowing the water supply without entering into the reactor hall. But because of the possibly high dose rate in the reactor halls in case of an emergency, the RSK recommends a suitable update of existing measures regarding this point.

3.3 Sealing of reactor pool

The measures for sealing of reactor pool were taken into account during development of the emergency manual. It was identified that introduction of specific measures is not necessary. Depending on the leakage position suitable actions may be taken individually. For the scenario with a large leakage, when the water level in the reactor pool cannot be kept stabile, alternative measures were developed.

FRM II
In case of a large leakage the fuel element needs to be replaced into the set-down pool. This action may start at the earliest 3 hours after reactor shutdown, when the residual heat decayed sufficiently. However for this power supply is required.

BER II
Also here, in case of a large leakage the fuel element needs to be replaced into the set-down pool, but this can be realised manually without power supply. The set-down pool is very sturdy, it has massive cover and double walls, its damage due to external events may be practically excluded.

FRMZ
Considering the sturdy design of the reactor pool and the fact that the leakage of the coolant will not lead to a recriticality of the core no specific measures are necessary here. To minimize possible radiological consequences an optional water supply using mobile fire pumps is sufficient.

The RSK confirmed that the facility specific solutions regarding sealing of reactor pool are adequate and no further improvements are needed.

3.4 Emergency power supply

The facilities have implemented measures for the emergency power supply taking into account the requirements for the redundancy, diversity and physical separation where it is necessary.

FRM II
According to the design and normal operation conditions, the power supply is required only for the first 3 hours after the reactor shutdown. After this time the residual heat is removed by means of nature convection. Even if the demand for the emergency power supply is very limited, following systems are available:

- 20-kV-emergency distribution grid,
- two emergency diesel generators,

- 400-V-emergency power system, which may be supplied from a third grid or from the mobile emergency diesel generators. For connection of this system an emergency transformer with a permanent line to the switchgear is installed on the site. A mobile emergency diesel generator is planned to be purchased.

BER II

According to the design and normal operation conditions, the requested capacity of power supply is 10 minutes. The residual heat removal using pumps take place only for the first 60 seconds, after this time cooling is continued by means of nature convection. Even if the demand for the emergency power supply is very limited, following systems are available:

- two emergency diesel generators with capacity of at least 72 h to supply important energy loads, e.g.: +/- 24-V-emergency distribution for instrumentation for monitoring of reactor parameters and radiological parameters as well as for the negative pressure system of reactor hall,
- batteries with capacity of at least 70 h available for divers instrumentation,
- two redundant connection points for mobile emergency diesel generators for parallel supply of instrumentation and control technology as well as negative pressure system. The mobile diesel generator itself is not on the site, it needs to be rented extern.

FRMZ

For maintaining the fundamental safety functions of the FRMZ reactor, the emergency power supply is not required. However, it may be needed for the instrumentation for monitoring of the reactor and radiological parameters (see below 3.5).

Considering the reactor-physical and safety-related features of the individual facilities, the implemented measures are adequate and were confirmed by the RSK. Nevertheless, in the case where the mobile diesel generators are not in the possession of the research reactor and its rental is foreseen, the RSK recommends a contract with an external company to guarantee the availability of the device with requested power class in any situation.

3.5 Robustness of instrumentation for monitoring of reactor parameters and radiological parameters

The facilities have sufficient monitoring systems for controlling the reactor and radiological parameters. The instrumentation in the reactor hall is very robust. It is designed to withstand high temperatures, humilities and radiation dose rates. The reactor parameters (such as: water level and temperature in reactor pool, pressure in emergency cooling system, neutron flux) and radiological parameters (such as: dose rate in the reactor hall, noble gases in the exhaust air) are continuously measured. They are displayed not only in the control room but also in the emergency control room, where it is applicable.

FRM II

The instrumentation is designed against design basis earthquake and aircraft crash. For power supply batteries are used. The measurement of the most important parameters - water level, temperature of coolant in reactor pool and radiation dose rate in reactor hall - are two-channel based and have two physically separated transmission lines. Additionally, for the radiological measurements in the vicinity of the reactor, a variety of mobile equipment and vehicle equipped with radiological instrumentation are in place.

BER II

The monitoring system for the reactor parameters is designed against design basis accidents. For important parameters diverse measurement systems, including also hand-held measuring devices are available.

FRMZ

For some monitoring instrumentation a power supply is necessary. For this reason, in case of emergency situation the redundant power supply in means of the diesel generators is foreseen. These can be provided by the external organisations (the fire department of city Mainz and the THW-technical assistance organization). There is no contract ensuring delivery of the generators, but the fire department of city Mainz is included in the emergency management as an integral part of the entire emergency response team.

In general, the available systems for monitoring the reactor and radiological parameters are adequate to the risks potential of the individual facilities. However, the information according its robustness is not always precisely documented. The RSK recommends to consider the complete verification and documentation of the robustness of the instrumentation. The analysis should include hypothetical effects of internal and external design extension conditions. Following, the adequate countermeasures should be introduced, if necessary.

3.6 Mitigation of radioactivity release in case of core melt down

The most important measure to mitigate the radioactivity release is maintaining the safety barriers. This includes ensuring of:

- a sufficient water level in the reactor pool in order to keep the core covered entirely under water even during long-lasting situations,
- confinement of radioactive material.

FRM II

There exist several different measures for the emergency water supply into the reactor pool (see 3.2). In case of malfunction of the containment isolation, disconnection of the supply and exhaust air systems in the reactor control area is foreseen.

BER II

Also here exist several different measures for the emergency water supply into the reactor pool (see 3.2). The confinement of radioactive material is ensured by means of the negative pressure in the reactor hall, exhaust air filtering and ventilation isolation system.

FRMZ

According to the reactor design, the reactor core may be sufficiently cooled by the air. Here, even in case of design extension conditions the core melt down may be practically excluded. Additionally, the analysis of an airplane crash scenarios with a kerosene fire showed [5] that in such scenario the temperature evolution will not be sufficient to induce a core melt down.

The RSK confirmed that the facility specific solutions regarding mitigation of radioactivity release in case of core melt down are adequate and no further improvements are needed.

3.7 Aggravated boundary conditions

The facilities took into consideration scenarios with severe damages of the infrastructure in the vicinity of the reactor. According to their design, the two larger reactors – FRM II and BER II – require no power supply to maintain the fundamental safety functions. For cooling of the fuel elements in an emergency situation nature convection is sufficient. Nevertheless, they have redundant, divers and physically separated systems for water and for power supply available as well as diverse systems for reactor shutdown. The smallest facility – FRMZ – is inherently safe and requires neither power and water supply nor personnel in order to maintain its fundamental safety functions. Here air cooling is sufficient.

FRM II

The reactor may be shutdown using shutdown rods or heavy water from moderator tank. In an emergency case, the moderator may be drained into the reactor pool. However, for this action power supply is necessary.

The internal fire department possess some rescue clearing devices and a vehicle equipped with several mobile emergency diesel generators of 10 to 20 kW. Other heavy devices will be provided by an external organization. There is a contract with the THW-technical assistance organization, ensuring arrival of external supporting emergency team together with necessary equipment within 8 hours.

BER II

The reactor may be shut down by means of the shutdown rods and borating system. None of this action requires power supply.

The HZB possess some rescue clearing equipment, like e.g. forklift. Other heavy devices will be provided by external organizations. There is a contract with KHG-technical assistance organization, ensuring arrival of an emergency team together with necessary equipment within 24 hours. Some equipment may be provided by the fire department of city Berlin. Furthermore, support from the police department, THW-technical assistance organization and several qualified companies in the neighbourhood may be used and additional devices for the clearance of infrastructural demerges may be rented.

FRMZ

For the clearance of infrastructural demerges the support from external organisation is foreseen. This task is assigned to the fire department of city Mainz and the THW-technical assistance organization. These will provide necessary rescue clearing equipment as well as the diesel generators to supply instrumentation for monitoring of the reactor parameters and radiological parameters.

The RSK confirmed that the facility specific solutions regarding the aggravated boundary conditions are adequate and no further improvements are needed.

3.8 Communication equipment for emergency situation

All three facilities have several diverse systems ensuring internal communication and allowing contact with the competent authority as well as external organisations in emergency situations.

Indeed, the facilities have a large number of adequate communications systems, e.g. telephone system equipped with emergency batteries, dedicated lines and emergency alarm button to alert the police or fire department. However, the RSK recommends consideration of a contract ensuring the emergency secured priority for the public telephone network.

3.9 Education and training for emergency situation

All three facilities introduced regular training courses and emergency exercises adjusted to the individual conditions. There are a.o. block seminars organised, which include theory and practice of radiation protection and emergency preparedness. In some courses also external organisations participate, like e.g. fire departments, so they are familiar with the facility and the site.

The RSK stated that the education and trainings for emergency situation are generally adequate. As an advice it gives specific recommendation for minimal frequency of emergency exercises:

- at least one per year for the on-site emergency preparedness, including the entire emergency response team,
- at least every five years big exercises under assumption of severe scenarios and requiring participation of external disaster control organisations.

These are relevant for all facilities, even for the FRMZ the large scale emergency exercises with participation of entire emergency response team and disaster control organisations are recommended.

4. Conclusions

The recommendations from the RSK from the first safety assessment in 2012 are principally implemented. For all three research reactors the re-evaluation of the robustness taking into account design extension conditions was performed. In the further development of the emergency manual severe conditions, including long-lasting situations and aggravated boundary conditions were taken into account. The facilities strengthened measures of the emergency preparedness, improving a.o. emergency water and power supply and measures for mitigation of radioactivity release in case of the core melt down. The robustness of the instrumentation for monitoring of reactor parameters and radiological parameters as well as the communication system was increased. In spite of the so far performed improvement, the RSK gave some advices for further optimisation. Concluding, it stated that although the robustness of German research reactors is already at the high level, it may still be optimised in the details.

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