Note:
This is a translation of the RSK statement entitled “Bewertung der Umsetzung der Empfehlungen der RSK aus der Sicherheitsüberprüfung deutscher Forschungsreaktoren”
In case of discrepancies between the English translation and the German original, the original shall prevail.

RSK Statement

(492nd meeting of the Reactor Safety Commission (RSK) on 22 March 2017)

Assessment of the implementation of the recommendations of the RSK resulting from the safety review of German research reactors

Contents

1 Reason for the consultations

Due to the events at the Fukushima-I nuclear power plant in Japan in 2011, the Reactor Safety Commission (RSK) was asked to carry out a safety review of three operating German research reactors as a supplement to the safety review of German nuclear power plants [RSK-SÜ]. The review concerned the research reactor Berlin II (BER-II), the research reactor Munich II (FRM-II) and the research reactor Mainz (FR-Mz). At its 447th meeting on 3 May 2012, the RSK adopted the statement "Plant-specific safety review (RSK-SÜ) of German research reactors under consideration of the events at Fukushima-I (Japan)" (RSK-SÜ-FR) [RSK-SÜ-FR].

Within the framework of the RSK-SÜ-FR, a systematic review of the robustness of the research reactors – as it was carried out for power reactors [RSK-SÜ] - was carried out for the first time in the form of a stress test. Therefore, the RSK also included events other than those observed at Fukushima in its scope of consideration. In addition to earthquakes and flooding, these include other natural external hazards, possible overlaps of such impacts, and human-induced external hazards, such as aircraft crashes. In addition, the RSK considered postulates independent of concrete event sequences (as far as they are of safety relevance for research reactors) and aggravating boundary conditions for the implementation of emergency measures. From this safety review, the RSK derived plant-specific recommendations with regard to the robustness of the research reactors in case of beyond-design-basis hazards and postulates [RSK-SÜ-FR].

At its 472nd meeting on 14 January 2015, the RSK established the ad-hoc working group ROBUSTNESS ANALYSIS RESEARCH REACTORS (WG RARR) and mandated it to review the status of the implementation of the RSK recommendations resulting from the RSK-SÜ-FR. The RSK statement in hand presents the results of this review.

2 Course of discussions

At the 472nd RSK meeting, the RSK confirmed the advisory concept submitted by the WG RARR [RSK472_4.1].

At the first meeting of the WG RARR on 31 March 2015, the discussion focused on an expert opinion [BER-05] on the deliberate aircraft crash on the research reactor BER-II. The expert opinion was to determine whether the research reactor BER-II fulfils degree of protection 2 according to the RSK-SÜ-FR in the event of an aircraft crash. In addition, the effectiveness of the existing emergency measures and emergency equipment was to be checked under consideration of the effects of an aircraft crash. The results of the expert opinion as well as the structure of the emergency organisation and the relevant emergency measures were presented to the WG [EP_RAFR1].

At the 2nd meeting on 2 July 2015, the WG received further information on the implementation of recommendations and findings from the plant-specific safety review of BER-II [RSK-SÜ-FR] as well as on some remaining points from the deliberations of the 1st WG meeting regarding the deliberate crash of a commercial airliner [EP_RAFR2].

The 3rd meeting on 30 September 2015 served to review the implementation of the RSK recommendations at FRM-II [EP_RAFR3].

At the 4th meeting on 21 January 2016, in addition to the discussion of some remaining points on FRM-II, the hearing on the research reactor Mainz (FR-Mz) took place [EP_RAFR4]. Further information on FRM-II in connection with the topics of earthquakes and load crash was provided to the WG RARR at the 5th meeting on 5 September 2016 [EP_RAFR5].

In the further course, the WG prepared the draft statement, which it approved at the 7th meeting on 09 February 2017, submitting it to the RSK at its 492nd meeting. The RSK adopted the present statement at the 492nd meeting on 22 March 2017.

3 Preliminary remarks on the content and structure of the statement

With this statement, the RSK reviews to what extent the recommendations and findings resulting from the safety review of German research reactors in 2012 [RSK SÜ FR] have been implemented by the respective operators and authorities. Separately for the three research reactors considered (Chapters 4, 5 and 6), the recommendations of the RSK from the 2012 review are first quoted, looking at the individual review topics. Subsequently, the state of affairs regarding the implementation of the recommendations is presented with reference to the oral and written statements by the operators and authorities. Finally, the implementation of the recommendations made by the RSK is assessed.

In Chapter 7, the status of implementation is assessed and, for the sake of clarity, the recommendations formulated in Chapters 4, 5 and 6 for the three plants under consideration are summarised again.

The three annexes to this recommendation contain brief technical descriptions of the three research reactors for a better understanding of the explanations.

4 Research reactor Berlin II (BER-II)

4.1 Emergency measures

4.1.1 Recommendations of the RSK from the safety review of German research reactors in 2012

Generic recommendations:

"Depending on the risk potential of the research reactors, a plant-specific concept for plant-internal preventive and mitigative accident management measures (in addition to the external disaster response measures) should be drawn up or further developed. The following points should be included:

- *For this concept, the General guidelines for emergency planning by nuclear power plant operators /1/ should be used for orientation, taking into account the respective hazard potential. The defined accident management measures (AM) should be available or developed in the operating rules as part of the control room documentation. An emergency response organisation should be established in any case.*

- *In the context of the further development of AM measures, aggravating boundary conditions in the case of external hazards, such as extensive destruction of the infrastructure incl. communication facilities in the site environment, impeded technical and personnel support from outside as well as inaccessibility and impairment of work possibilities due to debris formation, smoke gases, increased dose rate, etc., should also be taken into account, insofar as this is to be expected depending on the scenario.*

- *With regard to beyond-design-basis scenarios involving a loss of coolant, the AM measures should also include sealing and make-up feeding options for the pools.*

- *For beyond-design-basis scenarios in which the existing instrumentation for monitoring the reactor parameters and the radiation dose, including its power supply, is assumed to have failed, sufficient AM measures have to be provided for this purpose.*

- *Design of AM measures to limit activity release in case of core meltdowns".*

Specific recommendations on BER-II

"According to statements by the authorised expert, an emergency manual for BER-II is expected in this context, which is currently not available or not available to the extent expected. The RSK considers it expedient to carry out a review of the emergency concept in accordance with the generic assessment with reference to Chap. 5.1 in order to ensure an updated and systematic presentation and further development."

"The expert recommends that the design of the existing accident monitoring system be reviewed, taking into account the adverse boundary conditions to be considered in the context of this robustness test."

"Although, according to the descriptions, there are sufficient power supply options, the RSK recommends specifying this partial aspect within the scope of the review of the emergency protection concept and the preparation of an emergency manual and, if necessary, supplementing it by technical measures (e.g. installation of fixed feed points for the power supply)."

"The RSK recommends specifying the feeding of cooling water into the reactor pool as an emergency measure within the scope of the review of the emergency protection concept and the preparation of an emergency manual and, if necessary, supplementing it by technical measures that do not require access to the reactor hall.

With regard to emergency measures for the cooling of irradiated fuel elements in the storage and transfer pools, the authorised expert sees a need for review and recommends further considerations within the framework of the preparation of the emergency manual. The RSK agrees with the expert's opinion."

4.1.2 Implementation

Revision of the emergency response concept based on the General guidelines for the planning of emergency measures and establishment of a crisis management team organisation

At the meetings of the WG RARR on 31 March 2015 and 02 February 2015, the operator of BER-II [EP_RAFR1], [BER-01], [BER-02], [EP_RAFR2], [BER-03] reported that the emergency response organisation of the Helmholtz Centre Berlin (HZB) had been revised, inspired by the recommendations of the RSK following the safety review of German research reactors [RSK-SÜ-FR].

During the revision, the "General guidelines for emergency planning by nuclear power plant operators" [REmp-NFM] had been largely implemented. There were exceptions, among other things, in the composition of the crisis team, since not only the reactor but the entire HZB could be affected by emergency situations. In addition, in the event of a disaster, information of the public was not provided by the crisis team of the HZB, but by the Joint Operations Management of the Berlin Fire Brigade and the Central Operations Management of the Senate Administration for the Interior and Sport of the Land of Berlin [BER-03].

The HZB Central Safety Staff Department is responsible for the plant's internal emergency protection organisation and fire protection and thus also for the plant fire brigade and the provision of the HZB Crisis Team.

The head of the crisis team ("HZB Head of Operations") is the HZB security officer or, in his/her absence, the duty officer from a group of 8 other persons (deputies). In the event of a disaster, the "HZB Head of Operations" is responsible for coordinating all parties involved and communicating with the authorities and the Joint Operations Management of the Berlin Fire Brigade, in which the HZB is represented by an expert advisor. Coordination does not include technical decisions on necessary measures for reactor safety, radiation protection and plant security. These measures remain the responsibility of the Head of Reactor, the Head of Radiation Protection, and the Site Safety Officer.

The Head of Operations and his/her deputies are called to the operations centre in the event of an alarm. The HZB operations centre is bunkered and has an emergency power supply and communication links with the Berlin Fire Brigade, among others. From there, there are also dedicated lines to the control room and the emergency control centre of BER-II. Environmental, weather and radiological data can be recorded by the operations centre. Since 2004, a network of LDR[1] measuring stations within a radius of 4 km around the reactor has been integrated into the KFÜ[2] and is also used.

The bunkered operations centre is not designed for operation over days. Therefore, if necessary, the "HZB Crisis Team " can be relocated to the Berlin Fire Brigade.

The initiation of measures at the reactor is the sole responsibility of the Reactor Plant Manager or the shift supervisor. According to the so-called "Line of Command for Plant Operation" [BER-07NHB], the shift supervisor on duty assumes the function of Reactor Plant Manager until the higher-ranking supervisor arrives. The Reactor Plant Manager or one of his deputies is on call and is alerted by the control room personnel in the event of a malfunction. The Reactor Plant Manager is authorised to issue instructions to all persons in the reactor area. If necessary, he/she can request additional forces from the "HZB Crisis Team " but is not authorised to issue instructions to third parties. The " HZB Head of Operations " is responsible for all other measures within the scope of on-site emergency preparedness (e.g. evacuation of the Institute premises and communication with the Joint Operations Command of the Berlin Fire Brigade).

For his part, the "HZB Head of Operations" is obliged to include the technical matters of the reactor, radiation protection and plant security as well as the technical decisions taken by the respective persons in charge in the course of the implementation of emergency measures in the higher-level coordination without making any changes.

The plant fire brigade, which is similar to a works fire brigade, is ready for action during duty hours. After hours, a guard is available. In the event of damage, the plant fire brigade takes over first aid measures and initial extinguishing measures and provides technical assistance during duty hours. It alerts the Berlin Fire Brigade, instructs it and supports it [BER-03]. After the Berlin Fire Brigade has arrived, it takes over the technical-operational management of its operation.

The HZB conducts regular training and inspections with the Berlin Fire Brigade so that they have local and plant knowledge - including of BER-II. The emergency exercises relate exclusively to BER-II. This also includes the regular practicing of emergency measures in accordance with the Emergency Manual (NHB) [BER-07NHB]; for example, the establishment of the water supply for the reactor pool via various feed options.

At its second meeting on 02 July 2015, the WG RARR was informed by the licensing and supervisory authority of the State of Berlin about changes in disaster control planning with regard to BER-II [EP_RAFR2].

[1] local dose rate
[2] Nuclear Reactor Remote Monitoring (Kernreaktor-Fernüberwachung) System

The authority assumes that an exceedance of radiological action levels for measures of civil protection [REmp-Kat] is only conceivable due to a massive external impact and a leak of the reactor pool caused by this that cannot be compensated. Due to the associated rapid scenario and the high number of potentially affected individuals, the greatest possible speed in the implementation of disaster control measures is deemed extremely important.

Against this background, a "reflex phase" had been introduced so that selected measures could already be initiated in the course of the alert without further delaying decisions. To implement this concept, the gradation between early warning and alert was dispensed with, i.e. reaching one of the criteria for an early warning or emergency alert immediately triggers the recommendation of an emergency alert. The operator's recommendation to trigger an emergency alert is followed without further official decisions. This means the immediate alerting of all authorities and structures responsible for emergencies by the Berlin Fire Brigade and immediate initiation and preparation of relevant measures by the respective agencies in charge. This also includes an initial general information of the population and the call for sheltering in the vicinity of the research reactor.

The authority is aware that this places a great responsibility on the licence holder. However, with regard to the emission criteria, there is a clear gap between the emission value of a design basis accident and the early-warning criterion, so that the risk of a wrong decision is reduced.

Anchoring of emergency measures as part of the control room documentation and transition from the operating manual (BHB) to the emergency manual (NHB)

At its first and second meeting on 31 March 2015 and 02 July 2015, respectively, the operator of BER-II informed the WG RARR that the emergency measures for BER-II had been reviewed and further developed following the safety review of German research reactors [RSK-SÜ-FR] and that the NHB had been revised in accordance with KTA 1203 [KTA 1203].

Among other things, the NHB [BER-07NHB] defines criteria for the initiation of emergency measures and regulates the organisation of the on-site emergency preparedness, e.g. with regard to competences and responsibilities, the convening of the emergency preparedness organisation, the cooperation with external agencies, and the alerting procedures. It also describes the various emergency measures for reactor pool injection and the fuel element transfer pool as well as for controlling reactivity, for backup power supply with mobile emergency diesel generators and for shutting down and connecting the operational I&C after station blackout (SBO).

The transition from the BHB to the NHB is triggered in accordance with the alarm regulations of the BHB when a dose criterion is exceeded (increase of the emission to 1% of the emission criterion for early warning[3]) as well as when a fundamental safety function is endangered or violated. In addition, the emergency organisation is convened in case of a loss of normal and emergency power supply.

In addition, the description of the individual emergency measures defines specific initiation criteria and also includes, among other things, descriptions of the goal of the measure, the system and personnel requirements and the grace period as well as the implementation and effectiveness control.

The Reactor Plant Manager decides on the choice and initiation of the on-site emergency measure.

The NHB also contains regulations on radiological monitoring. According to these, exercises are carried out once a month with the instrument carriage, following the incident/accident measuring programme. The incident/accident measuring programme is initiated by the radiation protection supervisor. Corresponding regulations for radiation protection are in place. Apart from the emission criterion for the early warning, no other criteria for the initiation of the incident/accident measuring programme are mentioned in the NHB

Within the scope of the expert assessment by TÜV Rheinland, it is planned to mirror the NHB on the General guidelines for emergency planning [REmp-NFM] and KTA 1203 [KTA 1203]. Among other things, a technical discussion (authorised expert, authority, operator) is reported to have been held on the organisational regulations, as a result of which the regulations on responsibilities within the emergency protection organisation and the provisions on radiation protection were to be specified and supplemented. The authorised expert sees potential for further optimisation of the NHB and suggests that the lessons learned from exercises be taken into account in further revisions of the NHB.

Emergency measures for injection into the operating pool and the storage pool

According to the revised NHB of the BER-II [BER-07NHB], [BER-03], [EP_RAFR2], the emergency measure for water injection into the operating pool/storage pool (reactor pool = operating pool + storage pool) can make use of three diverse injection options, whereby different injection paths and water sources can be used in each case:

i. via the operational KTJ system[4],
ii. via the dry riser of the fire extinguishing system,
iii. direct injection into the reactor pool via hose connections.

During normal operation, the KTJ system serves to compensate for water losses from the reactor pool. In the event of major leakages, this is considered a beyond-design-basis accident and the NHB is applied. If the KTJ system is still intact, it can be used as an emergency measure (i) in addition to other measures with the aid of various injection sources. Due to the delivery capacity of the KTJ system (approx. 5 m^3/h), it can be assumed that this measure alone is not sufficient to overfill a large leak. The additional injection options ii.

[3] Since 2014, following a decision by the SenInnSport (Senate Department for the Interior and Sport) of the State of Berlin, the gradation between early warning and alert has been dispensed with.
[4] System for make-up feeding in the event of operational leakages from the reactor pool

and iii. (up to about 20 m³/h) are suitable for overfilling larger leaks, but (in contrast to the use of the KTJ system) require access to the reactor hall.

Sealing of leaks in the operating or storage pool

Emergency measures for sealing the operating or storage pool are not provided according to the NHB [BER-07NHB], [EP_RAFR2]. The operator points out that the measures for the injection of water into the operating pool could also be used for the storage pool.

Furthermore, in the event of a leakage from the operating or storage pool, it would be possible to reload the fuel elements into the respective intact pool by manual action. The reloading could also be carried out in such a way that the entire core is shuffled. In an emergency, this could be done without a power supply. A leakage from the operating pool as a result of a beam tube defect would not have any significant impact on the storage pool, as both are separated by a concrete hatch.

In addition, according to the operator it is possible in principle to move fuel elements from the reactor pool to the transfer pool. However, this would require more time. From experience, it is known that 7 fuel elements (there are a total of 30 fuel elements in the core) can be moved per shift in a transport cask from the storage pool to the transfer pool. In addition, the measure requires the availability of the overhead crane.

Emergency measure for cooling the fuel elements in the transfer pool

An emergency measure for injecting into the transfer pool is defined in the NHB [BER-07NHB]. The operator assumes that the transfer pool will remain intact in the event of external hazards due to the massive cover and the double-walled design (see also the comments on aircraft crash). For this reason, the measure was designed for the case that the redundant cooling systems of the transfer pool fail in the event of an increased evaporation rate as a result of the emergency unloading of fuel elements from the operating or storage pool. In the event of failure of the power and municipal water supply, the measure can be implemented using mobile pumps of the fire brigade and fire-fighting water supplies. The non-intervention time for this is at least one day.

Emergency measures to restore the three-phase AC power supply

Already during the safety review of German research reactors in 2012 [RSK-SÜ-FR], it was determined by the RSK that sufficient power supply options exist and that neither power nor water supply is needed to maintain vital safety functions. The shutdown rods drop in gravity-driven and even in case of a failure of the battery-buffered pump run-down (60 s according to specification, minimum battery capacity 10 minutes), there is no damage to the fuel elements.

In addition to the operational power supply, the BER-II has two emergency power diesels that supply the safety-related consumers of the redundant system train assigned to them for at least 72 h, such as the +/-24 V busbar for supplying the instrumentation, the negative pressure system in the reactor hall and the KFÜ. In addition, a battery capacity of at least 70 h is available for the instrumentation. In addition, there are two physically separate feed points for mobile emergency diesel generators, which can be used to supply both the instrumentation and control system (e.g. accident monitoring system and radiation protection instrumentation) and the negative-pressure system for the reactor hall [BER-01], [BER-03]. The feed points are located on different sides of the reactor building and have a distance of about 125 m as the crow flies. The connections to consumers still present and to mobile equipment (e.g. submersible pump in the KBB[5] storage tank room) are established temporarily. A corresponding emergency measure was included in the NHB [BER-07NHB]. A mobile diesel generator for simultaneous supply of the I&C and the negative-pressure system is not available on the HZB site. A generator of the required power class, including the necessary accessories, must be procured from a rental company. There is no contractual agreement with a rental company to provide such a unit. A basic availability enquiry is regularly carried out by the HZB.

Robustness of the accident monitoring system and emergency measures for monitoring the reactor parameters and the radiological situation

Already during the safety review of German research reactors by the RSK in 2012 [RSK-SÜ-FR], the RSK had agreed with the expert's opinion that there was no need for further review with regard to the acquisition of radiological data due to the manifold stationary and mobile measuring options.

The water level measurement and the temperature measurement in the reactor pool as well as the neutron flux instrumentation are designed to be accident-proof. For important parameters, various hand-held measuring devices were also available. Within the framework of the 2012 safety review [RSK-SÜ-FR], the fault resistance was again tested under the boundary conditions to be taken into account. Only in the case of massive mechanical impacts was the failure of the equipment to be assumed.

As stated in [RSK-SÜ-FR], preventive measures ensure that a hydrogen-air reaction ("H_2 explosion") will not occur at the cold neutron source (KQ). The licence holder also explained [EP_RAFR2] that a hypothetical hydrogen-air reaction at the KQ had nevertheless been assumed as early as in 1987. The analysis of the effects had shown that no inadmissible damage to the reactor plant was to be expected and that there was therefore no need for further preventive measures. In particular, no effect on the accident monitoring system and on the core was to be feared. Even in the event of leakage, no failure of the instrumentation was to be expected.

In order to safeguard the operation of the accident monitoring system during a station blackout (SBO) over a longer period of time, an emergency measure for shutting down the operational I&C is first taken, which relieves the batteries of the 24V DC supply within the first 5 hours [BER-07NHB]. In addition, the emergency measures to restore the three-phase AC power supply are initiated.

[5] KBB: Coolant treatment and storage system. The KTJ system can also transfer leakage water and fire-fighting water that collects in the KBB storage tank room to the reactor pool.

Emergency measures to limit the release of activity during core meltdowns

The design takes into account the melting of a single fuel element due to a cooling channel blockage [BER-01], [EP_RAFR1].

If a core meltdown occurs, the priority is to ensure that the core is covered with water, regardless of the extent of the core damage. If the reactor hall is intact, the ventilation isolation and the filtering of the exhaust air prevent a release into the environment (except for the noble gases). For this purpose, an external emergency power supply via a large emergency diesel is required in the case of a simultaneously postulated SBO. In the event of a defective hall, the water cover of the core ensures retention of the fission products to a large extent, except for the noble gases. In the event of a dry core meltdown and a defective hall, a partial release of all volatile fission products will occur.

The essential measures for limiting the release are therefore in any case the water injection into the reactor pool, the ventilation isolation, and the restart of the negative-pressure system with exhaust air filtration with the reactor hall intact.

Consideration of aggravating boundary conditions during the implementation of emergency measures

In the operator's opinion, aggravating boundary conditions (inaccessibility, debris formation, smoke gases, etc.) have been taken into account in the planning of the emergency measures anchored in the NHB [BER-01], [BER-03].

The connections for the electrical power supply via mobile emergency diesel generators are physically separated (see also emergency measures for restoring the three-phase AC power supply). It is therefore assumed that a mobile emergency power supply can be set up even in the event of difficult access to the reactor hall and serious destruction on the site.

An analogous argument applies to the emergency feeding of the pools. With the alternative, physically separate injection via the KTJ system or the dry risers of the fire extinguishing system and the possible direct injection into the reactor pool via fire hoses on the one hand, and through diversity in the water tapping points (cooling tower basin, municipal water supply, sprinkler system, KBB storage tank room, Lake Stölpchensee) on the other hand, potential destruction within the plant and on the site was taken into account. When injecting via the KTJ system, it is not necessary to enter the reactor hall.

In the emergency measure "Alternative shutdown of the core by boration", the boric acid present in crystalline form can be dissolved and introduced via the emergency water injection system.

According to the operator, the communication facilities between the control room, the supplementary control room, the HZB operations centre, the Joint Operations Management of the Berlin Fire Brigade and the Central Operations Management of the Senate Administration for the Interior and Sport of the Land of Berlin are laid out in a diverse and physically separate manner (including independent telephone systems, digital radio connection to the Berlin Fire Brigade, dedicated lines between the operations centre and the control room and supplementary control room).

The operator says that forklift trucks are available on the HZB premises for clearing debris. Larger lifting and clearing equipment to remove debris would have to be provided by external companies if needed. In addition, the HZB has concluded a contract with the Kerntechnischer Hilfsdienst GmbH (KHG). If necessary, their emergency forces will arrive within 24 hours at the facility with the appropriate equipment. In addition, in the event of a disaster, equipment needed can be requested from the Joint Operations Management of the Berlin Fire Brigade or from companies in the vicinity. A list of companies with appropriate equipment is available. The Berlin Fire Brigade and Berlin police would be called in to assist in such a case. In addition, the Federal Agency for Technical Relief could be involved (via the Joint Operations Management of the Berlin Fire Brigade).

According to the operator, accessibility of the HZB with heavy equipment (emergency diesel generators, lifting equipment, etc.) is not endangered even in the event of external hazards. The island on which the HZB is located is accessible via three bridges located far enough from each other. According to the operator's opinion, access is guaranteed even in the event of flooding. A flood wave is not to be feared, as there are no barrages.

4.1.3 Assessment by the RSK

With the further development of the emergency measures, the revision of the emergency manual and the revision of the emergency response organisation, the operator, in cooperation with the authority, has largely implemented the relevant recommendations of the RSK from the safety review in 2012 [RSK-SÜ-FR]. The RSK sees further possibilities for optimisation, for which it makes recommendations in the following.

The "reflex phase" introduced by the competent authority for disaster control planning and the thus created possibility to initiate or prepare the necessary disaster control measures already immediately after the alarm recommendation by the operator are seen positively by the RSK. In addition, this regulation implements an RSK/SSK recommendation [REmp-NFM] on the procedure to be followed in case of "rapidly unfolding events" with an expected high release.

With regard to the emergency response organisation of BER-II, the RSK is of the opinion that this organisation is special in that it is not only originally composed of the BER-II personnel responsible under atomic law and is not only geared to BER-II, but is also integrated into the emergency response organisation of HZB. This means that the highest-ranking person responsible under atomic law is not - as is the case, for example, with the power reactors - also the head of the emergency response organisation and consequently also authorised to issue instructions for the areas of radiation protection and physical protection.

Rather, at BER-II, the person responsible under atomic law for the safe operation of BER-II (Head of Reactor) is also subordinate to the management of the emergency response organisation of HZB in the event of an emergency. Due to the specific structure, the persons responsible for radiation protection and physical protection are integrated into the emergency response organisation of HZB on an equal footing with the Head of Reactor. The RSK is aware of the special nature of the embedding of the emergency response organisation of BER-II in the emergency response organisation of HZB. Notwithstanding, the RSK holds the view that a hierarchy of authority should also be clearly recognisable in the emergency response organisation of BER-II. In particular, the Head of Reactor should also be authorised to issue instructions to the Physical Protection Commissioner and Radiation Protection Supervisor in all matters of reactor safety in emergency situations. Instructions of the "HZB Head of Operations" must not override the responsibility of the Head of Reactor under atomic law /E1/.

E1 The RSK recommends that in the emergency response organisation of BER-II, the hierarchy of the authority to issue directives should be clearly recognisable. In particular, the Head of Reactor should also be authorised to issue instructions to the Physical Protection Commissioner and the Radiation Protection Supervisor in all matters of reactor safety in emergency situations. The instructions of the "HZB Head of Operations" must not override the responsibility of the Head of Reactor under atomic law.

In the emergency manual of BER-II, the fire brigade is used as a resource for some emergency measures. No distinction is made here as to whether it is the plant fire brigade or the professional fire brigade of the city of Berlin. Since the HZB fire brigade is only available during normal working hours, it would be necessary to call on the professional fire brigade of the city of Berlin outside of normal working hours. However, since BER-II has no right to issue instructions to the Berlin Fire Brigade in this regard, this aspect should be sufficiently taken into account in the selection of emergency measures. In the emergency manual, a corresponding differentiation should be made in the presentation /E2/.

E2 With regard to the implementation of emergency measures, the RSK recommends differentiating between the deployment of the plant fire brigade and the Berlin Fire Brigade in the emergency manual. When naming resources and describing emergency measures, the emergency manual should take into account the circumstances that the plant fire brigade is only available during normal working hours and that the Berlin Fire Brigade is not subject to the instructions of the operator.

Against the background of the operator's statements that the operating rules do not contain any unambiguous criteria for triggering and initiating the incident/accident measurement programme according to the Guideline on Emission and Immission Monitoring of Nuclear Installations [*Richtlinie zur Emissions- und Immissionsüberwachung kerntechnischer Anlagen - REI*], the RSK recommends reviewing to what extent unambiguous criteria for triggering the incident/accident measurement programme in case of events involving a release can be included in the operating rules /E3/.

E3 The RSK recommends examining to what extent clear criteria for triggering the incident/accident measurement programme in case of events involving a release can be included in the operating rules.

The robustness of the accident monitoring system under beyond-design-basis conditions has been reviewed again by the operator. Diverse measuring options are available for important parameters. In addition, an emergency measure for shutting down the operational instrumentation and control system has been introduced in order to relieve the 24V DC power supply and thus achieve a longer supply for the accident monitoring system. In addition, an emergency power generator can be connected via physically separated feed points to restore the three-phase power supply.
The RSK does not see any further need for review in this respect.

The RSK states that possible aggravating boundary conditions due to external hazards were taken into account in the development of the emergency measures, among other things by the physically separated feed points for the emergency diesel generators and by the diverse options for emergency feeding of the reactor pool.

In accordance with the RSK's recommendation, the operator reviewed the emergency measures for the power supply and supplemented technical measures. However, the RSK identified further potential for optimisation in order to ensure the effectiveness of the power supply by means of a mobile emergency diesel generator. In particular, the RSK believes that without a corresponding contractual obligation, it is not ensured that the required resources can be provided by a rental company in the event of a prolonged failure of the three-phase power supply, as a large number of users will resort to such resources in the event of a widespread power failure. In this respect, from the RSK's point of view, a contractual guarantee is recommended. Specific accessories for connecting the equipment within the facility should be kept with sufficient protection. Furthermore, in the view of the RSK, the boundary conditions (e.g. required power) and switching operations (e.g. to avoid the automatic connection of consumers) for the connection of the mobile emergency diesel generator should be clearly indicated in the emergency manual. As this is not the case in the current emergency manual, the RSK recommends a corresponding specification /E4/.

E4 The RSK recommends concluding a contractual arrangement for the provision of a mobile emergency diesel generator that also allows the operation of the ventilation system and the exhaust air filtration of the reactor hall. The necessary cable connections should be available at the plant with sufficient protection. The boundary conditions (e.g. required power) and switching operations (e.g. to avoid automatic connection of consumers) for connecting the mobile emergency diesel generator should be clearly stated in the emergency manual.

Due to the manifold options for feeding water into the reactor pool in connection with the possibility to transfer the fuel elements into the storage pool, the RSK can understand that no measures are planned to seal leakages from these pools. In this context, however, sufficient make-up feeding into the reactor pool should be possible without having to enter the reactor hall. The RSK recommendation in this regard from the 2012 safety review has not yet been realised. This results in recommendation /E5/.

E5 Due to the pumping capacity of the KTJ system, it can be assumed that the measure alone is not sufficient to compensate for a large leak in the reactor pool. The additional feed options available are suitable for overfeeding larger leaks but require access to the reactor hall. Likewise, electrical consumers and mobile equipment still present inside the buildings have to

be connected to the external emergency feed points of the three-phase power supply by temporary cable connections. The RSK recommends checking to what extent fixed pipelines or cables can be used to avoid that endangered room areas have to be entered in case of an emergency.

The operator explained which emergency measures had been introduced for cooling spent fuel elements in the transfer pool. The corresponding recommendation was implemented.
The RSK does not see any further need for review.

4.2 Other natural external hazards

4.2.1 Recommendations of the RSK from the safety review of German research reactors in 2012

„With regard to the exhaust stack, the authorised expert basically confirms that the design principles are up to date but sees a need for additional review within the framework of supervision in connection with the consideration of fatigue stresses.

With regard to loads caused by heavy rain and extreme snowfall, the authorised expert confirms the robustness of the reactor building and the experimental hall, taking into account load margins due to the relief provided in the meantime by the removal of gravel fill on the roof surface and existing emergency rainwater drains and drains yet to be retrofitted.“

„Based on the statements of the operator, the up-to-dateness of the structural design fundamentals and, in particular, the positive assessment by the authorised expert, the RSK does not see any further need for review with regard to the review aspect mentioned here, provided that the mentioned supplementary reviews and retrofitting measures are implemented.“

4.2.2 Implementation

The verifications for the fatigue stress of the stack were prepared within the scope of the design. They were submitted to the authorised expert after the safety review by the RSK in 2012, together with an assessment by an engineering firm for civil engineering. On this basis, the authorised expert from TÜV Rheinland confirms that there is no concern that the integrity of the stack will be impaired by fatigue [BER-10], [EP_RAFR2].

The additional emergency rainwater drains to prevent water from entering the reactor building have been retrofitted in the meantime [EP_RAFR2].

4.2.3 Assessment by the RSK

The recommendations from the 2012 safety review have been implemented.

4.3 Protection against explosion

4.3.1 Recommendations of the RSK from the safety review of German research reactors in 2012

„Based on the examinations submitted and the assessment by the authorised expert, the RSK comes to the conclusion that degree of protection 1 (preservation of the vital safety functions in case of impacts according to the present state of knowledge) is basically fulfilled. However, the RSK sees a need for additional review with regard to the maximum transport quantities of hydrogen during the filling of the buffer tank and their consideration in the assessment of possible effects of explosion hazards.“

4.3.2 Implementation

In the safety review in 2012 [RSK-SÜ-FR], the hydrogen buffer tank for the cold neutron source and the hydrogen transport quantities during the filling of the buffer tank were identified as significant sources regarding the release of explosive gases. According to estimates by the operator [BER-09], an explosion of the hydrogen in the buffer tank will not lead to serious damage to the reactor building and not to a loss of vital safety functions. There is no comparable proof of harmlessness in case of a simultaneous explosion of the hydrogen quantities in the buffer tank and in the cylinder bundle (12 cylinders) used for filling the buffer tank.
In the meantime, it has been administratively determined by the operator that no bundles of 12 but only individual hydrogen cylinders may be transported when filling the buffer tank for the cold neutron source [EP_RAFR2]. Filling is carried out by BER-II personnel.

In addition, it was determined that the transport of explosive substances on the premises of BER-II is prevented by checking incoming vehicles and rejecting inadmissible transports. The authorised expert considers the latter measure to be sufficient [EP-RAFR2].

4.3.3 Assessment by the RSK

In the safety review of BER-II by the RSK in 2012, the hydrogen buffer tank for the cold neutron source and the hydrogen transport quantities during the filling of the buffer tank were identified as significant sources for the release of explosive gases. It was found that an explosion of the hydrogen in the buffer tank and in the connecting line to the reactor building will not lead to a loss of vital safety functions. There is no comparable proof of harmlessness in the case of a simultaneous explosion of the hydrogen quantities from the buffer tank and a cylinder.

The RSK considers the operator's administrative regulation according to which only individual hydrogen cylinders may be used by the personnel of BER-II for filling the buffer tank for the cold neutron source to be basically expedient. Since, to the RSK's knowledge, this regulation has not yet been included in the operating rules, it is recommended anchoring this requirement in the operating rules.

In addition, the RSK recommends demonstrating that the explosion of the entire hydrogen amount of a hydrogen cylinder, the buffer tank and the connecting line will not lead to the impairment of vital safety functions of BER-II /E6/.

E6 The RSK recommends anchoring the requirement according to which only individual hydrogen cylinders may be used by the BER-II personnel when filling the buffer tank for the cold neutron source in the operating rules. Furthermore, the RSK recommends proving that the explosion of the entire hydrogen amount of a hydrogen cylinder, the buffer tank and the connecting line will not lead to an impairment of vital safety functions of BER-II.

4.4 Aircraft crash

4.4.1 Recommendations of the RSK from the safety review of German research reactors in 2012

"In the opinion of the RSK, there should be further considerations on the robustness of BER-II with regard to an aircraft crash with a view to maintaining the effectiveness of emergency and disaster control measures and their improvement under the conditions of such an event. This concerns both measures to avoid a core meltdown (e.g. further options for water injection into affected pools) and mitigative measures to reduce a release from a core meltdown. In this context, the existing fire-fighting measures should also be reviewed to determine whether they are also suitable for controlling fuel fires, such as could occur in the event of a crash of a large commercial airliner on the plant site, in such a way that the effectiveness of pre-planned and, if necessary, also further developed emergency and disaster control measures relevant in this scenario is not significantly limited."

4.4.2 Implementation

<u>Effects of the crash of a commercial airliner (Airbus A320)</u>

After the 2012 safety review [RSK-SÜ-FR], the effects of the deliberate crash of an Airbus A 320 on the research reactor BER-II were investigated on behalf of the Land authority under the leadership of TÜV NORD EnSys Hannover GmbH & Co. KG [BER-04], [BER-05], [BER-06]. The investigations concentrated on the experimental hall, the reactor hall, and the reactor pool (operating pool and storage pool).

The analysis showed that the preservation of the vital safety functions cannot be demonstrated. Therefore, degree of protection 2 according to the safety review of German research reactors [RSK-SÜ-FR] regarding the preservation of vital safety functions is not achieved.

Alternatively, degree of protection 2 can be achieved if, as a result of the crash of an aircraft of this class and the associated fuel fire, the radiological effects in the vicinity of the plant remain below the values for disaster control measures even if vital safety functions fail. The study therefore addressed the question of whether the radiological impacts remain below the action level of 100 mSv effective dose for the measure "evacuation" [REmp-Kat].

On the basis of the results of the available investigations, the authorised expert cannot confirm compliance with degree of protection 2, also with regard to the radiological effects of the aircraft crash, since the action level for the whole-body dose of 100 mSv for the "evacuation" measure may be reached under certain boundary conditions.

Emergency measures to prevent a core meltdown in the event of an aircraft crash and to limit releases from a core meltdown

In principle, the emergency measures for shutting down the reactor, restoring the three-phase electrical power supply and injecting water into the reactor pool can also be used to prevent a core meltdown or to limit the effects of a meltdown in the event of an aircraft crash. The emergency measures that can be taken depend on the degree of destruction caused by the aircraft crash. It can be assumed that the measures will be hampered by debris, fire, and increased local dose rates.

The consideration of aggravating boundary conditions in connection with the implementation of emergency measures is dealt with in 4.1.2.

Suitability of measures to fight kerosene fires with regard to the effectiveness of emergency and disaster control measures

The fire protection concept has been revised by the operator and takes into account the building regulations. All structural, organisational and preventive measures are summarised in the new fire protection concept. The concept is being examined by the authorised expert TÜV Rheinland within the framework of the supervisory procedure. The initial assessment is available [EP_RAFR1]. The authorised inspector has suggested further optimisations, among other things that a further adaptation to KTA 2101 [KTA 2101] should be carried out. In addition, a fire door to the reactor building and smoke outlets should be upgraded.

The operator explains that the entry of kerosene from outside into the experimental hall and adjacent buildings is prevented by thresholds at the entrances. As part of the investigations into the deliberate aircraft crash, the question of whether larger quantities of kerosene could accumulate on the site near the BER-II buildings was also investigated. No particular potential hazards were identified.

In addition, in the course of the safety review of German research reactors [RSK-SÜ-FR], the possibility of gaseous and liquid ingress from outside into the buildings had already been investigated. In particular, the entry of flue gases into the reactor hall and the control room had also been investigated. The monitoring equipment and the ventilation systems are suitable to limit this to such an extent that no vital safety functions are endangered.[6].

[6] For flammable gases, degree of protection 3 and for toxic gases, degree of protection 2 was determined by the RSK.

On the question of the extent to which the emergency feed points for electricity and water are protected against kerosene fire, reference is made to the sufficient physical separation of the two feed points for electricity and the diverse options for water injection [BER-03] (see also 4.1 of this statement).

The operator also states that diverse water extraction options are available in addition to the design (see also 4.1 of this statement), which could also be used for fire-fighting.

The plant fire brigade, which is similar to a works fire brigade, is ready for action during working hours. After hours, a guard is available. The plant fire brigade takes over first aid and initial fire-fighting measures and provides technical assistance during working hours in the event of damage. It alerts the Berlin Fire Brigade and provides instructions and support [BER-03]. After the Berlin Fire Brigade has arrived, the latter takes over the technical-operational command of its operation.

The operator also states that the HZB is in close contact with the Berlin Fire Brigade. Training courses or briefings are held regularly every two weeks with the Berlin Fire Brigade. The trainings take place particularly under the aspect of imparting specific local and plant knowledge as well as knowledge in the area of radiation protection. In addition, special emergency scenarios and communication with the Joint Operational Command are practised once a year as part of the legally required emergency exercise. A large kerosene fire in particular has not been the subject of an exercise so far. It is pointed out that in the event of an aircraft crash, flight operations at Berlin Airports would be largely suspended and firefighters from the airport fire brigade could be requested. This fire brigade is the only one in Berlin that is specially prepared for large kerosene fires. They could be on site within about 30 minutes.

Impairment of the transfer pool due to the aircraft crash

In its written report on the possible damage to the transfer pool caused by an aircraft crash [BER-08], the authorised expert TÜV NORD EnSys Hannover GmbH & Co. KG comes to the conclusion that a direct hit on the transfer pool is not possible and therefore damage leading to a loss of integrity of the transfer pool is not to be postulated. Even in the case of an assumed failure of the residual-heat removal of the spent fuel elements, the authorised expert from TÜV Nord estimates that the fuel elements can only be expected to dry out after approx. 24 days. This would be sufficient to take countermeasures and avoid a release from the transfer pool. An emergency measure for injection into the transfer pool is described in the emergency manual.

4.4.3 Assessment by the RSK

The RSK considers itself sufficiently informed by the expert opinion [BER-05] about the possible consequences of the deliberate crash of a medium-sized commercial airliner (Airbus A320). From the point of view of the RSK, the postulated scenarios and the expected impacts are comprehensible. Severe damage to the reactor building and the technical infrastructure is to be expected as a consequence of the crash. In all worst-case scenarios considered, the non-intervention times until core exposure are too short to avoid core meltdown by preventive emergency measures. The mitigative emergency measures can be seriously impeded by the fire, the debris formation, and the increased local dose rate.

The authorised expert comes to the conclusion that the vital safety functions cannot be maintained, that core meltdown will occur in an air/water vapour atmosphere and that the action level of 100 mSv effective dose for the evacuation of the residents can just about be reached.

Consequently, both possible criteria for degree of protection 2 are not fulfilled in case of an aircraft crash. The RSK agrees with the authorised expert's opinion.

With regard to the recommendation from the safety review of German research reactors that the firefighting measures should be reviewed to determine whether they are suitable to control fuel fires after an aircraft crash in such a way that the emergency and disaster control measures relevant in such a scenario are not significantly restricted, the RSK is of the opinion that this recommendation has been or will be implemented in parts. The fire protection concept was revised and further adaptations to KTA 2101 are planned. Individual fire protection measures have been upgraded. The possible entry of kerosene and flue gases into the buildings of BER-II was considered; the existing precautions (monitoring devices, ventilation systems, smoke extractors, thresholds, measures against pool formation near the buildings) are considered sufficient.

So far, no special precautions have been taken for extinguishing kerosene fires. From the point of view of the RSK, the reference to alerting the airport fire brigade is not expedient, since according to the operator, the time until they are ready for action is about 30 minutes. According to the expert opinion of TÜV Nord EnSys and GRS [BER-05], however, the kerosene fire will already have gone out after 30 minutes. Therefore, the RSK recommends examining whether and under what conditions the Berlin Fire Brigade will be able to extinguish kerosene fires at or in the reactor building before 30 minutes have elapsed. If this is possible, this measure, including the prerequisites to be ensured by the operator, should be included in the emergency planning of BER-II. The measure should be practised regularly /E7/.

E7 The RSK recommends examining whether and under what conditions the Berlin Fire Brigade will be able to extinguish kerosene fires at or in the reactor building before 30 minutes have elapsed. If this is possible, this measure including the prerequisites to be ensured by the operator for this purpose should be included in the emergency planning of BER-II. The implementation of this measure should be practised regularly.

With regard to the emergency feed points for electric power and water supply, it is stated that due to the respective physical separation of the feed points and the diversity of the water sources, a simultaneous failure is not postulated.

With regard to the emergency measure for cooling the fuel elements in the transfer pool after an aircraft crash, the RSK does not see any need for further review.

With regard to the rapid reaction of the competent disaster control authorities, which is particularly relevant for the event of an aircraft crash, the RSK refers to its positive assessment of the "reflex phase" in this respect in Section 4.1.3.

4.5 Precautionary measures

4.5.1 Recommendations of the RSK from the safety review of German research reactors in 2012

"The RSK considers the implementation of sufficiently reliable measures to prevent the failure of the power supply due to flooding to be necessary. Taking into account the implementation of these measures, the RSK considers the existing precautionary measures for flooding scenarios to be sufficiently robust and considers robustness level 2 to be achievable for this partial aspect."

"An update of the fire protection concept within the framework of the supervisory procedure should be carried out in the opinion of the RSK."

"The operator and the authorised expert identify maintaining the integrity of the reactor pool and the transfer pool as the most important vital safety function. In the opinion of the RSK, it is not sufficient to consider their hazard potential only with regard to the effects of an aircraft crash and an external blast wave, but plant-internal effects should also be included.

"With regard to the robustness of the plant against plant-internal fire scenarios in which the integrity of the reactor pool and the transfer pool (e.g. leaktightness of the beam tubes) could be affected, the documents do not contain sufficient information to assess the level classification.

In the opinion of the RSK, the conceptual justification (presence of multiple mechanical "barriers") in the present review reports alone is not sufficient to justify a high robustness of this precautionary measure. Overall, the RSK comes to the conclusion that a Level 1 classification is considered achievable. For this purpose, additional evidence is required with regard to fire resistance in case of fires spreading between rooms."

4.5.2 Implementation

Precautions against power supply failure in the event of flooding

The operator states that the batteries and the inverters, which ensure continued operation of the reactor coolant pumps of the operating pool for one minute[7] after failure of the three-phase power supply, are located in the basement of the reactor building. The redundant batteries as well as the inverters could be damaged in the event of a prolonged influx of water from a defective municipal water mains or by rainwater.

[7] Within the framework of the licensing procedure, it has been demonstrated that no fuel element damage will occur after reactor shutdown, even in the event of a failure of an overrun (60s) of the reactor coolant pumps.

Additional emergency rainwater drains have been installed to prevent flooding caused by heavy rainfall (see also 4.2 Other natural external hazards).

As a precaution against the failure of the batteries and inverters in the event of flooding from the municipal water mains, moisture detectors have been retrofitted, the signals of which are displayed in the control room. In addition, a camera has been installed in the corridor to the basement. The batteries and the inverters were installed about 20 cm above the basement floor. Without countermeasures, the inverters would be submerged after about 50 minutes [BER-11]. This would give sufficient time to take countermeasures and shut down the reactor as a precaution.

Revision of the fire protection concept / precaution against cross-room fires

The fire protection concept has been revised by the operator and is being reviewed as part of the supervisory procedure (see also 4.4 Aircraft crash: fighting kerosene fires). During the revision, the potential for cross-room fires had also been taken into account. The operator explained that the fire protection concept covered all redundancies and that the possibility of a fire spreading from one redundancy to the neighbouring redundancy had been considered. The structural design of all important rooms complied with fire protection class F90. The reactor hall had a sprinkler system. The emergency diesel generators were housed separately. The authorised inspector suggested a further adaptation of the fire protection concept to KTA 2101 [KTA 2101].

Precautionary measures against loss of integrity of the reactor and transfer pool in case of plant-internal hazards / fires

With regard to the robustness of the transfer pool in the event of internal fires, reference is made to the considerations covering aircraft crash and kerosene fire (see also 4.4 Aircraft crash, impairment of the transfer pool by the aircraft crash, and [BER-08]). Furthermore, the operator claimed that the crash of a transport cask for spent fuel elements onto the transfer pool had been considered within the scope of the design. In this case, the concrete cover of the pool could be destroyed, but the double-walled steel pool would remain intact.

The operator further explains that in the event of a fire in the experimental hall, a loss of the integrity of the concrete wall of the reactor pool is not to be expected due to the dimensioning of the concrete wall and in this respect also refers to the investigations on deliberate aircraft crash [BER-05] (see also 4.4 Aircraft crash, suitability of control measures against kerosene fires with regard to the effectiveness of emergency response and disaster control measures).

It is also explained that the beam tubes are located further down in the operating pool than the cooling circuit. Therefore, a beam tube failure due to fire was to be regarded as the worst case with regard to pool water loss (centre of beam tube +1.1 m, upper edge of core +1.5 m). The aluminium beam tubes are designed in such a way that there are always two passive barriers against pool water loss as a precautionary measure; the 1st barrier (inner) is the wall of the beam tubes themselves, the 2nd barrier is formed by an insert in the

beam tube (so-called thimble-type tube). The beam tubes are anchored in the concrete and welded to the aluminium lining of the reactor pool. The welded joint is located on the inner side of the beam tube niche of the pool wall (wall thickness is 2.1 m). The beam tube and the welded joint are protected from direct exposure to fire by the niche itself and by the heavy concrete blocks in and in front of the niche and by the thimble-type tube. The beam tubes are cooled from the outside by the pool water. The thimble-type tubes prevent a leakage of pool water in case of a leakage from the jet tubes. Only in the case of a loss of the beam tube insert and the shielding by the heavy concrete blocks would high temperatures be possible due to the effect of fire inside the beam tube, which, however, would continue to be cooled by the pool water. In this respect, a loss of integrity of the beam tubes due to internal fire effects would not be expected.
The operator also explains [EP_RAFR2] that a hypothetical hydrogen-air reaction ("H2 explosion") of the cold neutron source had already been assumed in 1987. The analysis of the effects had shown that no inadmissible damage to the reactor plant was to be expected and that there was therefore no need for any further precautionary measures.

4.5.3 Assessment by the RSK

The improvements of the precautionary measures against power failure due to flooding recommended by the RSK in the course of the safety review of German research reactors [RSK-SÜ-FR] have been implemented. Even if it is assumed that the measures to prevent further water ingress are not effective, there is sufficient time to shut the reactor down as a precaution after detection of the onset of flooding. Even without pump overrun, no fuel element damage will occur.
In this respect, all vital safety functions can be maintained. The RSK does not see any further need for review in this respect.

The plant operator and the authorised expert presented the considerations on the integrity of the transfer pool in case of an aircraft crash with kerosene fire and in case of a crash of the transport cask for spent fuel elements. They come to the conclusion that the integrity of the transfer pool is not endangered by these impacts and that the non-intervention times for emergency injection into the transfer pool are long (see also 4.4 Aircraft crash, impairment of the transfer pool by an aircraft crash, and [BER-08]), so that the cooling of the fuel elements in the transfer pool can be ensured. The RSK agrees with this opinion.

The fire protection concept has been revised by the operator and will be reviewed by an authorised expert in the course of the supervisory procedure. With regard to precautions against cross-room fires, the plant operator refers to the design of essential rooms according to fire protection class F90, to the sprinkler system in the reactor hall, and to the physical separation of the emergency diesel generators. The RSK recommendation to review the fire protection concept in the supervisory procedure has been implemented.

On the basis of the report of the plant operator, the RSK comes to the conclusion that the double barriers of the beam tubes are sufficiently protected against the effects of fire. Furthermore, it was shown that the explosion of the hydrogen of the cold neutron source will not lead to any inadmissible damage to the reactor plant.

The crash of heavy loads into the reactor pool was already considered during the safety review in 2012 with the result that a loss of pool integrity is not to be suspected [RSK-SÜ-FR].

From the RSK's point of view, there is no need for further examination with regard to precautionary measures against pool water loss in case of internal hazards.

5 Research reactor Munich II (FRM-II)

5.1 Emergency measures

5.1.1 Recommendations of the RSK from the safety review of German research reactors in 2012

Generic recommendations: see 4.1.1.

Specific recommendations regarding FRM-II

"According to the information provided by the plant operator, a plant-specific implementation of the "General guidelines for emergency planning by nuclear power plant operators" of 2010 has been carried out; however, the implementation has not been demonstrated in detail. The RSK considers it expedient to perform a review of the emergency concept according to the generic assessment with reference to Chapter 5.1 in order to ensure an updated and systematic presentation and further development."

"Various options are available for external communication if an event occurs, from satellite telephone to dedicated lines to the police and fire brigade. A statement as to whether these communication facilities also function in the event of a power failure is not included in the operator's documents. Organisational measures in this regard, such as alarms, are regulated in the alarm regulations. The formation of a crisis team organisation has so far not been planned."

"For the power supply of accident management measures, the operator states that only pool water emergency feeding with external pumps (including external power supply) is possible in the event of a total power failure.

With reference to the review of the emergency response concept to be provided in Chapter 5.1, the RSK recommends supplementing the injection of cooling water into the reactor pool as an emergency measure by technical measures that do not require access to the reactor hall. Furthermore, the RSK recommends an examination of the non-intervention times and the limits for initiating emergency measures in the supervisory procedure. Furthermore, it recommends the formation of an emergency organisation with the specification of tasks and responsibilities to be laid down in the operating rules."

5.1.2 Implementation

<u>Revision of the emergency response concept based on the General guidelines for the planning of emergency response measures and establishment of a crisis team organisation</u>

as well as

Anchoring of emergency measures as part of the control room documentation and transition from the operating manual to the emergency manual

The operator reports [FRM-01] that the emergency concept has been revised since the safety review in 2012 [RSK-SÜ-FR]. The General guidelines for emergency measures in NPPs [REmp-NFM] and KTA Safety Standard 1203 "Requirements for the Emergency Manual" [KTA 1203] have been taken into account. The emergency manual [FRM-02NHB] has been integrated into the operating manual [BHB] as Part 3, Chapter 4.

The revised emergency manual describes, among other things, the structure and tasks of the emergency response organisation (crisis management team) and the criteria for its entry into force. Furthermore, it defines the technical and spatial equipment of the emergency organisation and lays down the rules for cooperation with external bodies.

In accordance with the alarm regulations of FRM-II [FRM-03], the emergency organisation is convened by the plant's Head of Operations "as soon as it becomes apparent that a beyond-design-basis event (emergency) will occur and the criteria for an early warning or emergency alert have been reached or it is suspected that they will be reached ...". The emergency organisation refers exclusively to FRM-II.

The emergency measures in view of systems design include

- draining the heavy water from the moderator tank,
- shutting off the supply and exhaust air in the controlled area,
- the pool water emergency injection and the emergency unloading of the core
- and the switching on if the 400 V emergency power supply via the emergency transformer.

For each of the above-mentioned emergency measures in view of systems design, the emergency manual describes, in addition to the objective, the initiation criteria, the effectiveness conditions and non-intervention times, the personnel and time requirements, and the necessary resources. The implementation is explained in the corresponding appendices. Furthermore, exercise instructions are given for each measure.

The crisis management team (emergency organisation) is composed of the plant's Head of Operations and representatives of the Reactor Monitoring Division (if necessary, supported by the radiation protection supervisor), the physical protection commissioners as well as representatives of the Reactor Operation, Irradiation and Sources, Electrical and Instrumentation and Control and Reactor Development Divisions. Furthermore, representatives of the fire brigade of Technical University Munich (TUM), the press office of TUM, if necessary represented by the press officer of FRM-II and - in an advisory capacity - the nuclear safety officer may be members of the crisis management team. The minimum composition of the crisis management team consists of the plant's Head of Operations, the Head of the Reactor Monitoring Division, and the Head of the Reactor Operation Division.

The management of the crisis management team is the responsibility of the plant's Head of Operations. He bears overall responsibility for the measures to be taken in connection with the beyond-design-basis situation at the site and for the cooperation between TUM, the nuclear supervisory authority and the competent disaster control authority [FRM-02NHB]. He is authorised to give instructions to all persons in the enclosed area with the exception of employees of the nuclear supervisory authority, the fire brigade and the police, who are to coordinate their activities with him as far as possible.

The specifications concerning the plant's Head of Operations and the tasks, responsibilities and authority to issue instructions to the members of the crisis management team are laid down in the Alarm Regulations [FRM-03] and in the emergency manual [FRM-02NHB]. The highest-ranking operational commander is the Technical Director of FRM II.

A necessary change of location of the crisis management team members between the control room and the crisis management team room can be done quickly and easily. Alternative rooms for the crisis management team are also defined.

The operator reports that in accordance with the guideline on maintaining technical qualification, a block seminar is held once a year, which also includes the performance of emergency response exercises. The associated exercises are carried out theoretically and practically. Exercises with the participation of the crisis management organisation have not been carried out so far. Two unannounced fire brigade exercises are held annually and there have also been disaster control exercises assuming a postulated accident at FRM-II.

On 4 February 2015, TÜV SÜD issued a positive statement on the revision of the emergency preparedness concept. It confirms that the emergency manual complies with the requirements of KTA 1203 and that the General guidelines for emergency planning by nuclear power plant operators have been sufficiently taken into account.

The StMUV[8] approved the inclusion of the emergency protection concept in the operating manual on 12 February.

Emergency measures for sealing and injecting into the reactor pool

The entire pool group consists of the reactor pool, the storage pool and the primary cell. All water-carrying pipes (e.g. water purification and cooling) run over the pool edge or in pipe penetrations of the pool wall above the upper edge of the fuel elements. The storage pool and the reactor pool can be separated by a gate but are connected with each other during operation. The two pools have a total water volume of about 700 m^3.

Up to now, the emergency manual has included the emergency measure "Emergency pool water injection/emergency unloading". The plant operator explained that the emergency injection of water into the reactor pool was carried out via wall hydrants that were normally fed from the drinking water system. Furthermore, the hydrants could also be supplied with water from the buffer basins of the fire-fighting

[8] Bavarian State Ministry for the Environment and Consumer Protection (Bayrisches Staatsministerium für Umwelt, und Verbraucherschutz - StMUV)

system, with an emergency power supply available. In addition, it would be possible to draw water either from the buffer basins or from system back-up ponds or the Garching mill stream, using mobile fire-fighting pumps, and thus supply the hydrant line directly. In order to lay a connection line between the wall hydrant and the reactor pool or the storage pool, the reactor hall would have to be entered.

The operator further explained that if the drinking or industrial water supply was available, the injection into the buffer tanks of the fire-extinguishing system (2 x 50 m^3) could be done without electrical power supply. The booster pumps in the reactor building and the pumps for filling the buffer tanks from the well are emergency-powered. However, the buffer tanks could also be filled with mobile fire-fighting pumps from various water reservoirs, as there is also an external feed option for the buffer tanks.

The measure is carried out by the plant fire brigade and can also be implemented if the emergency power supply fails.

In the event of a large water loss where the pool water level cannot be maintained in the long run, the fuel element should be moved from the operating position to the storage pool as soon as possible, but not before 3 hours have elapsed after reactor shutdown (operating manual Part 4, Section 6.7). The indoor crane is required for this measure, which would take a total of about 10 hours to complete.

Specific sealing measures are not planned but could be carried out depending on the location of the leak.

In addition, analyses were carried out on the required injection rates and the necessary minimum pipe cross-sections for the leak accident scenarios to be assumed. The pool water cleaning system and the pool water cooling system have direct pipe access into the pool and could in principle be used for overfeeding leakages without entering the reactor hall. The water reservoir (pool water storage tank) is located in the basement area of the Neutron Guide Hall West and is easily accessible for refilling. Pumps are available. As long as the cross-sections of the pipelines are sufficiently large, no retrofitting measures would be necessary. If necessary, an additional pipeline for injecting cooling water into the reactor pool from the pool water storage tank would be permanently installed.

The pool water storage tank in the basement is empty when the reactor is in operation and would have to be filled from the inside or outside if necessary in order to inject water into the reactor pool with the help of the existing pumps.

The extinguishing water collection pool (capacity: 300 m^3) is located in the basement of the reactor building. The extinguishing or leakage water collected there can be pumped back into the reactor pool either directly or via the pool water storage tank, if required.

Neither of the options for emergency injection into the reactor pool - from the pool water storage tank or the extinguishing water collection pool - have yet been specified in the emergency manual.

Emergency measures to restore a three-phase power supply

According to the operator, the emergency measure "Connection of the 400 V emergency power supply" is planned after the supply via the 20 kV main distribution grid ring, the 20 kV emergency power grid ring and the two emergency diesel generators have failed. For this purpose, the emergency transformer (feeding from a third-party grid), which has meanwhile been relocated to the premises of FRM-II and has been reinforced in terms of power, is connected to the 400 V emergency power grid of the two emergency power busbars [FRM-04]. The lines from the emergency transformer to the switchgear are permanent. The connection is made via a switch in the switchgear in the basement of the access building.

When converting the emergency power transformer, the operator installed a feed-in switch as an additional feed-in point on the low-voltage side of the transformer for the connection of a mobile emergency power generator that has yet to be procured.

Robustness of the accident monitoring system and emergency measures for monitoring the reactor parameters and the radiological situation.

The operator explains [FRM-12], [FRM-13] that the instrumentation primarily serves to provide information about the condition of the plant, since the level in the pool must essentially be maintained as a heat sink and for activity retention in order to maintain vital safety-related functions. Active switching operations from the emergency control room are neither necessary nor technically planned.

According to [FRM-13], [FRM-14], the relevant equipment of the accident monitoring system is designed for the ambient conditions during the accidents to be considered, i.e. within the reactor hall area for ambient conditions up to a temperature of 50°C, up to 100 % humidity and up to a dose rate of 1000 Gy/h in case of a core meltdown. In the case of a radiological design basis accident, the dose rate would be 100 Gy/h. With regard to external events, the accident instrumentation was designed for the design basis earthquake and the aircraft crash case. The design against accelerations had been carried out for the design basis earthquake by the structural decoupling of the reactor group from the reactor building. In the event of an aircraft crash on the reactor building, it is not assumed that the emergency control room would be destroyed. The most important reactor parameters (pool water level, pool water temperature, emergency cooling pressure, neutron flux) and radiological parameters (local dose rate of the reactor hall, noble gases in the exhaust air) are displayed in both the control room and the emergency control room. The measuring instruments recording "reactor pool coolant temperature", "reactor pool level" and "reactor hall local dose rate", which are arranged in or at the reactor pool, have two channels and the transmission of these signals from the reactor building to the emergency control room is carried out via physically separate cable routes.

The power supply for the accident monitoring system is provided without an external three-phase power supply from batteries, which are supplemented by a remote battery in the emergency control room.

For monitoring radiological parameters, FRM-II has a large number of mobile and battery-powered measuring instruments in addition to the permanently installed accident monitoring system. In addition, the radiation protection staff of FRM-II has at its disposal a radiation protection measurement vehicle with extensive equipment for a radiological measurement programme in the vicinity of the plant. The possibility to measure the radiation dose in the environment would thus be given even in the event of a complete failure of the permanently installed instrumentation.

According to the assessment by *TÜV Energie und Systeme* [FRM-14], the requirements to be met by the accident monitoring system of FRM-II are fulfilled. With regard to the radiological measurements, the TÜV stated that the scope of the planned instrumentation for monitoring in case of an accident with regard to the measurement tasks meets the special requirements of FRM-II and the requirements of KTA 1507 [KTA 1507].

<u>Emergency measures to limit the release of activity during core meltdowns</u>

As a radiological design basis accident, Siemens/KWU postulated that an equivalent of 15 of the 113 fuel plates would melt under water [FRM-06]. The radiological loads result primarily from the noble gases released, while iodine and other fission products are retained to a large extent in the water pool. In the above-mentioned report [FRM-06], radiation doses of 1.9 mSv for the infant reference person and 1.6 mSv for the adult reference person are given for this design scenario. The statement by the German Commission on Radiological Protection (SSK) on the 3rd partial licensing of FRM-II [FRM-07] confirms the statements by the authorised expert consulted and arrives at a maximum effective dose of 1 mSv for the melting of 15 of the 113 fuel plates. Due to the higher dose factors for tritium newly introduced at that time, the release of tritium in the event of a simultaneously assumed leakage from the moderator tank leads, in the opinion of the SSK, to an additional maximum effective dose of 6 mSv.

Furthermore, TÜV Süd states in its annotation [FRM-15] that the effects of a steam explosion in the event of complete meltdown of the fuel element under water would be limited to the interior of the central channel and that the central channel itself would not be at risk. Even in the case of a postulated core meltdown with steam explosion, the preservation of the water cover of the core would not be at risk.

For a rough estimate of the radiological effects in the event of meltdown of the entire fuel element, the operator therefore assumes sufficient water coverage of the core and scales the value of 1 mSv (SSK) or 1.9 mSv (Siemens/KWU) from the radiological design basis accident to a complete core meltdown (factor 113/15) and additionally conservatively takes into account the effective dose of 6 mSv from the release of tritium. Thus, the effective dose of about 13.5 mSv (at 1 mSv from the meltdown) or 20.3 mSv (at 1.9 mSv from the meltdown) would still remain clearly below the accident planning level of 50 mSv according to Section 50 StrlSchV in conjunction with Section 117 para. 16 StrlSchV [FRM-11].

In this respect, the highest priority for the limitation of the radiological effects of a core meltdown accident is given to the emergency measure for the long-term injection of water into the reactor pool and the emergency measure for shutting off the air supply and exhaust air systems in the controlled area in the event of failure of the reactor hall isolation. Both measures are specified in the emergency manual.

Consideration of aggravating boundary conditions in the implementation of emergency measures

The consideration of aggravating boundary conditions (e.g. debris, formation of flue gas, increased local dose rates) must be seen against the background that FRM-II is very robust against external hazards. In the event of a crash of a large commercial airliner, the vital safety functions can be maintained [RSK-SÜ-FR]; in the event of a beyond-design-basis earthquake, the loss of water from the reactor pool and storage pool is not to be expected (see Section 5.2.2 of this statement); the equipment required for the safety functions is not endangered by beyond-design-basis floods [RSK-SÜ-FR].

The operator also notes that no power supply is required to maintain the vital safety functions of FRM-II. In the event of failure of the three-phase power supply, reactor scram is triggered and the central control rod drops into the fuel element, gravity-driven and supported by the downward flow in the core. Diversely, the core is shut down by 5 shutdown rods (necessary for long-term shutdown are 4 out of 5) in the moderator tank. In the event of a power failure, the shutdown rods drop in gravity- and spring-accelerated.

In accordance with the specifications, the residual heat is removed for 3 hours after reactor scram with the help of the battery-powered emergency cooling pumps. In this case, cooling takes place in a closed system in the pool. Within the framework of the licensing procedure, it has been shown that the fuel element will not be damaged even if all emergency cooling pumps fail [FRM-05]. In this scenario, the core is cooled by immediate transition to natural circulation.

The emergency measure for injecting into the pools (see this chapter, section on injecting into the pools) is possible with mobile fire-fighting equipment alone in the event of a failure of the emergency power supply. For this measure, the reactor hall must be entered in order to lay a hose connection between the wall hydrant and the pools. The wall hydrants are operationally supplied from the drinking water system, but can also be supplied, with emergency power, from the buffer basins of the fire-extinguishing system. Alternatively, the hydrant line can be supplied directly with mobile equipment from diverse and physically separate water sources. The buffer tanks can also be refilled with mobile equipment from diverse and physically separate water sources. Other possible emergency measures that do not require access to the reactor hall are analysed (see this chapter, section on injecting into the pools).

The emergency measure "Switching on the 400 V emergency supply" has been upgraded. Among other things, a feed-in switch for a mobile emergency diesel generator has been installed (see this chapter, section on restoring the three-phase supply). No potentially hazardous room areas need to be entered to connect the emergency transformer or mobile diesel generator to the emergency busbars. The distance between the emergency diesel generators of FRM-II and the emergency transformer is approximately 80 m.

According to the emergency manual [FRM-02NHB], a three-phase power supply is required for the emergency measure "Draining the moderator tank" for emergency shutdown of the reactor because the indoor crane is needed, the primary cell must be accessed, and valves must be moved electrically. The indoor crane is also needed for emergency unloading of the core into the storage pool.

For the removal of debris and the creation of access routes during the implementation of emergency measures, the TUM plant fire brigade has clearing equipment, some of which is owned by FRM-II. Several mobile emergency power generators with an output of 10-20 kW are stationed on the emergency vehicles of the plant fire brigade [FRM-01]. Maintenance of the equipment is carried out by the fire brigade. There are also contracts with the THW. It is agreed that the THW will be ready for action with the appropriate equipment and personnel on the site after approx. 8 hours at the latest, if required. The THW is familiar with the site through exercises. The FRM-II site is easily accessible for technical support from outside.

Availability of communication facilities in the event of a power failure

The TUM telephone system has an emergency battery (battery capacity is sufficient for at least 4 hours). In addition, there is a dedicated line and an emergency alarm to the police in Munich. FRM-II also has an independent telephone connection that is not connected to the TUM telephone system. There is also a radio connection (BOS radio (a non-public mobile radio service used by authorities and organisations with safety-relevant tasks), handheld radios) to the plant fire brigade. An additional satellite radio connection is currently out of service because it was terminated by the satellite operator. It has been replaced by a diverse mobile telephone system that can use different mobile network operators.

The operator declares that the communication facilities at FRM-II do not have a privilege according to the PTSG[9] [EP_RAFR3].

5.1.3 Assessment by the RSK

After the safety review in 2012, the operator of FRM-II extensively revised the emergency protection concept and largely implemented the RSK's recommendations.

The RSK agrees with the authorized expert's opinion that the emergency manual meets the requirements of KTA 1203 and that the General guidelines for emergency planning by nuclear power plant operators were sufficiently taken into account. Furthermore, in the opinion of the RSK, the emergency measures are appropriately anchored in the operating manual and the transition from the operating manual to the emergency manual is clearly regulated.

According to the operator, no emergency drills are performed that include the entire emergency organisation. However, in the view of the RSK, such exercises are necessary for the implementation and continual further development of a suitable emergency protection concept. Therefore, the RSK recommends that FRM-II should implement an exercise concept in accordance with the relevant specifications of [REmp-NFM]. Part of this concept should also be at least annual plant-internal emergency drills in which the entire emergency organisation of FRM-II is integrated (plant-internal full-scale drills). Likewise, the disaster control authorities have to be involved in the exercises at least every five years /E8/.

[9] PTSG: Postal and Telecommunications Security Act

E8 The RSK recommends that FRM-II should implement an exercise concept for emergency protection measures - in analogous implementation of the requirements of [REmp-NFM]. Part of this concept should be at least annual plant-internal emergency drills in which the entire emergency organisation of FRM-II is integrated (plant-internal full-scale drills). Likewise, the disaster control authorities have to be involved in the exercises at least every five years.

In the present emergency manual, the emergency measure "Emergency pool water injection/emergency core unloading" is specified. In this measure, the fire brigade establishes a hose connection between the wall hydrants in the reactor hall and the affected pool (reactor pool or storage pool). A power supply is not necessary for this, but the reactor hall must be entered. Alternative emergency measures for pool injection that do not require access to the reactor hall are under consideration /E9/.

E9 The RSK recommends defining an emergency measure for injecting into the reactor pool and the storage pool, the implementation of which will not require access to the reactor hall nor the availability of the plant's electrical power supply. The measure must not have any adverse repercussions on the other functions of the systems used.

In view of the fact that FRM-II does not require a power supply for maintaining the vital safety functions and taking into account the redundant three-phase power supply of FRM-II via the 20 kV main distribution system ring, the 20 kV emergency system ring and the two emergency diesel generators, the RSK considers the emergency measure "Connection of the 400 V emergency power supply" with the possibility of connecting a mobile emergency diesel generator via the additional feeder breaker as sufficient, provided that the mobile emergency diesel generator for supplying the 400 V emergency power busbars is sufficiently protected against the external hazards to be assumed and the connection to the low-voltage side of the emergency power transformer can also be protected after the hazards.

With regard to the availability of instrumentation for reactor parameters and radiology in the event of beyond-design-basis events, the plant operator refers to the accident-proof design for the design-basis earthquake and aircraft crash and to the fact that the radiological parameters can be recorded diversely with battery-powered measuring instruments.

With regard to the availability of radiological parameters, the RSK does not see any further need for review, even under beyond-design-basis conditions.

Regarding the availability of the accident monitoring system, however, the generic recommendation of the 2012 safety review has not yet been fully implemented from the RSK's point of view. An analysis of the availability of the accident monitoring system under beyond-design-basis conditions has not been submitted to the RSK. Since the effective implementation of emergency measures depends on reliable information on, among other things, pool water temperature and pool water level, the RSK recommends an analysis of the effects of beyond-design-basis events, e.g. an earthquake with an intensity of two levels above the design basis earthquake, plant-internal fires and explosions, on the accident monitoring system. If the required information for the implementation of emergency measures is not available for the analysed hazards, suitable substitute measures for the provision of measured values have to be provided /E10/.

E10 The RSK recommends an analysis of the effects that beyond-design-basis internal and external hazards may have on the accident monitoring system. If, in the case of the analysed hazards, the required information is not available for the implementation of emergency measures, suitable substitute measures for the provision of measured values have to be provided.

FRM-II has diverse and battery-backed facilities for emergency communications. The availability of communication via public networks should be further secured by means of preferential treatment in accordance with the Postal and Telecommunications Security Act (PTSG) /E11/.

E11 The RSK recommends applying for preferential treatment under the PTSG for communications via public networks.

With regard to the emergency measures to limit the release of activity in case of a core meltdown, the RSK shares the view of the plant operator that the emergency measures for the injection of water into the reactor pool and for reactor hall isolation have the highest priority. Beyond the recommendation on the qualification of the emergency injection into the reactor pool (see this chapter above, recommendation E9), the RSK does not see any further need for action in this respect.

When considering aggravating boundary conditions for the implementation of emergency measures as a consequence of external hazards, the RSK does not see any further need for review beyond the recommendations on the emergency injection into the reactor pool and the storage pool, on the robustness of the accident monitoring system and on the preferential communication according to the PTSG (see this chapter above, recommendations E9, E10, E11) and on the emergency shutdown of the reactor (see Chapter 5. 2.3, /E12/), provided that the mobile emergency diesel generator is sufficiently protected against external hazards and the connection to the low-voltage side of the emergency transformer can also be protected against the postulated hazards.

5.2 Earthquake

5.2.1 Recommendations of the RSK from the safety review of German research reactors in 2012

"With regard to the effects of increased seismic impacts on the plant, the operator states that compliance with the fundamental safety functions is ensured even in the event of a beyond-design-basis earthquake: They assume that the shutdown will also function in the event of a beyond-design-basis earthquake and that the passive systems for residual-heat removal will be available to such an extent that the cooling of the core will continue to be ensured. A relevant loss of pool water need not be assumed even in the event of an earthquake of intensity VIII (MSK)."

"Based on the operator's statements, the RSK considers it possible that assessment criteria of level 1 and, if applicable, level 2 can be fulfilled. The possible fulfilment of the level depends on the submission of additional demonstrations and their confirmation".

5.2.2 Implementation

For robustness level 2, it must be shown that in the event of an earthquake of intensity I +2, the vital safety functions are ensured (emergency measures can be taken into account here) or that the radiological effects are below the values that require disaster control measures [RSK-SÜ-FR].

For FRM-II, this means that for an earthquake of intensity I+2 it must be shown that the reactor can be shut down and that sufficient cooling of the fuel element in the reactor and the spent fuel elements in the storage pool is ensured. The cooling of the fuel elements is given if there is a sufficient water cover by maintaining the confinement of the water in the pool. This requires **a)** the preservation of the integrity of the pool structure, including the beam tubes and the pipe manifold penetrations, and **b)** effective measures in view of systems layout to prevent the pools from leaking and being syphoned via the engineered equipment located in the pools.

The StMUV commissioned TÜV SÜD with analyses on the possible fulfilment of robustness level 2 of FRM-II in the event of a beyond-design-basis earthquake [FRM-01]. Stangenberg und Partner Ingenieur-GmbH (SPI) was involved in the analyses by subcontract from TÜV Süd.

To a)

The experts first show in their study [FRM-08], [FRM-09], [FRM-10] that with the present subsoil conditions, no soil liquefaction is to be presumed and the stability of the building is not at risk in the case of an earthquake of intensity I+2.

Based on the soil characteristics determined and taking into account the structure-soil interaction, static and dynamic analyses of the stresses on the concrete structures were carried out. In addition, the floor response spectra for the installation locations of the system components with barrier function against water loss from the pool were determined and, based on this, the resulting stresses in these components were calculated [FRM-10].

To b)

To prevent the pool water from leaking, pipelines are either routed over the pool edge or run in pipe penetrations in the pool wall above the upper edge of the fuel elements. Furthermore, the relevant engineered equipment has built-in siphon breakers that interrupt the flow in the piping in question if required.

In addition, the moderator intercooling system is equipped with so-called aircraft crash valves (FZA valves) that close automatically when the pool water level falls below a specified minimum value, thus interrupting further water discharge from the reactor pools [FRM-10] in the event that an impact (e.g. an aircraft crash) results in a flow connection between the reactor pool and the moderator tank and the moderator system would simultaneously empty into the basement via a further leakage.

Based on **a)** and **b)**, the experts conclude that the integrity of the concrete structures of the pool group will be maintained even in the event of an earthquake of intensity I+2, that the components with a barrier function against water loss from the pool, including the beam tubes, will remain intact, and that the provisions against leakage and syphoning will be effective [FRM-09].

In its message of 28 November 2016 [FRM-20], the StMUV informs that, on the basis of the expert opinions of TÜV SÜD and SPI, it confirms the proof required by the RSK of the fulfilment of Level 2 with regard to the integrity of the pool group (primary cell, reactor pool and storage pool) in the event of a beyond-design-basis earthquake.

In the event of a power failure as a result of an earthquake, the magnetic holders of the central control rod and the shutdown rods disengage and the rods drop in (for details, see 5.1.2 under: Consideration of aggravating boundary conditions in the implementation of emergency measures). The control rod alone can keep the core subcritical in the long term; diversely, 4 of the 5 shutdown rods in the moderator tank are necessary for this. The magnetic holders and the rods are designed to withstand the design earthquake of intensity I = VI ½.

The representative of the StMUV explained that the authorised expert had not checked whether the shutdown capability would be maintained in the event of a beyond-design-basis earthquake.

If neither the control rod nor a sufficient number of shutdown rods should drop in due to the beyond-design-basis earthquake effect, the core would initially remain critical, provided no loss of reactivity occurs due to other damage. If, for example, a flow connection between the moderator tank and the reactor pool were to occur during the event, heavy and light water would mix and the reactor would become subcritical.

Long-term subcriticality can basically be ensured by the emergency measure "moderator drainage". The drainage of the moderator takes about 8 hours and requires the availability of the crane including a sufficient three-phase power supply for the operation of the crane.

An emergency measure for borating the pool water as an alternative to draining the moderator tank has not yet been provided.

5.2.3 Assessment by the RSK

The RSK agrees with the opinion of the StMUV according to which the results of the analyses performed by TÜV Süd and SPI proved that in case of a beyond-design-basis earthquake of intensity I+2, no non-overfeedable leakages from the reactor pool and the storage pool are to be assumed and that FRM-II fulfils robustness level 2 in this respect.

The RSK does not have equivalent proof of the maintenance of the shutdown capability of the core. In the opinion of the RSK, it cannot be excluded that in case of an earthquake of intensity I+2, the establishment or maintenance of long-term subcriticality (cold state, xenon-free) fails (simultaneous blocking of the control rod and of more than one shutdown rod). Depending on the availability of primary core cooling, emergency cooling and cooling by natural circulation, scenarios are not excluded in which the core remains critical or becomes re-critical several times or in which the core melts completely under water (more detailed considerations can be found in the minutes of the 5th meeting of the working group [EP_RAFR5]). In scenarios with complete or partial core meltdown, it is likely that the core will become subcritical as a result. TÜV Süd states in its note [FRM-15] that the preservation of the water cover of the core would not be at risk even in the case of a postulated core meltdown with steam explosion. In the case of complete meltdown of the fuel element under water, according to a rough estimate (see Chap. 5.1.2 under: Emergency measures to limit the release of activity in the event of core meltdown), the accident planning level of 50 mSv pursuant to Section 50 of the Radiation Protection Ordinance (StrlSchV) in conjunction with Section 117 para. 16 of the Radiation Protection Ordinance (StrlSchV) would be complied with.

The emergency measure "moderator drainage" in case of failure of reactor shutdown but a still intact core requires the use of the indoor crane and takes approx. 8 hours. Therefore, no emergency measure is available for shutting down the reactor core that will not require more extensive measures. Such an emergency measure should be developed /E12/.

E12 The RSK recommends developing and introducing another emergency measure for reactor shutdown (besides the drainage of the moderator tank) in order to prevent criticality or uncontrolled recriticality as early as possible after the simultaneous mechanical blocking of the control rod and of more than one shutdown rod.

5.3 Precautionary measures

5.3.1 Recommendations of the RSK from the safety review of German research reactors in 2012

- *"Precautionary measures to prevent cross-room fires....*

With regard to the robustness of the plant against plant-internal fire scenarios in which the integrity of the reactor pool and the shuffling pool (e.g. leak-tightness of the beam tubes) might be affected, no information is provided in the documents. These fires could have repercussions on the building structures as well as on the barriers of the beam tube units."

- *„ Precautionary measures to prevent a loss of integrity of the reactor pool and the FE storage pool. ....*

Even if the operator's documents show that the plant is shut down as a precaution when heavy loads are transported in the pool area, the documents submitted are not sufficient overall to allow a level classification to be made."

"The operator's documents do not contain any information on effects from the failure of precautionary measures against plant-internal explosions due to the radiolysis gas formed in the moderator system during

operation, due to the D2 present in the cold neutron source, or due to the hot graphite core (approx. 2,600 K) of the hot neutron source. An assessment requires the submission of additional information."

5.3.2 Implementation

Possible effects of plant-internal fires on the integrity of the reactor and the storage pool and of the beam tubes

The operator and the expert from TÜV Süd state [FRM-16] that cross-room fires with the consequence of putting the integrity of the concrete structures of the pools at risk are not to be assumed since the concrete structures are not combustible and have poor thermal conductivity.

The beam tube units in the reactor pool are covered with water, the beam tube shielding plugs made of steel are filled with heavy concrete, and the beam tube end plates in the experimental hall are completely covered for radiological reasons with so-called shielding castles made of steel/concrete and are located in niches which largely reduce the fire impact on the beam tube. Based on these plausibility considerations, the operator and the authorised expert do not see any risk to the pool water levels due to the loss of beam tube integrity in the event of a fire. Nevertheless, a follow-up of possible fire loads in the experimental hall in the form of lists is planned. There would be no combustible material in the neutron guide tunnel of beam tube SR1, which is inaccessible during operation [FRM-01].

Furthermore, the sprinkler system in the experimental hall is pointed out. In addition, the experimental hall is easily accessible for fire brigade operations via the truck lock.

Precautionary measures against load drop into the reactor pool

The handling of loads in the reactor hall of FRM-II is regulated in the operating manual [FRM-17]. This results in the following.

The indoor crane has a main hoist with a load capacity of 20 t and an auxiliary hoist with a load capacity of 3.2 t. The crane and the load chain are designed according to KTA 3902 [KTA 3902]. Main and auxiliary hoist can be used for handling loads in the area of the reactor pool and in the reactor pool. The following restrictions apply:

- During reactor operation, only loads up to a maximum of 80 kg may be moved in the area of the reactor pool. Any handling of larger loads during operation requires the approval of the supervisory authority.

- When using load attachment rigging and attachment points designed in accordance with KTA 3902, there are no further restrictions for the transport of loads outside the reactor pool and outside the area of the floor channels housing the lines for the cold and hot neutron source.

- When handling loads of up to 80 kg within the reactor pool, the reactor must be shut down and the residual heat must be removed (i.e. it is no longer necessary to actively cool the core). In addition, either the deuterium must be removed from the cold source or damage to the cold source must be excluded by special measures.

- If the loads in the pool exceed 80 kg, the fuel element must have been removed from the central channel and the deuterium from the cold source must have been removed beforehand.

With the exception of the transport of fuel elements, the load limitation measures are based solely on administrative regulations.

During a fuel element transport, lifting and travelling movements are only possible at creep speed. A positioning aid for the FE transport is installed. The positioning aid only allows movements within the specified travel range.

According to the operator's explanations [EP_RAFR3], the transport cask for spent fuel elements (18 t) is the heaviest load handled by the crane above the pool. The cask is only moved to a designated loading position in the storage pool and is not moved in or above the reactor pool.

The bottom of the storage pool has a total thickness of 130 cm. In the area of the storage position for the CASTOR MTR2 transport cask, the floor is additionally protected by a steel plate. An expert report by TÜV SÜD [FRM-18] is available on the crash of the transport cask (CASTOR MTR2, approx. 18 t) in the area of the storage position. In the authorised expert's opinion, the investigations prove that with a water cover of 4.2 m at the bottom of the pool, no damage to the floor structure is to be expected that would lead to a water loss from the storage pool.

In addition, a load crash on the spent fuel elements in the storage rack was investigated by the operator [EP_RAFR4]. It had been assumed that all fuel elements in the storage pool would be damaged and that the entire volatile radioactive inventory would be mobilised. A conservative calculation would result in a release of approx. $2*10^{16}$ Bq into the ambient air of the reactor hall. This value is below the design value ($2.7*10^{16}$ Bq). The design value results from the assumption that 15 of the 113 fuel plates of the active fuel element will melt under water at the end of the cycle (see also 5.1.2 under Emergency measures to limit the release of activity in the event of a core meltdown).

The operator does not consider it plausible that the crash of a load of up to 80 kg would lead to damage of the fuel element due to the protection by design. They also note that an assumed crash of a "narrow", heavy load in the area between the pool wall and the moderator tank could lead to damage of the expansion joint tube (made of aluminium) of a beam tube. However, it was not conceivable that the 2nd barrier (beam tube end plate with beam tube window) lying on the outside of the pool polygon would be affected. A loss of pool water was therefore not to be assumed.

The representative of TÜV Süd is of the opinion that only very heavy loads would be capable of damaging the pipes in the pool or the natural circulation dampers to such an extent that natural circulation would be blocked. In this respect, TÜV Süd points out in the sense of conservative considerations [FRM-15] that analyses of a beyond-design-basis event with core cooling failure, core meltdown and steam explosion were carried out within the framework of the 3rd partial licence. These analyses had shown that the effects of a steam explosion did not put the integrity of the central channel at risk. Effects on the cold and hot neutron source and subsequent D2 explosions that could lead to a loss of the pool integrity could therefore be ruled out. The preservation of the water cover of the core and the retention of the radioactive inventory would thus remain ensured even in the event of a postulated core meltdown. In the opinion of the TÜV, this scenario also covers the event "Failure of natural circulation".

With regard to the radiological effects, reference should be made to the operator's estimates regarding the complete meltdown of the fuel element under water (see also 5.1.2 under Emergency measures to limit the release of activity in the event of core meltdown). This results in a maximum effective dose of about 20.3 mSv. This is below the accident planning level of the Radiation Protection Ordinance. However, the action level for sheltering would be exceeded.

Analyses on the impairment of reactor shutdown due to load crash have not been submitted to the RSK. In this context, the plant operator explains [EP_RAFR5] that, in his opinion, damage to the shutdown rods in the moderator tank by a crashing load would only be possible if the nozzles of the shutdown rods at the moderator tank itself were also damaged and, consequently, the moderator tank would become leaky. As a result, the D_2O in the moderator tank would mix with the pool water and the reactor would become subcritical due to the lack of thermal neutrons.

Precautionary measures against plant-internal explosions

The operator refers to the statements of TÜV SÜD in which the precautionary measures to avoid internal explosions were assessed as being sufficient from a safety point of view [FRM-16], [FRM-19]. These assessments were confirmed by the results of commissioning and by operating experience. In these statements, the possible causes of the formation of molecular deuterium radiolysis gas in the D_2O-carrying systems, the D_2 inventory of the cold neutron source (KQ), and the generation of D_2 at the hot graphite of the hot neutron source (HQ) in contact with moderator water were considered.

To avoid the formation of explosive mixtures and ignition sources, the following precaution is effective according to the operator [EP_RAFR3]:

1. earthing of components and explosion-proof design of electrical equipment,
2. safeguarding of all systems that (may) carry D_2 by means of inert gas compartments with extraction devices,
3. recombination of D_2-O_2 mixtures,
4. permanent concentration monitoring with reactor shutdown if limit values are exceeded and subsequent gas exchange.

In addition, possible leaks in the moderator system as a result of the tritium content can be detected quickly and with high sensitivity.

The cold source consists of two containers [FRM-15], with one lying inside the other. The inner container is filled with D_2 (approx. 12 to 15 litres). The space in between is vacuum-isolated. The D_2 of the cold source is separated from the atmospheric oxygen by the vacuum space, the heavy water, the inert gas of the moderator tank, and the pool water.

The hot graphite of the hot source is separated from the D_2O by two passive barriers. In this respect, TÜV SÜD rules out contact between the hot graphite and the D_2O [FRM-16]. In addition, the formation of ignitable mixtures with the protective gas system is prevented.

In the course of the robustness considerations, investigations were carried out on the resulting pressures and on the effects on the pools and the internals in the event of an explosion of D2 from the various sources [FRM-16], [FRM-19]. As a result, it was found that the preservation of the water cover is ensured in all cases under consideration.

5.3.3 Assessment by the RSK

From the point of view of the RSK, the operator's and the authorised expert's statements that a loss of pool water in case of a fire within the plant is not to be assumed due to the structural protection of the beam tubes, the reduction of the fire loads and the possible fire-fighting measures are comprehensible. No further need for review is seen.

With regard to the load crash of the transport cask for spent fuel elements onto the storage location in the storage pool or onto the spent fuel elements in the storage pool, the RSK considers the analyses of TÜV Süd and the operator to be sufficient.

Due to the administrative character of the precautionary measures for load limitation in the area of the reactor pool, it cannot be excluded in the opinion of the RSK that loads exceeding 80 kg above the reactor pool will also be handled during operation or during decay heat removal by natural circulation. In this respect, it also cannot be excluded that the fuel element itself will be damaged or that cooling will be impaired. The RSK was not provided with proof that the crash of loads up to 80 kg will not lead to damage of the fuel element or to an impairment of cooling. However, the RSK agrees with the opinion of TÜV Süd that damage to the fuel element or an impairment of cooling as a consequence of a load crash is covered by the postulated event "Core meltdown with steam explosion," which was analysed within the framework of the 3rd partial license of FRM-II.

No further need for review is seen.

Proof that reactor shutdown is not impaired by the load crash was not submitted to the RSK. If the central channel and simultaneously two or more shutdown rods were damaged by a load crash while the plant is in operation with the result that the central control rod can no longer drop in and the number of remaining shutdown rods is no longer sufficient to shut down the core and keep it permanently subcritical, draining of the moderator tank would be provided as an emergency measure. This measure takes about 8 hours and requires the availability of the overhead crane and the load attachment rigging, whose failure could be the cause of the load crash. In the opinion of the RSK, the introduction of an additional emergency measure for reactor shutdown in the reactor pool (see /E12/) also sufficiently takes into account the assumed shutdown failure in case of a load crash.

With regard to the risk to the integrity of the pools by an explosion of D_2 from radiolysis in the moderator tank or from the failure of the cold and hot neutron source, the RSK does not see any further need for review beyond the analyses presented.

6 Research reactor Mainz (FR-Mz)

6.1 Emergency measures

6.1.1 Recommendations of the RSK from the safety review of German research reactors in 2012

Generic recommendations: see 4.1.1.

Specific recommendations on FR-Mz

"The operator's report deals with the feasibility, completeness and effectiveness of the listed emergency measures, also under the boundary conditions of external hazards. However, the statements are essentially limited to local radiation protection aspects."

"From the point of view of risk minimisation, the RSK considers it necessary that, within the framework of the nuclear supervisory procedure, a review of the emergency preparedness concept be carried out in accordance with the generic assessment with reference to Chapter 5.1".

6.1.2 Implementation

<u>Revision of the emergency response concept based on the general guidelines for emergency planning and establishment of a crisis management team organisation</u>

According to information from the authority (MWKEL[10]) [Mz-01], even in the enveloping emergency scenario "Aircraft crash with subsequent kerosene fire", the action levels for disaster control in the vicinity of nuclear installations [Mz-02] are clearly undercut. In addition, due to the inherent safety of FR-Mz, the vital safety functions would remain unimpaired even in the event of a prolonged emergency power failure, SBO, and complete loss of coolant. Therefore, a specific crisis management organisation was already introduced earlier at FR-Mz instead of the usual planning for emergency and disaster control measures. The tasks of emergency management are performed at FR-Mz by the crisis management organisation.

Following the safety review in 2012, the crisis management organisation for FR-Mz was revised several times (in 2013 and 2015).

In the course of revising the crisis management organisation, two new positions were created and filled: one position to reinforce radiation protection and half a position each in the nuclear safety area (KSB) and the physical protection area (OSB) [Mz-07].

The revision to the 2015 status [Mz-05], [Mz-06] was carried out to improve the interlinking of the two crisis teams (internal and external), to take into account the new personnel situation in the reactor area, and to staff the operational command centre of the internal crisis team at the technical level. The latest drafts of the

[10] Ministerium für Wirtschaft, Klimaschutz, Energie und Landesplanung, Rheinland-Pfalz (Ministry of Economic Affairs, Climate Protection, Energy and Regional Planning, Rhineland-Palatinate)

revised alarm regulations [Mz-05] and the crisis management manual [Mz-06] are being examined by the supervisory authority.

The draft of the crisis management manual of 2015 [Mz-06] regulates, among other things, the crisis management team organisation, the tasks of the internal and external crisis management teams, internal and external alerting and communication, situation analysis and situation reporting as well as the necessary qualifications, training, and exercises. The crisis management manual of 2013 [Mz-03] also contains specifications for the technical and spatial equipment of the crisis management team.

According to [Mz-06], the crisis management organisation covers the cases of (1) earthquakes and similar natural disasters, (2) an aircraft crash on FR-Mz and (3) sabotage, terrorist attacks, bomb threats. All other hazardous situations that are locally limited to FR-Mz are covered by the operating manual Part 1, Chap. 7, "Alarm regulations TRIGA Mainz" [Mz-05]. These include internal fire, increased radiation levels and activity as well as technical incidents (e.g. reduced water level in the reactor tank).

According to the draft of the crisis management manual [Mz-03], [Mz-06], the organisation of crisis management is composed of the internal crisis management team of FR-Mz and the external crisis management team of the Johannes Gutenberg University.

The municipal fire brigade is located only 1.3 km from the university campus and regularly attends courses at FR-Mz. In this respect, it has good local knowledge of the FR-Mz premises.

According to the new concept, it is also planned to conduct drills on a regular basis. Annual training and tests of the telephone alarm chain are to be carried out for the staff working at FR-Mz as part of the safety briefings. This is the responsibility of the Nuclear Safety Officer. Every three years, practical exercises involving the fire brigade and rescue services are to be held in coordination with the nuclear supervisory and licensing authority [Mz-06].

In its report [Mz-01], the supervisory authority comes to the conclusion that the general guidelines for emergency planning [REmp-NFM] were adequately taken into account in the revision of the crisis management concept for FR-Mz in view of the fact that the potential consequences of an accident are low compared to a power reactor. It also concludes that the crisis management organisation is suitable for reducing the impact on the environment after an aircraft crash on the research reactor. Accordingly, the crisis management organisation is also considered suitable for counteracting effects less severe than those of an aircraft crash.

<u>Anchoring of emergency measures as part of the control room documentation and transition from the operating manual to the emergency manual</u>

Due to the inherent safety features of FR-Mz, emergency measures to maintain vital safety functions are not required in the operator's opinion. The preservation of vital safety functions requires neither active, power-supplied technical systems, nor water, nor the deployment of personnel.

Consequently, according to the operator it is also not necessary to define emergency measures, to set non-intervention times for the initiation of emergency measures or of measures to deal with very rare human induced external hazards, and to specify limit values for the triggering of emergency measures.

The emergency protection for FR-Mz is claimed to be appropriately anchored in the operating rules with the alarm regulations [Mz-05] and the crisis management manual [Mz-06]. The criteria for activating the alarm regulations and crisis management are specified.

Crisis management:

(1) earthquakes and similar natural disasters,
(2) aircraft crash,
(3) sabotage, terrorist attacks, bomb threats.

Alarm regulation:

(1) fire,
(2) increased radiation levels and activity,
(3) intrusion and sabotage alarms,
(4) technical incidents.

In the event of a fire, the measures to be taken are regulated in the fire protection regulations according to the operator. The fire safety regulations have also been revised.

<u>Emergency measures for the sealing and injection of water into the reactor tank</u>

The operator states that after the reactor has been shut down, cooling of the fuel elements with water is not necessary. If the water level drops down to the area of the core, the reactor becomes subcritical. Cooling in air is to be considered as a diverse cooling system. According to the safety report,[11] a maximum fuel temperature of approx. 250 °C would result, based on full power with 100 kW in the case of a sudden loss of cooling water. If air convection is also assumed to cease, the value increases to a maximum of 300 °C. This is far below the melting points of the cladding tube materials used, namely aluminium and stainless steel (aluminium 660 °C, stainless steel 1500 °C). Consequently, the residual heat could be dissipated by air cooling alone.

Irrespective of this, there are possibilities to feed water into the reactor tank, e.g. with measures taken by the fire brigade. For this purpose, it might be necessary to enter areas at risk. Measures for sealing the reactor tank were not presented to the RSK working group.

[11] from [Mz-04]: Institut für Anorganische Chemie und Kernchemie der Johannes GutenbergUniversität Mainz, Sicherheitsbericht TRIGA Mark II Kernreaktor mit Pulseinrichtung, Anhang I, März 1962

Emergency measures to restore a three-phase power supply

Since a power supply is not required either for safe shutdown or for emergency cooling, no emergency measures are planned to restore the three-phase power supply.

The operator explains that emergency diesel generators might, however, be needed for the electrical power supply of the reactor instrumentation and the radiation protection measuring equipment in the event of a crisis (natural disasters, aircraft crash, sabotage/terrorist attacks). Such generators would be available from the Federal Agency for Technical Relief (Technisches Hilfswerk) and the fire brigade. There are no contractual agreements for the provision of these devices.

Robustness of the accident monitoring system and emergency measures for monitoring the reactor parameters and the radiological situation

Systematic analyses on the robustness of the accident monitoring system and emergency measures for monitoring the reactor parameters and the radiological situation have not been presented to the RSK working group. However, it was pointed out that mobile emergency generators could be provided to supply the instrumentation (see previous paragraph) with electricity. In addition, the authorised expert confirmed that the effects of explosions of the hydrogen and deuterium in the ultracold neutron source would be limited to the internal facilities of the source (see Chapter 6.6 Precautionary measures). The results report of the authority [Mz-01] does not address the robustness of the instrumentation and the radiation protection measuring equipment.

Emergency measures to limit the release of activity during core meltdowns

A core meltdown is not to be assumed for FR-Mz even in the case of beyond-design-basis hazards since the fuel elements can be sufficiently cooled in air without water coverage. Even in the event of an aircraft crash with kerosene fire, core meltdown would not occur.

Consideration of aggravating boundary conditions in connection with the implementation of emergency measures

The operator states that no electrical power supply and no water are required to bring the reactor to a safe state. For the implementation of measures in the course of crisis management, emergency diesel generators and clearing equipment could be needed, among other things, for the electrical power supply of the instrumentation and the radiation protection measuring equipment or for the rescue of individuals. There are organisations in the vicinity of the campus, such as the THW in Mainz and the fire brigade, that could provide such equipment in a timely manner. No contractual agreements for the provision of such equipment have been concluded.

The campus of the Johannes Gutenberg University Mainz is bordered by three roads, each of which has one or two access points for emergency services. The grounds of the KCH, where FR-Mz is located, are enclosed by four roads and can be accessed by emergency services via any of these roads. This means that access for rescue and emergency vehicles is possible via several independent access routes. The obstruction of an access road to the campus or to FR-Mz by debris therefore does not lead to the hindrance or prevention of external support in crisis management [Mz-01].

Various options would be available for communication in the event of a crisis. Calls and announcements (e.g. evacuation call) could be made via the in-house intercom system. In addition, the reactor operating team and the radiation protection personnel have their own mobile telephones at their disposal. Mobile phone reception is possible everywhere in the plant; duplexer stations are sufficiently installed in the plant. There is no preferential right under the Post and Telecommunications Security Act (PTSG). In addition, an emergency telephone with line monitoring by Deutsche Telekom is located at the plant management, which can also be used in the event of a power failure. The telephone is fail-safe and is regularly checked for functionality. Walky-talkies are also available in the control room. The police and fire brigade are alerted via emergency and fire alarms.

6.1.3 Assessment by the RSK

FR-Mz does not have an emergency manual. This is justified by the significantly lower potential impact of beyond-design-basis events compared to power reactors. The emergency response measures in the event of beyond-design-basis events are governed by the crisis management manual and the alarm regulations. The criteria for activating the crisis management manual and the alarm regulations are clearly specified.

Following the safety review by the RSK in 2012, the crisis management organisation was revised. The RSK appreciates that the crisis management organisation has been reinforced by two new staff positions.

The competent supervisory authority comes to the conclusion [Mz-01] that the General guidelines [REmp-NFM] were adequately considered during the revision and that the crisis management organisation is suitable to reduce the impacts of beyond-design-basis effects on the environment. The RSK agrees with this opinion with some reservations. Regarding the limitations, the following recommendations are formulated.

The first recommendation refers to options for sealing and emergency feeding of the reactor tank. Due to the massive construction of the reactor pool, the RSK does not assume any major leakages. Nevertheless, in case of missing or insufficient water coverage of the core in the reactor tank, high local dose rates are to be expected in the reactor and experimental hall, which complicate any measures in this area. Therefore, the RSK considers a measure for emergency injection into the reactor tank which does not require access to the reactor hall to be recommendable. A corresponding measure should be implemented in the operating rules /E13/.

The second recommendation is aimed at securing communication in the event of a crisis. According to the operator, the research reactor has various facilities for communication in an emergency. However, there is no preferential treatment under the Post and Telecommunications Security Act (PTSG). The availability of communication via public networks should be further ensured by means of preferential access in accordance with the PTSG /E14/.

With regard to the exercises planned so far at the Mainz research reactor, the RSK has the following comments. According to the operator, training courses and tests of the telephone alarm chain are to be conducted annually for the staff working at FR-Mz within the scope of the safety briefings. Every three years, practical exercises involving the fire brigade and rescue services are planned in agreement with the nuclear supervisory and licensing authority. From the point of view of the RSK, these approaches are to be welcomed; in particular, the planned regular three-yearly involvement of external bodies is seen positively. However, in analogous implementation of the relevant specifications of the General guidelines for emergency preparedness [REmp-NFM], plant-internal emergency preparedness exercises in which the entire crisis management organisation of FR-Mz is involved (plant-internal full-scale exercises) should also be performed. This should be anchored in the exercise concept /E15/.

E13 The RSK recommends developing an emergency measure for emergency feeding of the reactor tank that does not require entering the reactor hall. The measure should be laid down in the operating rules and exercised.

E14 The RSK recommends applying for preferential treatment under the PTSG for communications via public networks.

E15 The RSK recommends that FR-Mz - in analogous implementation of the relevant specifications of the General guidelines for emergency preparedness [REmp-NFM] - should implement an exercise concept that also provides for plant-internal emergency preparedness exercises in which the entire emergency organisation of FR-Mz is integrated.

6.2 Earthquake

6.2.1 Recommendations of the RSK from the safety review of German research reactors in 2012

"In the opinion of the RSK, the cited documents on the site hazard due to earthquakes are not up to date and the statement that there are no recent findings in this respect is not comprehensible. However, since the operator has included maximum damage as a result of increased earthquake effects in their considerations, a classification of different levels is possible.

On the basis of the plant operator's statements, the RSK considers it possible that the assessment criteria of Level 1 or 2 (the radiological impacts in the vicinity of the plant remain below the values that require an evacuation of the population or no disaster control measures) can be fulfilled. However, the cited documents do not indicate whether the operator's statements on the maximum radiological impacts have been examined and confirmed in the nuclear supervisory and licensing procedure. In this respect, the possible fulfilment of the level depends on the confirmation of the operator's statement."

6.2.2 Implementation

The supervisory and licensing authority informs [Mz-01] that the presentation submitted to the RSK in 2012 [RSK-SÜ-FR] on the site hazard due to earthquakes is still valid. With reference to the earthquake zone map of KTA 2201.1 [KTA 2201], it was stated that an earthquake of intensity VII (MSK scale) could be expected at the site. This has been confirmed in the meantime by the State Office for Geology and Mining.

The report of the authority [Mz-01] shows that the operator and the authorised expert TÜV Rheinland, consulted according to § 20 of the Atomic Energy Act, did not carry out detailed seismic analyses, but considered alternative boundary scenarios.

In one of the two scenarios, it was assumed that all fuel elements would be damaged as a result of the earthquake, but that the reactor hall would remain intact. This essentially limits the effects to the reactor hall. Even if it is additionally assumed in this scenario that the reactor tank leaks and the fuel elements dry out, i.e. that not only the fission gases enter the reactor hall, the supervisory authority confirms on the basis of the investigations submitted that in this case the accident limits pursuant to §50 of the Radiation Protection Ordinance (StrlSchV) in conjunction with §117 para. 16 of the Radiation Protection Ordinance (StrlSchV) as assessment standard are considerably undercut [Mz-01].

In the second scenario, it was additionally assumed that the reactor hall would also be damaged and radioactive substances would be released into the environment in airborne form. In the opinion of the authority, the radiological effects of this scenario are covered by the releases in the postulated crash of a large commercial airliner onto FR-Mz with destruction of the building without fuel fire [Mz-01]. In his calculation, the expert TÜV Rheinland comes to the conclusion that for this scenario (aircraft crash without kerosene fire), the action levels according to the "Guideline for the Consultant on Radiation Protection of the Operational Command for Disaster Response in Nuclear Emergencies" [Mz-02] are exhausted by less than 1 %.

The authority thus considers the classification in robustness level 2 to be confirmed [Mz-01].

6.2.3 Assessment by the RSK

With regard to the robustness assessment of FR-Mz for the case of a beyond-design-basis earthquake, the RSK largely follows the competent supervisory authority and regards robustness level 2 as fulfilled.

In the analyses, it had been assumed that the reactor core would become subcritical due to the water loss from the reactor tank or due to the shutdown systems. In the opinion of the RSK, it has to be considered that in case of an earthquake, a blast wave or other shocks, mechanical deformations of equipment in the reactor pool, including the control rods and the control rod guides, could occur, which would cause the shutdown system to fail. Provided that the reactor tank remains intact in such a scenario, the core will remain critical. The plant operator has mentioned that it is possible to insert the control rods into the core by manual measures. Based on this, the RSK recommends anchoring this measure as an emergency measure in the operating rules /E16/.

E16 The RSK recommends adopting the already existing option of shutting down the reactor by manual measures as an emergency measure and including it in the operating rules.

6.3 Other natural hazards

6.3.1 Recommendations of the RSK from the safety review of German research reactors in 2012

"The RSK assumes that the statements of the operator on the design basis have been reviewed and confirmed in the nuclear supervisory and licensing procedure. It is not recognisable to the RSK that these correspond to the current status. Depending on their respective risk potential, the other natural hazards should be reviewed with regard to their current relevance within the framework of the supervisory procedure".

6.3.2 Implementation

The authority informs that the design bases for the natural hazards affecting FR-Mz as a result of floods, storms, snow loads, high and low temperatures, heavy rain, lightning and landslides have been compiled by the operator and partly checked by independent experts.

In its results report [Mz-01], the authority confirms that vital safety functions are not at risk in the events assumed. Accordingly, the authority considers robustness level 3 to be fulfilled in each case.

6.3.3 Assessment by the RSK

The RSK recommendation from the safety review of FR-Mz in 2012 has been addressed to the full.

6.4 Explosion protection

6.4.1 Recommendations of the RSK from the safety review of German research reactors in 2012

"In the operator's report /7[12]/, the site-specific potential for blast waves is shown. The operator comes to the conclusion that due to the small quantities, the spatial conditions and the distances to the reactor hall, effects on the reactor hall or even the reactor pool are not to be expected."

"However, the documents cited do not indicate whether the operator's statements have been examined and confirmed in the nuclear supervisory and licensing procedure. In this respect, the possible fulfilment of the degree of protection depends on the confirmation of the operator's statement."

[12] Statement by the Johannes-Gutenberg-Universität Mainz on the RSK's catalogue of questions for the TRIGA Mainz research reactor of October 2011

6.4.2 Implementation

The operator and the authority reported that after publication of the RSK statement on the robustness of German research reactors [RSK-SÜ-FR], possible explosion sources were systematically analysed again [EP_RAFR4].

A gas pipeline that ran not far from FR-Mz has been decommissioned and partially dismantled in the meantime. A recommissioning of the gas pipeline is therefore impossible. The locations of liquid gas and fuel tanks are at a distance of at least 350 m from FR-Mz. The access road for refuelling these tanks is also 350 m away.

The emergency diesel and the associated fuel tank are located at a distance of 15 m from the reactor building and are physically separated from the reactor building by the cooling tower standing in between.

In addition, the authorised expert confirmed that the effects of explosions of hydrogen and deuterium in the ultracold neutron source are limited to the internal facilities of the source (see Chapter 6.6 Precautionary measures).

Based on these circumstances, the authority confirms degree of protection 3 [Mz-01].

6.4.3 Assessment by the RSK

The operator's documentation on the explosion hazard has since been updated and reviewed by the supervisory authority. The authority considers degree of protection 3 to be fulfilled.

The RSK sees no further need for review.

6.5 Aircraft crash

6.5.1 Recommendations of the RSK from the safety review of German research reactors in 2012

"On the basis of the operator's statements, the RSK considers it possible that assessment criteria of degree of protection 1 or 2 (the radiological impacts in the vicinity of the plant remain below the values requiring an evacuation of the population or other disaster control measures even under maximum load assumptions) can be fulfilled, with the impacts of fuel fires, however, having to be taken into account. Nevertheless, the cited documents do not indicate whether the operator's statements have been examined and confirmed in the nuclear supervisory and licensing procedure. In this respect, the possible fulfilment of the degree of protection depends on the confirmation of the operator's statement."

6.5.2 Implementation

Authority and operator explain that the statement submitted to the RSK in 2012 was based on analogy considerations to the crash of a large commercial airliner onto the TRIGA research reactor in Vienna.

In the meantime, the operator has calculated the current, specific nuclide inventory of the core of FR-Mz and made these results available to the authorised expert TÜV Rheinland, who was commissioned by the authority to carry out the review. The expert has confirmed the operator's calculations and used them as a basis for the radiological analyses [Mz-01], [Mz-04].

The expert has examined two scenarios for aircraft crash (FLAB) with and without kerosene fire [Mz-04]. For the radiological assessment, it was conservatively assumed in both scenarios that all fuel elements in the reactor pool would be destroyed.

For both scenarios, the authorised expert has determined the release rates for the radiologically relevant nuclides and the resulting accident doses for a release time of 1 hour.

In the case of the aircraft crash without kerosene fire, the calculated radiation doses amount to less than 1 % of the action levels for disaster control according to the "Guideline for the expert consultant for radiation protection of the operational command of disaster control in nuclear emergencies" [Mz-02]. In the case of an aircraft crash with kerosene fire, the action levels amount to a maximum of 28% (the value of 28% is reached in relation to the action level for long-term resettlement (100 mSv)) [Mz-01]. In both cases, no evacuation of the population or other disaster control measures are required.

The authority therefore considers degree of protection 2 to be fulfilled [Mz-01].

6.5.3 Assessment by the RSK

After the safety review of FR-Mz in 2012, the analyses on the aircraft crash scenarios were updated by the operator and by the expert TÜV Rheinland consulted by the authority. In all the scenarios examined, the action levels for disaster control are not reached. The analyses have been reviewed and confirmed in the nuclear supervisory and licensing procedure.

The RSK sees no further need for review.

6.6 Precautionary measures

6.6.1 Recommendations of the RSK from the safety review of German research reactors in 2012

"The presence of double barriers on the beam tubes is referred to in connection with explosion potentials during operation of the " ultracold neutron source" due to hydrogen/deuterium."

"However, the conceivable effects of a failure of the above-mentioned barriers are covered by the considerations regarding earthquakes and aircraft crashes. ....."

"However, the documents cited on the topics of earthquake and aircraft crash do not indicate whether the operator's statements have been examined and confirmed in the nuclear supervisory and licensing procedure. In this respect, the possible fulfilment of the level depends on the confirmation of the operator's statement."

"In FR Mainz, the maximum excess reactivity of the reactor charge is 3 $ according to /8/. Also according to /8/,[13] *the sudden addition of 4 $ reactivity is theoretically possible, but this would require a series of (intentional) faulty operator actions. In the opinion of the RSK, pulse tests carried out by General Atomic suggest that fuel element damage would have to be expected for this case.*

According to the presentation of the competent supervisory authority /9/,[14] *the operator is currently reviewing whether statements on the max. possible reactivity addition, on the necessary conditions and on the possible consequences are still valid.*

Beyond this assessment, the RSK recommends subjecting all relevant precautionary measures (see Chapter 4.3) to a systematic review and assessment within the framework of the supervisory procedure, also taking into account the limited reliability of administrative measures."

6.6.2 Implementation

Precautions against pool water loss: Integrity of the beam tubes

During the safety review in 2012, the RSK had found that the loss of beam tube integrity is covered by the events 'earthquake' and 'aircraft crash.' The analyses on the effects of a beyond-design-basis earthquake and an aircraft crash have since been updated and reviewed in the supervisory procedure (see Chapters 6.2 and 6.5 of this statement).

The authority explains that it did not base its assessment of the robustness of the double beam tube barriers or the robustness of the vital safety functions in the event of a loss of these barriers solely on conservative considerations of earthquakes and aircraft crashes, but that it also had the effects of plant-internal explosions on the reactor, including the beam tubes, examined by an authorised expert [Mz-01].

To generate ultracold neutrons at beam tubes C and D, about 8 mol of deuterium and 20 mol of hydrogen are required in the ultracold neutron source (UCN source). The systems carrying deuterium and hydrogen are designed according to the double-barrier principle to exclude contact with atmospheric oxygen. The space in between is either filled with inert gas (nitrogen) or evacuated. Outside of the experiment times, the

[13] Sicherheitsbericht TRIGA Mark II Kernreaktor mit Pulseinrichtung der Johannes-Gutenberg-Universität, März 1962

[14] Schreiben des Ministeriums für Wirtschaft, Klimaschutz, Energie und Landesplanung (MWKEL) vom 17.04.2012 an das BMU und die RSK/ESK-Geschäftsstelle zum Entwurf der RSK Sicherheitsüberprüfung (SÜ) für Forschungsreaktoren vom 26.03.2012

flammable gases are enclosed in a safe pressure vessel. Other flammable gases are not used in the reactor hall.

The authorised expert consulted in accordance with Article 20 of the Atomic Energy Act (TÜV Rheinland) analysed the maximum accident pressures occurring under beyond-design-basis conditions in the ultracold neutron source and came to the conclusion that the effects of accidents would remain limited to the interior of this facility. Damage to the fuel elements, the reactor shutdown system, the reactor tank or the beam tubes is not to be feared according to the expert. Thus, from the point of view of the authority, the assessment criteria of degree of protection 3 are fulfilled [Mz-01].

Precautions against inadmissible reactivity addition

The operator explained [EP_RAFR4] that for a short time, there was a reactivity of 2 $ during pulse operation. This value had been approved and the pulse device required for this was checked periodically. The pulse duration was limited to about 25 ms (half-amplitude width) by the inherent feedback via the moderator temperature coefficient in the fuel rod. Two seconds after the pulse has been triggered, the core is shut down via the control rods before the fuel cools down.

Only through a massive violation of the operating manual would it be possible to achieve a reactivity addition higher than $2. This would require a modification of the core, which would in turn require reactor physics expertise, several people, tools and several hours. This conversion could not be carried out unnoticed during working hours. Outside working hours, several safety barriers would have to be overcome for such an intervention, which would, however, trigger alarms to the on-call service and the police.

Regular reloading of the core is performed very rarely and would be monitored according to the four-eyes principle and recorded in the logbook. Consequently, the probability of accidental misloading is also very low. The probability that an accidental misloading during pulsed operation could result in a reactivity addition of more than $3.3 is much lower again.

The authority is therefore of the opinion that an impermissible reactivity addition of $4 could only be achieved by sabotage during core reloading and is only a "theoretical" possibility. Even if it were nevertheless assumed that all fuel elements with aluminium cladding tubes would be damaged in the event of a reactivity addition of $4 and that the entire noble gas inventory were to escape, no radiologically relevant exposure of the personnel or the population outside the reactor building would have to be expected [Mz-01].

Thus, the authority considers robustness level 1 to be fulfilled for this precautionary measure.

Systematic analysis and assessment of precautionary measures

The authority and the operator refer to the fact that neither electricity nor water supply is needed to maintain vital safety functions. The precautionary measures against a loss of integrity of the beam tubes with regard to plant-internal explosions and the precautionary measures against inadmissible reactivity addition have been analysed and reviewed.

A systematic robustness analysis of all precautionary measures going beyond this has not been presented to the RSK working group.

6.6.3 Assessment by the RSK

The effects of the loss of beam tube integrity are covered by the effects of a beyond-design-basis earthquake or an aircraft crash. The analyses regarding earthquake and aircraft crash have been updated and reviewed in the supervisory procedure (see Chapters 6.2 and 6.5 of this statement).

Furthermore, it has been confirmed by the authorised authority that no safety-related effects on FR-Mz are to be assumed in case of an explosion of the hydrogen and deuterium in the UCN source. This statement was examined and confirmed by the authority [Mz-01]. With regard to flammable gases in the reactor plant, the authority considers degree of protection 3 to be fulfilled.

The RSK sees no further need for review.

The operator's information on precautions against inadmissible reactivity addition has been updated and reviewed in the supervisory procedure. Even in case of failure of the precautionary measure, there are no radiological effects outside the reactor hall that would require the evacuation of the population. The RSK does not see any further need for review in this respect.

In 2012, the RSK had recommended [RSK-SÜ-FR] carrying out a systematic analysis of the robustness of all relevant precautionary measures and taking into account the limited reliability of administrative measures. For this purpose, it had specified a list of relevant precautionary measures in its statement [RSK-SÜ-FR]. No systematic analysis of the robustness of the precautionary measures relevant to FR-Mz has been presented to the RSK working group. For example, no analyses of the robustness of precautionary measures against cross-room fires or against the drop of heavy loads into the reactor pool have been presented.

However, the operator and the supervisory authority have comprehensibly demonstrated that the consequences of a postulated failure of precautionary measures are covered by the effects of an aircraft crash. For the aircraft crash scenario, it has meanwhile been confirmed by the authorised expert that the action levels for disaster control will not be reached. Therefore, the RSK does not see any need for further review of the precautionary measures in terms of a robustness analysis.

7 Recommendations

The review of the implementation of the recommendations of the RSK from the safety review of the research reactors [RSK-SÜ-FR] has shown that the recommendations from 2012 have already been largely implemented by the operators of the research reactors and the respective competent supervisory authorities.

The RSK particularly appreciates the revision of the emergency protection concept at all three facilities, the re-evaluation of the robustness of the reactors in case of beyond-design-basis earthquakes, the analyses of the effects of an aircraft crash, and the review of the robustness of precautionary measures against the loss of vital safety functions. In addition, it is positively noted that safety measures to increase the robustness of the three-phase power supply have been implemented at BER-II and FRM-II, and that further retrofits to improve the emergency feeding of the reactor pool are under preparation at FRM-II. It is also positively emphasised that the crisis management organisation at FR-Mz has been strengthened by an increase in personnel.

The RSK would like to explicitly thank the operators and the competent supervisory authorities for their comprehensive and constructive support in the current review of the implementation of the recommendations of 2012.

With the new recommendations from the current review, the RSK makes suggestions for further improving the already achieved high robustness of the three research reactors.

In the following, these recommendations are summarised on a plant- and topic-specific basis.

Research reactor Berlin II (BER-II)

Emergency measures

E1 The RSK recommends that in the emergency response organisation of BER-II, the hierarchy of the authority to issue directives should be clearly recognisable. In particular, the Head of Reactor should also be authorised to issue instructions to the Physical Protection Commissioner and the Radiation Protection Supervisor in all matters of reactor safety in emergency situations. The instructions of the "HZB Head of Operations" must not override the responsibility of the Head of Reactor under atomic law. 15

E2 With regard to the implementation of emergency measures, the RSK recommends differentiating between the deployment of the plant fire brigade and the Berlin Fire Brigade in the emergency manual. When naming resources and describing emergency measures, the emergency manual should take into account the circumstances that the plant fire brigade is only available during normal working hours and that the Berlin Fire Brigade is not subject to the instructions of the operator. 15

E3 The RSK recommends examining to what extent clear criteria for triggering the incident/accident measurement programme in case of events involving a release can be included in the operating rules. 15

E4 The RSK recommends concluding a contractual arrangement for the provision of a mobile emergency diesel generator that also allows the operation of the ventilation system and the exhaust air filtration of the reactor hall. The necessary cable connections should be available at the plant with sufficient protection. The boundary conditions (e.g. required power) and switching operations (e.g. to avoid automatic connection of consumers) for connecting the mobile emergency diesel generator should be clearly stated in the emergency manual. 16

E5 Due to the pumping capacity of the KTJ system, it can be assumed that the measure alone is not sufficient to compensate for a large leak in the reactor pool. The additional feed options available are suitable for overfeeding larger leaks but require access to the reactor hall. Likewise, electrical consumers and mobile equipment still present inside the buildings have to be connected to the external emergency feed points of the three-phase power supply by temporary cable connections. The RSK recommends checking to what extent fixed pipelines or cables can be used to avoid that endangered room areas have to be entered in case of an emergency. 16

E6 The RSK recommends anchoring the requirement according to which only individual hydrogen cylinders may be used by the BER-II personnel when filling the buffer tank for the cold neutron source in the operating rules. Furthermore, the RSK recommends proving that the explosion of the entire hydrogen amount of a hydrogen cylinder, the buffer tank and the connecting line will not lead to an impairment of vital safety functions of BER-II. 19

E7 The RSK recommends examining whether and under what conditions the Berlin Fire Brigade will be able to extinguish kerosene fires at or in the reactor building before 30 minutes have elapsed. If this is possible, this measure including the prerequisites to be ensured by the operator for this purpose should be included in the emergency planning of BER-II. The implementation of this measure should be practised regularly. 22

E8 The RSK recommends that FRM-II should implement an exercise concept for emergency protection measures - in analogous implementation of the requirements of [REmp-NFM]. Part of this concept should be at least annual plant-internal emergency drills in which the entire emergency organisation of FRM-II is integrated (plant-internal full-scale drills). Likewise, the disaster control authorities have to be involved in the exercises at least every five years. 35

E9 The RSK recommends defining an emergency measure for injecting into the reactor pool and the storage pool, the implementation of which will not require access to the reactor hall nor the availability of the plant's electrical power supply. The measure must not have any adverse repercussions on the other functions of the systems used. 35

E10 The RSK recommends an analysis of the effects that beyond-design-basis internal and external hazards may have on the accident monitoring system. If, in the case of the analysed

8 References

[RSK-SÜ-FR] Stellungnahme der RSK „Anlagenspezifische Sicherheitsüberprüfung (RSK-SÜ) deutscher Forschungsreaktoren unter Berücksichtigung der Ereignisse in Fukushima-I (Japan)“
Anlage 1 zum Ergebnisprotokoll der 447. Sitzung der Reaktor-Sicherheitskommission (RSK) am 03.05.2012

[RSK472_4.1] Prof. Dr. Weiß, Beratungskonzept zur Umsetzung der Erkenntnisse aus der Robustheitsanalyse für Forschungsreaktoren

[RSK-SÜ] RSK-Stellungnahme „Anlagenspezifische Sicherheitsüberprüfung (RSK-SÜ) deutscher Kernkraftwerke unter Berücksichtigung der Ereignisse in Fukushima-I (Japan)“
437. RSK-Sitzung vom 11. - 14. Mai 2011

[REmp-NFM] „Rahmenempfehlungen für die Planung von Notfallschutzmaßnahmen durch Betreiber von Kernkraftwerken“, Empfehlung der Strahlenschutzkommission und der Reaktor-Sicherheitskommission,
verabschiedet in der 242. Sitzung der Strahlenschutzkommission am 01./02. Juli 2010,
gebilligt in der 244. Sitzung der Strahlenschutzkommission am 03. November 2010,
verabschiedet in der 429. Sitzung der Reaktor-Sicherheitskommission am 14. Oktober 2010.
Ergänzung verabschiedet in der 468. Sitzung der RSK am 04.September 2014 und in der 271. Sitzung der SSK am 21.Oktober 2014

[REmp-Kat] „Rahmenempfehlungen für den Katastrophenschutz in der Umgebung kerntechnischer Anlagen“, Empfehlung der Strahlenschutzkommission,
verabschiedet in der 277. Sitzung der SSK am 19./20. Februar 2015

[REI] BMUB, Richtlinie zur Emissions- und Immissionsüberwachung kerntechnischer Anlagen

[EP_RAFR1] RSK-Ad-hoc-Arbeitsgruppe ROBUSTHEITSANALYSE FORSCHUNGSREAKTOREN (AG RAFR) Ergebnisprotokoll der 1. Sitzung am 31.03.2015

[EP_RAFR2] RSK-Ad-hoc-Arbeitsgruppe ROBUSTHEITSANALYSE FORSCHUNGSREAKTOREN (AG RAFR) Ergebnisprotokoll der 2. Sitzung am 02.07.2015

[EP_RAFR3] RSK-Ad-hoc-Arbeitsgruppe ROBUSTHEITSANALYSE FORSCHUNGSREAKTOREN (AG RAFR) Ergebnisprotokoll der 3. Sitzung am 30.09.2015

[EP_RAFR4] RSK-Ad-hoc-Arbeitsgruppe ROBUSTHEITSANALYSE FORSCHUNGSREAKTOREN (AG RAFR) Ergebnisprotokoll der 4. Sitzung am 21.01.2015

[EP_RAFR5] RSK-Ad-hoc-Arbeitsgruppe ROBUSTHEITSANALYSE FORSCHUNGSREAKTOREN (AG RAFR) Ergebnisprotokoll der 5. Sitzung am 26.09.2015

[KTA 1203] Sicherheitstechnische Regel des KTA, KTA 1203 „Anforderungen an das Notfallhandbuch“, Fassung 2009-11

[KTA 1507] Sicherheitstechnische Regel des KTA, KTA 1507 „Überwachung der Ableitungen radioaktiver Stoffe bei Forschungsreaktoren“, Fassung 2012-11

[KTA 2101] Sicherheitstechnische Regel des KTA, KTA 2101.1 „Brandschutz in Kernkraftwerken
Teil 1: Grundsätze des Brandschutzes“, Fassung 2015-11
Teil 2: Baugrund, Fassung 2012-11
Teil 3: Bauliche Anlagen, Fassung 2013-11

[KTA 2201] Sicherheitstechnische Regel des KTA, KTA 2201.1 „Auslegung von Kernkraftwerken gegen seismische Einwirkungen“,
Teil 1: Grundsätze, Fassung 2011-11
Teil 2: Baugrund, Fassung 2012-11
Teil 3: Bauliche Anlagen, Fassung 2013-11

[KTA 3902] Sicherheitstechnische Regel des KTA, KTA 3902 „Auslegung von Hebezeugen in Kernkraftwerken“, Fassung 2012-11

BER-II

[BER-01] Helmholtz Zentrum Berlin für Materialien und Energie, Herbert Krohn, „Der Forschungsreaktor BER II“, Foliensatz

[BER-02] HZB Helmholtz Zentrum, Dr. B. Schröder-Smeibidl, „Notfallmaßnahmen am HZB**“,** 31.03.2015, Sitzung der ad-hoc Arbeitsgruppe der RSK, Foliensatz

[BER-03] HZB Helmholtz Zentrum, Dr. B. Schröder-Smeibidl, „Sitzung der ad-hoc Arbeitsgruppe der RSK - 2.07.2015“, Stand März 2015, Foliensatz

[BER-04] TÜV NORD EnSys Hannover GmbH & Co. KG, Dipl.-Ing. G. Gerding und Dr.-Ing. O. Braaß, VS-nfD, „Forschungsreaktor BER II in Berlin Wannsee - Ergebnisse des Gutachtens zu den Auswirkungen des Absturzes eines Verkehrsflugzeuges (Airbus A320) entsprechend dem Schutzgrad 2 der RSK-SÜ“, 1. Sitzung der RSK AG RAFR am 31.03.2015 in Berlin, Foliensatz

[BER-05] TÜV NORD EnSys Hannover GmbH & Co. KG, VS-nfD „Forschungsreaktor BER II in Berlin Wannsee, Gutachten zu den Auswirkungen des Absturzes eines Verkehrsflugzeuges (Airbus A320) entsprechend dem Schutzgrad 2 der RSK-SÜ“, erstellt im Auftrag der Senatsverwaltung für Stadtentwicklung und Umwelt, Berlin unter Mitwirkung der Gesellschaft für Anlagen- u. Reaktorsicherheit GmbH (GRS) und der Stangenberg und Partner Ingenieur-GmbH, Januar 2015

[BER-06] TÜV NORD EnSys Hannover GmbH & Co. KG, Kurzfassung „Forschungsreaktor BER II in Berlin Wannsee, Gutachten zu den Auswirkungen des Absturzes eines Verkehrsflugzeuges (Airbus A320) entsprechend dem Schutzgrad 2 der RSK-SÜ“, erstellt im Auftrag der Senatsverwaltung für Stadtentwicklung und Umwelt, Berlin unter Mitwirkung der Gesellschaft für Anlagen- u. Reaktorsicherheit GmbH (GRS) und der Stangenberg und Partner Ingenieur-GmbH, Januar 2015

[BER-07NHB] BER II, Notfallhandbuch (NHB), Stand 01.03.2015

[BER-08] TÜV NORD EnSys Hannover GmbH & Co. KG, „Zum Gutachten der TÜV NORD ENSys GmbH & Co. KG zu den Auswirkungen des Absturzes eines Verkehrsflugzeuges (Airbus A320) entsprechend dem Schutzgrad 2 der RSK-SÜ vom September 2004 - Betrachtung des Umsetzbeckens des BER II“, ETB-Dr. Bß, 26.06.2015

[BER-09] A. Axmann / C. O. Fischer, „PL Ausbau BER II“, Notiz KNQ EVA, 18.08.1987

[BER-10] TÜV Rheinland Industrie Service, „Sonderüberprüfung „STRESSTEST“ für den Forschungsreaktor BER II des Helmholtz-Zentrums Berlin für Materialien und Energie GmbH – Stellungnahme zu Fragen der Robustheit der Anlage in Anlehnung an die Sicherheitsüberprüfung für Leistungsreaktoren erstellt im Auftrag der Senatsverwaltung für Gesundheit, Umwelt und Verbraucherschutz des Landes Berlin“, Berlin, Oktober 2011

[BER-11] Helmholtzzentrum Berlin, Zentralabteilung Reaktor, Technische Mitteilung Nr. 11.015, „Bruch Trinkwasserleitung im Reaktorbereich“, 30.06.2011

[BER-12] Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, „Kurzbeschreibung des BER II“, Oktober 2011

FRM-II

[FRM-01] FRM II Forschungs-Neutronenquelle Heinz Mayer-Leibnitz, Technische Universität München (TUM), „Kurzvorstellung des FRM II und Stand der Umsetzung der RSK-Empfehlungen", Foliensatz

[FRM-02NHB] Hochflussneutronenquelle München (FRM II), BETRIEBSHANDBUCH (BHB), Teil: 3, Kap. 4, Titel: Notfallmaßnahmen, 24.02.2015

[FRM-03] Hochflussneutronenquelle München (FRM II), BETRIEBSHANDBUCH (BHB), Teil: 1, Kap.: 6, Titel: Alarmordnung, 16.12.2013

[FRM-04] Siemens/TUM, FRM II „Übersicht-Schaltplan 20-kV- und 400-V-Systeme", Zeichnungs-Nr: ZZD544-YU-B-001

[FRM-05] Betrachtungen zu den Folgen eines postulierten Ausfalls des Notkühlsystems bei freiem Auslaufen der Primärpumpen; Siemens Arbeitsbericht: 2B 0320.0002, 1994

[FRM-06] Strahlenexposition in der Umgebung des FRM-II nach einem postulierten Schmelzen von 15 BE-Platten (Radiologischer Auslegungsstörfall); Siemens Arbeitsbericht: B0520.007, 1994

[FRM-07] SSK-Empfehlung zur 3. Teilgenehmigung des Forschungsreaktors München II (FRM-II), 175. Sitzung der SSK, Dezember 2001

[FRM-08] TÜV SÜD Industrie Service GmbH, „FRM II, Erdbeben Auswertung Robustheitslevel", RSK, Sitzung mit Anhörung am 30.09.2015, Foliensatz

[FRM-09] TÜV SÜD Industrie Service GmbH, „Hochflussneutronenquelle München (FRM II), Anlagenspezifische Sicherheitsüberprüfung (RSK-SÜ), 3. Sitzung der ad-hoc-Arbeitsgruppe am 30.09.2015 bei der GRS in Garching"
Robustheitsanalyse, Kurzzusammenfassung der Ausführungen des Sachverständigen zum Thema „Erfüllung des Level 2 bei der Einwirkung eines Erdbebens der Intensität I+2"

[FRM-10] SPI, „Hochflussneutronenquelle München FRM II, Bericht zum Stand der Umsetzung der RSK-Empfehlungen, zur Robustheit des FRM II, Bautechnische Stellungnahme zur Erfüllung des Levels 2 bei der Erdbebenauslegung", 3. Sitzung der ad-hoc-Arbeitsgruppe „Robustheitsanalyse Forschungsreaktoren (RAFR)" der RSK □ 30.09.2015, GRS Garching, Foliensatz

[FRM-11] Kastenmüller, „AW:RSK AG Forschungsreaktoren", E-Mail vom 26.09.2016

[FRM-12] Kastenmüller, „Stellungnahme zur Robustheit deutscher Forschungsreaktoren", E-Mail vom 18. und 20.11.2016

[FRM-13] TÜV Energie und Systeme, Auszug aus dem Gutachten zur 2. TG (Oktober 1997) „FRM-II Errichtung Systeme - 13.2 Störfallinstrumentierung", Stand 02.10.97

[FRM-14] TÜV Energie und Systeme, Auszug aus dem Gutachten zur 2. TG (Oktober 1997) „FRM-II Errichtung Systeme - 18.3 Strahlungs- und Aktivitätsüberwachung für Stör- und Unfälle", Stand 02.10.97

[FRM-15] TÜV SÜD Industrie Service GmbH, „Hochflussneutronenquelle München (FRM II), Anlagenspezifische Sicherheitsüberprüfung (RSK-SÜ), 3. Sitzung der ad-hoc-Arbeitsgruppe am 30.09.2015 bei der GRS in Garching"
Robustheitsanalyse, Zusammenfassung zu den Themen
„Postuliertes Versagen der Kalten (KQ) und der Heißen Neutronenquelle (HQ) mit anschließender D_2-Explosion" und
„Ausfall Naturumlauf infolge eines postulierten Absturzes einer schweren Last in das Reaktorbecken auf die Primärkühlmittelleitung unterhalb des Ansaugsiebes"

[FRM-16] TÜV SÜD Industrie Service GmbH, „Stand der Umsetzung der RSK-Empfehlungen zur Robustheit des FRM II", 3. Sitzung der Ad hoc-Arbeitsgruppe der RSK, 30.09.2015, Foliensatz

[FRM-17] Hochflussneutronenquelle München (FRM II), Auszug aus dem BETRIEBSHANDBUCH (BHB), Stand 16.11.2015

[FRM-18] TÜV SÜD IS, „Hochflussneutronenquelle München (FRM-II), Anlagenspezifische Sicherheitsüberprüfung (RSK-SÜ), 3. Sitzung der RSK-ad-hoc-Arbeitsgruppe „Robustheitsanalyse Forschungsreaktoren" am 30.09.2015 bei der GRS in Garching" Robustheitsanalyse - Zusammenfassung zum Thema „Bewertung der Folgen eines postulierten Absturzes schwerer Lasten in das Absetzbecken",
München, den 12.02.2016

[FRM-19] TÜV SÜD Industrie Service GmbH, „Hochflussneutronenquelle München (FRM II), Anlagenspezifische Sicherheitsüberprüfung (RSK-SÜ), 3. Sitzung der ad-hoc-Arbeitsgruppe am 30.09.2015 bei der GRS in Garching"
Robustheitsanalyse, Kurzzusammenfassung der Ausführungen des Sachverständigen zum Thema „Vorsorgemaßnahmen zur Vermeidung interner Explosionen"

[FRM-20] R. Mallick, STMUV, „RSK-SÜ: Integrität des Reaktor- und Absetzbeckens bei Erdbeben Level 2 beim FRM II", E-Mail vom 28.11.2016

FR-Mz

[Mz-01] Schreiben des Ministeriums für Wirtschaft, Klimaschutz, Energie und Landesplanung Rheinland Pfalz (MWKEL) vom 07.01.2016, Az: 84 321-00003/2011-002, Dok-Nr. 2016/001814, Referat: 8606
einschließlich der Anlage:
Ergebnisbericht der atomrechtlichen Aufsichtsbehörde, Ministerium für Wirtschaft, Klimaschutz, Energie und Landesplanung Rheinland-Pfalz (MWKEL)
Überprüfung der Betreiberangaben zur „Anlagenspezifischen Sicherheitsüberprüfung der Reaktorsicherheitskommission (RSK-SÜ) deutscher Forschungsreaktoren unter Berücksichtigung der Ereignisse in Fukushima-1 (Japan) - hier: Forschungsreaktor TRIGA an der Johannes Gutenberg-Universität Mainz (TRIGA Mainz)"

[Mz-02] Bericht der Strahlenschutzkommission, „Leitfaden für den Fachberater Strahlenschutz der Katastropheneinsatzleitung bei kerntechnischen Notfällen", Heft 37 (2010)

[Mz-03] Krisenmanagement für den Forschungsreaktor Mainz, Vorlage der Johannes Gutenberg-Universität Mainz vom 16.04.2013

[Mz-04] TÜV Rheinland Industrie Service GmbH, „Stellungnahme zu den radiologischen Auswirkungen eines Flugzeugabsturzes auf den Forschungsreaktor TRIGA Mainz", TÜV-Aktenzeichen: T17.27.1.4, 30.11.2012

[Mz-05] TRIGA Mainz, BETRIEBSHANDBUCH (BHB), Teil 1, Kapitel 7 „Alarmordnung TRIGA Mainz" SSp, Stand 23.11.2015

[Mz-06] Johannes Gutenberg-Universität Mainz (JGU) D 55099 Mainz, „Krisenmanagement-Handbuch für den Forschungsreaktor TRIGA Mainz, Stand November 2015, Teil I, TRIGA-spezifische Komponenten und Handlungsanweisungen"

[Mz-07] JGU, Fachbereich 09, Johannes Gutenberg-Universität Mainz, „Vorstellung des Forschungsreaktor TRIGA Mainz (FR Mz)", Folienvortrag

9 Annexes

Annex 1: **Brief description of the research reactor Berlin II (BER-II)**

The BER-II (*Berliner Experimentier-Reaktor II* - Berlin Experimental Reactor II) is a pressureless light-water reactor in an open reactor pool (pool-type reactor) with a thermal power of 10 MW [BER-05]. It is used exclusively for the generation of neutron radiation for research (thermal neutron density up to $2*10^{14}$ neutrons/(cm^2*s)).

In the years 1997 - 2000, the conversion from HEU (high-enriched uranium) to LEU (low-enriched uranium) was carried out. The reactor is scheduled for final shutdown at the end of 2019.

The reactor building consists mainly of the experimental hall and the reactor hall, which are steel skeleton structures.

The reactor pool filled with approx. 200 m^3 of water consists of the operating pool and the storage pool. The outer ground plan of the reactor pool facility is oval. The basins are interconnected and can be separated from each other by a gate that can be inserted from above.

The reactor core consists of 24 fuel elements (322 g of U_{235} per fuel element) and 6 control fuel elements of the MTR type as well as 6 fork-type absorbers (hafnium) as control and shutdown rods. The reactor core is suspended from a core support structure at a depth of 8 m below the water level. Each control/fuel element is composed of 17 or 23 thin plates which contain the U_3Si_2-Al dispersion fuel enclosed by aluminium.

At core level, the operating pool is penetrated by nine horizontally arranged beam tubes that serve for the transmission of the neutrons produced. One of the beam tubes contains an experimental device for the production of cold neutrons (cold neutron source (KNQ)). In the operating position, the core is surrounded by beryllium blocks as reflectors. When shut down, the core can be transferred from the operating position to the storage pool.

The water in the reactor pool heats up to a temperature of around 40°C during operation. In BER-II, heat is removed to the atmosphere via cooling towers by three water circuits connected in series (primary cooling system, intercooling system, and cooling tower system), which are interconnected via heat exchangers. The primary cooling system is located entirely in the reactor pool. Three primary pumps, each of whose drives is fed from a battery-buffered uninterruptible power supply, generate the primary coolant flow rate through the core from top to bottom. The throughput of two pumps is sufficient for full-load operation.

Parts of the fully demineralised water of the reactor pool are continuously pumped out through two purification systems for cleaning.

The reactor protection system (ISKAMATIK) includes the diverse data acquisition system for power, temperature and water level and, in addition to the control rods, controls the respective redundant ventilation and pool isolation systems (singly redundant). A redundant emergency power supply is available. The ventilation systems and all active safety equipment have redundant emergency power supplies.

The beam tubes penetrating the reactor pool are designed in such a way that there are always two passive barriers against pool water loss as a precautionary measure; the 1st barrier is the wall of the beam tube itself, the 2nd barrier is formed by an insert in the beam tube (e.g. experimental insert with neutron window).

All hydraulic connections to the pool are also secured by two barriers, with one of the barriers being located in the area of the pool wall in each case.

The beam tubes are installed deeper in the basin than the cooling system. Therefore, a beam tube failure is to be regarded as the worst case with regard to pool water loss.

In a reactor emergency shutdown (reactor scram), the control rods fall in by gravity within approx. 400 ms. Of the six rods, one is sufficient to keep the core subcritical until xenon depletion.

The specification-compliant residual-heat removal after a reactor shutdown takes place for one minute via battery-buffered pump operation (at least one of three primary pumps, battery operation for at least ten minutes) and then by natural convection. Two natural circulation check vales are installed for this purpose, which open automatically in the event of forced-air cooling failure. The pool water serves as a heat sink. There are no separate residual-heat removal pumps. With the core covered with water, no further active measures are necessary after one minute. Even if active residual-heat removal fails, there will be no damage to the fuel elements. The most important fundamental safety function is therefore to keep the core covered with sufficient water.

The design was based on the "cooling channel blockage" accident. Here it is assumed that one or more cooling channels are blocked by foreign material, which interrupts the flow. As a result, water evaporation occurs in the affected channel and the adjacent fuel plates overheat until they melt at approx. 660°C. The assumption is that the entire fuel element will melt. Due to the void effect, there is a sudden drop in power and, as a consequence, reactor scram with subsequent ventilation isolation. In this scenario, it is to be assumed that the noble gases will enter the environment, i.e. first into the reactor hall, while the fission products (apart from the noble gases) will largely be retained by the pool water. Negative pressure prevails in the reactor hall. In the event of a design basis accident, the exhaust air is guided to the outside via the double-redundant ventilation system and filter facilities, including iodine filters.

During normal operation, the reactor hall exhaust air is discharged unfiltered to the outside to maintain negative pressure. A pool exhaust extracts the hall air above the pool and guides it through particle filters to avoid increased aerosol concentrations.

The underground storage pool is used for the interim storage of up to 80 spent fuel elements. It has a double shell made of austenitic steel and is embedded in a recess in the floor of the experimental hall. The storage pool is sealed off from the experimental hall by a removable concrete cover.

Sources

[BER-01] Helmholtz Zentrum Berlin für Materialien und Energie, Herbert Krohn, „Der Forschungsreaktor BER II", Foliensatz

[BER-05] TÜV NORD EnSys Hannover GmbH & Co. KG, VS-nfD „Forschungsreaktor BER II in Berlin Wannsee, Gutachten zu den Auswirkungen des Absturzes eines Verkehrsflugzeuges (Airbus A320) entsprechend dem Schutzgrad 2 der RSK-SÜ", erstellt im Auftrag der Senatsverwaltung für Stadtentwicklung und Umwelt, Berlin unter Mitwirkung der Gesellschaft für Anlagen- u. Reaktorsicherheit GmbH (GRS) und der Stangenberg und Partner Ingenieur-GmbH, Januar 2015

[BER-12] Helmholtz-Zentrum Berlin für Materialien und Energie GmbH, „Kurzbeschreibung des BER II", Oktober 2011

Annex 2: **Brief description of the research reactor Munich II (FRM-II)**

FRM-II started its user operation on 29 April 2005. It is a central scientific facility of the Technical University of Munich (TUM) and is located on its campus in Garching. The premises are separated from the rest of the campus by a massive fence. FRM-II includes the reactor building, consisting of the reactor hall and the experimental hall, the neutron guide halls east and west, and ancillary buildings. All activity-carrying systems are located in the controlled area. The controlled area comprises the reactor hall, the experimental hall, the basement area of the reactor building, and some rooms in the basement area below the neutron guide hall west. The reactor building houses the safety-relevant mechanical, electrical and ventilation equipment.

The research reactor Munich II (FRM-II) is a pressureless reactor in an open reactor pool (pool-type reactor) and serves as a neutron source for scientific studies. The undisturbed thermal neutron flux is 8×10^{14} neutrons/(cm^2s) at a thermal power of 20 MW.

Reactor pool, storage pool and the primary cell together form the pool group. The two pools can be separated by a gate but are connected during power operation due to the then withdrawn separating gate. The primary cell contains, among other things, the reactor coolant pumps and heat exchangers. All water-carrying pipes (e.g. water purification, cooling) run over the edge of the pool into the pool, which has a water volume of about 700 m^3.

The fuel element (FE) (hollow-cylindrical, height 133 cm, outer diameter 24 cm, 113 evolute-curved fuel plates with two radial zones of different uranium density, enrichment level up to 93 % of U235 with a total of about 8 kg of uranium) is located in a vertical central channel separating the primary cooling system with light water from the surrounding moderator tank with heavy water. The moderator tank houses secondary neutron sources: cold source (KQ, D2-filled, 25 K), hot source (HQ, graphite core, approx. 2200 K), converter facility for generating fast neutrons. In the moderator tank, 10 beam tubes, two inclined beam tubes and some irradiation equipment protrude horizontally from above.

The beam tubes penetrate the pool wall (approx. 1.5 m thick concrete wall), run through an annular gap with light pool water and then lead into the moderator tank. They have two barriers (beam tube nose with compensator tube and beam tube end plate with neutron double window) against moderator or pool water loss. The beam tubes are also closed during measurements by the neutron double windows (part of the 2nd barrier). The beam tube closure plates with the neutron double windows are located in niches protected by heavy concrete blocks.

In the middle of the central channel, the control rod is moved vertically. It is connected to the drive via a magnetic coupling. In the event of reactor scram, the control rod drops in both by gravity and by the flow of cooling water (from top to bottom). Diversely, five shutdown rods are magnetically coupled outside the fuel element in the moderator tank. Four of the five shutdown rods are sufficient for long-term shutdown. In the event of a power failure, the magnetic holders disengage and the shutdown rods drop in accelerated by gravity and spring force.

The chain reaction in FRM-II only takes place if there is light water inside the fuel element and heavy water outside in the moderator tank. If one of the two components is missing or light water mixes with heavy water, the chain reaction ends.

The digital three-train TXS system is installed as safety instrumentation and control system. This system is diverse because it processes different measured variables in two subsystems.

The cooling system consists of three cooling circuits (primary, secondary and tertiary). The primary cooling circuit has four pumps, two in parallel in each string. During power operation, the cooling water flows through the fuel element from top to bottom at a mass flow rate of approx. 300 kg/s. The temperature of the cooling water entering the core is approximately the same as the pool water temperature of 35 °C, while the outlet temperature is around 50 °C.

The pumps and two heat exchangers that transfer the heat from the primary to the secondary circuit (line-to-line) are located in the primary cell. Two further heat exchangers transfer the waste heat from the secondary circuit to the tertiary circuit with four small cooling towers as heat sinks. Primary water is continuously extracted, purified with filters and ion exchangers, and recirculated. A separate pool cooling system removes heat from the pool water, and another separate cooling system removes heat from the moderator tank via the secondary circuit. After reactor shutdown, the FE is cooled in the active residual-heat removal phase by means of the emergency cooling pumps, with the pool water serving as a heat sink.

After shutdown of the core, pump operation for residual-heat removal is provided for approx. 3 h by design. After that, the core can be cooled in natural circulation. After the pumps have been shut down, the natural circulation check valves, which were previously closed by the internal pressure in the primary circuit, open. In natural circulation, the direction of flow is reversed and the cooling water flows through the fuel element from bottom to top. In the case of reactor scram, three emergency cooling pumps start automatically, one of which is sufficient for heat removal. At the end of a cycle, reactor scram is triggered. In this case, primary pumps and emergency cooling pumps run together. The emergency cooling pumps are supplied by batteries and are thus available even in the event of a complete failure of the AC power supply. In the event of failure of any of the power supplies, i.e. including the battery systems, natural circulation starts immediately. The analysis of this scenario has shown that the FE is not damaged even in case of immediate transition to natural circulation.

The campus has a 20 kV medium-voltage supply via the normal grid (ring grid) and a separately laid 20 kV backup grid connection (emergency grid ring via a combined heat and power plant with its own emergency diesel). Switching to the emergency grid ring is done manually. The emergency power supply is of line-to-line design and can be supplied via two stationary emergency power diesels (each 800 kVA rated power, 575 kW generator terminal output) in addition to the above-mentioned supply options. One emergency diesel can also be switched to the neighbouring busbar via section switches. In addition, there is a further supply (400 V) to the emergency busbars via an emergency transformer, which has been relocated to the reactor site in the meantime and whose connections are routed to the switchgear. Furthermore, a connection option for a mobile emergency power diesel has been created.

Batteries are available in case of failure of the three-phase power supply. For this purpose, two of three battery banks are permanently assigned to one busbar each. The third battery bank can optionally be switched to one of the two busbars.

Sources

[FRM-01] FRM II Forschungs-Neutronenquelle Heinz Mayer-Leibnitz, Technische Universität München (TUM), „Kurzvorstellung des FRM II und Stand der Umsetzung der RSK-Empfehlungen“, Foliensatz

[Brochure] Forschungs-Neutronenquelle Heinz Maier-Leibnitz FRM II, TUM, „Forschung mit Neutronen Methoden entwickeln, Natur befragen, Antworten bekommen“, Broschüre Stand Juni 2009

Annex 3: **Brief description of the research reactor Mainz (FR-Mz)**

The research reactor Mainz (FR-Mz) is a light water reactor in an open reactor pool (swimming pool reactor) with a "lifetime core". The TRIGA[15] reactor is operated by the Johannes Gutenberg University Mainz (JGU) and is used for research, education, and isotope production. In continuous operation, the reactor has a power of 100 kW_{th}, which can be increased for a short time to 250 MW_{th} in pulsed operation (average pulse duration 25 ms).

The core, surrounded by a graphite reflector, is located in an aluminium tank with a water volume of about 18 m^3. The filling level in the tank is about 6.2 m above the tank bottom. The upper edge of the core is covered with 4.8 m of water. The reactor has four horizontal beam tubes (A to D) and the thermal column for special "large-volume" experiments. The thermal column is shielded by a movable concrete radiation protection gate. There is also a central, vertical irradiation tube. This is where the neutron flux is highest. Samples can be introduced into and removed from the reactor core via three pneumatic tube systems without interrupting reactor operation.

The upper part of the graphite reflector contains the irradiation carousel for up to 80 irradiation samples in 40 positions.

The cylindrical fuel elements (FEs) (fuel rods) have been in use since the start of operation in 1965. The burn-up amounts to about 4 g per year and a total of about 200 g over the operating period to date (50 years). Every 4 to 5 years, a new fuel element (fuel moderator element, see below) is additionally inserted into the core. The FEs consist of 91 wt.% zirconium, 1 wt.% hydrogen and 8 wt.% uranium. There are currently 76 FEs in the core (~ 2.7 kg U-235). Seven unirradiated fuel elements are in stock.

The FEs have partly aluminium and partly stainless-steel cladding tubes. The fuel consists of uranium enriched to 20% (LEU) in a zirconium hydride matrix. Zirconium hydride is relatively stable against oxidation because a thin oxide layer forms on its surface, which also represents an effective diffusion barrier against the release of fission products. At temperatures above 600 °C, thermal decomposition of the zirconium hydride occurs at an increasing rate. The resulting hydrogen is also retained by the outer oxide layer up to temperatures of 900 °C to 1000 °C but is increasingly released thereafter. The fuel element temperature in continuous operation (100 kW) is approx. 90 °C.

The zirconium hydride matrix of the fuel element causes the moderation of the neutrons at the hydrogen to decrease with an increase in temperature. This leads to a negative moderator temperature coefficient in the fuel element and thereby to an inherent power reduction. This effect sets in at temperatures of about 200°C. At lower temperatures, the neutrons in the fuel matrix are slowed down to about 130 meV. Further moderation is provided by the pool water. If the water is lost (e.g. leakage), the core becomes subcritical.

The power of the core is actively controlled by three control rods (pulse rod, trim rod, control rod). Reactivity of up to approximately $2 can be introduced via the pulse rod. Either the trim rod or the pulse and

[15] TRIGA stands for Training, Research, Isotope Production, General Atomic, with General Atomic being the manufacturer of TRIGA.

control rod are necessary for shutdown. In the event of a power failure, the magnetic holders disengage and all rods drop into the core, driven by gravity. Boron carbide serves as neutron absorber. The decay power is about 80 W per fuel rod immediately after shutdown.

According to the safety analysis report, the maximum fuel temperature in the event of a sudden loss of cooling water is approx. 250 °C, based on continuous operation at full power of 100 kW. If air convection is also assumed to cease, the value increases to a maximum of 300 °C. This is far below the melting points of the cladding tube materials (aluminium 660 °C, stainless steel 1500 °C). Consequently, the residual heat can be removed by air cooling alone. FR-Mz therefore requires neither active operational residual-heat removal nor emergency residual-heat removal systems.

Pulsed operation is started after the power has been set to approx. 50 W with the trim and control rod. The pulse bar is controlled via a control valve and compressed air (5 bar). The neutron pulse intensity is adjusted via the upper end stop of the shock absorber. In case of a loss of power, the control valve closes the compressed air and the pulse rod drops back into the core due to its weight. The device for controlling the pulse rod is located above the water level in the tank.

The pulse duration (half-amplitude width approx. 25 ms) is determined by the physical properties of the core and not by any technical equipment. After the pulse has been triggered, the inherent feedback and power reduction due to the temperature increase of the moderator in the fuel takes place within a few ms. After approx. 2 s, all three control rods drop in. Should the pulse rod remain in the upper end position due to a mechanical defect, the trim rod alone is sufficient to shut the reactor down. During a pulse, the core heats up to approx. 300°C. After the pulse, the core cools down to ≤ 100 °C after approx. 30 s. If the shutdown via all three rods were to fail, the core would settle to a temperature below 200°C and a power level that corresponds to the power that can be dissipated.

Since a power supply is not required for either safe shutdown or emergency cooling, the unit only has a simple mains connection. In addition, there is an emergency power supply consisting of the battery-buffered UPS (Uninterruptible Power Supply) and an emergency diesel. The design of the UPS ensures a supply of the safety-related consumers for at least one hour. The range of the UPS is determined in regular tests. The capacity of the UPS is sufficient for a supply of almost 2 hours. The emergency diesel is regularly inspected internally on a monthly basis and every two years with the involvement of the authorised expert. The existing diesel supply allows for 40 hours of operation.

In the event of a grid failure, reactor scram is triggered and the supply via the UPS is maintained until the emergency diesel takes over the supply after 15-20 seconds. During this time, the cooling pumps are switched off. The UPS supplies the instrumentation, the radiation protection monitoring systems, and the exhaust air systems. After the diesel generator has started, it takes over the supply of the systems protected by the UPS and other systems such as the exhaust air monitoring system, the supply air system, the waste water system, the fire alarm system, and the cooling pumps.
Two nozzles for the flow and return of the primary circuit protrude into the reactor tank. The pool water is circulated in the primary circuit by the cooling pumps. The water is sucked out of the reactor tank via the intake nozzle and fed into the machine room via a pipe through a floor duct, where it is cooled by the heat

exchanger to the secondary circuit and after that returned to the reactor. From the closed secondary circuit, heat is removed via the cooling tower in the outdoor area, which can switch on a sprinkler system in addition to air cooling if required. The primary, secondary and purification circuits are redundant in their active components, i.e. they each have two pumps, one of which is in operation. Switching between the redundant pumps takes place weekly.

With the help of the cleaning circuit, approx. 4 m^3/h of water is skimmed off the tank surface, cleaned via a fine filter (ion exchanger), and returned. The ion exchanger is renewed every two years. The cut-off limit value of the conductivity of 2 µS/cm has so far been undercut by far (on average 0.05 µS/cm).

The irradiation carousel and the pneumatic tube systems are used for neutron activation analysis, i.a. for trace element determination, for example in archaeological samples and for the further development of solar cells. The facility is also used for isotope production for a wide range of applications. Furthermore, the source for "ultra-cold neutrons" ($v_N < 10$ m/s) is used in basic research. Another research area concerns high-precision mass determination and laser spectroscopy of fission products. In addition to training and promoting young scientists, TRIGA Mainz is used to maintain competence in the fields of nuclear chemistry, radiochemistry, reactor physics and radiation protection. Numerous courses are offered for this purpose. For example, all practical NBC protection training for the fire brigades of Rhineland-Palatinate is conducted at FR-Mz.

Sources

[Mz-07] JGU, Fachbereich 09, Johannes Gutenberg-Universität Mainz, „Vorstellung des Forschungsreaktor TRIGA Mainz (FR Mz)“, Folienvortrag