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Complementary Safety Assessment of RR following the Fukushima-Dai-Ichi NPP's Accident

SAFETY REVIEW OF GERMAN RESEARCH REACTORS AS A CONSEQUENCE OF THE FUKUSHIMA ACCIDENT

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ABSTRACT

In connection with measures carried out following the accident at the TEPCOs nuclear power plant in Fukushima on 11th March 2011, the Reactor Safety Commission (RSK), working on behalf of the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and applying an approach similar to that used for the safety review of power reactors, has performed a review of the robustness of research reactors in Germany. This review, which was concluded on 3rd May 2012 with the Commission's statement, covers research reactors with a continuous thermal power of more than 50 kW. Specifically, this includes the TRIGA Mark II research reactor in Mainz (FRMZ), the BER-II experimental reactor in Berlin and the Heinz Maier Leibnitz research neutron source (FRM II) in Garching (near Munich).

1. Introduction

On 14th March 2011, in the light of events in Japan, the federal government and the prime ministers of the five federal states with nuclear power plant (NPP) sites decided to review the safety of all German nuclear power plants. The autonomous RSK, responsible for advising the BMU on issues of nuclear safety, and staffed by a panel of recognised experts, was commissioned with the formulation and final assessment of the safety review procedure - in the form of a stress/robustness test - for all German nuclear power plants. In summary, the RSK observed in its first statement dated 16th May 2011 [1] that the German facilities apparently featured safe concerning the power supply and the possibility of flooding. Further robustness tests revealed no uniform findings that could be related to either plant design or age. The RSK did however pinpoint areas requiring further investigation and analysis. Concurrent with the work of the RSK, the federal government convened the Ethics Commission for a Safe Energy Supply at the beginning of April 2011 with the aim of establishing a public consensus on future sources of energy, in consideration of the risks of using nuclear energy. The Ethics Commission submitted its recommendations on 30th May 2011 [2], concluding that although the risks associated with nuclear energy may not have changed owing to the events in Fukushima, the way these risks are perceived has. The possibility of an accident spiralling out of control is therefore of crucial importance at a national level.

On the basis of the findings of reviews, discussions and reports submitted by both the RSK and the Ethics Commission, the 'Thirteenth Amendment to the Atomic Energy Act' on the phase out the use of nuclear energy for the commercial generation of electricity was passed by huge majority in the German Parliament on 30th June 2011. It is aimed to achieve this goal within a decade.

Additionally a similar review of the robustness was performed also for research reactors. Due to lower radioactive inventory, the risk potential of research reactors is also lower than of the nuclear power plants. Nonetheless, all research reactors in operation with a continuous thermal power of more than 50 kW had to be reviewed. Specifically, this includes the TRIGA Mark II research reactor in Mainz (FRMZ), the BER-II experimental reactor in Berlin and the

Heinz Maier Leibnitz research neutron (FRM II). The review of the robustness of the research reactor installations has been carried out also by the RSK. The protective goals "control of reactivity", "cooling of fuel elements" and "confinement of radioactive material" have been checked. Furthermore, also the robustness of instrumentation for monitoring of reactor parameters and radiation dose was checked in order its operability in emergency situation. The installations robustness was reviewed with regard to natural hazards (such as earthquakes, floods), expanded postulated events (such as station blackouts, emergency power failures), emergency preparedness, accident management and man-made hazards (such as airplane crash, gas release). The review was concluded on 3rd May 2012 [3]. It was proven, that even failures of the external power supply would not endanger vital safety functions of the reviewed installations.

2. Research reactor installations

2.1 Research reactor Mainz (FRMZ)

The FRMZ at the Mainz University is an open pool reactor of the TRIGA Mark II type. It is a light-water cooled and moderated reactor with homogeneous fuel moderator elements of low-enriched uranium (LEU) and zirconium hydride. Nuclear commissioning was on 3rd August 1965. In continuous operation the thermal power of FRMZ is 100 kW_{th} and the thermal neutron flux is $4 \cdot 10^{12}$ $1/cm^2 \cdot s$. Additionally, the reactor can be operated in pulsed operation above 30 ms with a power peak of 250 MW_{th} and a thermal neutron flux of $8 \cdot 10^{15}$ $1/cm^2 \cdot s$. The TRIGA Mark II reactor with its entire shielding is erected above ground. Four horizontal beam tubes and a thermal column penetrate the concrete shielding, reaching the reflector and the core, respectively. The thermal column is closed by a mobile concrete shielding. A rotary specimen rack at the upper part of the graphite reflector allows to simultaneously irradiate up to 80 samples at 40 positions. The plant is operated for basic research in nuclear physics and is especially suitable for examining short-lived radionuclides with rabbit systems because of the high neutron flux density which can be managed in pulsed operation for short periods of time [4, 5].

2.2 Research reactor Berlin (BER-II)

The BER-II, the experimental reactor operated at the Helmholtz-Centre in Berlin, is a pool reactor with LEU fuel elements of the MTR type. The thermal power is 10 MW_{th} and the thermal neutron flux is $1.5 \cdot 10^{14}$ $1/cm^2 \cdot s$. The reactor was commissioned on 9th December 1973. The reactors core is suspended in an open pool of water. This water functions as a moderator, coolant, and radiation shield in equal measure. The reactor core consists of thirty to forty fuel elements. Each of these is made up of twenty three thin plates, each containing a uranium-aluminium compound sealed in aluminium. The core is enclosed in a beryllium reflector that serves to raise the neutron intensity. The cold source consists of a layer of very cold hydrogen about ten centimetres thick applied to the edge of the reactor core. This is used to generate particularly slow neutrons that open up special fields for scientific research [4, 6].

2.3 Research reactor Munich (FRM II)

FRM II, the Heinz Maier Leibnitz research reactor in Garching (near Munich) is a modern neutron source of high performance. The FRM II is the newest commissioned research reactor in Germany, a light-water cooled pool reactor with a compact core where high-enriched uranium (HEU) is used as fuel and heavy water as moderator. The reactor went critical for the first time on 2nd March 2004. With a thermal neutron flux of $8 \cdot 10^{14}$ $1/cm^2 \cdot s$ the plant – having a comparatively low thermal power of 20 MW_{th} – is the most intensive German neutron source for beam pipe experiments and irradiations for scientific, industrial and medical purposes. Almost 50 % of experiments at FRM II reactor are performed using cold neutrons. The neutron source provides a very high unperturbed thermal peak flux in the moderator and ensures short measuring times and allows new applications [4, 7].

According to an obligation of the operating licence of 2nd May 2003 and agreements between federal government and Bavaria of 30th May 2003 and 22nd October 2010 it is intended to convert the reactor core from HEU to fuel with a reduced enrichment level of 50 % uranium 235 (MEU) by 31 December 2018 at the latest [4].

3. Safety review

On 7th July 2011 the BMU asked the RSK to perform the safety review of research reactors. On 2nd August 2011 the BMU forwarded a similar request of performing the safety review of research reactors to the competent supervisory authorities of federal states (*Laender*). The catalogue of requirements for the installation specific safety review was developed by the Working Group "Research Reactors" of the RSK and presented on the following session on 11th October 2011. The safety assessment was performed by the licensee and handed over to the competent authorities of the federal states (Laender) which forwarded it together with their advisory reports to the RSK by the 25th November 2011. The official statement of the RSK was published on the 3rd May 2012 [3].

In an approach similar to that applied to Germany's nuclear power reactors, the installations' robustness was reviewed with regard to:

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

The performed review was installation specific with regard to the individual risks potential and summarising their report the RSK assumed that the installation status meets the requirements of current approved status. The RSK assessed the research reactors' robustness by defining assessment criteria for the robustness levels regarding natural hazards, postulates, precautionary measures and accident management measures and the degrees of protection for the man-made hazards. As regards the assessment criteria, there are generally – specific to each topic – three levels or degrees of protection each defined. In general, the higher the safety margins that can be demonstrated against impacts on the installation regarding the fulfilment of the safety objectives, the higher is the degree of robustness.

3.1 Natural hazards

The installations are located in the areas of different **earthquake** risks. FRMZ is in the seismic exposed area. Earthquake of intensity of 7 MSK-scale can be expected. According to the licencee, the reactor shut-down bases on "failsafe" control system and is in any case guaranteed. Moreover, due to the inherent safe reactor core design, the core melt can be excluded even in the worst case scenario. BER-II reactor is outside of defined earthquake zones. Based on deterministic approach the intensity level of 4 MSK-scale was assumed for this area and the design basis of the installation corresponds to the intensity level of 6 MSK-scale. FRM II is in a slightly seismic exposed area, the design basis of the installation corresponds to the earthquake intensity of level 6,5 MSK-scale. In the opinion of the RSK, for BER-II the Robustness Level 2 (catastrophic effects in the vicinity of the plant excluded even for the seismic intensity of two levels higher than assumed) and for FRMZ and FRM II the Robustness Level 1 (catastrophic effects in the vicinity of the plant excluded even for the seismic intensity of one level higher than assumed) are fulfilled. However, if the licences of FRMZ and FRM II provide complementary evidence, classification of these installations in the Robustness Level 2 may also be possible.

As for the fulfilment of the robustness criteria regarding impacts caused by **flooding**, the assessment by the RSK showed for all three installations that there are significant design margins with respect to the 10,000-yearly flood postulated according to the current state of the art in science and technology. Due to their topographical location and/or their plant layout, all reviewed research reactors are classified as having the highest Robustness Level (Level 3, i.e. due to the topology and the design concept loss of the vital safety functions due to the flooding can be excluded).

In case of **other natural hazards** as e.g. storm, extreme low or high temperatures, snow load or lighting strike the licencees refer to the design margin resulting from relevant engineering standards. These hazards are covered by the consideration of extended postulates with regard to their effects on the safety-relevant building structures and the vital functions. For FRM II, where also the aircraft crash was considered in the design, the safety margins for mechanical load transfer are even higher, than for the two other installations.

3.2 Expanded postulated events

In contrast to the NPPs loss of auxiliary service water and, with an exception of FRM II, also long lasting loss of off-site power are not relevant for the considered research reactors. In general, for those reactors the nature convection in the pool is enough for the removal of the residual heat after reactor shut-down. This means, that loss of active auxiliary service water will not cause fuel damage. Nevertheless, the FRM II installation for heat removal is equipped with the battery supported emergency power, which provides electricity for at least 3 hours. The RSK sees this robustness criterion as fulfilled.

3.3 Precautionary measures

Precautionary measures are systems and measures to prevent risks to the installation from hazardous incidents. These are installation specific, thus for the purpose of this safety review they were considered individually. FRMZ refers in its approach to the aircraft crash scenario. Because of insufficient evidence the RSK stated the opinion, that the precautionary measures in FRMZ should be re-proved during the supervision procedure according to the actual state of the art in science and technology. But even apart from that, at least the lowest Robustness Level 1 is fulfilled, i.e. according to the Intervention Reference Levels for Protective Actions there is no need for evacuation of the citizens out of the vicinity of installation. For BER-II the licencee considers single incident scenarios, as e.g. flooding, fire and crash of heavy loads. In the opinion of the RSK, an update of the concept of fire protection is necessary and should be performed in frame of the supervision procedure. The limited blockage of cooling channel with a local core melt under the water, which is considered as a design basis accident, will be kept under control. The beyond design basis accident with a total blockage of cooling channel will lead at most to the total core melt under the water. BER-II, similar as FRMZ, fulfils the Robustness Level 1 and a possible upgrade depends on further evidence. In case of FRM II the provided documentation was also not complete. The RSK could not classify the precautionary measures in the frame of defined robustness level. Further documents and if necessary also further test are required, especially concerning crash of heavy loads in the reactor pool.

3.4 Accident management

The RSK stated the opinion that the accident management measures in all installations have to be improved and correspondingly has formulated different recommendations. First of all there is a need for (further) development of plant-specific, preventive and mitigative accident management measures, which are meant to be supplementary to the external disaster control measures. The accident management measures should be incorporated in operating regulations and it should address following topics:

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

3.5 Man-made hazards

Regarding the capacity to withstand the loads from **blast waves**, the assessment by the Reactor Safety Commission shows for all installations that at least the Degree of Protection 1 is fulfilled, i.e. the vital safety functions are maintained assuming impact of blast waves. If the licences provide complementary evidence classification in a higher level of protection may also be possible.

In regard to **explosive materials** particularly the ventilation isolation and specific sources related to the experiments performed at the research reactor installations were considered. Due to small amount of the explosive materials and the local conditions at the three reviewed installations, the RSK stated the opinion, that the Degree of Protection 3, i.e. the vital safety functions are not endangered, is fulfilled.

The site-specific consideration of **toxic gases** is part of the design concept of research reactor installations in Germany. In the opinion of the RSK the Degree of Protection 2, i.e. the vital safety functions are maintained also in case of non-availability of personal, is fulfilled for all installations.

In frame of terroristic hazards the maintenance of vital safety functions in case of **aircraft crash** was considered. FRMZ refers to research reactor at the Technical University in Vienna, which is also TRIGA type but has a higher thermal power. According to that, the release of activity into environment in result of the aircraft crash with complete damage of reactor building and fuel elements should not exceed the accident planning values. Furthermore, even if the reactor building of reactor in Mainz would be destroyed but the reactor pool stay intact, the vital safety functions are not endangered. The core melt for TRIGA reactor in Mainz can be excluded even considering accompanying thermal impact. For the worst case scenario with the aircraft crash on BER-II the loos of integrity of the reactor pool can not be excluded. The core melt in a dry reactor pool will lead to the release of radioactive material to the atmosphere, which is higher than the Intervention Reference Levels for Protective Actions. In such a case e.g. evacuation of citizens in radius of 3 km would be necessary. In the opinion of the RSK the actions to improve the robustness of installation and to prevent core melt (e.g. additional water supply) as well as mitigative measures to reduce the release of radioactivity in case of core melt should be taken. The design of FRM II reactor building bases on the RSK-Guideline for PWR (Pressured Water Reactor), where the crash of military aircraft is considered. In one of the later reviews of authorised technical support organisation of the federal state Bavaria, TÜV-Süd, the installations design against the crash of big commercial airliner was proved. Additionally reactor and setdown pools are decoupled from reactor well, which ensures the integrity of installation. Resulting kerosene fire outside the reactor building and blast wave will not impair constructional protection.

4. Conclusions

The performed robustness review was the first safety review of German research reactors in such an extended scope as for the nuclear power plants. Although, compared to the nuclear power plants the risk potential of research reactors is lower, the same full spectrum of external events was considered. This means, that not only natural and man-made hazards but also associated expanded postulated events such as emergency power failures were under investigation.

For further specific topics of the robustness review of the research reactors, there are differentiated assessments with plant-specific recommendations proposed. First of all, the plant-specific preventive and mitigative accident management measures should be improved.

Overall the RSK attested the three investigated installations, FRMZ, BER-II and FRM II to be highly robust with regard to external flooding events. Due to the conditions prevailing at their sites and to their designs, they should withstand even under extreme conditions. Furthermore, the RSK determined that even failures of their external power supply would not endanger the installations' vital safety functions.

5. References

[1] RSK-Stellungnahme vom 437. RSK-Sitzung am 11. – 14.05.2011: Anlagenspezifische Sicherheitsüberprüfung (RSK-SÜ) deutscher Kernkraftwerke unter Berücksichtigung der Ereignisse in Fukushima-I (Japan), (RSK-Statement from 437. Session on 11. – 14.05.2011, Plant-specific safety review (RSK-SÜ) of German nuclear power plants in the light of the events in Fukushima-1 (Japan)), http://www.rskonline.de/

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[4] *State and Development of Nuclear Energy Utilization in the Federal Republic of Germany 2011*, I. Bredberg, J. Hutter, K. Kühn, F. Philippczyk, J. Dose, Bundesamt für Strahlenschutz (BfS), 26.10.2012 http://doris.bfs.de/jspui/handle/urn:nbn:de:0221-2012102610019

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The Regulatory Implications of the Fukushima-Dai-Ichi NPP's Accident to Russian Research Reactors

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ABSTRACT

The report dedicated to the implication of the Fukushima accident to regulatory safety activities for Nuclear Research Facilities (NRFs)[1] in the Russian Federation. The complementary safety assessment of higher risk RRs focused on technical and organizational safety issues such as elaboration of internal and external postulated initiating events, ability of facility to withstand extreme external events and reliability of defense-in-depth, emergency management including severe accidents, which pose the hazard to the public and the environment. The Rostechnadzor organized conducting of the complementary safety assessments of RRs using national categorization of NRFs rated with their potential radiological risk and recommendations of international organizations. The result is ability to compare at the international level the regulatory approaches and findings from reviews of complementary safety assessments with the objective to identify common activities for safety enhancements of NRFs operation and to harmonize regulatory performances that could be undertaken by other countries operating NRFs.

1. Introduction

On 22 September 2011 the IAEA General Conference endorsed the Action Plan on Nuclear Safety that has been declared at the Ministerial Conference of IAEA's members states in June 2011. The Action Plan defines, under the leading role of the IAEA, the process of acting upon lessons following the accident at Fukushima Daiichi Nuclear Power Station (Fukushima NPP) in order to strengthen nuclear safety, emergency preparedness and radiation protection [1]. In further under the leading role of the IAEA, the Western European Nuclear Regulators' Association (WENRA), and the Nuclear Energy Agency of the Organization for Economic Co-operation and Development (NEA/OECD) a few meetings have been organized to discuss a scope and methodology of complementary safety assessments of NRFs in the light of the accident at Fukushima NPP, format of the reports and procedures of their review [2,3,4]. The feedback from discussions of safety of Research Reactor (RR) including application of the Code of Conduct on the Safety of RRs [5], causes of events in the Incident Reporting System of RRs [6], evaluation of ageing mechanism of RRs systems and equipment [7], and RRs operating experience did not discover any significant gaps in safety regulation and safe utilization of RRs. Nevertheless, taking into account that many RRs have old design basis, insufficient containment characteristic of the building, ageing systems and elements important to safety and are typically located nearby or in populated area, the regional and international meetings recommended to carry out complementary safety assessment of RRs to withstand the effect of extreme external impacts in the light of the accident at Fukushima NPP ("stress-tests"). The objective of "stress-tests" for NRFs and related nuclear facilities is to evaluate their ability to withstand the effects of multiple extreme external events (robustness) as appropriate for their site that had not been considered before in the design and during facility modifications. This objective is in line with the Russian

[1] NRFs –nuclear facility including research nuclear reactors (RR), critical (CA) and subcritical (SCA) nuclear assembles, and related complex of premises, structures, systems, elements, experimental facilities, and personnel that are in boundary of territory (NRF site) defined by the design for utilization of neutrons and ionizing radiation for research purposes.

fundamentals of the state policy to provide nuclear and radiation safety through consecutively decreasing to socially acceptable level a risk of technogenic (*man-induced*) impact to public and environment in the use of nuclear energy, to prevent emergency situations and accidents at nuclear and radiation hazardous objects, to strengthen effective communication between federal bodies and empowered authorities effecting state control of the use of atomic energy, as well as to improve clarity and transparency of reporting to public about emergencies [8].The Federal Environmental, Industrial and Nuclear Supervision Service (Rostechnadzor), being the state regulatory authority in the field of the use of atomic energy, develops and enacts regulatory documents for NRFs safety, supervises over activities associated with the use of atomic energy, and issues licenses for activities in the field of the use of atomic energy, in particular, for operation of NRFs. The Rostechnadzor has requested the empowered Federal Authorities (Ministries) and the State Atomic Energy Corporation "Rosatom", which are effecting state control of the use of atomic energy at the federal level and manage activities at NRFs, to carry out complementary analysis of NRFs' robustness against external extreme impacts (including earthquakes and floods) as well as preparedness to manage of beyond design basis accidents (BDBAs), including BDBAs that pose the most hazard to the public and the environment (herein below – severe accident). In the paper the following aspects are given:

- Categorization of Russian NRFs rated to their potential radiological risk;
- Subject and scope of "stress tests";
- Main regulatory findings of "stress tests" reviews.

2. Categorization of Russian NRFs rated on their potential radiological risk

In "stress-tests" methodology for RRs it had been recommended to apply graded approach [9] and categorization of nuclear facilities on their potential radiological risk to workers, public and environment [10]. Categorization of NRFs on the basis of all factors of potential radiological risk is an intricate problem so a simplified approach is being used in regulatory and oversight practice that based on installed facility power [11] and fusion products possible release to the environment [12,13]. In Russia nuclear facilities are classified in four groups of their potential radiation hazard [14]:

Group 1 – off-site radiological consequences beyond the urgent protective action planning zone (UPZ);
Group 2 – off-site radiological consequences within the UPZ;
Group 3 – on-site radiological consequences only;
Group 4 – no on-site radiation consequences beyond the immediate facility hall and associated experimental facility areas.

Above mentioned categorization of nuclear facilities is used to identify the set of requirements to site, urgent protective action planning zone (UPZ) and precautionary action zone (PAZ), arrangements of radiation monitoring, emergency response measures.The category definition of the radiation object is based on evaluation of consequences of accidents which occurrence is not a result of transportation of radiation sources outside territory of the object or hypothetical external impact (explosions as a result of rocket hit, aircraft crash or terrorism act). The category of radiation objects should be established at design stage. For objects in operation a category should be established by administration and agreed by the state sanitary-and-epidemiologic supervision authority.Categorization of Russian NRFs' sites according to [14] is given in the table 1.

3. Subject and scope of "stress tests"

3.1. Subject of complementary safety analysis of NRFs

The subject of complementary safety assessment (reassessment) for NRFs consisted in the following activities:

№	Operating Organization, Site	Category	Authority*
1.	Joint Stock Company “State Scientific Center – Research Institute of Atomic Reactors”, Dimitrovgrad, Ulyanovsk region	1	SCR
2.	Filial of the Federal State Unitary Enterprise “Karpov Institute of Physical Chemistry”, Obninsk, Kaluga region	1	SCR
3.	The Federal State Unitary Enterprise «Institute of Physics and Power Engineering», Obninsk, Kaluga region	1	SCR
4.	Join Institute for Nuclear Research, Dubna	1	MEC RF
5.	The Federal State Unitary Enterprise “Krylov State Research Center”, St.Petersburg	2	MIT RF
6.	National Research Nuclear University MEPhI, Moscow	2	MEC RF
7.	National Research Tomsk Polytechnic University, Tomsk	2	MEC RF
8.	Federal State Budget Institution “B.P. Konstantinov Petersburg Nuclear Physics Institute”, Gatchina, Leningrad region	2	MEC RF
9.	Federal State Budget Institution "State Scientific Center of the Russian Federation-Institute for Theoretical and Experimental Physics", Moscow	2	MEC RF
10.	National Research Centre "Kurchatov Institute", Moscow	3	MEC RF
11.	Joint Stock Company “Institute of Nuclear Materials”, Zarechny, Sverdlovsk region	3	SCR
12.	The Federal State Unitary Enterprise “Research Institute of Scientific Instruments”, Lytkarino, Moscow region	3	SCR

* SCR - State Corporation ”Rosatom”; MES RF- Ministry of education and science of Russian Federation; MIT RF- Ministry of Industry and Trade of the Russian Federation

Tab 1: Categorization of radiological risk of NRFs’ sites according to [14]

- Examining the accepted technical and organizational safety basis in compliance with the national effective safety requirements for NRFs;
- Definition of scenarios of BDBA that may potentially result in impact to the public and the environment (severe accidents) generated by:
  - ⇒ long-time blackout including loss of emergency power supply of NRF accompanied by failure of an element of containment system or by personnel error to control this system;
  - ⇒ loss of coolant of primary circuit accompanied by malfunction of emergency cooling system and by failure of an element of containment system or by personnel error to control this system;
  - ⇒ full loss of ultimate heat sink;
- Assessment of efficiency and sufficiency of existing equipment and administrative measures to manage BDBAs and mitigate their consequences in case of extreme external impact at the same time to all nuclear facilities and constructions that are situated at the site;
- Strengthening of interdepartmental information exchanging, and implementation of findings of complementary safety assessments (reassessments) to enhance safety of NRFs.

3.2. The design basis of NRFs

The “stress-tests” and review of their results have been carried out on basis of the Federal Norms and Rules in the field of atomic energy use that include safety requirements for NRFs:

- General Provisions for Nuclear Research Installations Safety, NP-033-11;
- Nuclear safety regulations for research reactors, NP-009-04;

- Nuclear safety regulations for pulse research reactors НП-048-03;
- Rules for design and safe operation of actuators of reactivity controls, PNAE-7-013-89;
- Requirements to Contents of Safety Assessment Report for NRIs, NP-049-03;
- Rules for Design and Safe Operation of Equipment and Pipelines of Nuclear Power Installations, PNAE G-7-008-89 (version 2008);
- Standards on strength analysis of equipment and pipelines of nuclear power installations, PNAE G-7-002-86;
- Accounting of external impact of natural and man-induced origin on nuclear energy facilities, NP-064-05. In line with NP-064-05 for review of external impacts on a particular site the following requirements shall be considered:
  - ⇒ Maximal parameter values of the hydrometeorological, geologic and engineering-geological phenomena shall be determined for the time interval of 10,000 years.
  - ⇒ Man-induced factors with the frequency of occurrence equal of greater than 10^{-6} 1/year.
  - ⇒ Conditions of processes, phenomena and factors of man-induced and natural origin be accompanied by other interrelated and interdependent processes (phenomena and/or factors).
  - ⇒ If facilities are located at site, where an especially hazardous process (phenomenon, factor) may be accompanied by natural and/or man-induced catastrophes, or where a hazardous process (phenomenon, factor) may be accompanied by tangible consequences for the environment, the evacuation routes for the personnel and population shall be analyzed and protected (if necessary) to prevent formation of temporary obstacles on them (landslides, avalanches, floods, fractures, etc.).
  - ⇒ For nuclear installations, which had been designed with consideration of natural and man-induced external impacts of an especially hazardous process (phenomenon, factor) accompanied by natural and/or man-induced catastrophes, automated systems for recording external events and automatic systems for facility shutdown in proper time shall be implemented.

3.3. Organization of “stress-tests” of RRs

The State Corporation ”Rosatom” has sent to subordinated operating organizations “The Programme of Safety Assessment of Complexes with Research Reactors in Case of Emergencies from Technogenic or Natural Origin (stress-tests)” that has included the Rostechnadzor's considerations. This Programme prescribes fulfillment of “stress-tests” for any RR that is managed by the SC ”Rosatom”.

The Rostechnadzor has applied to SC ”Rosatom”, Ministry of education and science of Russian Federation, Ministry of Industry and Trade of the Russian Federation that control the use of atomic energy and activities at NRFs with proposals of “stress-tests” and further review of their results.

Research Reactor, IAEA code	Nominal Power, MW	Start of operation
JSC “State Scientific Center – Research Institute of Atomic Reactors”		
VK-50, RU-0043	200	1965
MIR.M1, RU-0013	100	1966
SM-3, RU-0024	100	1961 / 1993
BOR-60, RU-0027	60	1969
RBT-10/2, RU-0020	10	1984
RBT-6, RU-0022	6	1976
JSC “Institute of Nuclear Materials”		
IVV-2M, RU-0010	15	1966

Tab 2: RRs, “stress-test” reports of which have been evaluated by expert organization and reviewed by the Rostechnadzor

The operating organizations submitted to the Rostechnadzor reports on “stress-tests” and planned actions if needed to strengthen safety at RRs. In 2012 the Rostechnadzor, with involvement of its technical support organization-Scientific and Engineering Center for Nuclear and Radiation Safety- reviewed the reports on “stress-tests” of seven RRs that are listed in the table 2. The reviews of other “stress-tests” reports is going on.

4. Main regulatory findings of “stress tests” reviews

The following scenarios of BDBAs have been analyzed in reports on “stress-tests” of mentioned above RRs [15]:

1. **Earthquake + tornado + error of personnel**, that accompanied by blackout during 24 hours including diesel-generators and non earthquake-resisting accumulator batteries, and failure of the confinement safety system or error of personnel
2. **Earthquake + fire at the neighboring area** accompanied by blackout during 24 hours including non earthquake-resisting accumulator batteries and diesel-generators in the reactor building as a result of fire.
3. **Tornado + fire at the neighboring area** accompanied by blackout during 24 hours including non earthquake-resisting accumulator batteries and diesel-generators as a result of fire.

The main expert remarks on "stress-tests" reports evaluations are given in table 3.

<table>
<tr><th colspan="3">Site of JSC “State Scientific Center – Research Institute of Atomic Reactors”</th><th colspan="2">Site of JSC “Institute of Nuclear Materials”</th></tr>
<tr><td colspan="5">To carry out reassessment of quantitative values of parameters of extreme external impacts as appropriate for the site</td></tr>
<tr><td>External impact</td><td>Used in “stress-test”</td><td>Recommended value</td><td>Used in “stress-test”</td><td>Recommended value</td></tr>
<tr><td>Safe shutdown earthquake (SSE)</td><td>5-7 units on International Earthquake Intensity Scale MSK-64</td><td>8 units on MSK-64 scale</td><td>6 units on MSK-64</td><td>7 units on MSK-64</td></tr>
<tr><td>Maximal wind speed</td><td>62 m/sec (tornado)</td><td>94,8 m/sec</td><td>24 m/sec (hurricane one time per 20 year)</td><td>47 m/sec</td></tr>
<tr><td>Maximal snow loads to building and structure roofs</td><td>4,85 kPa</td><td>4,85 kPa</td><td>2,3 kPa</td><td>3,6 kPa</td></tr>
<tr><td>Aircraft crash</td><td>Does not reviewed (probability 1,5 10^{-9} 1/year)</td><td>Shall be reviewed</td><td>Does not taken into account</td><td>Shall be reviewed</td></tr>
<tr><td colspan="5">To assess efficiency and sufficiency of existing equipment and administrative measures to manage BDBAs in cause of extreme external events impact to all facilities of the site at the same time</td></tr>
<tr><td colspan="3">To carry out safety analysis of RR in cause of blackout and loss of all emergency power supply equipment</td><td colspan="2">--</td></tr>
<tr><td colspan="3">To work out measures to strengthen RR building elements, which destruction may lead to failure of systems important for safety</td><td colspan="2">To carry out analysis of the BDBA with loss of coolant in primary circuit taking into account possible loss of water while its boiling</td></tr>
</table>

Tabl 3: The expert remarks on evaluations of "stress-tests" reports of RRs

The results of evaluation “stress-tests” of seven RRs have been discussed at the session of the Section of Scientific and Technical Board of Rostechnadzor with participation of all stakeholders [16], the findings of which is given below. Review of “stress-tests” reports showed that existing equipment and administrative measures taken in designs provide safety of RRs for reviewed in SAR BDBAs that are not leading to severe accident.

The programme of “stress-tests” of RRs is not completed yet in full scope and contents. Taking into account implementation of obtained additional equipment the operating organizations are continuing improvement of manuals on emergency management including extreme external impacts.

In framework of Action Programme of Russian Authorities and Organizations Concerned in Implementation of the IAEA Action Plan on Nuclear Safety [17] the recommendations have been prepared and measures are being realized, which intend on safety enhancement of RRs operation, strengthening of emergency preparedness of operating organizations and Rostechnadzor' s functional sub-system for monitoring of nuclear and radiation hazardous facilities in structure of the Russian Unified System of Prevention and Mitigation of Emergencies.

Measures on enhancement of RRs ability to withstand the effect of extreme external events include:

- improvement of reliability of emergency power supply systems;
- redundancy of external self-contained power supply lines;
- redundancy of mobile motorized equipment of coolant (high-pressure monoblock pump, mobile disel-generators).

The review of “stress-tests” reports revealed the direction of strengthening federal norms, rules and safety regulations of RRs in development of safety requirements to:

- emergency power supply of RR;
- set of emergency measurement devices with appropriate scales that may be used in conditions of severe emergency;
- automatic system for predicted shutdown of RR in proper time when parameter values of extreme external process (phenomenon, factor) at the site of scientific center reached the limit level;
- definition of severe accidents in scope of BDBAs that shall be analyzed in Safety Assessment Report of RR (SAR);
- contents of the result of severe accidents analysis in the SAR;
- management of severe accident in cause of extreme external impact at the same time on all nuclear facilities at site (common cause failure);
- contents of manual for personnel activity in case of severe accident at RR site;
- organization of interdepartmental information exchange concerning the event at RRs.

The measures for enhancement the ability of RRs to withstand the effects of multiple extreme external events is planned to complete in 2015. The Rostechnadzor is communicating with the empowered Federal Authorities (Ministries) and the State Corporation ”Rosatom”, which control the use of atomic energy at the federal level, to complete "stress-tests” of NRFs in full scope.The operating organizations have been recommended to update SAR and operational documents of NRFs and submit them to the Rostechnadzor in the order approved for license and periodic safety review.

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Saftey re-assessment for the TRIGA® Mainz

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1. Introduction

Following the Fukushima Daiichi accident and with reference to a change of the German Atomic Law in June 2011 that followed, it was decided by the Federal Council of Germany, that the safety re-assessment mandated by this change should be extended to all nuclear facilities, including research reactors with a thermal power higher than 50 kW. Therefore, the TRIGA[1] Mark II of the University Mainz with a maximum power of only 100 kW(t) was required to participate in the saftey re-assessment.
Due to its inherent safety and its low maximum licensed power of 100 kW (t), the questionnaire developed for power reactors by the German reactor safety commission (RSK) was reduced for the safety re-assessment of the TRIGA Mainz. However, it includes the same 4 subjects but in a shorter form compared to higher power research reactors or nuclear power plants:

1. natural events as earthquakes, flooding, extreme weather situations and combined events
2. civilian events, such as airplane crash, including the burning of kerosene, leakage, release of gas and terrorist attacks (confidential)
3. other events, such as station blackout, loss of emergency power for long periods, loss of cooling
4. discussion of actions in emergency cases in difficult situations (possibilities of emergency aid when the infrastructure is destroyed)

2. Methodology

For each one of the above categories, it needed to be demonstrated that the reactor is robust enough and complies with requirements after an accident, as well as for a combination of the events.
In August 2011, the TRIGA Mainz was informed by their authority that the facility has to take part in the German saftey re-assessment. The answers to the questionnaire were handed over the respective authority which forwarded the documents to the RSK until end of October 2011. Due to the low power and the inherent safety of TRIGA type reactors, the regulator for the TRIGA Mainz had decided that it is not necessary to involve external experts to review the safety re-assessment in this case. The response of the RSK was received and published on-line in June 2012.

In total 11 impacts were relevant for the TRIGA and were reviewed:

1. Generic perceptions
2. Robustness of the reactivity coefficient and reactivity events
3. Earthquake
4. Flooding
5. Other natural impacts

[1] TRIGA is a registered trademark of General Atomics, USA

6. Robustness of preventative measures
7. Complication boundary conditions for the performance of measures in emergncy cases
8. Crash of a big aeroplane including a kerosine fire
9. Explosion blast wave from outside
10. Flammable gas
11. Toxical gas

3. Results

For the cases of flooding, flammable gas and toxic gas no new safety requirements were found to be necessary for the TRIGA Mainz.
For the other 8 impacts, the additional safety re-assessment confirms the robustness of the installation in terms of its safety functions. However, RSK nevertheless recommended the review of the facility responses by external experts for these 8 events.

The impact “robustness of the reactivity coefficient and reactivity events” includes the question what would happen with the fuel in the core in the case of a $4 transient. However, since TRIGA-type reactors are routinely pulsed to very high reactivity insertions, the most important subjects for the TRIGA Mainz reactor are the crash of a large airplane including a kerosene fire and the development of a preventive and mitigative emergency plan. The crash of the large airplane includes also the other acident scenarios.

4. Crash of a large airplane

To estimate the radiological consequences to the environment in the case of a crash of a large plane on the TRIGA Mainz the University had used the results of work performed at the University Vienna [1]. In this work, the radiological consequences were calculated for the case of a crash at the TRIGA in Vienna without kerosine fire. The power of the TRIGA Vienna is a factor of 2.5 higher than the power of the TRIGA Mainz.
As result of the safety report of the RSK, the regulator for the TRIGA Mainz has authorized the German company TÜV-Rheinland Industrie Service GmbH (TÜV) to perform radiological calculations for a crash of an airplane on the TRIGA Mainz with and without kerosene fire. Measures of the emergency management should be regarded whereas the emergency reference levels corresponding to the German guidelines (see Table 1) were taken as basis for the emergency measures.
The radiological calculations were carried out for a crash of a large aircraft. The incident doses were calculated as effective dose over a time periode of 50 years. This value delivers the comparative value to the data calculated for the TRIGA Vienna. For the incident case also the effective dose and the dose of the thyroid for exposure times of seven days, one month and one year were determined. The incident doses were calculated without and with a kerosene fire of 1100°C and with and without rain. The minimal distance for the incident calculations was 200 m.
The fission product inventories of all fuel elements in the core of the TRIGA Mainz were taken from a calculated using the established ORIGEN programme [2]. The calculations were then validated using neutron flux measurements. The release of fission products from TRIGA fuel was taken from the

literature and based on information provided by the reactor designer General Atomics [3] as part of the development and qualification of it´s uranium-zirconium-hydride ($UZrH_x$) fuel, and on an IAEA saftey report [4]. For the atmospheric dispersion modeling the TÜV has devloped his own computer code.

The TÜV achieved the following result in his advisory report:
Due to the smaller nuclear inventory of the TRIGA Mainz compared to the TRIGA Vienna and the resulting smaller amount of gaseous fission products which could be released in the case of an incident the dose values for the TRIGA Mainz are much lower than for the TRIGA Vienna. Therefore, the dose values for the airplane crash without kerosene fire given by the University of Mainz using the data of the TRIGA Vienna were conserative estimations.

Furthermore, for the accident scenario the crash of the aircraft without kerosene fire the determined dose values are less than 1% of the emergency reference levels corresponding to the German guidelines. The highest dose values occur for the scenario "crash of an airplane with kerosene fire". Also in this case the dose values are lower than the emergency reference levels. The following table summerized the results for the different emergency cases:

Measure / procedure	emergency reference level	exposure time	Amount of emergency reference level
Long-term population transfer	100 mSv	1 year	28 %
Temporary population transfer	30 mSv	1 month	17 %
Stay inside a building	10 mSv	7 days	24 %
Evakuation	100 mSv	7 days	2.4 %
Taking iodine pills for the poulation group „children and adolescent up to an age of 18 years and pregnant woman"	50 mSv	7 days	14 %
Taking iodine pills for the poulation group „Persons between 18 and 45 years"	250 mSv	7 days	1.3 %

The results demonstrate that in the extreme scenario of a crash of a large airplane with kerosine fire emergency measures, evacuations or population transfers are not considered necessary. Nevertheless, in this case the campus would be evacuated on large scale following the university emergency management procedures, and no special emergency evacuations are necessary as a result of any radiological consequences arising from the radioisotope inventory in TRIGA Mainz.

The low dose values are based on the special properties of the $UZrH_x$ fuel that gives all TRIGA reactors their inherently safe characteristics. Compared to other types of fuel the release of fission products is hindered and an oxide layer is formed, which serves as additional barrier against the release of fission products.

5. Emergency management for the TRIGA Mainz

Due to the RSK report, all German research reactors had to develop additional preventive and mitigative emergency plan in addition to the existing emergency plans and procedures already in place. The approach for the TRIGA Mainz for this purpose was based on the results of the review of the TÜV for the crash of a large airplane since this scenario encompassed all other events. Also in this extreme case, all dose values fell below the emergency reference levels which simplified the emergency planning.
The overall aim of the emergency plan is to ensure the safety of personnel, both occupational workers and visitors, in the reactor facility at the time of the emergency, at the institute and on the campus, and to protect the environment, whilst working towards a recovery of the situation and return to a safe state. The general public outside the campus would not be involved in such an accident.
The emergency management of the TRIGA Mainz was developed for the particular situation on the campus with a many buildings close together and a large number of effected persons. It based on the guideline of the German reactor safety commission and radiation protection commission for emergency planning.
The principal objectives adopted through any emergency plan for a research reactor are protecting life, obtaining early medical support, minimizing potential for events to escalate, advising and supporting the emergency services, collecting radiological and other data to feed into the strategy, identifying the reason of the event and restoring the situation to normal as soon as reasonably practicable.
At the TRIGA Mainz three incident classifications are defined: For the Class 3 and 2 the incidents (higher radiation level, contamination, fire, and injury) are contained within the reactor facility or the Institute of Nuclear Chemistry which hosts the TRIGA. Class 1 includes hazardous conditions with extreme impacts to the campus and needs urgent measures to protect the people on the campus (crash of an airplane, earthquake, and incidents because of extreme weather situations). The preventive and mitigative emergency plan which is being in development at the moment following the Fukushima Dai-ich accident focused on Class 1.

6. Summary and Outlook

The additional safety re-assessment for the TRIGA Mainz confirms the robustness of the installation in terms of its safety functions. However, the RSK has recommended a further review of the responses of the University of Mainz in 8 cases. All reports for this purpose are finished and proofed by the TRIGA authorities. The most important scenarios are the crash of a large airplane including a kerosene fire which also envelopes the other accident scenarios. A preventive and mitigative emergency plan is currently under development. The review of the documents will be send to the German Ministry of Environment.

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