

Safety Reviews of Research Reactors in Germany – Graded Approach for the periodic safety review according to § 19a of the Atomic Energy Act

K. Niedzwiedz¹, M. Schneider¹, H.-P. Berg¹

¹ Federal Office for Radiation Protection, Willy-Brandt-Straße 5, 38226 Salzgitter, Germany

E-mail contact of main author: kniedzwiedz@bfs.de

Abstract. According to the new legal requirements in Germany, in the year 2010 a periodic safety review became mandatory for all nuclear facilities, which includes also research reactors. Concerning the variety of German research reactors and taking into account, that there is no specific guideline on periodic safety review for research reactors, it became necessary to develop an appropriate procedure. For this purpose, research reactors are classified into different groups according to their individual risk potential. For each group a sequence of necessary safety requirements and a list of priorities for the periodic safety review is evaluated.

Key Words: periodic safety review, classification of research reactors, graded approach

1. Introduction

In Germany, it is mandatory to perform periodic safety reviews for nuclear power plants by law since 2002. In the 12th amendment of the Atomic Energy Act 2010 [1], such a requirement was also introduced for other nuclear installation by § 19a (3) and (4). Since this amendment, the licensee shall *perform a verification and evaluation of the nuclear safety of the respective installation every ten years*. Furthermore, it is specified, that the review *shall encompass the verification that measures are taken to prevent accidents and to attenuate the effects of accidents including the verification of the physical barriers as well as of the administrative preventions of the licensee which would have to fail before life, health and material assets are damaged by the effect of ionising radiation. The competent supervisory authority can issue orders concerning the extent of the verification and evaluation by the licensee*.

This new requirement does not replace the former duties of the operator, to take the prime responsibility for the safe operation of its own nuclear facility and to perform particular safety reviews

- within the licensing procedure according to § 7 of the Atomic Energy Act, i.e. in case of construction, operation, essential modifications of the installation or its operation as well as for decommissioning of the facility, and
- the safety upgrades, which are carried out within the continuous regulatory supervision pursuant to § 19 of the Atomic Energy Act.

This amendment obligates the operator to carry out additional regular safety review similar to the periodic safety reviews for the nuclear power plants for all German research reactors. This obligation became necessary for continuous improvement of nuclear safety of the installation and for ensuring the safety over the entire lifetime of the facility, since the operation licence for nuclear installations in Germany is granted unlimited in time and the majority of research reactors is older than 40 years.

Considering that research reactor facilities have much lower risk potential, as compared to a nuclear power plant and even they differ partially extremely from each other, the performance of a periodic safety review arises to a challenging task. Especially the questions on the specific regulatory requirements and the extent of the verification and evaluation of the nuclear safety for individual facilities have to be answered.

This paper deals with the classification of German research reactors in operation regarding to their risk potential and subsequently with the evaluation of a graded approach for the performance of an adequate periodic safety review. It is shown, that German research reactors may be classified into three different risk potential groups. Accordingly, a sequence of the necessary requirements for a periodic safety review is evaluated. The developed concept is going to be agreed in the competent Technical Committee for Nuclear Safety.

2. Legislative and Regulatory Framework

The legal basis to assure the safety of German nuclear installations constitutes of the Atomic Energy Act together with its associated ordinances. These documents are quite general but they are directly binding to all kind of nuclear installations in a common approach. The competent legislative authority in Germany is the Federal Government, represented by the Federal Ministry for the Environment, Nature Conservation, Building and Nuclear Safety (BMUB). On its behalf the respective ministries of the Federal States ("*Länder*") are in charge of executive competences, i.e. these are the competent authorities for licensing and supervision. More details on Nuclear Safety Regulations and Nuclear Licensing and Supervision Authorities in Germany may be found in [2].

The regulations of the legal basis are put into concrete terms by various sublegal nuclear safety regulations and by conventional technical standards. On the contrary to the Atomic Energy Act, the sublegal nuclear safety documents are not directly legally binding for the nuclear facilities, but they can be used as a guideline or can be made obligatory in the individual licence. The most important document for periodic safety review is "Guides for the Periodic Safety Review of Nuclear Power Plants" [3]. Typically for the most sublegal nuclear safety regulations, this guide was developed with special respect to nuclear power plants and respectively rigorous are its demands. In general, the periodic safety review should include the following aspects:

- Current description of the facility
The facility description should give an up-to-date survey of the safety concept, the facility's design features and of all substantial measures, which are important for its safety. It should also contain the description of the structures, systems and equipment important for safety, including its task and safety function as well as configuration, arrangement and design.
- Deterministic safety status analysis
The deterministic safety status analysis should be a goal oriented review, which concentrates on the description how the analysed accidents are controlled by the facility's engineered safety features. The actual condition of the systems important for safety should be examined with regard to the availability of required safety functions for accident control with sufficient efficiency and reliability, and for this reason with the safety criteria. Furthermore, the deterministic safety status analysis should also consider the operational management and evaluation of operating experience.
- Probabilistic safety analysis
The probabilistic safety analysis should be used supplementary to the deterministic assessment of the facility's safety status and its operational safety. It should be referred to for the determination of the necessity and urgency of safety improvements.

- **Deterministic analysis on physical protection**
Deterministic analysis on physical protection should give an overview on an overall condition associated with security aspects of a facility. It should cover all areas of construction as well as other technical, personal and administrative - organizational measures associated to the nuclear security. It serves the purpose of demonstrating fulfilment of the protection goals by means of available measures for security functions.
- **In-depth analyses of individual aspects**
As far as it seems to be necessary in the particular case, further analyses regarding the technical contents and procedures should be performed. Analyses of scenarios and event sequences, e.g. fire, partial-load operation or human actions during respective operational states and event sequences, which already have been taken into consideration by the use of generally accepted methodologies, should not be a priori excluded.

As common in the regulatory practice, the “Guides for the Periodic Safety Review of Nuclear Power Plants” – see also [4] - may also be applied to research reactors. However, some interpretation in accordance with the risk potential of the research reactor by means of a graded approach is necessary.

3. Research reactors in Germany

In total 46 research reactors were built in Germany, now only seven are still in operation. All other research reactors are permanently shutdown, are currently in decommissioning or have already been dismantled completely and released from regulatory control. A complete compilation of all research reactors in Germany is presented in the annual report “State and Development of Nuclear Power Utilization in the Federal Republic of Germany” [5].

These facilities are still being in operation:

- 2 large pool reactors: FRM II in Garching near Munich and BER II in Berlin
- 1 TRIGA Mark II reactor in Mainz
- 4 smaller training reactors, the so-called zero-power reactors: AKR-2 in Dresden and 3 SURs (Siemens training reactors) in Stuttgart, Furtwangen and Ulm.

These research reactors are very diverse concerning among the other: their design, thermal power, radioactive inventory, nuclear fuel used, mode of operation and their site (e.g. central location in a city or in a suburb). An overview over the main technical features is presented in Table I.

4. Classification of Research Reactors

In a consequence of very different construction and technical features of research reactors their individual risk potential is also very different [6]. There is no predefined systematic methodology for the classification of research reactors. It is not legitimate to restrict the evaluation to one single parameter, or to predefine the most relevant one. The classification should take into account all safety specification parameters of each individual facility and if the consideration of different parameters leads to a different classification the prioritization should base on the conservative approach. In this paper the focus is put on the evaluation of three criteria: the thermal power, the hazard potential of the reactors including their consequences for the facility and its vicinity and the requirements to the systems for controlling the residual heat.

TABLE I: AN OVERVIEW OVER MAIN TECHNICAL FEATURES OF RESEARCH REACTORS BEING CURRENTLY IN OPERATION IN GERMANY

Name of the facility and site	Operator	Type	Thermal power [MW _{th}]	Fuel	Fuel enrichment [%]	Heat removal system	Representative elements of activity inventory	
							I-131 [Bq]	Cs-137 [Bq]
SUR Stuttgart Stuttgart, BW	University of Stuttgart, Institutes for Nuclear Energy and Energy Systems	Siemens Training reactor SUR 100	1·10 ⁻⁷	U3O8-PE	20	No cooling system	1,0E+08	5,1E+07
SUR Ulm Ulm, BW	Hochschule Ulm, Institute of Radiation Measurement (ISM)	Siemens Training reactor SUR 100	1·10 ⁻⁷	U3O8-PE	20	No cooling system	1,0E+08	5,1E+07
SUR Furtwangen Furtwangen, BW	Hochschule Furtwangen	Siemens Training reactor SUR 100	1·10 ⁻⁷	U3O8-PE	20	No cooling system	1,0E+08	5,1E+07
AKR-2 Dresden, SN	Technische Universität Dresden, Institute of Power Engineering	Training reactor, AKR 2	2·10 ⁻⁶	U3O8-PE	20	No cooling system	2,0E+09	1,0E+09
FRMZ Mainz, RP	Universität Mainz Institute for Nuclear Chemistry	Pool, TRIGA Mark II	0,1 (in a pulsed mode up to 250 MW for 0,03 s)	UZrH	20	Operational cooling system ¹	1,0E+14	1,9E+13
BER II Berlin, BE	Helmholtz-Zentrum Berlin für Materialien und Energie GmbH (HZB)	Pool, MTR	10	U3Si2-Al	20	Operational cooling system and Passive ² residual heat removal system	1,0E+16	4,2E+14
FRM II Garching, BY	Technische Universität München (TUM)	Pool, Compact core	20	U3Si2-Al	93	Operational cooling system and Passive ³ residual heat removal system	2,0E+16	1,6E+14

¹ Operational cooling system may also be used as a passive residual heat removal system

² Active residual heat removal not necessary, but implemented and is available for the first 10 min

³ Active residual heat removal not necessary, but implemented and is available for the first 3 h

a. Thermal power

In general, the risk potential of a research reactor correlates to its thermal power. This simple assumption is valid only in a first approach, as long as the facility specification, in particular the inherent safety and the reactor fuel, is not taken into account. Therefore, the thermal power criterion alone is insufficient to fulfil the classification.

b. Hazard potential

The estimation of the failure possibility of system engineering is very complex. For simplification a hypothetical conservative scenario with a failure of the cooling system and all safety barriers is assumed. This implies maximal release of the radioactive materials to the atmosphere, which corresponds to the reactor core inventory. The evaluation of the hazard potential is correlated here to the two most relevant radioactive materials, I-131 and Cs-137 (see Table I). The values are estimated taking into account the reactor thermal power as well as the reactor core parameters (U-235 weight, enrichment and its typical burn-up). It should be noted that there is no strict threshold value for the classification.

c. Safety relevant systems

To the safety relevant systems belong among the other reactor protection system, reactor scram system, operational cooling system and residual heat removal system as well as design against accidents. Comparison of these systems points first of all on the significant differences in the cooling of reactors. Accordingly, the classification can be done taking into account residual heat removal system, which is relevant for safety reasons to ensure the integrity of the reactor. Under this criterion the facilities may be distinguished into:

- No cooling system needed
- Operational cooling system sufficient
- Passive residual heat removal systems, e.g. reactor pool and cooling pipelines needed
- Active residual heat removal system, e.g. cooling pumps needed

A comparison of the three described criteria, which have been used for the classification of German research reactors is presented in Fig. 1. For comparison, the data for a typical German nuclear power plant are also included. Obviously for the considered seven research reactors, there is a clear correlation between these three parameters. It was found, that research reactors may be divided into three different risk potential groups and furthermore, the classification is consistent for the three different criteria.

5. Results

According to the resulting classification of research reactors the graded requirements on the periodic safety review are evaluated. The basis document is "Guides for the Periodic Safety Review of Nuclear Power Plants" [3] that is supported by the IAEA documents [8 - 14]. Moreover, for the technical and organisational features the recent safety reports and other relevant safety documents of single German research reactors were taken into account. The results are shown in Table II. While applying a graded approach one has to keep in mind that even for the facilities with a very low risk potential the safety requirements shall not be graded to zero. The minimal requirements are assigned to the zero-power research reactors.

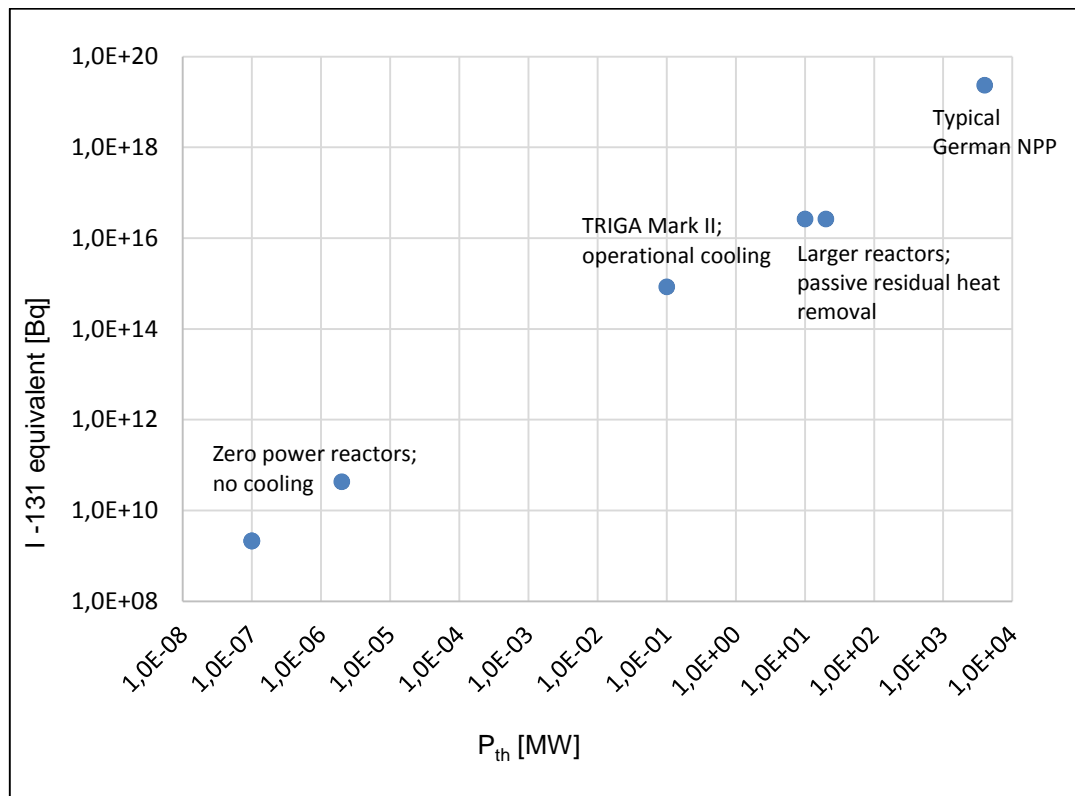


FIG. 1 An overview over classification of research reactors according to the three different criteria (thermal power, hazard potential and safety relevant systems). I-131 equivalent was calculated according to the World Nuclear Association [7] as the Cs-137 multiplied by 40 and added to the I-131.

They are obliged to update the facility description together with the operational and safety documentation. Special emphasis should be given to the safety modification of the facility and the relevant experiences from other facilities or researches. Also the safety concept in general, i.e. the relevant incidents and countermeasures, the aging issues as well as aspects of physical protection have to be included. For the TRIGA Mark II reactor, which belongs to the middle group, additionally the full scope deterministic protection goal oriented safety analysis have to be performed. For the two largest research reactors the requirements on a periodic safety review are similar to these for the nuclear power plants including supplementary probabilistic safety analysis of external events and IT-security. The introduced preceding is going to be agreed in the competent Technical Committee for Nuclear Safety.

The concept on a graded approach is quite general and is directed primarily at the competent authorities. Before preparing the periodic safety review, the operator should consult the competent authority, who decides on the individual case and provide further, more precise instructions. The same authority checks subsequently, if it seems to be necessary under involvement of its technical support organisation, the comprehension and plausibility of the submitted periodic safety review documents as well as the status of the facility and the upgrading measures and finally issues the approval.

TABLE II: GRADED REQUIREMENTS ON THE PERIODIC SAFETY REVIEW FOR GERMAN RESEARCH REACTORS

	FRM II, BER II	FRMZ	AKR-2, SURs
1. Current facility and systems description <ul style="list-style-type: none"> - an up-to-date facility description - description of systems and components (e.g. its safety function, design and configuration) - technical documentation 	✓	✓	✓
2. Operational management and experience <ul style="list-style-type: none"> - reactor organization - applications for the modification - operational documentation - deviations from normal operation - in-service maintenance and maintenance procedures - experiences from other reactors and research findings - operating and inspection manuals - quality assurance - maintenance of technical competences and knowledge - radiation protection - occupational safety - handling of irradiated samples 	✓	✓	✓
3. Deterministic safety status analysis <ul style="list-style-type: none"> - accident analyses und protection goal oriented system inspection (incl. availability and effectiveness) - ageing management of safety equipment - safety precautions (e.g. specific accident instrumentation, measures against internal and external events, measures against human factors, combination of different incidents) - concept of severe accident management (incl. measures for rare events) 	✓	✓	- ⁴
4. Probabilistic safety analysis (supplementary to the deterministic assessment in case of external events)	✓	-	-
5. Physical protection ⁵	✓	✓	✓
6. IT-Security ⁵	✓	- ⁴	- ⁴

⁴ May be included under pt. 1 to an adequate extend.

⁵ Has to be agreed with the department responsible for nuclear security.

References

- [1] Act on the Peaceful Utilisation of Atomic Energy and the Protection against its Hazards (Atomic Energy Act) of 23 December 1959, as amended and promulgated on 15 July 1985, amendment by the Act of 28 August 2013
- [2] Schneider, M., Berg, H.-P., “Research Reactors in Germany: An Overview” (Proc. International Conference on Research Reactors: Safe Management and Effective Utilization, Sydney, 2007), Contributed Papers http://www-pub.iaea.org/MTCD/publications/PDF/P1360_ICRR_2007_CD/Papers/M.%20Schneider.pdf
- [3] Guides for the Periodic Safety Review of Nuclear Power Plants of 18 August 1997, BfS Safety Codes and Guides, Translations Edition 08/97
- [4] IAEA Safety Standards, *Periodic Safety Review for Nuclear Power Plants*, SSG-25, Vienna (2013)
- [5] Bredberg, I., et al., Federal Office for Radiation Protection, “State and Development of Nuclear Energy Utilization in the Federal Republic of Germany 2014”, Salzgitter, 17 June 2015, http://doris.bfs.de/jspui/bitstream/urn:nbn:de:0221-2015061712777/3/BfS-SK-26-15_Statusbericht%202014_eng.pdf
- [6] Luven, D., et al., Gesellschaft für Anlagen- und Reaktorsicherheit mbH, Backfitting – Forschungsreaktoren, Teil 1: Zuordnung der Forschungsreaktoren zu Gruppen, GRS-28, Köln (1981)
- [7] Fukushima Accident, World Nuclear Association, <http://www.world-nuclear.org/info/Safety-and-Security/Safety-of-Plants/Fukushima-Accident/>
- [8] IAEA Safety Standards, *Safety of Research Reactors*, NS-R-4, Vienna (2005)
- [9] IAEA Safety Standards, *Maintenance, Periodic Testing and Inspection of Research Reactors*, NS-G-4.2, Vienna (2006)
- [10] IAEA Safety Standards, *Safety Assessment for Research Reactors and Preparation of the Safety Analysis Report*, SSG-20, Vienna (2012)
- [11] IAEA Safety Standards, *Use of a Graded Approach in the Application of the Safety Requirements for Research Reactors*, SSG-22, Vienna (2012)
- [12] IAEA Safety Standards, *Safety in the Utilization and Modification of Research Reactors*, SSG-24, Vienna (2012)
- [13] IAEA Safety Reports Series, *Safety Analysis for Research Reactors*, SRS – No. 55, Vienna (2008)
- [14] IAEA Safety Reports Series, *Safety Reassessment for Research Reactors in the Light of the Accident at the Fukushima Daiichi Nuclear Power Plant*, SRS – No. 80, Vienna (2014)