German contribution on the safety assessment of research reactors

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ABSTRACT: This contribution describes the safety assessment of German research reactors. First, a general overview of the existing German research reactors is given. The basic principles and the evolution with regard to the safety requirements are depicted followed by the evolution with respect to the licensing and supervising procedures. This includes the reporting of events and the operating experience for German research reactors. Upgrading measures as well as further developments for research reactors in Germany and consequences of ageing effects are described. The assessment of the operational experience of German research reactors by licensee event reports shows that most of the events reported to the authorities are not significant for the nuclear safety.
Finally, this contribution gives details on the approach adopted for the FRM-II, the only new research reactor in Germany in the past 25 years.

1 INTRODUCTION

In Germany, from 1957 up to many research reactors went into operation. Since that time most of them have been decommissioned.

The operating German research reactors are older than 30 years, except the FRM-II, which is under construction. These older reactors have been constructed according to safety requirements valid at their construction time. In the mean time, major efforts have been made by the licensees to comply with the status of science and technology as well as to extend their life time. The evolution is influenced by developments with regard to safety related requirements and backfitting with respect to the tasks and the purposes of the operating reactors. In this context, technical changes, for instance a power increase, the conversion from HEU to LEU or the implementation of additional experimental equipment are the principal reasons for upgrading measures

The table below shows operating research reactors in Germany.

Reactor type	Power	Purpose	Commissioning	Lifetime
1. TRIGA				
TRIGA Mainz	100 kW	Basic Research	03/08/1965	2010
2. MTR Type				
FRG-1	5 MW	Material testing	23/10/1958	2015
BER-II	10 MW	Beam tubes, CNS*	09 /12/1973	2015
FRJ-2 (DIDO)	20 MW	Material testing	14/11/1962	2015
FRM-II	20 MW	Beam tubes, CNS		2030

.* CNS: Cold Neutron Source

The purpose of this contribution is to present the German approach to the safety assessment of research reactors by means of the evolution with regard to safety requirements for German research reactors, their upgrading measures and developments and a description of the new neutron source FRM-II.

2 SAFETY REQUIREMENTS

2.1 Basic Principles and Evolution

The safety requirements have been developed since the commissioning of the first German research reactor. In general, these requirements, in particular the radiological ones follow the basic principles for nuclear power plants (NPPs). The safety requirements on engineered design features differ from those for NPPs because of the lower risk potential of the research reactors. For these reactors the essential points are focused on a safe core cooling (residual heat removal) with main emphasis on pool integrity and safe shutdown.
For research reactors a radiological risk potential is given, if the amount of nuclear inventory is safety significant on the one hand, and if event sequences with a relevant release of the nuclear inventory are possible on the other. In this context, it has to be mentioned that significant releases of the core inventory can only occur in case of fuel superheating.
The required system capacity for the removal of the residual heat (RHR) depends on the power level of the reactor. Accordingly, there are three groups of research reactors:

- Group 1: RHR is possible without active core cooling systems (training reactors, TRIGA type ones)

- Group 2: integrity of passive RHR has to be ensured (e.g. pool type reactors of ~ 1 - 15 MW power like the BER-II)

- Group 3: operability of active components and integrity of passive ones for RHR (e.g. FRJ-2 and prototype reactors)

Some of the design and licensing principles for research reactors are the same as for nuclear power plants (NPPs). The preventive design principles include:

- basic safety and quality assurance,
- safety systems for prevention of design basis accidents,
- systems components for the control and limitation of design basis accidents, and
- evidence of qualification of the personnel.

With regard to the basic safety and quality assurance, the concept contains the plant design, construction, inspections, the qualification of the personnel and operation.

It has to be ensured by safety analyses that abnormal events and accidents are kept under control by the design and that the release of radioactive material is limited to the limits given by the German Radiation Protection Ordinance [2]. For plant internal hazards there are only very few differences compared to the design requirements for NPPs. The protective measures have to ensure that the radioactive releases are below the acceptable limits. Hazards, such as plant internal flooding and fire have also been considered in the analyses. In this context, it has to be mentioned that flooding is not significant for research reactors because of the non-existing pressurised pipes.

For external hazards the design principles for research reactors differ from those for NPPs. As for NPPs, lightning, windstorms and other weather conditions have to be taken into account as plant external hazards in the analyses. Depending on the plant site, the earthquake sensitivity has to be analysed. The design against earthquakes is limited to the safe reactor shutdown, the coolant integrity, etc. The qualification process is the same as for NPPs, but the areas to be protected differ. For extreme hazards, such as aircraft crash or explosions with induced shock-waves it was proven that the risk is negligible. Therefore, there are no specific design requirements with regard to these hazards for the operating German research reactors.

Concerning the evolution with regard to the basic principles and design features for research reactors in Germany the main developments are depicted as follows: The aspect of a higher reliability has increasingly been taken into account also for research reactors. That means that the criteria “redundancy” and “diversity” were applied and that operational and safety systems were more and more separated from each other. The design should include independent safety related systems and components. The confinement of the nuclear inventory was improved.

The extent of the prevention against external hazards was improved with the consequence that earthquakes were more and more considered while the hazard aircraft crash was analysed but does not have to be taken into consideration in the design of older research reactors.

The radiological requirements resulting from the German Radiation Protection Ordinance [2] are nearly the same as for NPPs and they are used in the same manner.

2.2 Evolution with Regard to Licensing and Supervisory Procedures

In Germany the state authorities are responsible for the licensing and supervisory procedures. In addition, the German Reactor Safety Commission (RSK) issued statements and recommendations dealing with research reactor safety on behalf of the Federal Ministry for the Environment, Nature Conservation, and Reactor Safety (BMU). The BMU also developed special guidelines and directives regulating the evidence of qualification for research reactor personnel.

The RSK was involved from the design stage throughout all phases of construction and commissioning of the research reactors. Examples for such statements and recommendations are the required separation of the control system from the reactor safety system and the recommendation that design-basis accidents need to be detected and signalled by a minimum of two independent process variables.

When the first research reactors went into operation, the German Atomic Energy Act [1] was the basis for licensing and supervision. According to this act, the licensing procedures for the nuclear installations were divided into different classes, depending on the type and the safety significance of the reactors. Similar to NPPs for nearly all research reactors, besides the very small (SUR-type) ones for educational use, § 7 of the Atomic Energy Act [1] was valid for the licensing, in particular for the large prototype reactors, such as Merlin and DIDO (FRJ-2). There were no research reactor specific standards and guidelines existing. But several parts of the NPP-specific requirements and guidelines are also applicable to research reactors. In case that this is not possible, the procedures are symptom based for research reactors.

In contrast to NPPs, the supervising procedures for research reactors are characterised by operating licences being flexible enough for various kinds of experiments. To ensure the required supervision, each plant has its own reactor safety committee of the utility itself for consultation and specification of actual experiments and their performance, including the permission, as well as for other safety related questions. In some state authorities and consulting experts participated in these committees without vote. But in case of non-conformities with the licensee, the authorities may issue additional directives.

The safety requirements have further been developed. Quality assurance, for instance, became more and more evident. Nowadays, specifications and guidelines for the larger research reactors are comparable to those for power reactors. However, the very individual design of components and systems in research reactors makes it difficult to adopt requirements and guidelines from NPPs.

The degree of redundancies is not seen in the same manner as for NPPs: while the availability of operational systems is important for NPPs, the requirements concerning redundancy for research reactors are focused only for the safe shutdown and emergency power supply.

Meanwhile, an emergency manual (Accident Management) for accidents has been adopted, also for research reactors. But the approaches vary in the different states.

The evolution concerning the German requirements for research reactors gives no reason for short-term actions, but safety related optimisation and risk minimisation are aimed.

2.3 Reporting of Events for Research Reactors

Regarding the evolution of the safety level of nuclear installations, which also includes further developments in the standards and guidelines, the feedback from operating experience is essential. The acquisition of data from operating research reactors via licensee incident reports of the licensee is one approach for this feedback.

Due to the supervisory approach, there was no centralised evaluation of the operating experience from research reactor facilities up to 1975. When in 1975 the German reporting criteria for NPPs were established, these criteria could principally also be adopted for research reactors, but the proceeding was not regulated.

From 1976 on, the evidence of qualification of research reactor personnel has been regulated by BMI (Ministry of the Interior) or BMU directives (see refs. [3], [5], [6]).

In 1992, the present issue of the German Nuclear Safety Officer and Reporting Ordinance (AtSMV) [7] came into effect for all reactors with more than 50 kW thermal output, which contains uniform reporting criteria for power reactors and research reactors. These reporting criteria are the basis for the evaluation of licensee event reports for the feedback from operating experience. A special user instruction with regard to the application of the reporting criteria for research reactors was drawn up. With the AtSMV the guidelines for the qualification of the personnel were extended (see also ref. [3].

There is a formal classification of the events according to four categories:

- Category S: Events have to be reported to the authority without any delay; if necessary, inspections have to be carried out directly and corrective actions have to be taken.

- Category E: Events have to be reported during a period of 24 hours. These potentially significant events include those where the root cause has to be clarified and corrective actions have to be taken in the near future.

- Category N: Events which have to be reported to the authority to find out possible safety significant deficiencies. Generally, the safety significance is low.

- Category V: Events from facilities under construction, which have to be reported to inform the authorities with regard to the further safe plant operation.

The German reporting criteria are divided into radiological criteria and system specific criteria. There are some differences in the application of the reporting criteria for power reactors and research reactors.

The radiological criteria can be used in the same manner as for NPPs.

While the safety devices are exactly defined for NPPs, a direct application of the systems specific criteria is not possible for research facilities. Therefore, the approach has to be symptom based. All devices required to prevent superheating of fuel elements are safety relevant. For these devices the criteria for comparable safety devices in NPPs are applicable. The classification for most of the other safety devices differs.

Main differences compared to power reactors concern the integrity of structures for the confinement of the coolant. For research reactors, passive measures to ensure the pool integrity and the shutdown systems are significant.

In contrast to power reactors, events concerning experimental devices, which themselves are not significant but could affect the reactor safety (e.g. safety valves of an experimental device) have to be considered.

Events with regard to the secondary circuit are not considered for TRIGA type reactors and with restrictions for other reactor types.

For research reactors incidents which could affect the neutron balance have to be taken into account because of the direct impact by loading or extraction of material.

The blockage of coolant tubes and nozzles belongs to the more significant events and has to be reported in Category E (urgent).

The assessment of the operating experience from research reactors by the licensee event reports indicate that most of the events reported to the authorities are not significant with regard to nuclear safety. In 1993, the test phase for reporting incidents from research reactors to the INES (International Nuclear Event Scale) Reporting System started. Up to now, only incidents classified as INES level 0 or out of scale and only incidents classified in Category N were reported.

3 UPGRADING MEASURES AND DEVELOPMENTS, IN PARTICULAR WITH RESPECT TO AGEING EFFECTS, FOR GERMAN RESEARCH REACTORS

3.1 General Approach

Back fitting and upgrading measures for research reactors result from the general evolution with regard to the safety requirements and from modifications of the plant, such as expansions of buildings, the implementation of additional experimental equipment, the conversion from HEU to LEU or a power increase.

The addition of structures, expansions of neutron laboratories (e.g. for cold neutron sources) were included in the licensing and supervising procedures. Generally, these measures are only relevant with respect to possible effects on the reactor itself under licensing aspects or the radiological protection of the personnel.

The safety reviews are comparable to those for NPPs. But as there are no research reactor specific requirements and guidelines existing, in Germany the approach has to be symptom based.

For the pool type reactor BER II, safety analyses were carried out within the framework of power increase. The consequences were different back fitting and upgrading measure, such as:

- the expansion of the reactor protection system,
- the implementation of emergency power supplies and
- extended upgrading measures with respect to fire protection.

For the large prototype reactor FRJ-2 (DIDO), upgrading measures for reactor internal components were carried out during a longer shutdown period because of cracks found in these components. Furthermore, the fire protection concept has been adapted to the state of modern technology during this outage.

There were upgrading measures for other German research reactors, too, in particular with respect to fire protection measures. In the framework of the BMU study “Fire Protection Conditions of Research Reactors and their Safety Assessment” (ref. [4]) there have been walkthroughs and checks with regard to the fire safety for all research reactor plants. Recommendations for upgrading measures were given with the main goal to adjust them to the state of science and technology.

3.2 Consequences of Ageing Effects

In general, the licensee event reports for research reactors do not give an indication on significant ageing influences. But there are trends to be observed from the incidents reported so far for the older research reactor plants giving a first indication that ageing effects could influence the reliability of components and systems.
The strategy for inspection and maintenance in NPPs differs from that for research reactors because of the higher availability required for NPPs. Due to this many components are exchanged without any indications of unavailability after equipment specific periods taking into account operating experiences with these components in other comparable installations. Comparable exchanges are not practised for research reactors, these means that nearly all equipment is used for longer periods than in other facilities due to the lack of financial means of many research institutions. The long use of components may have the consequence that original exchange components are no longer available, so that the old components will stay in operation. This may be one of the reasons for ageing processes observed.
Some of the incidents reported to the authorities gave indications that there are also some incidents at research reactors which could be caused by ageing effect. Three aspects can be mentioned exemplary:

- humidity increase in the instrumentation,
- cracks found at reactor internal components, and
- corrosion problems.

For the German research reactor FRJ-2 (DIDO), the ageing of components was examined. In particular, ageing effects could be found for electrical relays and pneumatic assemblies. The conclusion from these examinations was that further operation is also allowable for equipment and components susceptible to ageing effects, if more frequent and tightened inspections will be carried out.

In this context, the cost-benefit aspect has to be mentioned. In general, the licensees of NPPs work for private economic purposes and therefore spend a lot of money for plant availability to ensure continuous electric power production. The licensees of research reactors, on the other hand, are generally public institutions. In most cases only lower financial means are available for the plant itself as well as for the experimental equipment. Therefore, availability and upgrading of the equipment with respect to continuous plant operation do not belong to the main interests of these institutions. Regarding the safety of research reactors it is evident that the further operation of old equipment should not affect plant safety.

4 SAFETY CONCEPT FOR THE NEW GERMAN RESEARCH REACTOR FRM-II

The FRM-II has been constructed at the Technical University of Munich (TUM) in Garching. Preparations are being made for the first criticality.. The configuration of the research reactor FRM-II, with a thermal power of 20 MW, consists of a single cylindrical fuel assembly which is located in the central cooling pipe leading through the heavy water moderator tank. The fuel assembly

consists of fuel plates containing Uranium-Silicid U_3Si_2 in an Aluminium matrix within the Aluminium frames. The fuel is highly enriched Uranium-235. The fuel plates are cooled by a light-water forced recirculation flow in the primary circuit embedded in the large water pool.
Due to the lower risk potential, the plant design may differ from the existing standards for NPPs but the requirements for this reactor also reflect some safety issues for modern power reactors. The safety concept for the new German research reactor FRM-2 considers the following safety characteristics:

- Two independent, fast operating systems for the safe shutdown of the reactor, which both ensure the undercriticality,
- core cooling by redundant trains for the primary cooling loops,
- most of the safety related systems designed triple redundant,
- prevention of rapid coolant flow discontinuities by passive components, such as check valves, and
- passive structures for prevention of a water loss from the pool.

The main design characteristics for the FRM-2 are:

- Active cooling of the pool after shutdown is not necessary. The forced circulation is limited to 3 hours. After that period natural circulation is sufficient.
- The external hazard earthquake is included in the design.
- Aircraft crash does not have to be considered as a design basis incident, but for minimising the risk, the protection of the reactor building against this hazard has been taken into account.
- External explosions and induced shock-waves are not taken into consideration for the design due to plant site conditions.
- The design principles for internal hazards, like fire, are comparable to NPPs.

The quality assurance concept for the FRM-2 includes the plant design and construction as well as the inspection and maintenance programme and the evidence of qualification of the personnel during operation.

For the design basis accidents to be analysed, the following incidents - as before for other research reactors - are considered:

- reactivity incidents,
- RHR incidents without loss of coolant accident (LOCA), and
- LOCA

As an example, the nuclear license process and the construction phases of the FRM-II are described in more detail.

The safety analysis report was completed and the application for the nuclear licensing of FRM-II was submitted to the licensing authority in February 1993. The first partial nuclear license covered the site selection, the general concept of design and safety and the construction of the reactor building. The general design of systems including the safety concept should be specified in such details to allow an assessment of the proposed technical solutions. The project obtained its first partial nuclear license in April 1996, and the construction work started in August 1996. The second partial nuclear license, October 1997, covered the construction of all buildings and technical installations except the handling of any fissile material. The third and final partial nuclear license covers the full range of reactor operation. This license, given in summer 2003, is obligatory for transporting nuclear fuel assemblies to the site and to begin with nuclear start-up experiments.

The participants of the licensing process are the following: The applicant is the Technical University of Munich (TUM), which will also be in charge for the operation of the research reactor. SIEMENS was nominated as a general contractor for the project. Both were in charge to prepare the safety analysis report and supplementary technical documentations. The licensing authority is the responsible Bavarian State Ministry (BStMLU). The safety assessment was contracted to the TÜV Süddeutschland. For particular work packages was supported by subcontractors, e.g. the safety review of nuclear design was performed by GRS and the qualification of the fuel plates was assessed within an IPSN/GRS co-operation. Generally, the license permit of the state authority is based on the assessment of the technical support organization. All steps of the licensing process are monitored by the responsible Federal Ministry (BMU). For fundamental safety questions, the Reactor Safety Commission (RSK) is asked for their evaluation. This step-wise approach guarantees that during all stages of construction the status of science and technology is taken into account in the project.

5 CONCLUSIONS

The evolution with respect to safety requirements and upgrading measures in Germany shows that there are no safety deficiencies for research reactors. The actions to be taken are preventive ones with the aim of an optimisation concerning the safety culture and risk minimisation.
The main goals with regard to the nuclear safety of research reactors are:

- a safe shutdown of the reactor,
- to ensure the pool integrity, and
- RHR via active measures for single cases.

The radiation protection features are comparable to those for NPPs.

Possible ageing effects may influence the further operation of a research reactor. Therefore, the safe operation has to be ensured by a more frequent and tightened inspection and maintenance programme for the older plants.
In future, the operation of the existing German research reactors will continue taking into consideration the present status of science and technology and world-wide operating experience, as

far as possible.
Particularly for the older research reactors, a safety assessment cannot strictly be made with regard to the existing requirements and guidelines as for NPPs.

6 REFERENCES

1 Act relating to the Peaceful Utilisation of Nuclear Energy and Protection Against its Hazards (Atomic Energy Act), as promulgated on July 15, 1985, amended on February 18, 1986 and last amended on December 27, 1993

2 Ordinance on the Protection against Hazards from Ionising Radiation (Radiation Protection Ordinance), Bundesanzeiger 1989

3 Guideline for the Proof of the Technical Qualification of Research Reactor Personnel, GMBl. 1994, Nr. 11

4 Fire Protection Conditions of Research Reactors and their Safety Assessment, BMU-1992-383

5 Guideline to the Content of the Examination of the Technical Qualification of the Responsible Research Reactor Shift Personnel, GMBl. 1990, p. 290

6 Guideline relating to the Assurance of the Necessary Knowledge of the Persons otherwise Engaged in the Operation of Nuclear Power Plants, GMBl. 1980, p. 652

7 Ordinance on the Nuclear Safety Officer and the Reporting of Accidents and other Events (Nuclear Safety Officer and Reporting Ordinance (AtSMV)), BGBl. 1, 1992, Nr. 48