Advanced reactor experimental facilities

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For many years, the NEA has been examining advanced reactor issues and disseminating information of use to regulators, designers and researchers on safety issues and research needed. Following the recommendation of participants at an NEA workshop, a Task Group on Advanced Reactor Experimental Facilities (TAREF) was initiated with the aim of providing an overview of facilities suitable for carrying out the safety research considered necessary for gas-cooled reactors (GCRs) and sodium fast reactors (SFRs), with other reactor systems possibly being considered in a subsequent phase. The TAREF was thus created in 2008 with the following participating countries: Canada, the Czech Republic, Finland, France, Germany, Hungary, Italy, Japan, Korea and the United States. In a second stage, India provided valuable information on its experimental facilities related to SFR safety research.

Study method

The TAREF members decided to build on the experience of a similar NEA activity described in *Nuclear Safety Research in OECD Countries: Support Facilities for Existing and Advanced Reactors* (SFEAR). The study method adopted entailed first identifying high-priority safety issues that require research and then categorising the available facilities in terms of their ability to address the safety issues.

The Task Group also agreed that the GCR-related task could be completed at an earlier stage than the SFR task given that a significant part of the safety issues to be addressed had already been compiled in an earlier United States Nuclear Regulatory Commission (USNRC) exercise (called the Phenomenon Identification and Ranking Tables – PIRT). Hence, two separate reports were produced for the GCR and SFR tasks. These reports are summarised below.

Approach for GCRs

The Task Group followed an approach similar to that performed by the USNRC for the PIRT, and identified the following technical areas for consideration: accidents and thermo-fluids (including neutronics), fission product transport, high-temperature metallic materials, graphite and ceramics, and fuel [tristructural-isotropic (TRISO) and other fuel types]. In the case of structural materials, graphite and ceramics experience can be broader than nuclear and was considered to the degree possible. Other technical areas such as seismic assessment (except for potential consequences on core compaction), fire safety, instrumentation and control, and human and organisational factors were not treated in the report since the issues are not specific to GCRs.

For each of the above technical areas, the TAREF members identified the safety issues still requiring research. Only the issues identified as being of high importance to safety and for which the state of knowledge is "low" or "medium" were included in the discussions.

Approach for SFRs

Based on discussions and the results of a questionnaire, the TAREF members identified the following technical areas to be addressed for SFRs: thermo-fluids, fuel safety, reactor physics, severe accidents, sodium risks, structural integrity and other issues. The first four technical areas address phenomena and issues specific to the nuclear industry. The other areas address phenomena that are relevant for the nuclear industry, but for which experience may be broader than nuclear.

In a similar way, seismic assessment (except for potential consequences on core compaction), instrumentation and control, and human and organisational factors were not treated since they are not specific to the nuclear industry, and within the nuclear area, are not specific to SFRs. Other technical areas such as fuel fabrication, fuel handling and irradiated material investigation techniques (as used in hot cell facilities) were not considered as they are more related to operational concerns or not specific to SFRs.

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For each of the above technical areas, the task members agreed on a set of safety issues requiring research and established a ranking with regard to safety relevance (high, medium, low) and the status of knowledge based on the following scale relative to full knowledge: high (100%-75%), medium (75-25%) and low (25-0%). As for GCRs, only the issues identified as being of high safety relevance and for which the state of knowledge is low or medium were included in the discussion, as these issues would likely warrant further study.

Safety issues and suitable experimental facilities

For each of the safety issues, the TAREF members identified appropriate facilities, providing relevant information such as operating conditions (in- or out-of-reactor), operating range, description of the test section, type of testing, instrumentation, current status and availability, and uniqueness. Based on the information collected, the task members assessed prospects and priorities for GCR and SFR safety research and developed recommendations as to priorities and options for facility utilisation through international programmes. In particular, the group agreed on the main criteria for priority setting, which was based on the following items (high, medium or low for each):

- Relevance of the facility to cover a specific issue.
- Uniqueness (e.g. one-of-a-kind for in-pile testing).
- Availability for addressing the issue. Due to the specific context of SFR development with significant R&D activity during the period 1970-1995, followed by a period of reduced effort and now restarting in several countries, three time windows were considered: 0-3 years, 4-8 years and more than 8 years.
- Readiness (e.g. staff availability to run it).
- Operating cost (<0.3, 0.3-1, >1 million USD) or construction cost (<0.5, 0.5-2, >2 million USD).

The group rated those facilities that were costly either to operate or to construct as being ranked high in this category as they were more suitable to host a multilateral co-operative programme than facilities of lower cost which could be supported by one country alone. TAREF members who had proposed facilities were requested to characterise the latter according to the above criteria. Based on this information, the following conclusions and recommendations were developed.

Conclusions and recommendations

1. The TAREF activity proved to be a useful exercise for achieving consensus on the technical areas and issues related to the safety of GCR and SFR systems, as well as for identifying a number of facilities that are or will become available in OECD/NEA member countries for supporting GCR and SFR safety research.
2. Existing facilities and facilities that are being constructed or planned in member countries cover all technical areas of concern and most of the safety issues identified in these areas. Hence, there is no apparent need for the NEA Committee on the Safety of Nuclear Installations (CSNI) to consider building a facility beyond what is currently planned in member countries. However, due to the specific context of SFR development, a large number of facilities operating in the past with sodium as coolant are no longer available

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The High-temperature Engineering Test Reactor (HTTR) in Japan.

or have been converted to address water reactor issues. This explains why for SFRs, the availability of relevant facilities for all technical areas is limited in the short term, and that the decision to restart or to modify some facilities is under consideration. This situation also led the group to rank the facilities over three time windows up to the long term (beyond eight years from now).

3. Based on the responses received, the highest-ranked facilities were identified. For SFRs, these facilities are considered for the short, mid- and long term; it should be noted, however, that the availability of facilities under construction or to be restarted or refurbished cannot be guaranteed at a given date. Facilities available in the short term are assumed to be available in the mid- and long term, and facilities available in the mid-term are assumed to be potentially available in the long term.

Recommendations specific to GCRs

4. The Japanese High-temperature Engineering Test Reactor (HTTR) constitutes a unique resource in that it is the only experimental high-temperature GCR available for a test programme in OECD/NEA member countries. It is a graphite-moderated, helium-cooled reactor that can reach temperatures as high as 1 600°C in some transient conditions. The experiments planned to study the effects of reactor cavity cooling system (RCCS) performance reduction are highly relevant for GCR safety assessments. The HTTR is also suitable for neutronics, fission product release and graphite dust issues related to prismatic fuel arrangements. Actions should be taken to develop an international programme focused on the HTTR's capabilities and on the safety issues identified by the TAREF.
5. The Czech High-temperature Helium Loop (HTHL) offers the opportunity to host separate-effect tests carried out both out of pile and in pile, hence offering the flexibility to address studies in which the combined effect of a high-temperature gas environment and radiation is relevant, for example fission product transport or high-temperature materials behaviour.
6. The HTTR and the HTHL plans are suitable for near-term initiatives, i.e. for proposals that could result in defining an experimental programme in a one- to two-year time frame. Following current practice for OECD/NEA joint projects, such initiatives depend on the proposal from the host country and facility as well as the co-operative support from other member countries. NEA support to set up such programmes will be required.
7. The French *Commissariat à l'énergie atomique* (CEA) is encouraged to keep the CSNI and relevant CSNI working groups abreast of the gas fast reactor (GFR) design developments and the analytical and experimental progress to support such development, including proposals for specific experimental programmes when appropriate. In particular, the CEA should provide updates related to its long-term plans for the GFR demonstration reactor (ALLEGRO), which in the long term (approximately ten years) could constitute a focus for joint international efforts.

Recommendations specific to SFRs

8. The TAREF members agreed that for new SFR projects, the most important R&D safety needs concern the following technical areas in order of priority: fuel safety and severe accident issues are of prime interest due to the lack of knowledge on new pin design and materials; thermo-fluids and core physics issues are of second priority as current knowledge is deemed roughly sufficient when margins for uncertainties are taken into account; sodium risks and structural integrity issues may be considered as third priority as they are more design-dependent.
9. The need for fuel pin irradiation capabilities under representative conditions of fast neutron flux has been identified as a crucial point for addressing safety issues of high priority.
10. In the short term, the Indian Fast Breeder Test Reactor (FBTR) can be a valuable resource for irradiation of SFR fuel pins and to generate new materials data; the American Annular Core Research Reactor (ACRR) could address issues related to fuel safety and severe accidents under specific conditions. In addition, the German KASOLA facility could provide data for the thermo-fluids issues apparent in computational fluid dynamics (CFD) modelling approaches. The Japanese SWAT-1R-3R facility can be appropriate for studying sodium water interaction in steam generator units; the Indian SFTF facility can be valuable for addressing several issues related to sodium fires; the American SURTSEY facility can be relevant for studies on sodium fires and sodium-water interaction in steam generators.
11. In the mid-term, the Japanese fast neutron reactor JOYO was identified as suitable to address fuel safety issues related to new fuel pin designs (fuel pin performance and new materials performance under irradiation, margin to fuel melting and impact of use of minor actinides) and certain other issues; however, uncertainty still exists as the decision for the possible repair and operating schedule has not yet been made. Severe accident issues can only be addressed in a comprehensive way from the mid-term to the long term, due to the lack of available facilities for simulation of representative transient conditions in the short term with irradiated fuel pins. The Kazakh IGR facility used for JAEA programmes and addressing fresh fuel (controlled fuel relocation and debris bed formation) may be a suitable option in the mid-term as plans are under considera-

The Fast Breeder Test Reactor (FBTR) in India.

tion for it to handle irradiated fuel. The French VULCANO can also help for severe accident issues, provided it is refurbished for sodium use. The American TREAT experimental reactor was also considered in the mid-term for its relevance to severe accidents issues (past experimental programmes simulating fast power transients), but restart of the facility has not yet been decided (the decision is expected in 2010). In addition, the French MASURCA reactor may be suitable for core physics issues for providing improved nuclear data of core materials (in relation with high burn-up levels and the use of minor actinides) and associated uncertainties.

12. In the long term, the French ASTRID SFR prototype, although at first designed as an industrial prototype to be transposed to a future first-of-a-kind commercial reactor, will offer some irradiation capabilities and may address mainly fuel performance issues (new cladding materials tests and impact of minor actinides under fast flux). The French Jules Horowitz Reactor (JHR), under construction and designed for material testing, may address fuel safety issues (new materials performance under irradiation, impact of use of minor actinides and slow transients under specific conditions). Availability for initial testing is foreseen in 2017-2020. The French CABRI experimental reactor was recognised by the group members as the most appropriate facility to address irradiated fuel behaviour under operational and accident conditions (fuel safety issues such as margins for fuel melting and deterministic pin failure, severe accident issues such as consequences of various accidents leading to fuel melting, with associated consequences and risk of critical events and energy release). The facility may be available for testing from 2020 (after completion of LWR safety research programmes). In the case of innovative design for secondary circuits, the Italian LIFUS5 facility would address sodium interaction with alternative coolant species.

Finally, it is recommended that relevant CSNI working groups should be encouraged to share modelling information and to discuss modelling activities relevant for GCR and SFR safety, in order to help focus the potential test programmes and/or to enhance the data utilisation for model development. In addition, the CSNI is to maintain an adequate level of exchange with the CNRA regarding needs and initiatives in the GCR and SFR safety areas.

OECD/NEA joint projects

As a result of the TAREF activity, an OECD/NEA joint project was proposed by the Japan Atomic Energy Agency (JAEA) and is being set up at the JAEA High-temperature Engineering Test Reactor (HTTR). The objectives of the proposed project are to conduct integrated, large-scale test of loss of forced cooling (LOFC) in the JAEA HTTR, to examine high-temperature, gas-cooled reactor (HTGR) safety characteristics in support of regulatory activities, and to provide data useful for code validation and improvement of simulation accuracy. The reactor performance under accidental conditions considered in the Phenomena Identification Ranking Tables (PIRT) set up by the USNRC will be assessed in this project.

It is expected that other OECD/NEA joint projects may be initiated based on the recommendations stemming from the TAREF activity. In particular, joint projects addressing first-priority SFR safety issues might be initiated within two or three years.