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Analysis of Results from Integrated Safety Assessment of Research Reactors (INSARR) Missions

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ANALYSIS OF RESULTS FROM INTEGRATED SAFETY ASSESSMENT OF RESEARCH REACTORS (INSARR) MISSIONS

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IAEA-TECDOC-2048

ANALYSIS OF RESULTS FROM INTEGRATED SAFETY ASSESSMENT OF RESEARCH REACTORS (INSARR) MISSIONS

INTERNATIONAL ATOMIC ENERGY AGENCY
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FOREWORD

The IAEA supports Member States in evaluating and enhancing the safety of their research reactors through its Integrated Safety Assessment of Research Reactors (INSARR) service. The service covers all areas important to the safety of research reactors and provides an objective and comprehensive safety review based on the IAEA safety standards.

INSARR missions are conducted upon request from Member States by a team of international, multidisciplinary experts with direct experience in the areas of review. The missions can be hosted by operating research reactors or by research reactors in the design, construction or commissioning stage, and can be requested by the operating organization or by the regulatory body of the Member State.

In carrying out INSARR missions, the team of experts reviews the safety documentation of the research reactor, interviews personnel and conducts field visits. It identifies gaps against the IAEA safety standards and provides recommendations and suggestions to address these gaps with the goal of improving safety. The review team also shares technical experience and good practices with the host organization.

This publication provides an analysis of the recommendations from 54 INSARR missions to research reactors in 32 Member States during the period 1995–2021 as well as from 8 safety review missions that were conducted according to the INSARR methodology during the same period. The missions were hosted by operating research reactors and by research reactors in the design or commissioning stage. The analysis identifies common safety issues and global trends that need increased attention from regulatory bodies, operating organizations, technical support organizations and designers. It also provides insights into areas needing improvements or additional effort to address safety issues in accordance with the IAEA safety standards. In this regard, the publication can be beneficial for self-assessment, for the allocation of resources dedicated to safety, and for the orientation and definition of training activities for operating personnel, regulatory staff and experts participating in future INSARR missions. The results of the analysis will also be used to provide feedback for the development of IAEA safety standards on research reactors.

The IAEA is grateful to all those who contributed to this publication. The IAEA officers responsible for this publication were D.F. Sears and A.M. Shokr of the Division of Nuclear Installation Safety.

CONTENTS

1. INTRODUCTION

1.1. BACKGROUND

This publication covers the analyses of the Integrated Safety Assessment of Research Reactors (INSARR) missions conducted between 1995 and 2021 and safety review missions conducted following IAEA Services Series No. 25, Guidelines for the Review of Research Reactor Safety: Revised Edition [1] and its predecessor guidelines[1].

As outlined in Ref. [1], the IAEA performed its first research reactor evaluation in 1959, and between 1960 and 1971, six more evaluations were conducted. The IAEA began to regularly review the safety of research reactors in 1972, through safety review missions conducted in accordance with the IAEA Statute at that time. These safety review missions were generally performed upon request by Member States operating research reactors.

The safety reviews of research reactors under Project and Supply Agreements were referred to as “safety inspections” from 1972 to 1976. The reviewers considered themselves IAEA safety inspectors with a focus on examination of the legal framework and organization of the radiation protection programme, and operational radiological practices. Safety analysis, operational procedures and other nuclear safety aspects were gradually introduced into the scope of missions.

The missions were referred to as ‘safety advisory missions’ from 1976 to 1987. Mission objectives were primarily concerned with operational safety aspects. Nuclear safety related areas including the safety analysis report and operational limits and conditions, as well as reactor modifications, operating and maintenance procedures, and regulatory supervision were gradually added to the scope. A questionnaire based on the IAEA safety standards at the time was used to conduct the reviews.

The IAEA formally announced the creation of a safety review service named Integrated Safety Assessment of Research Reactors (INSARR) in 1987. Since then, the objectives and scope of the INSARR safety reviews have been expanded to cover design, commissioning, and siting. The importance of the exchange of information between reviewers and the host organizations has also been emphasized. The mission report format was standardized, with minor differences depending on differences in mission objectives and scope.

IAEA Services Series No. 1[1], published in 1997, formalized the review procedures used for INSARR missions. A three-stage approach for INSARR missions was introduced in 2000 as described in Ref. [1]:

1. A pre-INSARR mission to present the review methodology, to discuss and define with the host organization the topics to be reviewed, the documentation to be sent to the IAEA in advance of the main mission, and to obtain preliminary information about the research reactor.

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidelines for the Review of Research Reactor Safety, IAEA Services Series No. 1, IAEA, Vienna (1997).

2. The main INSARR mission to conduct the review, to provide a summary report during the mission, and to provide a full report on the findings after the mission.

3. A follow-up INSARR mission to determine the status of actions taken by the host organization in response to the main mission findings, to clarify any misunderstandings in response to mission findings, and to obtain feedback on the effectiveness of the INSARR mission. A report is provided after the follow-up mission.

The pre-INSARR mission is normally done in-person at the reactor site, but during the global Covid pandemic the pre-INSARR missions were conducted remotely, and this may continue in future where appropriate. The main and follow-up INSARR missions are conducted in-person.

Although the main objective of an INSARR mission is to conduct a comprehensive safety review of research reactors based on the applicable IAEA safety standards, the mutual transfer of knowledge and experience among the mission experts and host organization personnel is also promoted. In addition, missions identify good practices and areas where the host organization had developed a particularly good approach to certain safety topics that could be recommended for application at other research reactors [1].

INSARR missions are based on a peer review approach and are not intended to be regulatory inspections. The main review areas have essentially remained unchanged since the programme's inception. However, the guidelines [1] have been revised to account for new and updated IAEA safety standards and the provisions of the Code of Conduct on the Safety of Research Reactors [2].

1.2. OBJECTIVE

This publication provides an analysis of the results of INSARR missions conducted at research reactors for the period between 1995 and 2021. It disseminates the results of this analysis within the research reactor community with the objective to continue to improve safety by creating awareness among operating organizations, regulatory bodies, future mission teams and others, about the findings, common safety issues and general trends identified at research reactors. The publication also promotes good practices in research reactors by providing information about a broad range of safety related topics that, if adequately addressed by Member States, could enhance the safety of research reactors worldwide. The information in this publication can be used, inter alia, to help plan future INSARR missions and to train future INSARR mission experts and mission team members. The publication also can be used in performing self-assessments of safety or periodic safety reviews of research reactors.

1.3. SCOPE

This publication provides a summary of the mission results and an analysis of the recommendations from 54 INSARR missions and 8 safety review missions conducted between 1995 and 2021. The missions cover 21 review areas ranging from siting, design, and commissioning through operating programmes to planning for decommissioning. Recommendations from the mission reports are considered in the analysis but suggestions and good practices are not included.

1.4. STRUCTURE

This publication is comprised of five sections and two appendices. Section 2 presents an overview of the analysis of the recommendations, including relevant statistics. Section 3 presents an analysis of the mission results classified by review area and identifies the findings and trends by review area. Section 4 provides a discussion of the results of the missions' results and Section 5 provides the summary and conclusions of the analysis of the INSARR missions. Annex I presents the number of operating research reactors in the geographic regions defined in the IAEA research reactor database[2].

2. OVERVIEW OF ANALYSIS AND RESULTS

This Section describes the assumptions and limitations of the analysis of the recommendations from 54 INSARR missions and 8 safety review missions (62 in total) carried out from 1995 to 2021, and an overview of the analysed missions, including the relevant safety review areas.

2.1. ASSUMPTIONS AND LIMITATIONS OF THE ANALYSIS

The assumptions used in the analysis are described in this section to clarify the limitations of the analysis and the validity of the results obtained.

Altogether, 62 missions resulting in 1426 recommendations have been analysed. These missions also generated 298 suggestions and 101 good practices, but these are not included in the analysis. The number of recommendations is sufficiently large to draw meaningful conclusions about general characteristics and trends in the safety of research reactors.

INSARR missions have a modular structure and the missions analysed in this document varied from full-scope missions where all safety review areas are included to limited-scope missions where the host organizations selected only a limited number of review areas according to their needs. Additional factors that might affect the results include the following:

- Composition, expertise mix and size of the review team;
- Focus areas of the mission and specific interest of the Member State's organization;
- Changes in the IAEA safety standards over the time period of the analysed missions;
- Evolution of the INSARR process over time.

While IAEA safety standards have evolved over the years, many of the underlying safety factors have been consistent over the analysed period. An important evolution in the IAEA safety requirements for research reactors occurred in addressing the lessons learned from the accident at the Fukushima Daiichi Nuclear Power Station (NPS). This evolution was reflected in the IAEA Safety Standards Series No. SSR-3, Safety of Research Reactors [3], which superseded the IAEA Safety Standards Series No. NS-R-4[3] as the main reference for the INSARR missions,

[2] https://nucleus.iaea.org/RRDB/RR/ReactorSearch.aspx.
[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Research Reactors, IAEA Safety Standards Series No. NS-R-4, IAEA, Vienna (2005).

including the consideration of design extension conditions (DEC) and combination of events in the safety analyses. Section 4 presents the changes over time in the IAEA safety standards.

The recommendations of the missions are not weighted in terms of safety significance. Furthermore, many recommendations cover cross-cutting areas or are combined when similar findings are addressed. Generally, the recommendations have been categorized according to the review area in which they were assigned in the INSARR mission reports. However, for the current analysis, some recommendations have been reassigned to a different safety review area where this would better align the safety issue identified with the observations in the report. The conclusions drawn in this publication are to be considered in view of the assumptions and limitations presented above.

2.2. REVIEW AREAS

A comprehensive list of review areas and the guidelines for an INSARR mission is given in Ref. [1].

An INSARR mission might not cover all the review areas. The host organization in conjunction with the mission team leader determine the review areas to include, depending on the scope and objectives of the review. The applicable IAEA safety standards form the basis and reference for the review. Other IAEA publications, such as safety reports, are helpful in considering the variety of different reactor designs and provide useful guidance and examples for the safety review.

The following review areas are covered by a full-scope INSARR mission [1]:

(a) Design;
(b) Safety analysis;
(c) Safety analysis report;
(d) Construction;
(e) Commissioning;
(f) Siting and protection against external events;
(g) Operational limits and conditions;
(h) Safety culture;
(i) Regulatory supervision;
(j) Safety committees;
(k) Operating organization and reactor management;
(l) Training and qualifications;
(m) Conduct of operations;
(n) Maintenance and periodic testing – including ageing management;
(o) Modifications;
(p) Utilization and experiments;
(q) Management system;
(r) Radiation protection;
(s) Radioactive waste management;
(t) Emergency planning;
(u) Decommissioning planning.

The IAEA offers separate review services to cover security aspects, safety culture and ageing management for continued safe operation of research reactors. However, the compatibility between safety and security provisions can be covered during an INSARR mission. The

INSARR recommendations or comments addressing security issues are not captured in the analysis presented in this publication.

The guidelines for an INSARR review are selected to meet the scope and objectives of the mission. The guidelines can be used in a modular manner to meet the needs of the mission. Guidelines for performing these activities also varies according to the level and depth of assessment needed [4] and applies a graded approach [5]. General guidelines are applied to reviews that are concerned with the overall safety of the research reactor, while specific guidelines are applied where a greater depth of evaluation is needed and these supplement the general guidelines.

There are no effective means to capture the distinction between general and specific recommendations which are collected in the INSARR database. Recommendations, in INSARR mission reports are catalogued in their respective review areas although other issues might be addressed in the recommendation. This is discussed further in Section 4.

The expectations for review team members are described in the INSARR guidelines [1]:

> "Review team members should cover their assigned individual review areas to the extent necessary to be able to make well informed judgments. It is not the intention that all the matters included in the guidelines for a given topic have to be addressed during a safety review. It is the responsibility of the reviewer to make an appropriate selection of subjects for questioning in accordance with the objectives, scope and duration of the review. This selection should be appropriate to identify weaknesses and strong points, to draw conclusions, to make recommendations on research reactor safety, and to fully address such issues in the mission report."

Recommendations are defined as follows for INSARR missions [1]:

> "**Recommendations**
>
> Recommendations are review team advice for improving safety based on IAEA safety standards and recognized good practices. The recommendations focus on WHAT is recommended to be done."

2.3. SUMMARY OF MISSIONS ANALYSED

This section covers the analysis of the missions conducted in various geographical regions and the number of recommendations in the various review areas included within the scope of the missions.

Table 1 shows the Member States that have participated in INSARR review missions, and the number of missions conducted from 1995–2021.

In addition, 8 safety review missions were conducted in three Member States not listed in Table 1, namely Australia, Colombia, and Egypt. In total, 35 Member States participated in 62 missions over the twenty-six-year period covered by this analysis. Tables 2 and 3 show the distribution of missions by year, as well as the total number of recommendations per year for INSARR and for safety review missions, respectively.

The recommendations from the INSARR missions and the safety review missions were analysed collectively in this report. Unless identified separately as INSARR missions/recommendations or safety review missions/recommendation, the generic terms "missions" and "recommendations" will be used hereafter to denote the collection of data analysed for this report.

TABLE 1. MEMBER STATE AND NUMBER OF INSARR MISSIONS HOSTED

Bangladesh	2
Belgium	1
Chile	1
Congo (DRC)[4]	3
Czech Republic	2
Finland	1
Ghana	2
Greece	1
Indonesia	3
Iran	1
Israel	1
Italy	1
Jamaica	2
Jordan	1
Kazakhstan	2
Libya	1
Malaysia	2
Morocco	1
Netherlands	6
Nigeria	2
Norway	2
Peru	2
Poland	2
Portugal	1
Romania	2
Slovenia	1
South Africa	1
Syria	1
Thailand	2
Türkiye	1
Uzbekistan	1
Viet Nam	2
Total	**54**

[4] The mission report retains the name of the Member State as it was at the time of the mission.

TABLE 2. NUMBER OF INSARR MISSIONS BY YEAR AND NUMBER OF RECOMMENDATIONS

Year	Number of missions	Number of recommendations
1995	2	35
1996	1	8
1997	4	42
1998	2	46
1999	2	6
2000	3	48
2001	1	14
2002	4	57
2003	2	13
2004	1	29
2005	2	116
2006	2	145
2007	3	81
2008	2	56
2009	2	31
2011	3	99
2012	1	23
2013	3	61
2014	2	59
2015	1	43
2016	3	71
2017	3	55
2018	2	27
2019	1	15
2020	1	13
2021	1	20
Total	**54**	**1213**

TABLE 3. NUMBER OF SAFETY REVIEW MISSIONS BY YEAR AND NUMBER OF RECOMMENDATIONS

Year	No. missions	Number of recommendations
2001	1	26
2003	1	78
2004	1	16
2007	1	24
2009	1	9
2010	2	35
2013	1	25
Totals	**8**	**213**

Figure 1 shows the distribution of missions among geographic regions as defined by the IAEA Research Reactor Database (RRDB). Africa, Eastern Europe, South East Asia and Western Europe hosted the highest number of missions, and combined account for 50 out of the 62 missions analysed. Figure 2 also shows the trend in the number of missions implemented in each region over time (in nominal 5-year increments). There appears to be no consistent discernible trend with time, but generally the number of missions requested by Member States in several regions remained about the same or increased slightly in subsequent time periods. South East Asia is the exception showing a decreasing trend over the time interval.

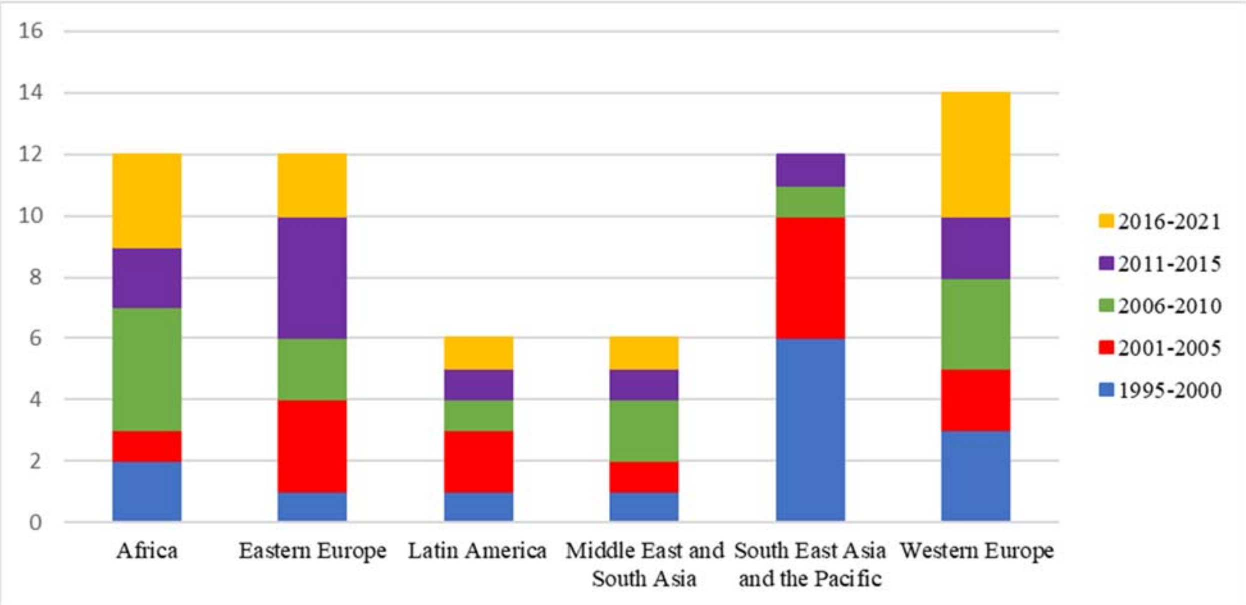

FIG. 1. Number of missions conducted by geographic region and time period.

Table 4 has the geographical data expressed as the ratio of INSARR and safety review missions per research reactor for each region. This gives an indication of the requests for missions by Member States in each region. It does not reflect the level of safety practices within a region, but it does reflect the amount of independent international reviews for research reactors that were requested by Member States in the regions.

TABLE 4. RATIO OF NUMBER OF MISSIONS PER NUMBER OF REACTORS BY GEOGRAPHIC REGION IN THE IAEA RRDB

Region	Number[5] of research reactors	Number of missions
Africa	10	12
Eastern Europe	90	12
Far East	40	-
Latin America	21	6
Middle East and South Asia	16	6
North America	50	-
South East Asia and the Pacific	6	12
Western Europe	42	14
Total	**275**	**62**

[5] Permanently shut down and decommissioned research reactors are not included.

The total number of recommendations per mission is highly variable, as shown in Tables 2 and 3. Figure 2 shows the average number of recommendations per mission with time. The graph shows the large spread in the average number of recommendations per mission, with a mean of 23 and a standard deviation σ = 15.

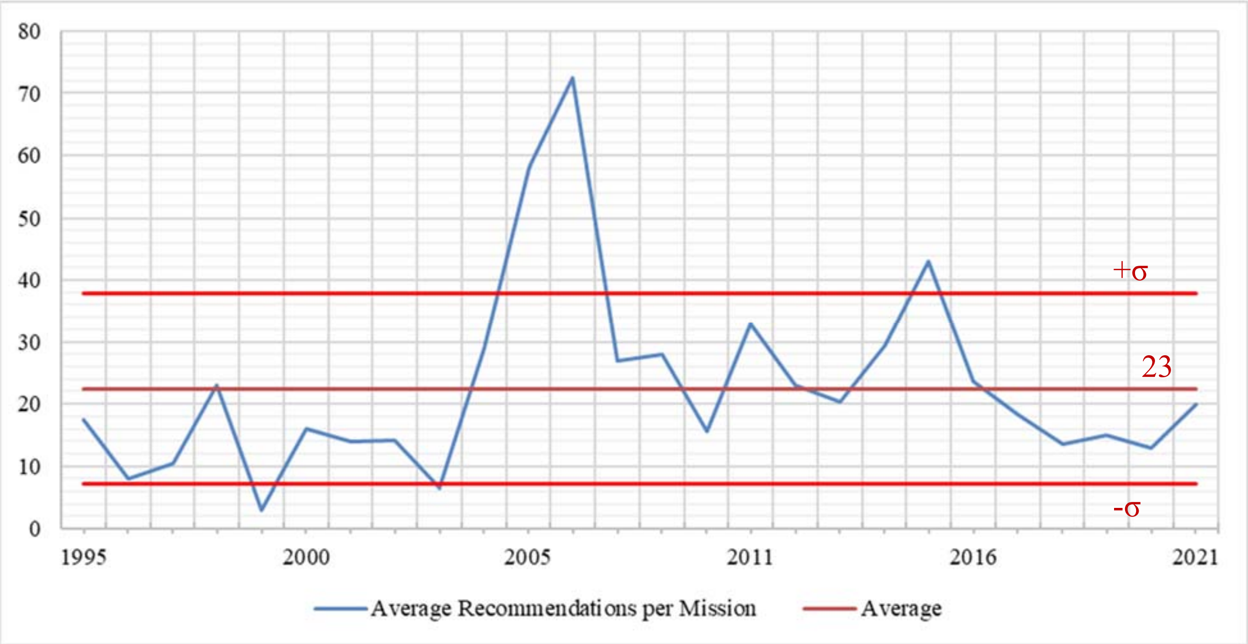

FIG. 2. Average number of recommendations per INSARR mission from 1995–2021.

Figure 3 shows the distribution of the total number of recommendations normalized by the number of INSARR missions per geographical region. The number of recommendations reported for a mission indicates areas that need attention to improve safety from research reactor operating organizations. It does not represent an indication of the level of nuclear safety in the operating organization nor the effectiveness of the regulatory body, and therefore it cannot be compared among missions in different Member States.

Care needs to be applied in interpreting these data, as in many cases for individual INSARR missions, there may have been correlations between findings in a mission resulting in grouping the corresponding recommendations into a single recommendation. Additionally, some recommendations may be more important in terms of safety significance, which is not reflected in the presentation of the data. However, the numbers and types of recommendations and their distribution over time may indicate general trends or highlight issues that need further analysis (e.g., the relative importance of specific INSARR modules (review areas) within the scope of the mission).

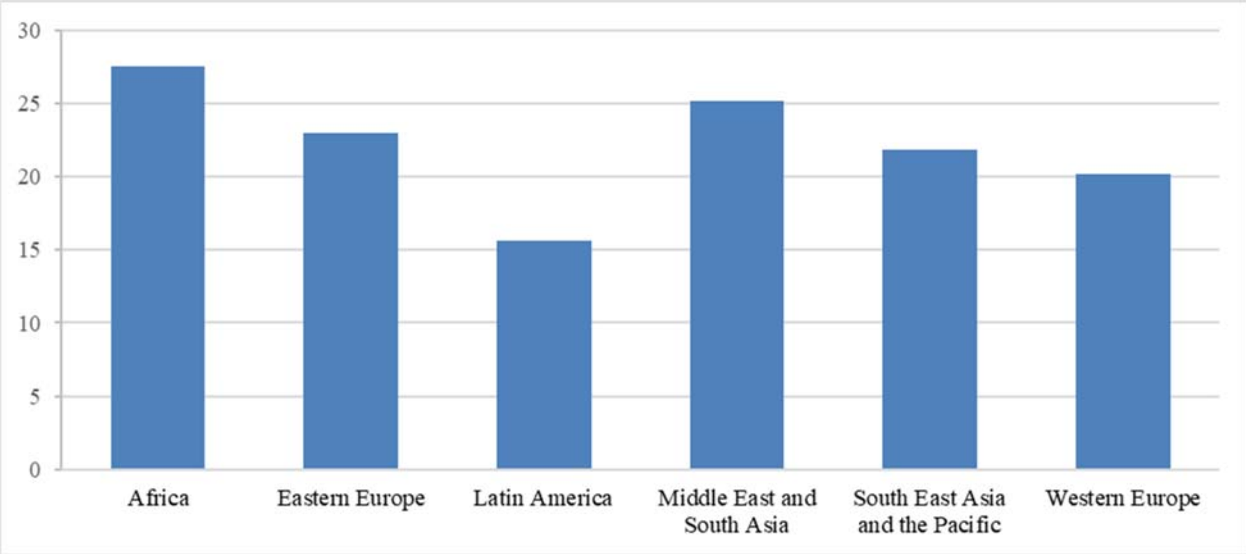

FIG. 3. Number of recommendations per INSARR mission by geographical region.

Figure 4 shows the number (percentage) of recommendations in a review area over the total number of recommendations in all missions ranked from highest to lowest for the period analysed. Six of the 21 review areas account for about 50% of the recommendations extracted from the mission reports. As shown in Figure 5, these are the following:

- Radiation protection;
- Safety analysis report;
- Conduct of operations;
- Maintenance, periodic testing, and inspections (including ageing management [6]);
- Safety analysis;
- Design.

The highest percentage of recommendations resulted from the reviews of radiation protection, the safety analysis report, and conduct of operations. The main findings identified in these review areas are described in Section 3 and discussed further in Section 4.

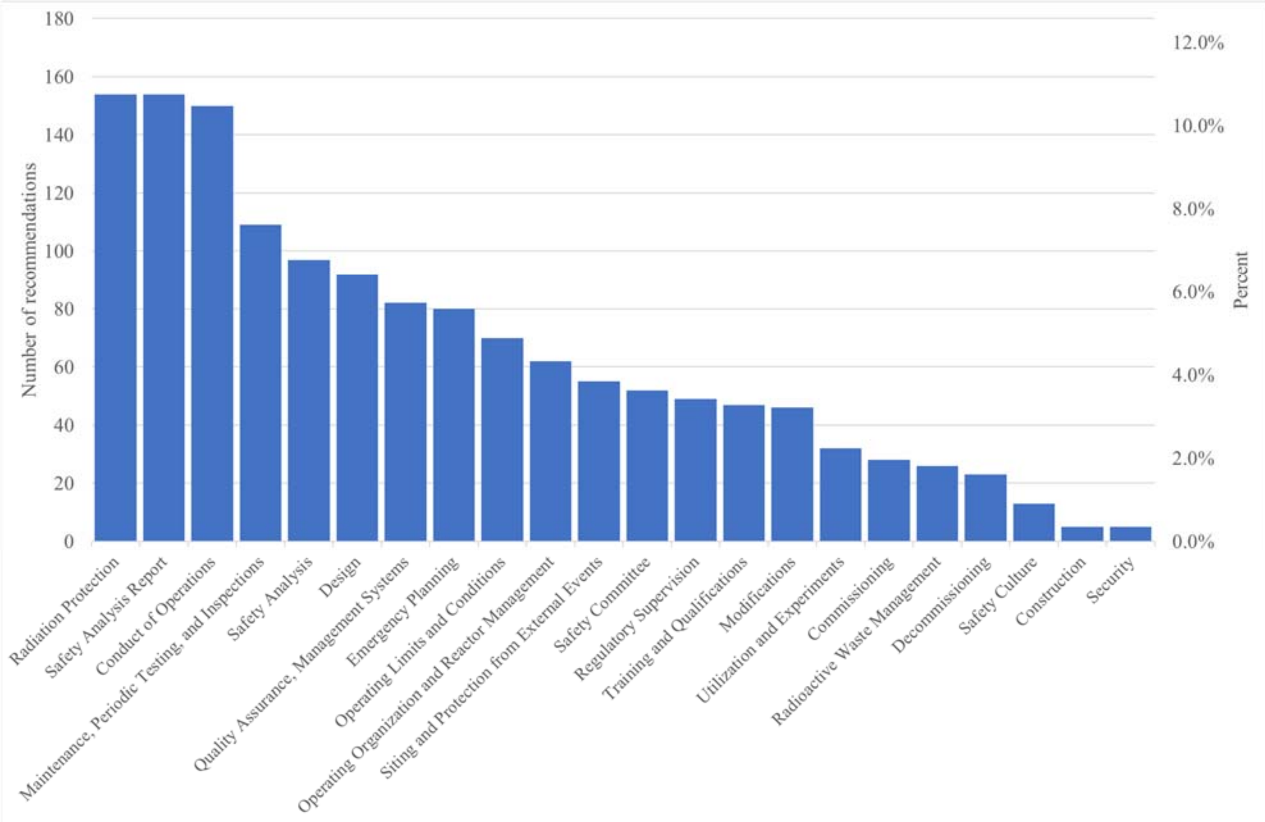

FIG. 4. Distribution of recommendations by review area for the period 1995–2021.

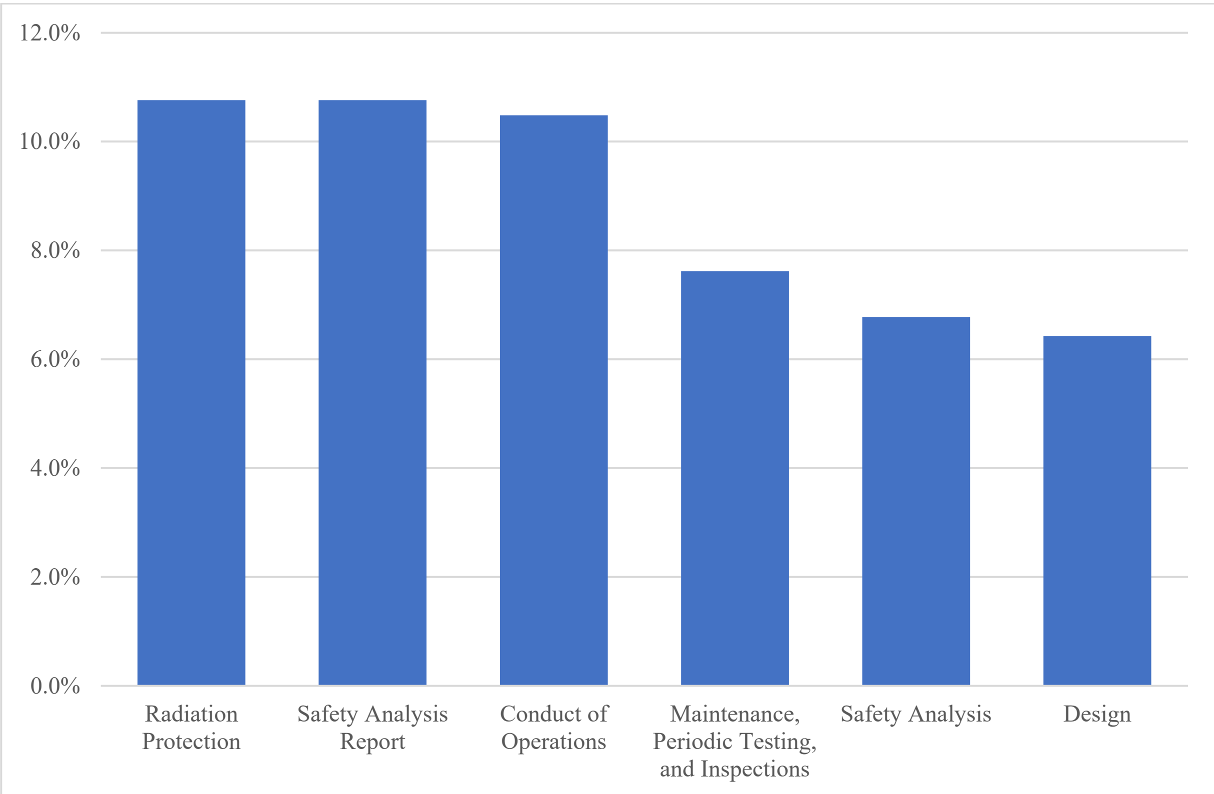

FIG. 5. Top 50 percentile of total INSARR mission recommendations for the period 1995–2021.

The review areas within the scope of an INSARR mission are usually defined by the host organization in conjunction with the mission team leader based on the operational status, stage in the lifetime of the research reactor and priorities of the host organization. Figure 6 shows the number of times a review area was included in the scope of the missions, ranked from highest occurrence to lowest, along with the number of recommendations provided in that area. The subset of the three review areas most commonly included in the scope, namely radiation protection, safety analysis report, and conduct of operations, provided the highest number of recommendations.

Conversely, the subset of the least included review areas, commissioning, safety culture, and construction (selected depending on the stage in the lifetime of the research reactor), provided the lowest number of recommendations. For example, during the review period, a small number of research reactors were under construction and only three missions covered these review areas in the scope of the review. In the aggregate, it may be expected that the total number of recommendations would be generally proportional to the frequency of occurrence of a review area in the mission scope. An exception is the review area ‘Design’, which was only included in 20 of the 62 missions considered in this analysis, but accounts for a disproportionately high number of recommendations. Further examination showed that these results are skewed by a mission that generated a high number of recommendations in the design review area (see Sections 3.2 and 4.2). The siting and protection from external events was another review area that was biased by recommendations from two missions that generated almost 50% of the recommendations in this area.

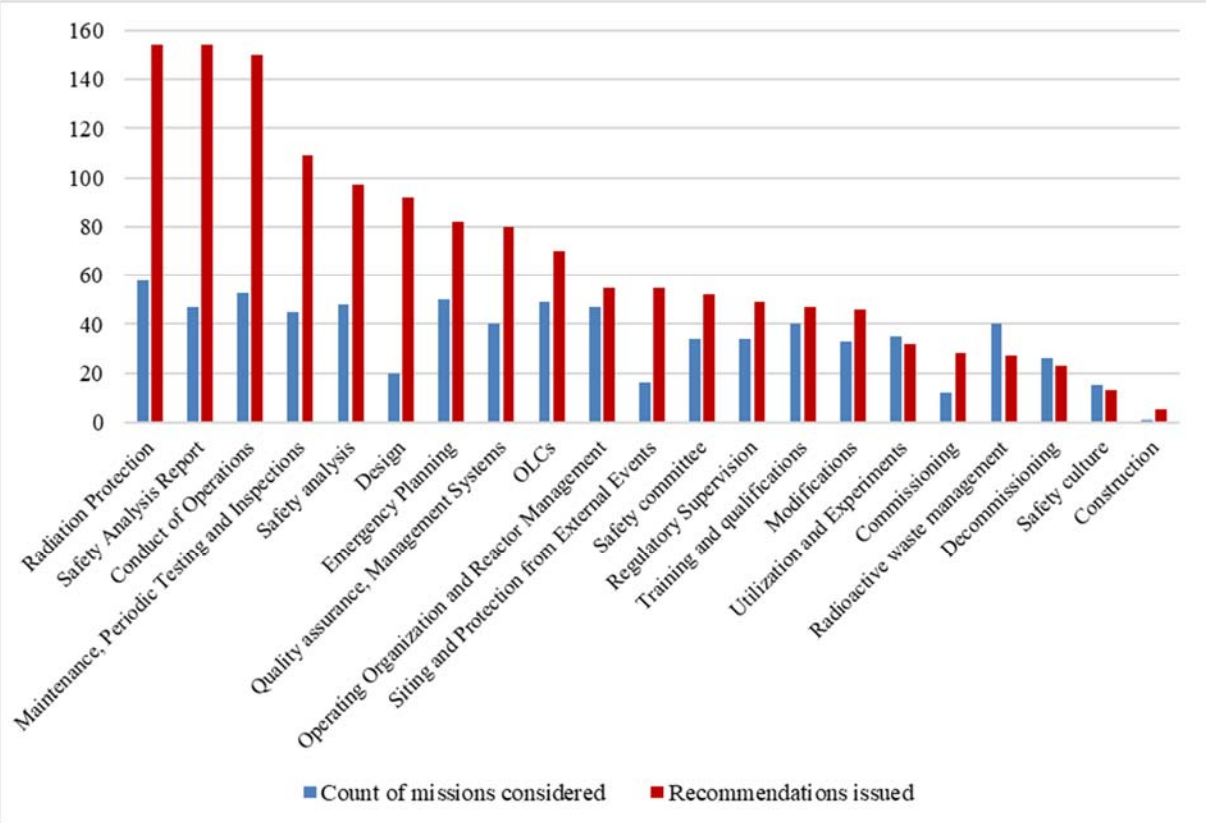

FIG. 6. Review areas considered in missions versus number of recommendations issued.

It would be incorrect to infer from the total number of recommendations in a given review area that the research reactors are not in a satisfactory state for the safe conduct of operations or are poorly prepared to receive an INSARR mission. The total number of recommendations in a safety review area is not considered as a basis for weighing the importance of safety issues in that area.

To examine trends with time, the mission data were grouped into 5-year periods, from 1995 to 2021 (6 years for 2016 to 2021). This allows for comparison between missions conducted in the early period when the INSARR guidance was first published, against those conducted during later periods when the peer review process was mature.

Figure 7 shows the number of mission recommendations for each of the 5-year time periods analysed, for each review area. Several of the review areas (e.g., design, safety analysis report (SAR), operational limits and conditions (OLCs), reactor management, conduct of operations, maintenance, periodic testing, and inspections) show a generally increasing trend with time but the scatter in the data suggests that for most review areas there is no strong correlation of the number of recommendations with time over the period analysed.

In Figure 8, the results are normalized as percentages of the total number of recommendations summed over each 5-year period to show the prominence of a given review area relative to all of the others in a given review period. The highest percentage of recommendations (16%) was found in the radiation protection review area during the period 1995–2000, followed by safety analysis report (15%) in 2006–2010.

The review areas were examined to see if there was an increase in recommendations following revisions of the IAEA safety standards. This is discussed further in Section 4.

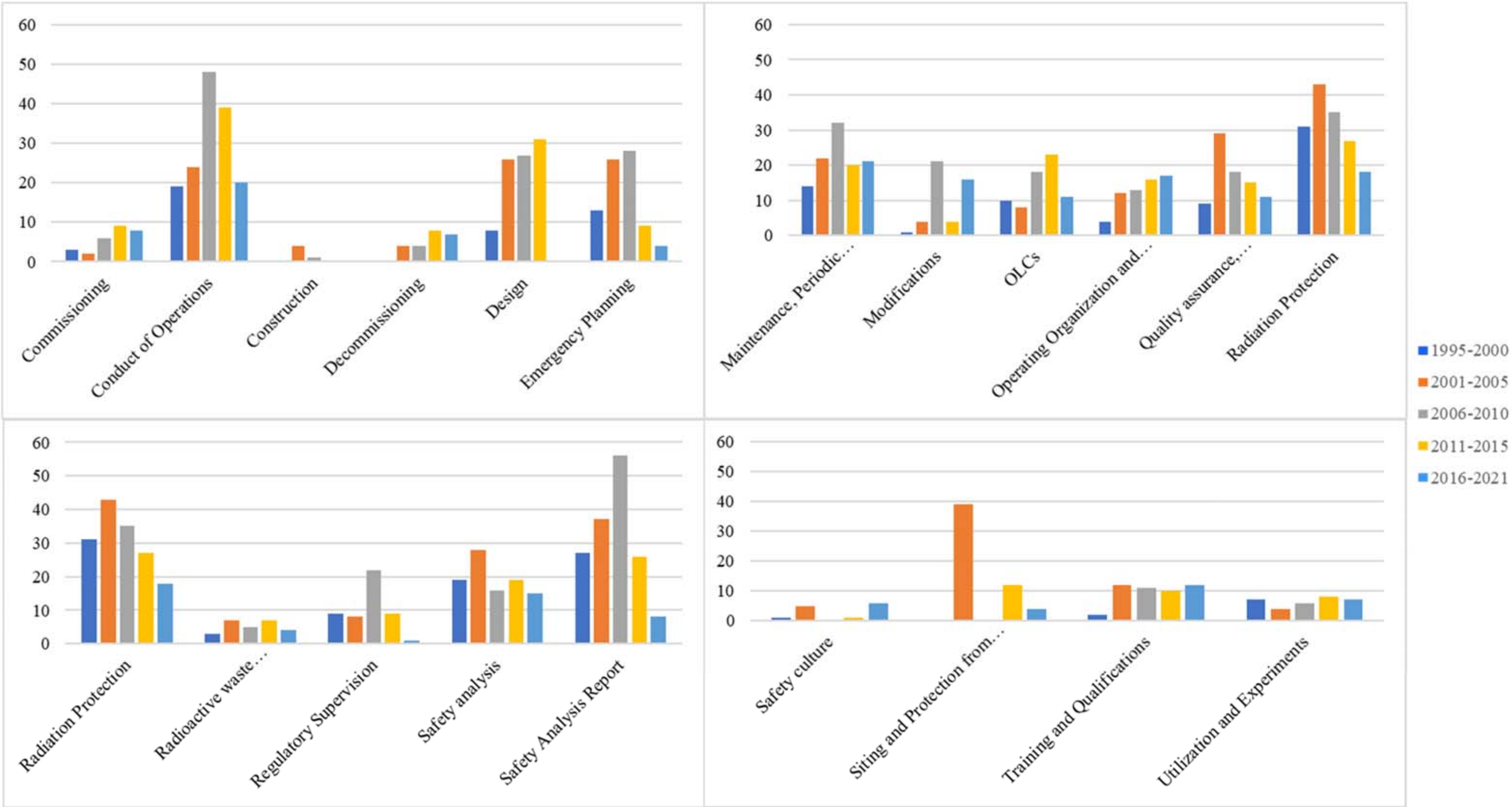

FIG. 7. Number of mission recommendations per review area in 5-year periods from 1995–2015 and 6-year period from 2016–2021.

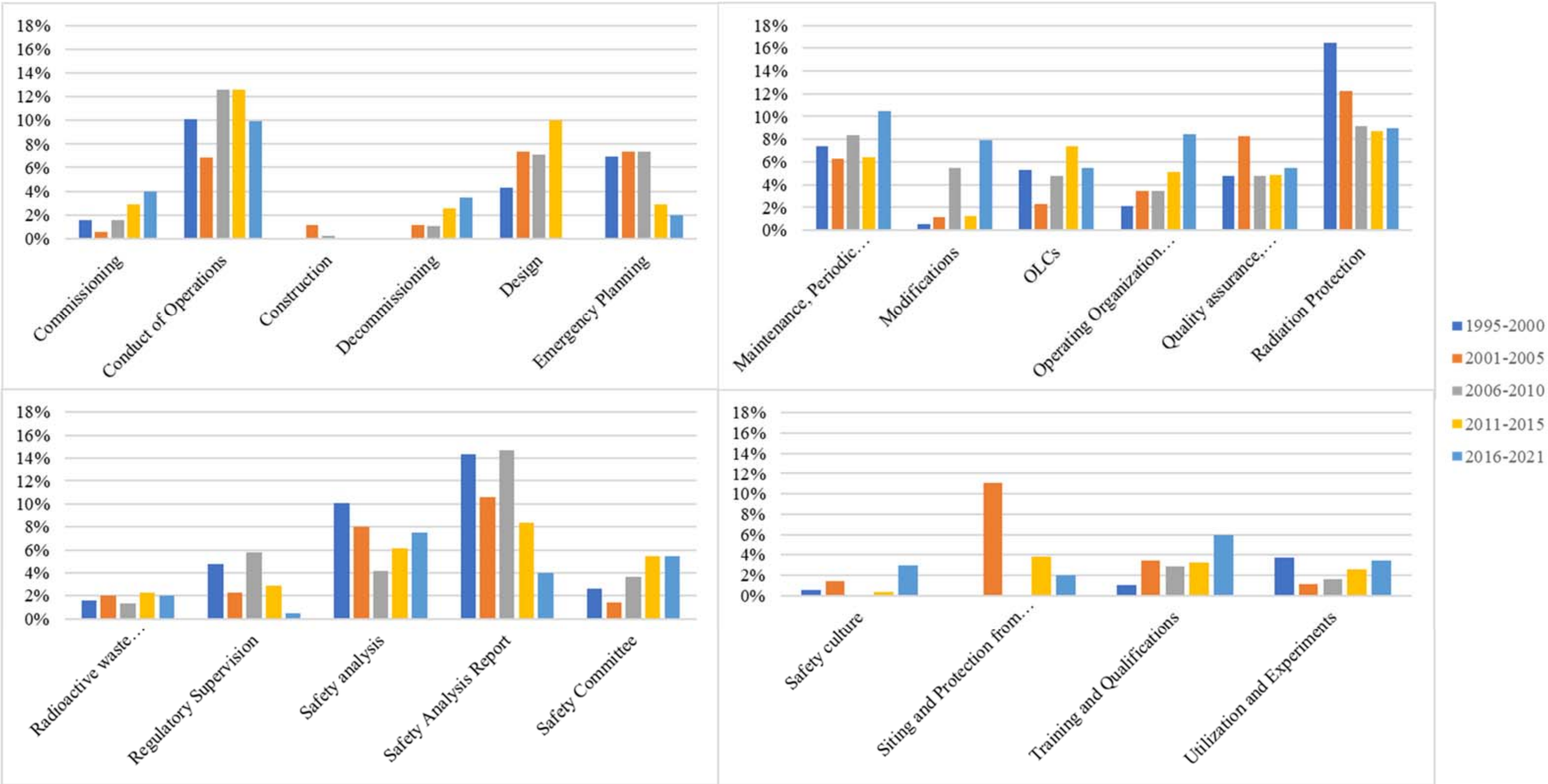

FIG. 8. Percentage of mission recommendations in 5-year periods from 1995–2015 and in six years from 2016–2021.

3. ANALYSIS OF MISSION RESULTS BY REVIEW AREA

This section summarizes the mission results from each review area and highlights the major findings and trends in each review area.

The list of review areas is given in Section 2.2. Each review area covers a broad range of topics, and the recommendations from a mission can likewise touch on several topics. The objective of this section is to review and analyse the mission recommendations, identify common issues and indicate trends that may be relevant across the research reactor community. Each review area was analysed to identify common topics which summarized the focus of the recommendations, and each recommendation was assigned to one or more of the topics that was addressed. These topics are not specifically identified in the review guidelines [1] but were selected to help illustrate the typical findings identified within each review area.

In the subsections below, requirements that pertain to the selected review area are first summarized and then the major findings are highlighted. The summary of requirements is intended to aid the reader and is not exhaustive; see Ref. [1] for details of the requirements considered in each review area. Tables are included to show the topics covered by the recommendations and the assignment of the findings among the topics. As the recommendations cover more than one topic, the distributions shown in the tables may sum to a total that is greater than the number of recommendations in the review area.

3.1. DESIGN

This review area was included in the scope of less than 50% of the INSARR missions. When design is included in the scope, the review team typically examines the overall design safety objective of the research reactor to verify conformance to a variety of requirements including those for radiation protection, the application of defence in depth, design of structures, systems and components (SSCs), internal and external hazards, utilization and modifications, and design provisions for maintenance.

In the 62 missions analysed, the design review area resulted in 92 recommendations. The recommendations address the topics in Table 5, which are presented in turn below.

TABLE 5. DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR DESIGN

Enhancements of safety functions and related SSCs	Radiation protection, and operation and maintenance considerations	Classification and Qualification of SSCs	Provision for utilization and modifications	Design for internal events/external hazards
34	28	26	25	22

3.1.1. Enhancements of safety functions and related SSCs

An important aspect of the review is to verify that the research reactor design is based on defence in depth concepts, that the principles of redundancy, diversity, independence, and fail-safe design are considered in the design, and that multiple layers of protection provide the necessary reliability in the performance of safety functions.

A significant number (34 out of 92) of the recommendations in the design review area were related to the need for additional redundant equipment or systems, improvement in protection of SSCs against internal and external hazards, and the need to address single failure and common cause failure mechanisms. Examples of findings addressed include the following:

- Alarms and monitoring for leaking and/or drainage of the reactor tank;
- Fire hazards and the need for improvement in fire protection;
- Separation of electrical systems;
- Redundant safety channels.

3.1.2. Radiation protection, and operation and maintenance considerations

Adequate provisions need to be made in the design for all operational states and design basis accidents, on the basis of a consistent radiation protection programme. The provisions are reviewed in accordance with the radiation protection objective for shielding, ventilation, filtration, and decay systems for radioactive material, and for monitoring instrumentation for radiation and airborne radioactive material inside and outside the controlled area.

The recommendations on this topic referred to the following:

- The need to improve the design to account for radiation protection, and operation and maintenance issues, including testing of equipment at periodic intervals;
- The need for the installation and testing of charcoal and high efficiency particulate air filters in the emergency ventilation system;
- The need for improvement in information provided to operators and maintenance personnel in various operational states (e.g., normal operation, anticipated operational occurrences) and in accident conditions.

In some cases, the layout of the research reactor needed the application of adequate area classification with physical barriers and checkpoints, including adequately zoned changing rooms and decontamination facilities.

3.1.3. Classification and qualification of Structures Systems and Components

The design review also checks that SSCs and software for instrumentation and control that are important to safety are first specified and then classified according to their function and significance for safety. SSR-3 [3] states (footnote omitted):

> "6.29. The method for classifying the safety significance of items important to safety shall be based primarily on deterministic methods complemented, where appropriate, by probabilistic methods (if available), with due account taken of factors such as:
>
> (a) The safety function(s) to be performed by the item;
> (b) The consequences of failure to perform a safety function;
> (c) The frequency with which the item will be called upon to perform a safety function;
> (d) The time following a postulated initiating event at which, or the period for which, the item will be called upon to perform a safety function.

> 6.30. The design shall be such as to ensure that any interference between items important to safety will be prevented, and in particular that any failure of items important to safety in a system in a lower safety class will not propagate to a system in a higher safety class."

Paragraph 6.32 of SSR-3 [3] states that "The basis for the safety classification of the structures, systems and components shall be stated and the design requirements shall be applied in accordance with their safety classification."

The missions resulted in several recommendations regarding the adequate classification and qualifications of SSCs, mainly because of a lack of evidence for:

- Proper safety classification and suitable qualification of SSCs;
- Adequate analysis to support the intended safety function(s) of SSCs;
- Seismic classification and/or qualification of SSCs.

3.1.4. Provision for utilization and modifications

To ensure that the configuration of the reactor is known at all times, special precautions are needed in design [3] regarding the safe utilization and modification of the research reactor. The refurbishment and modifications of research reactors or new designs which may be necessary to mitigate the consequences of accidents also need special attention. In the reviewed research reactors, most of the recommendations on this topic addressed the need for:

- Modernization and refurbishment of the instrumentation and control system;
- Replacement of failed or aged components;
- Improvement in fire protection.

3.1.5. Design for internal events and external hazards

An analysis of the postulated initiating events is needed to establish all the internal events and external hazards that could affect the safety of the research reactor. Recommendations on this topic mostly referred to the need to:

- Include equipment failures or malfunctions to a postulated initiating event, as appropriate;
- Determine the design basis for natural and human induced external events;
- Consider those events that have been identified in the site evaluation;
- Improve seismic resistance and fire safety provisions.

Seismic issues have been identified as a major contributor for this category and the lessons from the Fukushima Daiichi NPS accident have been addressed in recent missions.

3.2. SAFETY ANALYSIS

Requirement 41 of SSR-3 [3] states:

> **"A safety analysis of the design for a research reactor facility shall be conducted in which methods of deterministic analysis and complementary probabilistic analysis as appropriate shall be applied to enable the challenges to safety in all facility states to be evaluated and assessed."**

The safety analysis of a research reactor is reviewed to ensure that the analysis covers the response of the reactor to a range of postulated initiating events (PIEs) that could progress either to anticipated operational occurrences or to accident conditions. Such events include malfunctions or failures of equipment, operator (human) errors, special internal events, and external events. The review also checks that the safety analysis demonstrates the adequacy of the design of items important to safety and the selection of the OLCs for the reactor. The guidance on safety analysis in Ref. [4] or its predecessor publication was considered during the missions.

In the missions analysed, there were 97 recommendations in the review area 'safety analysis'. The recommendations pertaining to safety analysis were distributed among several topics as shown in Table 6.

TABLE 6. DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR SAFETY ANALYSIS

Validity of analysis	Incomplete analysis	Coherence with standards	Re-analysis for new systems	Miscellaneous	Periodic safety review
47	49	17	6	6	5

3.2.1. Validity of analysis

A large number of recommendations addressed the validity of analysis and coherence with the IAEA safety standards. These recommendations deal with:

- Validation of calculation tools;
- Treatment of uncertainties;
- Interpretation of results;
- Assumptions in modelling;
- Independent review process;
- Conservatism in the analysis.

3.2.2. Incomplete analysis

The largest number of recommendations indicated that the safety analysis was incomplete because important PIEs were omitted, or the PIEs considered were not appropriate for the research reactor. Examples of omitted PIEs noted in recommendations include:

- Heavy objects falling into the core;
- Loss of offsite power;
- Loss of flow, loss of cooling;
- Reactivity insertion transients;
- Fire hazards.

Some recommendations addressed the need to take into account DEC and combinations of events in the safety analysis considering the lesson learned from the Fukushima Daiichi NPS accident. Other recommendations focused on the need for fire hazard analysis, including a verification of suitability of fire detector locations for ensuring early detection of fire.

The recommendations highlighted that at some research reactors:

- The consequences of accident sequences following PIEs were not comprehensively analysed. Specific examples identified were incomplete or inadequate grouping of PIEs into categories, identification of the limiting PIE, description of the event sequences, the corresponding assessment and analysis of the consequences, and comparison against acceptance criteria;
- The neutronic and/or thermal hydraulic calculations were absent, incomplete, or outdated. The reason in some cases was the lack of available human resources to complete an analysis to the level necessary for a final safety analysis;
- The seismic and fire hazard analysis needed to be more comprehensive.

3.2.3. Coherence with the IAEA safety standards

Several missions noted differences between the safety analysis performed and the requirements and/or guidance provided by the IAEA safety standards which resulted in a recommendation to update the safety analysis.

3.2.4. Re-analysis for new systems and configurations

The recommendations on this topic addressed the need for:

- Analysis of the adequacy of the biological shielding;
- Analysis of the effect of a new experiment on reactor safety, including for example, consideration of new PIEs from the interaction of a new cold neutron source with the reactor;
- Analysis to support core conversions from high enriched uranium to low enriched uranium fuel.

3.2.5. Periodic safety review and miscellaneous

A few of the mission recommendations were related to the need to conduct a periodic safety review. Many of the research reactors that were reviewed during the analysed period did not perform periodic safety reviews. The reason for the low number of recommendations on periodic safety review might be that Ref. [1] does not mention periodic safety review under the guidance for reviewing safety analysis.

A few recommendations referred to specific and unique aspects of the safety analysis of the research reactor and were categorized as miscellaneous, for example, application of design rules and qualification of safety related equipment.

3.3. SAFETY ANALYSIS REPORT

Requirement 1 of SSR-3 [3] states that **"…The safety analysis report shall provide a justification of the site and the design and shall provide a basis for the safe operation of the research reactor."**

Further, para. 3.6 of SSR-3 [3] states:

> "The safety analysis report is one of the main documents for the authorization of the research reactor facility and an important link between the operating organization and the regulatory body. The safety analysis report shall contain a

detailed description of the reactor site, the reactor facility and experimental devices, and shall include all other facilities and activities with safety significance...”

The information in the safety analysis report (SAR) is used to demonstrate that the operating organization has achieved adequate safety for the research reactor. Additionally, the regulatory decision on licensing the research reactor and the criteria against which it is licensed and inspected are based on the information in the SAR. Depending upon the particular legal and regulatory system applied, the content of the SAR may differ among Member States.

The SAR is generally regarded as the most important licensing document detailing the safety of the reactor. Hence, it is important that the actual conditions of the reactor, including installed equipment and modifications, are reflected in the document so that the current status of the reactor’s safety is correctly represented.

An example of the content of the SAR according to the IAEA safety standards is presented in Ref. [4]. The amount of information in the SAR needs to be appropriate for the stage of the licensing process and commensurate with the potential hazard associated with the research reactor.

There were 153 recommendations on the SAR indicating gaps and deficiencies related to the topics listed in Table 7. It is worth noting that there was some overlap between recommendations in some topics, for example, where the SAR was incomplete there was also a need to update the SAR, or a need to update the SAR for coherence with the relevant IAEA safety standards [4]. These findings are analysed further below.

TABLE 7. DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR SAFETY ANALYSIS REPORT

Incomplete	Need to be updated	Coherence with IAEA safety standards	Errors and omissions	Self-consistency
95	50	47	12	9

3.3.1. Incomplete

While the bulk of the work done to develop a SAR will usually occur early in the lifetime of a research reactor, maintaining a current and valid SAR needs updates throughout the lifetime of the research reactor, to reflect changes in, or modifications to, the facility, its utilization and external factors that affect the safety case and that change with time. While the SAR might not contain a complete and detailed analysis of safety issues, it needs to provide a summarized description of all relevant analyses, sufficient to convey the important components of the safety case. If a part of the safety analysis is missing, then the SAR does not demonstrate the necessary safety provisions in this part, and it is considered incomplete.

Some SARs were reviewed as being incomplete when assessed against IAEA safety standards which had been developed after the particular SAR was first written. In such cases, it was recommended that the operating organization update the SAR so that the content is complete. The main findings regarding the SARs being incomplete were:

- Missing analysis: In some cases, important analyses were missing from the SAR. Examples include: (a) neutronic and thermal-hydraulic analyses under certain conditions to demonstrate adequate safety; (b) identification of all relevant PIEs and a summary of the associated analyses; (c) adding, modifying, or justifying input conditions for analyses; (d) taking account of human errors and human factors that can affect the safety analysis.
- Missing or incomplete sections: In some cases, whole chapters, or parts of chapters of the SAR were missing. Reference [4] provides a recommended structure for SARs, and while it is recognized that some SARs were developed prior to the structure being accepted by the IAEA Member States, the content of any SAR is expected to be consistent with this structure and to be sufficient to address the established requirements for content in terms of describing the issues relevant to safety of the research reactor. Examples of missing sections include: (a) missing OLCs; (b) incomplete descriptions of modifications and descriptions of how the radiological provisions are implemented (e.g., zoning, shielding, radiation monitoring, etc.) to reduce exposure to personnel; and (c) incomplete descriptions of measures to minimize the undesired production of radioactive material and generally maintain releases of radioactive material to the environment as low as reasonably achievable.
- In several cases, there were omissions or inconsistencies. The recommendations addressed findings such as the need to: (a) provide a summary of the commissioning results; (b) include as-built drawings and missing information on the experimental devices and utilization programme; and (c) update and correct references in an updated version of the SAR.

It was recognized in several recommendations that the ability to undertake detailed calculations and associated analyses can be limited in some operating organizations and this might have contributed to the incompleteness of documentation for some research reactors.

3.3.2. Need to be updated

Many recommendations pointed to deficiencies in the SARs that were associated with the need to update the document. SARs need to be updated to reflect changes in the research reactor in order to be compliant with current regulations and in accordance with the IAEA safety standards. Several recommendations noted that the SAR and other safety documents did not reflect physical modifications that had been made to the research reactor or changes that had been made to safety case assumptions and associated calculations. Some examples include changes to the I&C system; a new fire protection system; conversion to and use of LEU fuel; incorporation of a more realistic dispersion model for potential radioactive releases; and references to the latest operating and maintenance procedures.

A small number of recommendations referred to external factors which necessitated a change in the analysis, including changes of the surrounding environment.

3.3.3. Coherence with IAEA safety standards

Many research reactors were constructed decades ago, and the safety documents developed at the time are not fully in conformance with current IAEA safety standards. Most of the recommendations on coherence with standards are general in nature, mentioning that the SAR and its content needs to be revised in accordance with or be made coherent with the IAEA safety standards [4].

3.3.4. Errors and omissions

Some recommendations referred to errors including omissions of important quantities – for example omission of the liquid discharge limits stipulated by regulatory documents. Other recommendations in this topic referred to typographical errors, imprecise language, or quantitative errors which needed to be rectified.

3.3.5. Self-consistency

A small number of recommendations referred to the need to address self-consistency discrepancies in technical data or to resolve differences in the text within the SAR, between chapters of the SAR, or between the SAR and other documents.

3.4. CONSTRUCTION

Research reactors involve a substantial investment and despite the long-term benefits, the number of new reactors constructed over the past 20 years has been small. During that period, there were three INSARR missions that addressed construction, and one of those was conducted following an extended shutdown of an existing reactor. The requirements on construction in NS-R-4, which preceded SSR-3 [3], were considered during the missions.

There were 5 recommendations pertaining to the topics shown in Table 8.

TABLE 8. DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR CONSTRUCTION

Conformance and compliance	Electrical power
4	1

The main recommendations on conformance and compliance were related to codes and standards of systems and structures relevant to the safety analysis. For example, some materials used in a research reactor were not covered by codes and standards. It was recommended that changes in material properties over the lifetime of the structures subjected to a high neutron fluence be given careful consideration.

The recommendation on electrical power pertained to the need to connect the communication and alarm system to an uninterruptable power supply.

3.5. COMMISSIONING

Commissioning is an important stage in the lifetime of a research reactor. A commissioning programme needs to be established and implemented to demonstrate that the design requirements stated in the SAR have been met in accordance with the recommendations on commissioning of research reactors [7]. This defines the basis of all commissioning aspects, including the commissioning of major modifications of the research reactor and new experiments with major safety significance.

The commissioning programme needs to be comprehensive and cover all anticipated operational modes of the reactor, including fuel loading and initial criticality, planned core configurations and experiments, as well as their safety justifications and associated limitations. Organizational arrangements need to be established for the implementation of the commissioning programme, including the definition of roles and responsibilities of the personnel involved. The operating organization needs to update the SAR to integrate the commissioning results and conclusions.

There were 26 recommendations on commissioning. The recommendations were distributed as shown in Table 9.

TABLE 9. DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR COMMISSIONING

Commissioning programme	Implementation
14	16

3.5.1. Commissioning programme

The gaps identified in the commissioning programme included the need for coherence with the IAEA safety standards and the need to improve organizational aspects as follows:

- Coherence with the IAEA safety standards: Recommendations related to this topic addressed the need to improve the completeness and comprehensiveness of the commissioning programme, the justification of the information in this programme, the development of procedures for core loading and procedures for other commissioning tests.

- Organization: The recommendations on organizational safety were related to the need for defining the responsibilities of personnel participating in the hot commissioning and the need for indicating the different tasks to be achieved, with their priorities, as well as the operating procedures to be established and the actions and tests to be performed before fuel loading. For example, before fuel loading, operating procedures for the initial criticality should be prepared and an exercise to test the implementation of the emergency plan should be performed.

Other findings were related to the need to update the work plan, to the lack of integration of commissioning results in the safety documents, and the need to submit the commissioning programme to the regulatory body for review and approval.

3.5.2. Implementation

The findings related to implementation of the commission programme include the following:

- Fuel loading and measurements: The recommendations for this topic included the need for defining the pattern of loading of each fuel element and for testing the shutdown system before fuel loading.

- Commissioning results: The results of the missions show the need to summarize and incorporate commissioning results in an updated version of the SAR and, if necessary (e.g., when there are conditions with a potential impact on safety), submit them to the regulatory body for review and approval prior to their incorporation in the SAR. These results also show the need to address and correct observed non-conformances.

3.6. SITING AND PROTECTION AGAINST EXTERNAL EVENTS

The protection of the public and the environment against the radiological consequences of releases of radioactive material during normal and accident conditions needs to be recognized prior to choosing the site. This is demonstrated through the licensing and approval process and maintained during the operational and decommissioning phases of the research reactor lifetime. Therefore, the selection and justification of a site for a research reactor is an important consideration. The guidance on siting in Refs [8, 9] was considered during the missions.

There were 55 recommendations on siting. These recommendations pertained to the topics in Table 10.

TABLE 10. DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR SITING

Seismic events	Other external events	Environment	Internal events	Population and land use
39	23	21	9	7

3.6.1. Seismic events

Seismic events are one of the most important external events which need to be considered in the safety case of a research reactor. Items important to safety need to be designed to withstand a seismic event within the design basis such that the research reactor will be maintained in a safe state. Evaluations are to be undertaken during and after construction to demonstrate that the seismically qualified SSCs meet the seismic design requirements. Over the lifetime of the research reactor, the protection from seismic events is required to be maintained as changes are made to the research reactor, or updates to codes and standards relevant to seismic safety are made.

The recommendations from the missions cover a broad range of issues related to seismic events, including the need to: undertake surface faulting studies; consider lessons learned from the Fukushima Daiichi NPS accident; install seismic detectors and connect them to the reactor protection system; anchor SSCs that are considered important to safety; conduct plant walk-downs to examine for seismic interactions; perform seismic studies for specific SSCs, and global evaluations including seismic reanalysis for existing reactors; consider new protection measures, and carry out calculations and analysis for new reactors.

3.6.2. Other external events

The recommendations show a need to address other external events in the safety analysis and these include issues such as soil erosion and foundation instability, flooding, tsunami, aircraft crashes into the research reactor, missile impacts, extreme weather events and lessons learned from the Fukushima Daiichi NPS accident. Several recommendations referred to the need to undertake a screening analysis for external events.

3.6.3. Environment and population and land use

Some recommendations were made regarding reanalysis for potential releases of radioactivity because of changes in population density close to the site and changes in land use. These recommendations showed a need for analysis or reanalysis of local environmental conditions of air, land, and water, and in some circumstances related to changes in those conditions or related to new information that has become available.

3.6.4. Internal events

The recommendations on internal events related to the protection and anchoring of equipment in the control room and elsewhere to prevent damage to safety systems in case of events that could compromise safety.

3.7. OPERATIONAL LIMITS AND CONDITIONS

Requirement 71 of SSR-3 [3] states that **"The operating organization for a research reactor facility shall ensure that the research reactor is operated in accordance with the operational limits and conditions."**

Paragraph 7.33 of SSR-3 [3] states:

> "The set of operational limits and conditions important to reactor safety, including safety limits, safety system settings, limiting conditions for safe operation, requirements for surveillance, testing and maintenance and administrative requirements, shall be established and submitted to the regulatory body for review and assessment and approval before the commencement of operation."

Paragraph 7.34 of SSR-3 [3] also states:

> "The operational limits and conditions shall be adequately defined, clearly established and appropriately substantiated (e.g., by clearly stating for each operational limits and condition its objective, its applicability and its specification i.e. its specified limit and its basis). The selection of, and the values for, the operational limits and conditions shall be based on the safety analysis, on the reactor design and on aspects relating to the conduct of operations, and shall be demonstrably consistent with the updated safety analysis report, shall reflect the present status of the reactor..."

The guidance on OLCs in Ref. [10] or its predecessor publication was considered during the missions.

There were 71 recommendations on OLCs, pertaining to the topics shown in Table 11.

TABLE 11. DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR OPERATIONAL LIMITS AND CONDITIONS

Revision, updating	Correct values, missing elements	Coherence with standards	Miscellaneous	Need to develop
35	26	16	5	5

3.7.1. Revision, updating

It was found that many of the reviewed research reactors had not updated their SARs and associated OLCs for many years. In many cases the OLCs did not reflect the present status of the reactor as required by the IAEA safety standards. The majority of recommendations were related to the need to update the OLCs to reflect the actual status of the research reactor.

3.7.2. Correct values, missing elements

Several recommendations were related to missing elements such as surveillance or administrative requirements, and incorrect values in the OLCs. This is also linked to lack of coherence with the IAEA safety standards. Conflicting or incorrect values and missing elements are also connected to lapses in updating the SAR.

3.7.3. Coherence with IAEA safety standards

Several recommendations were related to outdated OLCs or to OLCs that were not inline with the current IAEA safety standards.

3.7.4. Miscellaneous

Some recommendations that were linked to OLCs were assigned to this category, such as recommendations to include protective actions in the design of new systems in case OLCs are exceeded, or to include measurement of control and safety rod drop time after changes in core configuration or maintenance work on the control rod drive mechanism.

3.7.5. Need to develop

In some cases, it was found that OLC documents were not available or the OLCs did not reflect the operational status of the research reactor (e.g., extended shutdown) at the time of the review, and the recommendations were to develop the OLCs accordingly.

3.8. SAFETY CULTURE

Only a few Member States requested the inclusion of this review area in the INSARR missions. This could be explained by the availability of a separate IAEA safety review service (ISCA) dedicated to safety culture. The recommendations were mainly related to the need to develop and implement a formal safety culture programme or to enhance specific aspects, including learning from operating experience feedback and knowledge management. However, it was not sufficient to identify the main issues and trends in safety culture at research reactors due to the low number of recommendations. Results and lessons learned from the IAEA Safety Culture review service could be incorporated into future training programmes on conducting INSARR missions. Table 12 shows the distribution of recommendations for this review area.

TABLE 12. DISTRIBUTION OF RECOMMENDATIONS FOR SAFETY CULTURE

Enhance safety culture	Develop and implement safety culture
10	4

3.9. REGULATORY SUPERVISION

The requirements that apply to the regulatory supervision of nuclear facilities are established in Ref. [11]. The review determines whether the research reactor is subjected to independent assessment and inspection and verifies that it operates in compliance with licence requirements. The guidance in Ref. [12] or its predecessor publication was considered during the missions.

There were 48 recommendations in this review area. These recommendations were related to the topics shown in Table 13.

TABLE 13. DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR REGULATORY SUPERVISION

Effectiveness	Licensing and authorization	Inspections	Legal framework	Role and responsibilities
22	14	11	7	3

3.9.1. Effectiveness

The recommendations on this topic were aimed at enhancing the independence and effectiveness of the regulatory body and ensuring the necessary qualified human and financial resources for performing the prescribed duties, including review and assessment of safety submissions, and the conduct of regulatory inspections. Some recommendations highlighted the importance for the regulatory body to follow up on the implementation of the INSARR mission's recommendations.

3.9.2. Licensing and authorization

Some recommendations pointed out the need for establishing a licensing process and defining the responsibilities for licensing in accordance with the IAEA safety standards. Several recommendations addressed the need for clearly documenting the authorization process associated with licensing.

3.9.3. Inspections

Some recommendations addressed the need for the establishment and implementation of a systematic regulatory inspection programme, for preparing regulatory guidance regarding safety assessment and inspections, and for clearly documenting all aspects of the regulatory inspection process including the topics to be covered by the inspections.

With respect to enforcement, a few recommendations addressed the need for documenting and implementing the enforcement process following a graded approach.

3.9.4. Legal framework

In several of the Member States which only have research reactors and not nuclear power reactors, an adequate legal framework was not in place or if in place was not consistent with IAEA safety standards. Several recommendations were related to the need to establish an adequate legal and regulatory framework or to upgrade the existing basis for regulatory supervision of research reactors.

3.9.5. Role and responsibilities

The recommendations on this topic addressed improving the terms of reference of the regulatory body and the definition of its role and responsibility for the control and supervision of research reactor safety.

A common finding was the interaction of the regulatory body with the operating organization. The recommendations on this topic were related to the need for improving the formalization of the communication between the regulatory body and the operating organization. Some recommendations were also related to the need for developing and making guidance available to the applicants on the content and format of documentation to be submitted in support of applications for authorizations.

3.10. SAFETY COMMITTEES

Requirement 6 of SSR-3 [3] states that **"A safety committee (or an advisory group) that is independent from the reactor manager shall be established to advise the operating organization on all the safety aspects of the research reactor".**

Further, para. 4.27 of SSR-3 [3] states:

> "The safety committee (or advisory group) shall advise the operating organization on: (i) the safety assessment of design, commissioning and operational issues; and (ii) relevant aspects of the safety of the reactor and the safety of its utilization. … The list of items that the safety committee is required to consider, provide advice on, or recommend approval of shall also be established."

The terms of reference, functions, authority, and composition of the safety committees need to be documented and submitted to the regulatory body, if requested.

The 52 recommendations related to this review area were distributed between two topics as shown in Table 14.

TABLE 14. DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR SAFETY COMMITTEES

Terms of reference	Effectiveness
38	22

3.10.1. Terms of reference

The INSARR mission recommendations highlighted the need to establish a safety committee in many operating organizations. In many cases, the roles and responsibilities of the safety committees and the list of items to be reviewed by these committees were not consistent with the IAEA safety standards. Common findings include the items listed below:

- Role of the safety committee: Recommendations on this topic addressed the need for clear terms of reference for the safety committees, defining their roles and responsibilities and stating their advisory role in a manner to avoid conflicts with the responsibilities of the research reactor manager.

- List of items to be reviewed: Many recommendations addressed the need to complete the lists of items to be reviewed by the safety committee, or to establish such lists according to the IAEA safety standards. The review by the safety committee needs to cover an annual report concerning the reactor safety performance presented by the reactor manager. In some cases, there was the need to revise the terms of reference of the safety committee to include specific members, to conduct review of the radiological issues and changes in the safety documentation, and to ensure the necessary follow-up on implementation of the safety committee recommendations.

- Competence: Some recommendations addressed the need for improving and strengthening the role and competence of the safety committee through adequate representation of the needed expertise, including reactor operation experience and human performance knowledge, as well as technical competence, covering safety areas related to the design, operation, modification, and utilization of the research reactor.

3.10.2. Effectiveness

Some recommendations emphasized the need for regular and frequent interaction with the senior management of the operating organization regarding findings and suggested actions for safety improvements. Common findings included:

- Independence: Several recommendations addressed the need for improving independence of the safety committees, through the inclusion of external experts.
- Frequency of meetings: Some recommendations addressed the need for increasing the frequency of safety committee meetings and emphasized the need for regular meetings of the safety committee, at least once per year and upon request.

3.11. OPERATING ORGANIZATION AND REACTOR MANAGEMENT

Requirement 68 of SSR-3 [3] states that **"The structure of the operating organization for a research reactor facility and the functions, roles and responsibilities of its personnel shall be established and documented."**

Requirement 2 of SSR-3 [3] states:

> **"The operating organization for a research reactor facility shall have the prime responsibility for the safety of the research reactor over its lifetime, from the beginning of the project for site evaluation, design and construction, commissioning, operation, including utilization and modification, and decommissioning, until its release from regulatory control."**

Effective management is necessary to lead the organization in terms of safety culture, planning of activities, day-to-day operations, and maintenance and effective utilization of the research reactor. The guidance in Ref. [13] or its predecessor publication was considered during the missions.

There were 61 recommendations in this review area, which were related to the topics shown in Table 15.

TABLE 15. DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR OPERATING ORGANIZATION AND REACTOR MANAGEMENT

Structure and responsibilities of the operating organization	Independence /authority	Operating personnel	Additional support personnel	Radiation protection personnel
35	23	16	8	5

3.11.1. Structure and responsibilities of the operating organization

The overarching policies and strategy of the operating organization featured in several recommendations for this topic. There is a need for the operating organization to express an overriding commitment to safety. Recommendations were made to define the functions and responsibilities of roles within the operating organization, often for high level management positions. Several recommendations also addressed the need to improve the structure of the operating organization and update its description in the SAR and other relevant operating documents, including in some cases the need to improve lines of communication between groups within the operating organization.

3.11.2. Independence and authority

The topics of independence and the clarity of roles, and the authority associated with each role, are important items for the operating organization to function properly. Some of the recommendations addressed the independence of the radiation protection group, and the management of the group, independently from reactor operations management.

Recommendations also indicate the need for establishing clear communication channels providing access to the top management by the safety committee, radiation protection, and quality assurance groups.

Other recommendations addressed the same principle of independence, but for the quality assurance group, separating the operations and utilization areas and senior management from operations management to avoid potential lack of quality assurance. Authorization processes, effectiveness in managing operational safety, and potential conflicts of interest were also addressed.

3.11.3. Operating personnel

Recommendations addressed requirements for the operating personnel and the need to maintain adequate financial and human resources for operations, engineering, and maintenance. Many of the recommendations noted personnel shortages and the need to retain or recruit adequately experienced personnel in the discipline where the shortage had been identified.

3.11.4. Additional support personnel

There were several recommendations on personnel necessary in other areas to support the safe operation of the reactor, including for utilization and experiments, safety analysis, safety committee, and financial and human resources.

3.11.5. Radiation protection personnel

Specific recommendations addressed inconsistencies with the requirements for radiation protection personnel, again noting that the independence of the radiation protection group from the reactor operations group is important for operation and safety of the research reactors.

3.12. TRAINING AND QUALIFICATION

Requirement 70 of SSR-3 [3] states that **"The operating organization for a research reactor facility shall ensure that safety related functions are performed by suitably qualified, competent and fit-for-duty personnel."**

Accordingly, only qualified persons are to be entrusted with performing functions important to the safe operation, supervision, and maintenance of a research reactor. For each category of personnel, the organization has the responsibility to develop and maintain an appropriate level of competence through education, experience, and formal training. Suitable training and retraining programmes need to be established for the operating personnel with provision for periodic confirmation of the competence of personnel, especially after an extended absence from authorized duties. The guidance in Ref [13] or its predecessor publication was considered during the missions.

The 47 recommendations analysed from the missions were distributed among the topics shown in Table 16. The topics are analysed further in the following paragraphs. Some of the recommendations are interrelated, for example, in the absence of a training programme it is impossible to obtain evidence of its implementation.

TABLE 16. DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR TRAINING AND QUALIFICATION

Training programme	Organization involvement	Evidence of implementation	Training materials and tools	Miscellaneous
36	5	3	3	5

3.12.1. Training programme

An appropriate training programme needs to be in place in order to develop the training activities necessary to prepare qualified staff to operate, utilize and maintain a research reactor. Three factors describing the main findings during the INSARR missions are analysed and addressed in the recommendations as follows:

- Existence of a training programme: There was no formal evidence that a training programme was in place to ensure that the training activities, training materials, examinations and other activities were being conducted in accordance with the research reactor's requirements. Several recommendations addressed the need for developing and implementing formal training and retraining programmes for reactor personnel, reactor users, and external personnel in accordance with IAEA safety standards [3].
- Adequacy of the training programme: A training programme was available, but it did not ensure that the qualification and skills required to safely operate, utilize, and maintain the reactor were at the appropriate level for all personnel.
- Allocation of responsibilities: Roles and responsibilities were identified as part of the training programme, but the operating organization did not formally allocate specific responsibilities for safety to personnel or provide them with the necessary authority. Therefore, it was unclear if the training was properly implemented.

3.12.2. Organization involvement

Involvement of other areas of the operating organization: The recommendations highlighted a need for the operating organization to support the implementation of the training programme by providing experts or trainers to deliver lectures and/or other forms of training on specific issues, as well as an adequate budget allocated to the related activities. The recommendations also highlighted a need for the operating organization to audit and verify the proper implementation of the training programme, and resources needed.

Involvement of the regulatory body: The regulatory body and the operating organization need to establish a clear process for licensing operating personnel. Recommendations on this topic highlight that the regulatory body needs to be involved in the training process, not by providing support, but rather by auditing the process. Resources need to be allocated within the regulatory body in line with the degree of their involvement in the training process, which may vary from simple witnessing of the training and examination process up to running full examinations of trainees and trainers.

3.12.3. Evidence of implementation

Availability of records of periodic training: In some cases, training programmes were provided by the reactor vendor or prepared by the initial operating personnel and documented according to the operating organization's procedures, but in cases where no evidence of its implementation was documented, it was challenging for the operating organization or the regulatory body to assess the competence of the research reactor personnel.

3.12.4. Training materials and tools

Training materials encompass all the elements required to effectively transfer the necessary knowledge and skills to trainees, including but not limited to textbooks, research reactor documents (i.e., design manuals, SAR, procedures, instructions), and training mock-ups. The recommendations were related to:

- Unavailability of training material: The absence of training material specifically developed for the research reactor and updated to the current design reduces effectiveness of the training programme.
- The need to increase the availability of a variety of training tools specific to the research reactors concerned, such as training mock-ups.

3.12.5. Miscellaneous

This topic accounted for other findings related to training identified during the missions, such as recommending that the operating organization utilizes training support offered by the IAEA or from other sources such as regional centres, scientific visits, and the use of operating experience feedback.

3.13. CONDUCT OF OPERATIONS

The review covers the organizational structure and the manner in which the operating organization conducts the safe operation of the research reactor. This includes verification that operations are conducted according to written procedures, personnel are adequately trained in the use of procedures, records and reports are maintained and housekeeping is acceptable. The review also covers core management and fuel handling; surveillance and periodic verifications; inspection and testing; compliance with OLCs and security aspects. Requirements on these topics established in SSR-3 [3] and guidance in Refs. [10, 14] or the predecessor publications were considered during the missions.

The 150 INSARR mission recommendations related to this review area addressed the topics in Table 17.

TABLE 17. DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR CONDUCT OF OPERATIONS

Operating procedures	Housekeeping	Documentation	Availability of equipment and human resources	Inspection and testing of equipment	Miscellaneous	Surveillance and periodic verifications
73	27	24	21	11	19	12

3.13.1. Operating procedures

The recommendations regarding this topic were mainly related to the need for developing and implementing new operating procedures or for improving and completing the contents of existing operating procedures. Some of the recommendations addressed the training on uses and application of procedures as well as the conformance of operating procedures with the OLCs. Common findings include:

- Existence of and adequacy of procedures: Several recommendations highlighted the need for developing and implementing emergency response procedures related to external event scenarios, including procedures to take actions to avoid reactor core uncovering and procedures to provide a long-term power supply to items important to safety. Some recommendations addressed the need for developing and implementing new operating procedures for normal operating conditions of the reactor. These included the need to address core calculations, core configuration changes, planning and implementation of experiments and modifications, periodic monitoring and control of the water chemical quality, radiological analysis of reactor coolant and liquid effluent storage, periodic radiological monitoring of underground water around the research reactor, periodic testing of the filtration system associated with the reactor ventilation, and fuel handling and loading in the reactor core. Other recommendations on this topic addressed the need to complete and improve the contents of existing procedures. For example, to include the approval of the reactor manager in the procedure for irradiation approval, and to ensure consistency of operating procedures with the OLCs.
- Training on procedures: For example, training of operating personnel on application of the latest revision of procedures before the fuel loading for hot commissioning in the case of a new reactor.
- Compliance with procedures: For example, the need for strict adherence to the procedure prohibiting smoking in the reactor hall was noted.

3.13.2. Housekeeping

The missions include a walkthrough of the research reactor to review the status of SSCs important to safety, to observe the housekeeping and to familiarize the expert team with the research reactor.

Several recommendations showed there is a strong need for improving the housekeeping of research reactors. In many cases, this could be achieved by the removal of unused material such as radioactive and / or flammable material, which were stored for no specific reason in the reactor hall or near SSCs important to safety. Many mission recommendations addressed the need for administrative procedures to be established and implemented for ensuring adequate housekeeping. Other recommendations addressed the need for performing a fire hazard analysis and to distribute the extinguishers accordingly. They also addressed the need for clearly marking emergency doors and exit paths.

- Labelling: Cable labelling was missing in several research reactors and many recommendations addressed the need to develop a labelling system for all research reactor equipment that clearly shows the system, and the component's type and number. All equipment and components including the valves of the coolant system need to be labelled and instructions for their operation need to be developed and made available to operating personnel.

- Fire load minimization: Several recommendations highlighted the need for improving housekeeping with the goal to minimize the combustible loads in order to limit the risk of fire initiation and propagation. Recommendations to develop and enforce procedures with provisions for combustible material control were also documented.

3.13.3. Documentation

These recommendations were related to the following findings:

- Research reactor documentation and drawings: Several recommendations addressed the need to update the drawings of the electrical system, and to create an inventory of the existing data and reports compiled in a reliable database. Others addressed the need to establish a filing system to easily find procedures and work instructions and to have one copy of all reactor documentation including drawings filed in an adequate manner in a dedicated room.
- Spent fuel storage maps: The recommendations addressed the need to establish fuel handling procedures with provisions to ensure clear identification and recording of fuel movements to prevent misplacement of fuel in the core, and to establish a chart depicting the actual core map in the fuel handling area.

3.13.4. Availability of equipment and human resources

These recommendations addressed several findings including:

- Availability or lack of equipment: Some recommendations highlighted the need to review the availability of flashlights for operating personnel in the event of a power outage and to review the adequacy of fixed emergency lighting for the whole research reactor facility. Other recommendations addressed the need to install a pressure measuring device to ensure the monitoring of the negative pressure in the reactor hall, to install aerosol filters and charcoal filters for the duct collecting all air exhausts from the different locations in the reactor building, to increase the number of fire detectors in the electrical room, and to implement an emergency ventilation system for different locations with potential risks of aerosols and iodine release.
- Availability of personnel to perform tasks related to operations: Some recommendations addressed the need to increase the number of operating personnel to comply with the required minimum number of operating personnel in the research reactor during reactor operation. Other recommendations were related to the need to increase the staffing level in the reactor maintenance area and to enhance the competences of the reactor operation division in nuclear calculations to improve core and fuel management.

3.13.5. Inspection and testing of equipment

These recommendations addressed several findings including:

- The need to establish a special periodic inspection of the pool liner internal surface and welded areas as part of the general programme of maintenance, and periodic testing and inspections;
- The need to perform periodic testing of the filtration system of the reactor ventilation;
- The need to measure periodically and at least once a year the control rods drop time.

3.13.6. Surveillance and periodic verification

The recommendations related to surveillance and periodic verification addressed the need for:

- Performing periodic sampling of the pool water using a verified method and calibrated equipment to check the trends in the corrosion process of the cladding and other aluminium components;
- Performing periodic radiological monitoring of the underground water around the research reactor;
- Provisions to be implemented to ensure the continuity of the reactor surveillance during the shutdown period, when the power supply to the reactor console is interrupted and the alarms and indicators are turned off.

3.14. MAINTENANCE AND PERIODIC TESTING

Requirement 77 of SSR 3 [3] states that **“The operating organization for a research reactor facility shall ensure that effective programmes for maintenance, periodic testing and inspection are established and implemented.”**

Paragraph 7.68 of SSR-3 [3] states that:

> “Maintenance (both preventive maintenance and corrective maintenance), periodic testing and inspection shall be conducted to ensure that structures, systems and components are able to function in accordance with the design intent, in compliance with the operational limits and conditions.”

The programmes for maintenance, periodic testing, and inspection of the reactor equipment, especially all items important to safety, need to be documented based on the SAR.

Guidance on meeting the requirements is provided in Ref. [15], which states in para. 5.2 that “Maintenance, periodic testing and inspection conducted on a programmatic basis should be performed following a prepared plan and procedures.”

Further, para. 5.5 of Ref. [15] states:

> “The programme for maintenance, periodic testing and inspection should cover all administrative and technical measures necessary for the performance of maintenance, periodic testing and inspection of the research reactor. The measures include service, overhaul and repair, replacement of parts, testing, calibration, and inspection.”

There were 107 recommendations from this review area, which covered the topics shown on Table 18.

TABLE 18: DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR MAINTENANCE AND PERIODIC TESTING

Development and revision of preventive maintenance plan, programme and procedures	Inspection and surveillance	Need for corrective maintenance	Ageing management	Work permit system	Documents
40	31	25	23	8	3

3.14.1. Development and revision of preventive maintenance plan, programme and procedures

Most of the recommendations regarding this topic were related to:

- The development and effective implementation of a preventive maintenance plan including updated procedures that covers all items important to safety, including experimental devices;
- The need for consistency of the existing plan with the SAR and OLCs, and updates of the plan to reflect the current status of the reactor;
- The need for ensuring quality verification for maintenance activities.

3.14.2. Inspection and surveillance

These recommendations addressed the need for:

- Instrument calibration;
- Operability checks;
- In-service inspection of SSCs;
- Filter efficiency and leak tightness tests;
- Ensuring consistency of periodic testing and inspection procedures with the IAEA safety standards.

3.14.3. Need for corrective maintenance

These recommendations addressed:

- The replacement or repair of failed or aged components;
- The replacement of an entire system (e.g., instrumentation and control system);
- The need for development of a corrective maintenance programme.

3.14.4. Ageing management

Ageing management was also subject to review in many INSARR missions. Although it is a separate programme from maintenance, periodic testing, and inspection, most of the host organizations requested review of the ageing management activities and their interface with maintenance, periodic testing and inspection. Most of the recommendations were related to the urgent need to develop and implement a comprehensive ageing management programme in accordance with SSG-10 [6], and to ensure availability of spare parts for items important to safety.

3.14.5. Work permit system

A few recommendations were related to the need for establishment and implementation of a formal work permit system for maintenance activities.

3.14.6. Documents

Some recommendations were related to the control of documents and keeping records, and the need for summary documents to provide an overview of the results of investigations and updates on system modifications, which could facilitate operating experience feedback and analysing trends in the outcomes of maintenance, and periodic testing and inspections activities.

3.15. MODIFICATIONS

Many research reactors have undergone modifications to upgrade SSCs important to safety, such as the instrumentation and control systems, core conversion, or to install experimental facilities that were not supplied as part of the original design.

Paragraph 7.103 of SSR-3 [3] states that "The reactor manager shall establish a procedure in accordance with accepted engineering practice, for the review and approval of proposals for experiments and modifications and for the control of their performance."

Paragraph 7.106 of SSR-3 [3] also states that "Any modifications made to experimental devices shall be subject to the same procedures for design, operation and approval as were followed for the original experimental device."

The guidance in Ref [16] was considered during the missions.

There were 44 recommendations in this review area. The recommendations addressed the topics shown in Table 19 and are summarized in the following paragraphs.

TABLE 19: DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR MODIFICATIONS

Formal process	Preparation of modifications	Implementation of modifications	Safety documentation update	Conformance with IAEA safety standards
26	8	11	6	2

3.15.1. Formal process

A formal process for preparing, implementing, and commissioning a modification to the reactor is vital for ensuring that all the necessary steps are adequately considered. The recommendations addressed two findings that are relevant in formalizing the process:

- A method for classifying each modification according to its importance to safety;
- A review and approval process commensurate with each level of classification to implement the modification.

3.15.2. Preparation of modifications

A proposed modification needs to be supported by a set of calculations and assessments according to its safety classification, following a graded approach. The recommendations in this group addressed findings at several research reactors relating to:

- The incompleteness or unsuitability of the analyses;
- The training of the personnel to install, operate, utilize, maintain, and decommission the proposed modification.

3.15.3. Implementation of modifications

A modification needs to be implemented and commissioned following a graded approach, according to the safety classification of the modification. The implementation process encompasses the procurement of material and components as well as their manufacturing, installation, commissioning, and utilization. Numerous recommendations addressed:

- Formalization of the implementation process;
- Quality control during the implementation process;
- Scheduling of the implementation process;
- Commissioning aspects of implementing the modification.

3.15.4. Safety documentation update

The set of safety related documentation needs to be updated to include the modification with proper timing in accordance with the implementation process. In particular, the safety analysis needs to be reviewed to account for changes to, or new, conditions with potential impact on safety, such as initiating events introduced by the modification. In several cases, deficiencies in adequately capturing the impact of modifications in the safety analysis and safety documentation led to recommendations to update the documentation.

3.15.5. Conformance with IAEA safety standards

IAEA safety standards (e.g. SSG-24 (Rev. 1) [16]) provide guidance for implementing a formal process for introducing modifications to research reactors. At some research reactors, INSARR recommendations addressed the observation that the process planned or being followed was not in accordance with IAEA safety guidance in Ref. [16].

3.16. UTILIZATION AND EXPERIMENTS

Paragraph 7.100 of SSR-3 [3] states:

> "Proposals for the utilization and modification of the research reactor shall be categorized and relevant criteria for this categorization shall be established. Proposals for utilization and modification shall be categorized either in accordance with the safety significance of the proposal or on the basis of a statement of whether or not the proposed change will put the operation of the reactor outside the operational limits and conditions."

Additionally, para. 7.101 of SSR-3 [3] states that "Utilization and modification projects … having major safety significance … shall be subject to safety analyses and to procedures for design, construction and commissioning that are equivalent to those … for the reactor itself."

The guidance in Ref. [16] was considered during the missions.

There were 31 recommendations in this review area, pertaining to the topics shown in Table 20. These topics are described in the following paragraphs.

TABLE 20: DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR UTILIZATION AND EXPERIMENTS

Formal process	Utilization and implementation	Supporting documentation	Inclusion in the safety analysis, OLC and emergency plan	Conformance with IAEA safety standards
20	7	7	5	4

3.16.1. Formal process

The utilization of the research reactor or the performance of experiments, as well as their review and authorization, need to be managed in a formal process of safety assessment and approval commensurate with their safety significance, in order to proceed in a safe manner using a graded approach.

The recommendations in this group addressed the lack of, or deficiencies in, such a formal process at the research reactor and in the requirements on qualification of personnel responsible for safety evaluation of proposed experiments.

3.16.2. Supporting documentation

New experiments or revised utilization of the research reactor need to be supported by adequate documentation including, but not limited to, properly documented justification, safety assessment, detailed descriptions (e.g., technical description, drawings), operating procedures and instructions, including the establishment of a utilization plan, and a list of materials forbidden to be irradiated in the reactor.

These recommendations addressed observed shortcomings in the completeness of the documentation and, in some cases, in the safety assessments.

3.16.3. Utilization and implementation

Recommendations in this topic addressed observed deficiencies in the process followed to implement and use a new experiment, including:

- The availability of procedures to operate the experiment or device and the adequacy of existing operating procedures;
- Incomplete verification of the adequacy of the design (e.g., instrumentation, supporting equipment) of an experiment;
- Inappropriate use or non-application of standards during design, procurement, manufacturing and installation of a new experiment;
- Insufficient attention to adequate staffing to conduct the experiment safely and/or to personnel training.

3.16.4. Inclusion in the safety analysis, OLC and emergency plan

The research reactor safety analysis, OLCs and the emergency plan need to be reviewed prior to the new experiment or revised utilization of the reactor to ensure that they are up-to-date and address any changes that might result, to ensure that the new experiment or planned utilization is properly bounded by these documents. In some cases, it was recommended that these aspects needed further attention.

3.16.5. Conformance with IAEA safety standards

Safety standards developed by the IAEA (e.g., SSR-3 [3] and SSG-24 (Rev. 1) [16]) provide guidance for the utilization of research reactors. During some INSARR missions, the process planned or being followed was not in accordance with the Agency guidance for utilization and experiments and it was recommended that the relevant guidance be implemented.

3.17. MANAGEMENT SYSTEM

The review focused on verifying that the responsibilities of the operating organization were defined and implemented in accordance with the management system. GSR Part 2 [17] establishes the safety requirements for leadership and management for safety.

Quality assurance programmes (QAPs) are an important component of an integrated management system which combines all aspects of managing a research reactor by incorporating safety, health, quality, environment, security, and economic elements into one coherent management system [17]. The review verifies that the operating organization has established and is utilizing a management system for the entire lifetime of the reactor. The guidance in Refs [17, 18] or the predecessor publications were considered during the missions.

There were 79 recommendations pertaining to the management system, grouped into the topics shown in Table 21.

TABLE 21: DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR MANAGEMENT SYSTEM

Detailed sub-programmes	Overall QAP for operation	Conformance to international standards	Implementation	Procedures and reports	QAP for commissioning
28	24	26	4	16	5

3.17.1. Detailed sub-programmes

Recommendations on this topic were broad, covering aspects of the QAP, or sub-programmes such as the development of a preventative maintenance programme, and the establishment of an operating experience feedback programme, including an incident investigation and a root cause analysis programme, which would contain the ability to record non-conformances and corrective actions. Other recommendations addressed the need for training programmes for quality assurance, establishing databases, ensuring that design documentation is available for retrieval and reference as necessary, developing a programme for fire protection, and identifying roles for specific functions.

3.17.2. Overall QAP for operation:

Most of the recommendations for the overall QAP for research reactors addressed:

- The establishment or development of a QAP and the need for the QAP to be consistent with IAEA safety standards;
- Improvements to an existing QAP and to make the QAP consistent with IAEA safety standards.

Establishing a quality assurance programme is a major undertaking which involves significant human resources and effort, and some recommendations made specific reference to the roles and responsibilities necessary to achieve this objective; for example, the recruitment of a quality assurance officer, definition of authority for the QAP, and the need for management commitment for the QAP over the long term operation of the facility.

3.17.3. Conformance to international standards

Recommendations for this topic addressed the need for conformance to international standards, particularly for the classification of SSCs in terms of safety class and quality level. The standards referenced most often were those from the IAEA, with some references to other international standards such as IEEE.

Conformance to national regulations and operating organization procedures were noted in a few recommendations.

3.17.4. Implementation

Recommendations on this topic addressed the need for establishment and implementation of integrated management systems in accordance with IAEA safety standards, for specific activities important to safety. They also addressed the need for improvement and full implementation of existing management systems and quality assurance programmes, and their transition to integrated management systems.

3.17.5. Procedures and reports

Recommendations on this topic ranged from establishing documentation for the overall organization, including procedures for safety, and the authorization conditions associated with the research reactor licence, documentation of processes used to perform work, and the forms used for safety related and maintenance work. Retraining of operators and retraining of personnel on the QAP were noted as important procedures to be documented.

3.17.6. QAP for commissioning

A few recommendations addressed establishing and effectively using a QAP for commissioning of a research reactor facility.

3.18. RADIATION PROTECTION

Requirement 84 of SSR-3 [3] states that **“The operating organization for a research reactor facility shall establish and implement a radiation protection programme.”**

Paragraph 5.1 of SSG-85 [19] states that “The goals of radiation protection are to ensure the effective control of external exposure and internal exposure of workers and of the public, and of releases to the environment, to ensure conformance with all regulatory requirements and to enable further optimization of operational practices.” An operational radiation protection programme is essential to achieving these goals.

The focus of this review area is to assess whether the radiation protection programme achieves these goals commensurate with the hazard potential of the research reactor and in accordance with IAEA safety standards (see SSG-85 [19], GSR Part 3 [20], GSG-7 [21]).

There were 153 recommendations related to radiation protection. These were grouped among the five topics shown in Table 22 and are analysed in the following subsections.

TABLE 22: DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR RADIATION PROTECTION

Radiation protection programme	Instrumentation	Area classification	Miscellaneous	Dosimetry	Conformance to regulations and international standards
69	36	33	23	19	3

3.18.1. Radiation Protection Programme

The main finding regarding this group of recommendations is inadequate development and implementation of the operational radiation protection programme and need to enhance its operational aspects related to documentation, and decontamination of personnel, areas and equipment. With regard to the development of documentation for the operational radiation protection programme, the findings include:

- Inadequate or incomplete procedures;
- Unclear or incomplete radiation protection policies;
- Unclear or lack of formal responsibility for the radiation protection function;
- The need to improve conformance or coherence with applicable regulations or IAEA safety standards;
- The need to complete the assessment of the radiological hazards within the reactor;
- The need for improvements of radiation and contamination monitoring at the workplace and of the environment;
- The need to improve the application of the optimization of protection.

3.18.2. Instrumentation

The main findings in this group included:

- Inappropriate calibration or lack of calibration of instruments according to a formal schedule, including a lack of retention of calibration records;
- Lack of appropriate instruments (i.e., some not available or inoperable), including their measurement ranges, for the abnormal conditions that could be expected at a classified area. This recommendation is particularly relevant for instrumentation for measuring neutron doses;
- Improper location of fixed instrumentation, both in terms of their detector locations as well as the locations of their readouts for providing important information to users of the classified area;
- Outdated instrumentation using obsolete units of measurement, requiring personnel to make complicated mental conversions to obtain the desired units;
- Improvements needed for stack monitors, including their range of measured parameters, appropriate conversion of their measurements to units necessary for emergency response (i.e., derived units), and their seismic stability.

3.18.3. Area classification

Recommendations in this group addressed inadequate, incomplete, or inappropriate measures for:

- Area classification (zoning), with particular attention to inter-area access controls, monitoring and other measures applied;
- Contamination control, including prevention of spread of contamination to other areas and the measures to adequately monitor and decontaminate affected areas or personnel;

- Availability and proper use of personal protection equipment (PPE);
- Area signage, notifications, and the display of parameters (readings) indicating the current radiation and contamination status of a controlled area.

One common finding was the lack of or non-use of appropriate protective equipment and another was the use of the same PPE between radiation and/or contamination zones. Findings relating to improper area classification often necessitated a review of the classification of areas for the entire research reactor, or of the barrier arrangements and controls between areas of different classification. The relatively high number of recommendations for area classification can be attributed in many cases to layout constraints in older research reactors that were built prior to the implementation of modern radiation protection safety standards. In these cases, the recommendations seek to achieve better conformance to the IAEA safety standards without a major redesign of the layout of the research reactor.

3.18.4. Miscellaneous

Several recommendations addressed other findings related to radiation protection, usually specific to a given situation, including:

- The need for additional shielding to reduce dose rates to personnel in a work area;
- A lack of control of access to specific areas in the research reactor;
- A lack of appropriate training of radiation protection personnel and operational personnel on radiation protection and on the use of radiation protection instrumentation (see also 3.13);
- Doses were not well estimated because of missing meteorological data and/or incomplete effluent data.

3.18.5. Dosimetry

Dosimetry findings led to recommendations on the following topics:

- Occupational exposure records were not maintained in accordance with the relevant IAEA safety standards;
- Insufficient dosimeters to adequately equip all personnel working in radiation areas, including neutron dosimeters where necessary;
- Inadequate whole body counting facilities or procedures and policies;
- Inadequate dosimetry procedures and policies.

3.19. RADIOACTIVE WASTE MANAGEMENT

Requirement 85 of SSR-3 [1] states that **"The operating organization for a research reactor facility shall establish and implement a programme for the management of radioactive waste."**

Paragraph 6.3 of [19] states:

> "The programme for the management of radioactive waste at a research reactor needs to include provisions for the following:
>
> (a) Keeping the generation of radioactive gaseous waste to the minimum practicable, in terms of both activity and volume, by using suitable technology;…"

In addition, para. 6.39 of [19] states “The radioactive waste generated by the operation of the research reactor is required to be processed in accordance with written procedures (see para. 7.118 of SSR-3).”

There were 26 recommendations in this review area, summarized in Table 23.

TABLE 23: DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR RADIOACTIVE WASTE MANAGEMENT

Radioactive waste management programme and procedures	Minimization of releases and waste	Handling of waste (housekeeping)
13	9	9

3.19.1. Radioactive waste management programme and procedures

Most of the recommendations of the missions addressed the need for:

- A formal operational waste management programme;
- Detailed procedures for the implementation of the programme, including a procedure for waste characterization and clearance with clearly established criteria.

3.19.2. Minimization of releases and waste

In most research reactors the quantity of solid and liquid waste is very low. In some high-power research reactors, the generation of noble gas (Ar^{41}) can be significant, and monitoring is needed to ensure compliance with authorized limits on release.

The recommendations addressed the need for:

- Clearly defined regulatory limits for radioactive release;
- The need to improve monitoring (e.g., installation of stack monitors) of gaseous release.

3.19.3. Handling of waste (housekeeping)

A few recommendations were related to the need for:

- Adequate storage for waste of various types (place and conditions);
- Proper labelling of waste containers.

3.20. EMERGENCY PLANNING

In this review area, the focus is to “verify that an emergency planning programme exists and that it is implemented through written procedures” [1]. The guidance provided in Refs [22, 23] or the predecessor publications were also considered during the missions.

There were 81 recommendations in this review area. These were grouped according to the topics listed in Table 24 and are detailed in the following paragraphs.

TABLE 24: DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR EMERGENCY PLANNING

Emergency plan suitability	Availability of resources	Drills, exercises and training	Conformance with IAEA safety standards	Supporting documentation	Organizational arrangements
33	26	15	10	9	7

3.20.1. Emergency plan suitability

A suitable emergency plan ensures that all aspects of the emergency situations identified for the research reactor are provided for and properly addressed in the plan and in the emergency response procedures. The recommendations in this group suggest that some of the research reactors reviewed were not as prepared for emergencies as they could be and improvements were recommended. The recommendations pertained mainly to deficiencies in addressing the following:

- Availability of procedures: A complete set of procedures developed for all the emergency situations identified for the research reactor needs to be readily available for the research reactor personnel. Procedures need to also cover the utilization of PPE, the conduct of exercises, and the maintenance of equipment essential to emergency response;
- Consideration of all relevant scenarios: The scenarios resulting from abnormal occurrences need to be categorized in order to facilitate the identification and the initiation of appropriate mitigatory actions. The scenarios include all the sequences identified in the safety analysis of the research reactor;
- Radiation pathways: All the radiation pathways need to be considered in the development of the protective actions and mitigatory actions;
- Outdated procedures: Outdated procedures need to be removed from the research reactor in order to prevent improper implementation of emergency preparedness measures.

3.20.2. Availability of resources

The effectiveness of the emergency plan depends on the availability of resources. Recommendations in this regard included addressing the need for improvements in the following:

- Availability of equipment: The need to ensure that appropriate, dedicated equipment for emergency scenarios (i.e., independent from equipment intended for routine use) is available and in working condition (e.g., charged, calibrated, properly maintained).
- Availability of personnel: The need to ensure that adequately trained personnel are available to execute the procedures and/or direct the emergency response.
- Equipment that needs to be replaced or relocated: At some research reactors, some items of emergency equipment were found to be improperly located for effective use under certain abnormal scenarios.

3.20.3. Drills, exercises and training

Periodic drills and exercises need to be performed in order to complement the training as well as refresh skills and test for possible updates or improvements for procedures and instructions. Research reactor personnel need to also be trained and periodically retrained on how the abnormal scenarios provided for in the emergency plan were derived, on their unmitigated consequences, and the importance of the mitigatory actions provided for in the emergency response procedures.

Recommendations included the need for training, exercises, and drills to include postulated accident conditions to ensure that operating personnel are adequately prepared.

3.20.4. Conformance with IAEA safety standards

Conformance with the requirements established in GSR Part 7 [22] and the guidance presented in other IAEA publications was recommended. Due to the diverse nature of all possible emergencies in a research reactor, adherence to local regulations on issues such as fire prevention by minimization of the fire load, and response was also encouraged in some recommendations.

3.20.5. Organizational arrangements

The operating organization needs to ensure the organizational arrangements include the availability of adequate resources to implement the emergency plan. The recommendations addressed deficiencies observed in the following:

- Organizational framework: The research reactor emergency plan needs to be aligned with the site infrastructure and site practices, taking account of both the advantages and the constraints of these factors in the effective implementation of the emergency plan. On-site emergency response groups need to also be aware of the research reactor emergency response procedures and requirements.
- External organizations: Coordination with external organizations tasked with supporting the off-site emergency response during an emergency needs to be properly managed.

3.20.6. Supporting documentation

Several documents need to be available in order to support the emergency plan. Among those identified in recommendations as needing improvement are the following:

- Results of drills and exercises: Well documented results of drills and exercises previously performed at the research reactor are a valuable source of information on the effectiveness of the emergency arrangements as well as on areas for improvement.
- Signage: The lack of appropriate signs (visual and audible) might impair the effectiveness of the emergency arrangements.
- Calculation of consequences: Pre-calculated scenarios are a valuable tool for categorizing abnormal scenarios, as well as identifying preventive and mitigatory actions and the time scales in which to implement them.
- List of responsibilities: Responsibilities need to be clearly allocated and lines of delegation clearly defined. This is particularly important where the intervention and safety of on-site and off-site response teams that are not part of the reactor personnel need to be coordinated.

3.21. DECOMMISSIONING

A decommissioning plan is required for the decommissioning process. Paragraph 8.4 of SSR-3 [3] states that "The decommissioning plan shall include an evaluation of one or more approaches to decommissioning that are appropriate for the reactor concerned and are in compliance with the requirements of the regulatory body."

Safety considerations for reactors in extended shutdown were also considered [24].

The missions focus on the availability and quality of the decommissioning plan, which could be one chapter of the SAR and needs to be revised periodically together with the SAR.

There were 23 recommendations in this review area, as shown in Table 25.

TABLE 25: DISTRIBUTION OF RECOMMENDATIONS BY TOPIC FOR DECOMMISSIONING

Decommissioning plan (development, review)	Coherence with IAEA safety standards	Spent fuel storage and repatriation
20	5	1

3.21.1. Decommissioning plan (development, review)

Most of the recommendations in this category addressed the need for:

- Development of the decommissioning plan with one or more approaches to decommissioning;
- Periodic updating of the decommissioning plan together with revision of the SAR.

3.21.2. Coherence with IAEA safety standards

The recommendations emphasized that the development of the decommissioning plan needs to be made in accordance with the IAEA safety standards.

3.21.3. Spent fuel storage and repatriation

Storage or repatriation of spent fuel is an extremely important issue for many research reactors including conversion from highly enriched uranium to low enriched uranium fuel. The recommendation addressed the need to verify the arrangements for repatriation of spent fuel stored in the research reactor and to develop plans accordingly.

4. DISCUSSION OF RESULTS

4.1. CHANGES OVER TIME

Over the 26-year period of assessment covered in this publication, the IAEA safety standards have evolved and matured. Two IAEA publications, Safety Series No. 35-S1 and No. 35-S2, were originally used as the basis for INSARR missions until 2005, after which they were superseded by NS-R-4 which was in turn superseded by SSR-3 [3] in 2016. The reference guidance publications have also been revised in accordance with the long term structure of the IAEA safety standards; for example, Safety Series No. 35-G1 and No. 35-G2 were superseded by SSG-20 (Rev. 1) [4] and SSG-24 (Rev. 1) [16], respectively. Several review areas of the INSARR have also evolved; for example:

- Ageing management: Previously, this topic was considered in the later stages of the lifetime of a research reactor or when life extension activities were being undertaken, but currently it is considered early in the lifetime of a research reactor, including at the concept design stage for new research reactors.

– Management system: The review focus has shifted from evidence that audits and reviews are conducted to verify the application of quality assurance, to a more complete review of the integrated management system.
– Siting and protection from external events: After the accident at the Fukushima Daiichi NPS in 2011 and the resulting worldwide focus on safety reassessments, the subsequent reviews in this area look for protection against extreme external events, including events in combination and consequential events, replacing the concept of beyond design basis accident with DEC.
– Radiation protection: The review has shifted from the legal and operational practices in radiation protection and as-low-as-reasonably-achievable concept in the early period first to a focus on systems to assess, manage, and control exposure to radiation and later to measures for the optimization of protection in keeping with the 2014 revision of GSR Part 3 [20].
– Safety culture: This review area is usually covered by a separate review service, but when included in an INSARR mission, the review looks for senior management engagement, accountability throughout all levels of the organization, and evidence of the promotion of a strong culture for safety.

This evolution has obvious impacts on the scope of the INSARR missions and the focus of the recommendations over the two and a half decades considered in this publication. In this regard, if we consider the recent period between 2010 and 2021 during which 30 INSARR missions were conducted in 19 Member States, the distribution per review area of the 517 recommendations resulting from these missions, shown in Figure 9, is significantly different from the one presented in Figure 5 for the period 1995–2021. The findings show the need of research reactor organizations to pay increased attention to leadership and management for safety and to enhancing the operational safety programmes and procedures.

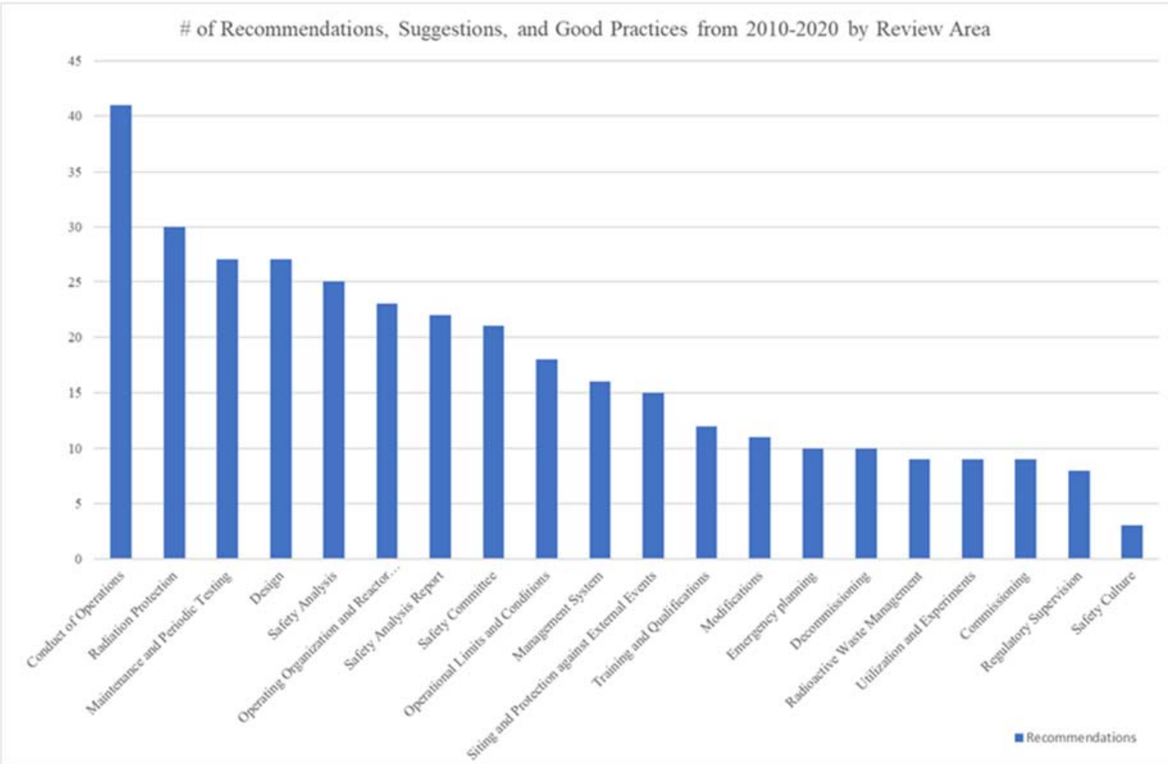

FIG. 9. INSARR mission recommendations from 2010 to 2020 by review area.

These changes over time also complicate the analysis of the INSARR recommendations and make it difficult to compare the results from different missions and to identify trends on the basis of statistics. In this publication, expert judgement is used to complement the statistical analysis and to identify trends from the recommendations.

During the period from 2003 to 2006, the number of recommendations per mission increased significantly (see Figure 2). Subsequently, efforts were made to combine and consolidate recommendations in order to present a more manageable number of recommendations to the host organization. However, as a result of consolidation, many recommendations address more than one topic, and this also makes it difficult to identify trends for a given review area. To address this issue, recommendations where reviewed and, where appropriate, reassigned to a different safety review area where this would better align the safety issue identified with the observations in the mission report.

As presented in Section 2.3, the mission data were grouped into 5-year periods, from 1995 to 2021, to examine trends over time. Some review areas show a generally increasing trend over time (see Figure 6) but the scatter in the data suggests that for most review areas there is no significant difference between the number of recommendations in the early period when the guidance in IAEA Services Series 1 (see footnote 1) was first published compared to the later periods.

4.2. COMMON ISSUES AND TRENDS

The recommendations reported for individual missions indicate areas that needed attention from research reactor organizations. While follow-up INSARR missions have not been analysed in detail in this publication, they are known to have showed significant improvements in many research reactors resulting from the implementation of the recommendations of the initial missions [25, 26]. As presented in Section 2 (see Fig. 5), over 50% of the recommendations were given in six review areas. Although the number of recommendations in a review area does not reflect the importance of safety issues in that area, the data are useful to draw inferences about general characteristics and trends. Some common issues and trends are discussed below, in order of the review areas with the highest number of recommendations.

4.2.1. Safety analysis and safety analysis report

The commonalities and cross-cutting nature of recommendations in the safety analysis and the SAR allow for both review areas to be considered together here. In a typical mission, the chapters on the reactor description and safety analysis of the SAR, are provided several weeks in advance to give the mission team sufficient time to review these documents and the relevant information. This advance preparation allows for a more detailed review, compared to that which might otherwise be conducted during the mission when other review areas are considered, and might result in more recommendations in these areas. Some of the common issues and trends identified in these review areas include:

- Incomplete safety analysis, including omission of relevant PIEs and inadequacies in validation of calculation tools.
- The need to update the safety analysis to take into account lessons learned from the Fukushima Daiichi NPS accident (i.e., the analysis of DECs). It should be noted that DEC analyses were in the scope of INSARR missions after the publication of SSR-3[3] in 2016 which superseded NS-R-4 and included feedback from the Fukushima Daiichi NPS accident.

- Incomplete safety documentation and out-of-date SARs and drawings that do not accurately reflect the current safety status of the research reactor.

4.2.2. Radiation protection

Inadequate area classification (zoning) and contamination control, improper use of PPE, lack of appropriate instruments, and insufficient dosimeters are common findings in this review area. Additional issues identified at several research reactors include:

- Inadequate development and implementation of the operational radiation protection programme;
- Inadequate policies and procedures, and a lack of clear responsibility and communication lines that ensure independency for the radiation protection function (see also the below paragraph on operating organization and reactor management), and inadequate application of optimization of protection;
- Inadequate area classification (zoning) and contamination control, inadequate radiation and contamination monitoring at the workplace and environment, improper use of PPE, and lack of adequate radiation protection instruments.

4.2.3. Conduct of operations

Recommendations regarding the availability of equipment, the inspection and testing of equipment, and the need to update drawings are common in this review area. Some of the issues include:

- The need for developing and implementing new operating procedures including operator response to anticipated operational occurrences, and emergency procedures for external event scenarios;
- The need for financial and qualified human resources;
- The need for training on the application and use of procedures, in compliance with OLCs;
- The need to improve housekeeping and reduce fire loads.

4.2.4. Design

Most of the reactors included in the analysis were designed in the 1950s and 1960s. Usually the original design was extremely conservative, allowing for significant power increase with minor modifications. Many of these designs are well established and may be considered proven. For these reasons it is noted that this area was not included in the scope of many missions. For those that included design, the reviews revealed the need for design improvements to protect SSCs, to prevent common cause failures of several SSCs due to fires and floods, and to adequately account for radiation protection and operation and maintenance issues. Some of the issues identified at research reactors include:

- Inadequate classification and qualification of SSCs, largely due to a lack of evidence of seismic classification and/or qualification, and lack of documentation indicating that SSCs can support their required safety functions;
- Design documents and drawings are not up-to-date, not fully in conformance with current IAEA safety standards, or do not reflect changes made since the initial construction of the research reactor.

4.2.5. Maintenance, periodic testing and inspections, including ageing management

Some research reactors need to develop and implement an effective preventive maintenance plan and update procedures to improve corrective maintenance activities. This includes replacement or repair of failed or aged components and strengthening of inspection and surveillance activities.

Although ageing management is a separate programme from maintenance, periodic testing, and inspection, it was also subject to review in many missions. For many research reactors, the recommendations show an urgent need for developing and implementing a systematic ageing management programme, including screening of SSCs for ageing management review, minimizing ageing degradation, assessing, detecting, and analysing trends in ageing degradation, and applying mitigatory measures.

In some reactors, the lack of information on the design bases and the design calculations creates difficulties in planning modifications to address ageing issues or life extension projects.

4.2.6. Emergency planning

Common findings at some research reactors include:

- The lack of completeness of emergency response procedures;
- The need to improve organizational arrangements involving on-site and off-site personnel during emergencies, and to conduct exercises and drills based on conditions in the SAR.

4.2.7. Management system

The main gaps identified in the missions were related to the adequacy of the overall QAP and sub-programmes such as training on quality assurance, preventive maintenance, incident investigation, root cause analysis, records of non-conformances and corrective actions. Findings regarding conformance to IAEA safety standards, national regulations, and operating organization procedures were commonly cited.

4.2.8. Operational limits and conditions

Many recommendations in this review area highlight the need to revise and update the OLCs to reflect the actual status of the research reactor, to correct erroneous values or include missing data, and to ensure coherence with current safety standards.

4.2.9. Siting and protection against external events

The main issues were related to seismic events and the need to consider the lessons from the Fukushima Daiichi NPS accident, to install seismic detectors, to undertake a screening analysis of external events, and to consider changes in the environment, population density, and land use around the research reactor.

4.2.10. Regulatory supervision

The scope of some missions includes the functions and processes related to research reactors carried out by the national regulatory body, but not the legal and regulatory framework. The recommendations highlight the need to enhance regulatory effectiveness, to establish a regulatory inspection programme, and to ensure sufficient qualified human and financial resources for performing the necessary activities including the review and assessment of safety submissions, and the conduct of effective regulatory inspections.

4.2.11. Safety committee

The recommendations indicate that many research reactors do not have a well-functioning safety committee, and need to improve the terms of reference, roles and responsibilities, effectiveness by increasing the representative specialties of the members, and to follow up on implementation of the recommendations of the committee. In general, the committees' roles and responsibilities need to be clearly identified in accordance with the IAEA safety standards. The safety committees also need to enhance their reporting and follow-up the implementation of their recommendations.

4.2.12. Operating organization and reactor management

In many research reactors there was a need to define and clarify the roles, responsibilities, and authority for key functions within the operating organization, and to ensure the independence of the radiation protection group and the quality assurance group.

4.2.13. Training and qualifications

Many of the recommendations addressed the need for a training plan, for the allocation of responsibilities for training and retraining of personnel, for adequate training tools, and for effective implementation of the training plan.

4.2.14. Modifications, utilization and experiments

Common issues in this review area include the lack of a formal review and approval process, inadequate classification of modifications, the need to update safety documentation to reflect the modifications and experiments. In addition, training operating personnel to install, operate, and safely utilize a modified research reactor, and training experimenters on safety procedures also was identified.

4.2.15. Commissioning

The main issues in this review area were related to the need for a comprehensive commissioning programme, and the need to submit the programme for regulatory approval, to clarify the responsibilities for hot commissioning, to establish actions and tests to be performed before fuel loading, and to incorporate the commissioning results in an updated SAR.

4.2.16. Planning for decommissioning

In many of the research reactors there was a need to establish decommissioning plans in accordance with IAEA safety standards and to periodically update the plans, together with a revision of the SAR.

4.3. OTHER OBSERVATIONS

4.3.1. Topics being addressed by other IAEA review services

Some topics are addressed by other IAEA review services, leading to some review areas that have an insufficient number of recommendations to identify trends or recommendations. However, these are discussed in this subsection. Safety culture is recognized as an important review area, especially considering lessons from the Fukushima Daiichi NPS accident, including the need for a questioning attitude. However, it appears to be under reported in the INSARR mission reports likely because it is covered by other review services provided by the IAEA.

Security is also covered by other IAEA review services. Although security is not identified as a separate review area in the INSARR guidelines, several mission reports included recommendations regarding security where there is an impact on safety or an issue with the interface between safety and security. These recommendations are not included in this publication.

Only three missions covered construction of research reactors and the recommendations are mainly related to the need for SSCs to conform with relevant codes and standards.

Only a few of the missions addressed challenges involving core conversion and the programme for repatriation of spent fuel. This important topic is underrepresented in the mission reports because the IAEA offers a separate service to assist Member States with core conversion activities and the return of spent nuclear fuel to the country of origin.

4.3.2. Feedback from other IAEA activities

The INSARR recommendations are consistent with the results of other IAEA activities on the safety of research reactors, including international and regional meetings on the Code of Conduct on the Safety of Research Reactors [2, 25, 26], expert missions, technical meetings, and workshops. Member States' self-assessments indicated a positive trend in the application of the Code in several areas including: regulatory inspection activities; implementation of processes for periodic safety reviews; refurbishment and modernization for safety improvements (ageing management and continued safe operation). The legal and regulatory framework is out of scope of INSARR missions, but recent IAEA activities show progress in several countries that have issued nuclear laws and initiated drafting of safety regulations for research reactors. However, efforts are still needed in many Member States to ensure effective implementation of the Code's provisions, mainly related to: human and financial resources (operating organizations and regulatory bodies); regulatory effectiveness; establishing and maintaining strong culture for safety; implementing upgrades identified by safety reassessments following the Fukushima-Daiichi NPS accident, including implementation of recently established safety requirements (e.g., for DEC); planning for decommissioning; and decisions regarding the future of the research reactors in extended shutdown.

4.3.3. INSARR recommendations, suggestions and good practices

The INSARR recommendations identify gaps in the application of the IAEA safety standards and provide guidance for improving the safety of research reactors. The mission reports confirm that many research reactors are generally in accordance with safety requirements and good practices have been identified at several research reactors. However, suggestions and good practices are not included in the analysis of the results in this publication. The benefits of INSARR may be seen in follow-up missions where safety improvements are implemented but these are not addressed in this publication.

4.3.4. Regional utilization of INSARR

Most Member States with research reactors utilize the INSARR service but some Member States that have research reactors (see Annex I) have not requested a mission up to the date of preparation of this publication. Several Member States that have not hosted missions have well-developed nuclear infrastructure and regulatory frameworks that stem from their early involvement in nuclear technology development for both research reactors and nuclear power plants. These factors might partially account for the under-utilization noted in some regions. Efforts continue to encourage all Member States to take advantage of the benefits obtained from open and transparent peer review missions to enhance the safety of their research reactors and strengthen the global nuclear safety regime.

4.3.5. Opportunities for improvement

To further improve the INSARR service, the results in this publication could be used to train future mission teams on the conduct of missions and on developing recommendations based on the lessons learned. The results may be used to understand the recommendations, findings, common safety issues and general trends identified at research reactors during the period considered.

5. CONCLUSIONS

INSARR is widely recognized as an IAEA service providing for continuous safety improvements of research reactors. This service has resulted in improvements in several review areas at these facilities during the period 1995–2021. The analysis of the INSARR mission recommendations over this period reflect mainly the need for:

- Increased attention from the operating organizations to the importance of leadership and management for safety, including the performance of self-assessment surveys and the establishment of an effective integrated management system covering the various stages in the lifetime of a facility;
- Improving the quality and contents of safety documentation, in particular the SAR, to conform with the current conditions of the facility and to the IAEA safety standards;
- Enhancing the operational radiation protection programme and procedures, including defining clear responsibility for the radiation protection function and ensuring its independence, with attention to area classification (zoning), access controls, monitoring, and proper use of PPE;
- Enhancing the operational safety programmes and procedures, in particular procedures for operators' responses to transients, design basis accidents, and DECs, and emergency response procedures for external event scenarios;
- Enhancing the maintenance, periodic testing and inspection programme, establishing a comprehensive ageing management programme, and improving the effective use of operational and maintenance procedures that covers all items important to safety, including experimental devices;
- Improving the safety of modifications and experiments including the categorization process, and for modifications or experiments with a major effect on safety, review by the safety committee and submission to the regulatory body for review and approval, as appropriate;
- Enhancing the effectiveness of the reactors' safety committees including defining the terms of reference, roles, responsibilities, review areas, and independence from reactor management;
- Improving regulatory supervision and oversight including regulatory inspections and establishing a licensing process for modifications of major safety significance;
- Implementing safety improvements identified from the safety reassessments carried out in light of the lessons identified from the Fukushima Daiichi NPS accident in 2011;
- Ensuring adequate consideration of eventual decommissioning of the facility during operation and utilization, including updating of the preliminary decommissioning plan and documentation that has an impact on decommissioning.

The findings from the analysis of the INSARR results are generally consistent with feedback from other IAEA activities on the safety of research reactors, including activities related to the IAEA Code of Conduct on the Safety of Research Reactors [25, 26]. Member State's self-assessments indicated a positive trend in the application of the Code of Conduct on the Safety of Research Reactors in several areas including: regulatory inspection activities; implementation of processes for periodic safety reviews; refurbishment and modernization for safety improvements, ageing management and continued safe operation.

INSARR missions have evolved over time and during the past ten years the findings have resulted in the following conclusions regarding the safety of research reactors [26]:

- Progress in safety improvements in many research reactor organizations in several review areas, including safety analysis and safety documentation, regulatory supervision, radiation protection, training of personnel, ageing management, maintenance, and safety of modification and refurbishment projects.
- Increased interest of research reactor organizations on development and implementation of programmes and activities on leadership and management for safety, including safety culture and self-assessments.
- Actions by research reactor organizations to enhance management systems through the establishment of an effective integrated management system, and to improve the effectiveness of safety committees, the quality of safety documentation, and the activities related to decommissioning.
- Progress by research reactor organizations to establish processes on periodic safety reviews, for identification and implementation of reasonable and practicable safety improvements based on the IAEA safety standards.

The results of the analysis presented in this publication are expected to be useful for Member States, operating organizations, regulatory bodies, the IAEA, and future mission teams, to understand the findings, general trends, and common safety issues identified from INSARR missions at research reactors during the period considered.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Guidelines for the Review of Research Reactor Safety: Revised Edition, IAEA Services Series No. 25, IAEA, Vienna (2013).

[2] INTERNATIONAL ATOMIC ENERGY AGENCY, Code of Conduct on the Safety of Research Reactors, IAEA, Vienna (2006).

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Research Reactors, IAEA Safety Standards Series No. SSR-3, IAEA, Vienna (2016).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Assessment for Research Reactors and Preparation of the Safety Analysis Report, IAEA Safety Standards Series No. SSG-20 (Rev. 1), IAEA, Vienna (2022).

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, Use of a Graded Approach in the Application of the Safety Requirements for Research Reactors, IAEA Safety Standards Series No. SSG-22 (Rev. 1), IAEA, Vienna (2023).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Ageing Management for Research Reactors, IAEA Safety Guide Series No. SSG-10 (Rev.1), IAEA, Vienna, (2023).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Commissioning of Research Reactors, IAEA Safety Standards Series No. SSG-80, IAEA, Vienna (2023).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Seismic Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-9 (Rev. 1), IAEA, Vienna (2022).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of New and Existing Research Reactor Facilities in Relation to External Events, IAEA Safety Report Series No. 41, IAEA, Vienna (2005).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, Operational Limits and Conditions and Operating Procedures for Research Reactors, IAEA Safety Standards Series No. SSG-83, IAEA, Vienna (2023).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Governmental, Legal and Regulatory Framework for Safety, IAEA Safety Standards Series No. GSR Part 1 (Rev. 1), IAEA, Vienna (2016).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Functions and Processes of the Regulatory Body for Safety, IAEA Safety Standards Series No. GSG-13, IAEA, Vienna (2018).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, The Operating Organization and the Recruitment, Training and Qualification of Personnel for Research Reactors, IAEA Safety Standards Series No. SSG-84, IAEA, Vienna (2022).

[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Core Management and Fuel Handling for Research Reactors, IAEA Safety Standards Series No. SSG-82, IAEA, Vienna (2023).

[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Maintenance, Periodic Testing and Inspection of Research Reactors, IAEA Safety Standards Series No. SSG-81, IAEA, Vienna (2023).

[16] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety in the Utilization and Modification of Research Reactors, IAEA Safety Standards Series No. SSG-24 (Rev. 1), IAEA, Vienna (2022).

[17] INTERNATIONAL ATOMIC ENERGY AGENCY, Leadership and Management for Safety, IAEA Safety Standards Series No. GSR Part 2, IAEA, Vienna (2016).

[18] INTERNATIONAL ATOMIC ENERGY AGENCY, Application of the Management System for Facilities and Activities, Safety Standards Series No. GS-G-3.1, IAEA, Vienna (2006).

[19] INTERNATIONAL ATOMIC ENERGY AGENCY, Radiation Protection and Radioactive Waste Management in the Design and Operation of Research Reactors, IAEA Safety Standards Series No. SSG-85, IAEA, Vienna (2023).

[20] EUROPEAN COMMISSION, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards, IAEA Safety Standards Series No. GSR Part 3, IAEA, Vienna (2014).

[21] INTERNATIONAL ATOMIC ENERGY AGENCY, Occupational Radiation Protection, IAEA Safety Standards Series No. GSG-7, IAEA, Vienna (2018).

[22] FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL CIVIL AVIATION ORGANIZATION, INTERNATIONAL LABOUR ORGANIZATION, INTERNATIONAL MARITIME ORGANIZATION, INTERPOL, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, PREPARATORY COMMISSION FOR THE COMPREHENSIVE NUCLEAR-TEST-BAN TREATY ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, UNITED NATIONS OFFICE FOR THE COORDINATION OF HUMANITARIAN AFFAIRS, WORLD HEALTH ORGANIZATION, WORLD METEOROLOGICAL ORGANIZATION,, Preparedness and Response for a Nuclear or Radiological Emergency, IAEA Safety Standards Series No. GSR Part 7, IAEA, Vienna (2015).

[23] INTERNATIONAL ATOMIC ENERGY AGENCY, EPR-Research Reactor-Generic Procedures for Response to a Nuclear or Radiological Emergency at Research Reactors, Emergency Preparedness and Response, IAEA, Vienna (2011).

[24] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety Considerations for Research Reactors in Extended Shutdown, IAEA-TECDOC-1387, IAEA, Vienna (2004).

[25] INTERNATIONAL ATOMIC ENERGY AGENCY, IAEA Meeting Focuses on Experiences in Application of Code of Conduct on the Safety of Research Reactors (2016), https://www.iaea.org/newscenter/news/iaea-meeting-focuses-on-experiences-in-application-of-code-of-conduct-on-the-safety-of-research-reactors.

[26] INTERNATIONAL ATOMIC ENERGY AGENCY, Highlights of INSARR Missions 2010–2020 (2021), https://www.iaea.org/sites/default/files/21/06/highlights-of-insarr-missions-2010-2020.pdf

ANNEX I

A.1. The IAEA research reactor database includes information on research reactors that have been constructed and operated throughout the world, as well as those that have been shutdown and decommissioned. The map in Fig. I-1 shows the countries with operating research reactors. Table I-1 shows the number of research reactors in the various regions defined in the research reactor database.

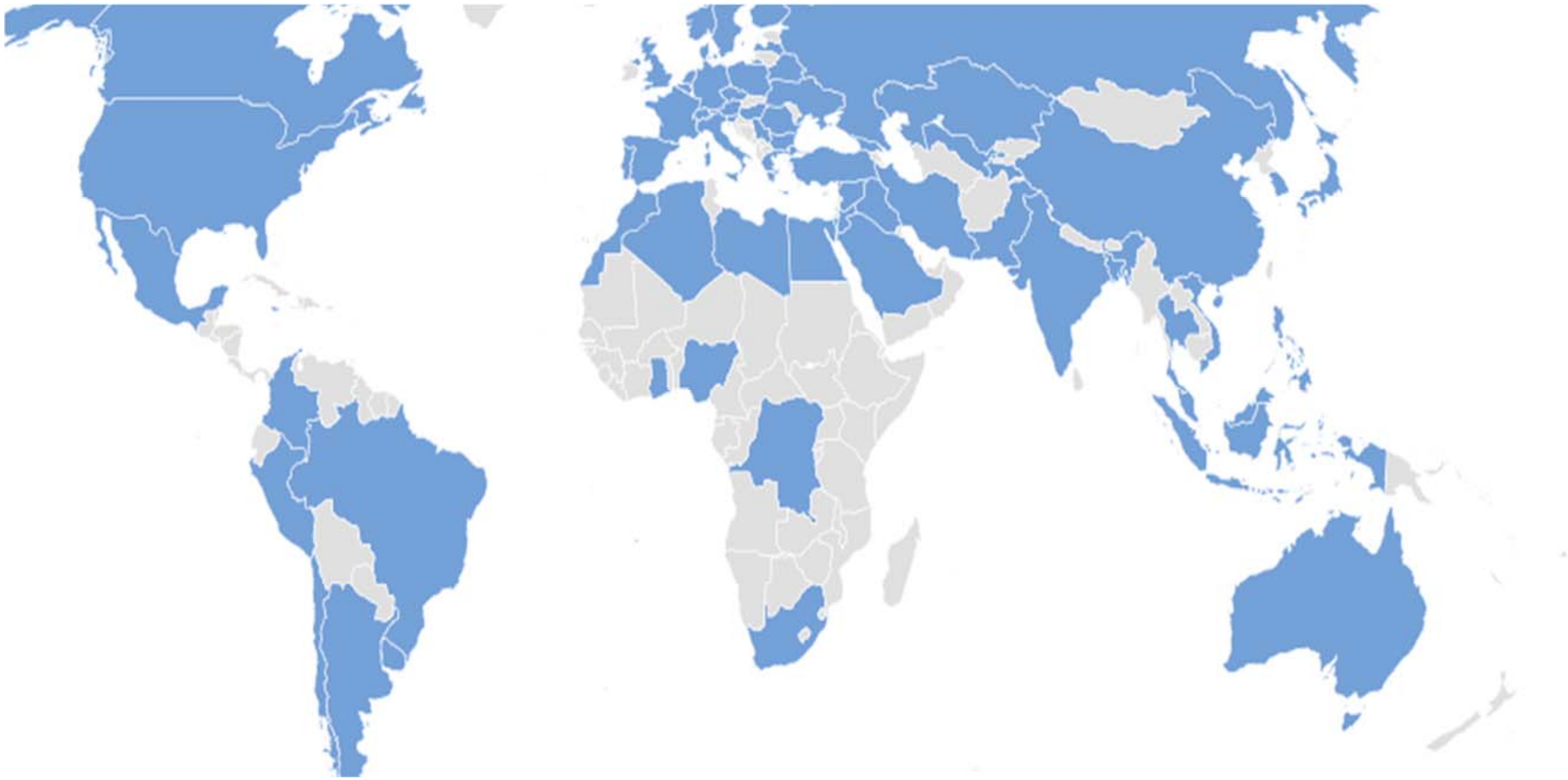

FIG. I-1. Countries with operating research reactors worldwide according to the IAEA Research Reactor Database.

TABLE I-1. NUMBER OF OPERATING RESEARCH REACTORS IN THE REGIONS DEFINED IN THE IAEA RESEARCH REACTOR DATABASE (2022).

Africa	**7**
Algeria	1
Egypt	1
Ghana	1
Libya	1
Morocco	1
Nigeria	1
South Africa	1

Far East	**26**
China	16
Dem. P.R. of Korea	1
Japan	6
Korea, Republic of	2
Taiwan, China	1

Middle East	**16**
India	5
Iran, Islamic Republic of	4
Israel	2
Jordan	2
Pakistan	2
Syrian Arab Republic	1

Latin America	**16**
Argentina	5
Brazil	4
Chile	1
Colombia	1
Jamaica	1
Mexico	2
Peru	2

Eastern Europe	**72**
Belarus	3
Czech Republic	3
Hungary	2
Kazakhstan	4
Poland	1
Romania	2
Russian Federation	52
Slovenia	1
Ukraine	3
Uzbekistan	1

North America	**55**
Canada	5
United States of America	50

Southeast Asia & Pacific	**8**
Australia	1
Bangladesh	1
Indonesia	3
Malaysia	1
Thailand	1
Viet Nam	1

Western Europe	**24**
Austria	1
Belgium	3
France	3
Germany	5
Greece	1
Italy	5
Netherlands	3
Switzerland	1
Türkiye	1
United Kingdom	1

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