IAEA
International Atomic Energy Agency

IAEA SAFETY STANDARDS

No. SSG-13 (Rev. 1)

for protecting people and the environment

Chemistry Programme for Water Cooled Nuclear Power Plants

SPECIFIC SAFETY GUIDE

IAEA SAFETY STANDARDS AND RELATED PUBLICATIONS

IAEA SAFETY STANDARDS

Under the terms of Article III of its Statute, the IAEA is authorized to establish or adopt standards of safety for protection of health and minimization of danger to life and property, and to provide for the application of these standards.

The publications by means of which the IAEA establishes standards are issued in the **IAEA Safety Standards Series**. This series covers nuclear safety, radiation safety, transport safety and waste safety. The publication categories in the series are **Safety Fundamentals**, **Safety Requirements** and **Safety Guides**.

Information on the IAEA's safety standards programme is available on the IAEA web site:

http://www-ns.iaea.org/standards/

The site provides the texts in English of published and draft safety standards. The texts of safety standards issued in Arabic, Chinese, French, Russian and Spanish, the IAEA Safety Glossary and a status report for safety standards under development are also available. For further information, please contact the IAEA at: Vienna International Centre, PO Box 100, 1400 Vienna, Austria.

All users of IAEA safety standards are invited to inform the IAEA of experience in their use (e.g. as a basis for national regulations, for safety reviews and for training courses) for the purpose of ensuring that they continue to meet users' needs. Information may be provided via the IAEA Internet site or by post, as above, or by email to Official.Mail@iaea.org.

RELATED PUBLICATIONS

The IAEA provides for the application of the standards and, under the terms of Articles III and VIII.C of its Statute, makes available and fosters the exchange of information relating to peaceful nuclear activities and serves as an intermediary among its Member States for this purpose.

Reports on safety in nuclear activities are issued as **Safety Reports**, which provide practical examples and detailed methods that can be used in support of the safety standards.

Other safety related IAEA publications are issued as **Emergency Preparedness and Response** publications, **Radiological Assessment Reports**, the International Nuclear Safety Group's **INSAG Reports**, **Technical Reports** and **TECDOCs**. The IAEA also issues reports on radiological accidents, training manuals and practical manuals, and other special safety related publications.

Security related publications are issued in the **IAEA Nuclear Security Series**.

The **IAEA Nuclear Energy Series** comprises informational publications to encourage and assist research on, and the development and practical application of, nuclear energy for peaceful purposes. It includes reports and guides on the status of and advances in technology, and on experience, good practices and practical examples in the areas of nuclear power, the nuclear fuel cycle, radioactive waste management and decommissioning.

CHEMISTRY PROGRAMME FOR WATER COOLED NUCLEAR POWER PLANTS

The following States are Members of the International Atomic Energy Agency:

AFGHANISTAN
ALBANIA
ALGERIA
ANGOLA
ANTIGUA AND BARBUDA
ARGENTINA
ARMENIA
AUSTRALIA
AUSTRIA
AZERBAIJAN
BAHAMAS
BAHRAIN
BANGLADESH
BARBADOS
BELARUS
BELGIUM
BELIZE
BENIN
BOLIVIA, PLURINATIONAL STATE OF
BOSNIA AND HERZEGOVINA
BOTSWANA
BRAZIL
BRUNEI DARUSSALAM
BULGARIA
BURKINA FASO
BURUNDI
CABO VERDE
CAMBODIA
CAMEROON
CANADA
CENTRAL AFRICAN REPUBLIC
CHAD
CHILE
CHINA
COLOMBIA
COMOROS
CONGO
COOK ISLANDS
COSTA RICA
CÔTE D'IVOIRE
CROATIA
CUBA
CYPRUS
CZECH REPUBLIC
DEMOCRATIC REPUBLIC OF THE CONGO
DENMARK
DJIBOUTI
DOMINICA
DOMINICAN REPUBLIC
ECUADOR
EGYPT
EL SALVADOR
ERITREA
ESTONIA
ESWATINI
ETHIOPIA
FIJI
FINLAND
FRANCE
GABON
GAMBIA, THE
GEORGIA
GERMANY
GHANA
GREECE
GRENADA
GUATEMALA
GUINEA
GUYANA
HAITI
HOLY SEE
HONDURAS
HUNGARY
ICELAND
INDIA
INDONESIA
IRAN, ISLAMIC REPUBLIC OF
IRAQ
IRELAND
ISRAEL
ITALY
JAMAICA
JAPAN
JORDAN
KAZAKHSTAN
KENYA
KOREA, REPUBLIC OF
KUWAIT
KYRGYZSTAN
LAO PEOPLE'S DEMOCRATIC REPUBLIC
LATVIA
LEBANON
LESOTHO
LIBERIA
LIBYA
LIECHTENSTEIN
LITHUANIA
LUXEMBOURG
MADAGASCAR
MALAWI
MALAYSIA
MALI
MALTA
MARSHALL ISLANDS
MAURITANIA
MAURITIUS
MEXICO
MONACO
MONGOLIA
MONTENEGRO
MOROCCO
MOZAMBIQUE
MYANMAR
NAMIBIA
NEPAL
NETHERLANDS, KINGDOM OF THE
NEW ZEALAND
NICARAGUA
NIGER
NIGERIA
NORTH MACEDONIA
NORWAY
OMAN
PAKISTAN
PALAU
PANAMA
PAPUA NEW GUINEA
PARAGUAY
PERU
PHILIPPINES
POLAND
PORTUGAL
QATAR
REPUBLIC OF MOLDOVA
ROMANIA
RUSSIAN FEDERATION
RWANDA
SAINT KITTS AND NEVIS
SAINT LUCIA
SAINT VINCENT AND THE GRENADINES
SAMOA
SAN MARINO
SAUDI ARABIA
SENEGAL
SERBIA
SEYCHELLES
SIERRA LEONE
SINGAPORE
SLOVAKIA
SLOVENIA
SOMALIA
SOUTH AFRICA
SPAIN
SRI LANKA
SUDAN
SWEDEN
SWITZERLAND
SYRIAN ARAB REPUBLIC
TAJIKISTAN
THAILAND
TOGO
TONGA
TRINIDAD AND TOBAGO
TUNISIA
TÜRKİYE
TURKMENISTAN
UGANDA
UKRAINE
UNITED ARAB EMIRATES
UNITED KINGDOM OF GREAT BRITAIN AND NORTHERN IRELAND
UNITED REPUBLIC OF TANZANIA
UNITED STATES OF AMERICA
URUGUAY
UZBEKISTAN
VANUATU
VENEZUELA, BOLIVARIAN REPUBLIC OF
VIET NAM
YEMEN
ZAMBIA
ZIMBABWE

The Agency's Statute was approved on 23 October 1956 by the Conference on the Statute of the IAEA held at United Nations Headquarters, New York; it entered into force on 29 July 1957. The Headquarters of the Agency are situated in Vienna. Its principal objective is "to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world''.

IAEA SAFETY STANDARDS SERIES No. SSG-13 (Rev. 1)

CHEMISTRY PROGRAMME FOR WATER COOLED NUCLEAR POWER PLANTS

INTERNATIONAL ATOMIC ENERGY AGENCY
VIENNA, 2024

Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
tel.: +43 1 2600 22529 or 22530
email: sales.publications@iaea.org
www.iaea.org/publications

Printed by the IAEA in Austria
December 2024
STI/PUB/2095
https://doi.org/10.61092/iaea.t6wx-2cry

IAEA Library Cataloguing in Publication Data

Names: International Atomic Energy Agency.
Title: Chemistry programme for water cooled nuclear power plants / International Atomic Energy Agency.
Description: Vienna : International Atomic Energy Agency, 2024. | Series: IAEA safety standards series, ISSN 1020–525X ; no. SSG-13 (Rev. 1) | Includes bibliographical references.
Identifiers: IAEAL 24-01727 | ISBN 978-92-0-125824-3 (paperback : alk. paper) | ISBN 978-92-0-125924-0 (pdf) | ISBN 978-92-0-126024-6 (epub)
Subjects: LCSH: Water cooled reactors. | Nuclear reactors — Cooling — Safety measures. | Water chemistry — Reactor moderators — Safety measures. | Nuclear power plants.
Classification: UDC 621.039.524.4:006.88 | STI/PUB/2095

FOREWORD

by Rafael Mariano Grossi
Director General

The IAEA's Statute authorizes it to "establish…standards of safety for protection of health and minimization of danger to life and property". These are standards that the IAEA must apply to its own operations, and that States can apply through their national regulations.

The IAEA started its safety standards programme in 1958 and there have been many developments since. As Director General, I am committed to ensuring that the IAEA maintains and improves upon this integrated, comprehensive and consistent set of up to date, user friendly and fit for purpose safety standards of high quality. Their proper application in the use of nuclear science and technology should offer a high level of protection for people and the environment across the world and provide the confidence necessary to allow for the ongoing use of nuclear technology for the benefit of all.

Safety is a national responsibility underpinned by a number of international conventions. The IAEA safety standards form a basis for these legal instruments and serve as a global reference to help parties meet their obligations. While safety standards are not legally binding on Member States, they are widely applied. They have become an indispensable reference point and a common denominator for the vast majority of Member States that have adopted these standards for use in national regulations to enhance safety in nuclear power generation, research reactors and fuel cycle facilities as well as in nuclear applications in medicine, industry, agriculture and research.

The IAEA safety standards are based on the practical experience of its Member States and produced through international consensus. The involvement of the members of the Safety Standards Committees, the Nuclear Security Guidance Committee and the Commission on Safety Standards is particularly important, and I am grateful to all those who contribute their knowledge and expertise to this endeavour.

The IAEA also uses these safety standards when it assists Member States through its review missions and advisory services. This helps Member States in the application of the standards and enables valuable experience and insight to be shared. Feedback from these missions and services, and lessons identified from events and experience in the use and application of the safety standards, are taken into account during their periodic revision.

I believe the IAEA safety standards and their application make an invaluable contribution to ensuring a high level of safety in the use of nuclear technology. I encourage all Member States to promote and apply these standards, and to work with the IAEA to uphold their quality now and in the future.

THE IAEA SAFETY STANDARDS

BACKGROUND

Radioactivity is a natural phenomenon and natural sources of radiation are features of the environment. Radiation and radioactive substances have many beneficial applications, ranging from power generation to uses in medicine, industry and agriculture. The radiation risks to workers and the public and to the environment that may arise from these applications have to be assessed and, if necessary, controlled.

Activities such as the medical uses of radiation, the operation of nuclear installations, the production, transport and use of radioactive material, and the management of radioactive waste must therefore be subject to standards of safety.

Regulating safety is a national responsibility. However, radiation risks may transcend national borders, and international cooperation serves to promote and enhance safety globally by exchanging experience and by improving capabilities to control hazards, to prevent accidents, to respond to emergencies and to mitigate any harmful consequences.

States have an obligation of diligence and duty of care, and are expected to fulfil their national and international undertakings and obligations.

International safety standards provide support for States in meeting their obligations under general principles of international law, such as those relating to environmental protection. International safety standards also promote and assure confidence in safety and facilitate international commerce and trade.

A global nuclear safety regime is in place and is being continuously improved. IAEA safety standards, which support the implementation of binding international instruments and national safety infrastructures, are a cornerstone of this global regime. The IAEA safety standards constitute a useful tool for contracting parties to assess their performance under these international conventions.

THE IAEA SAFETY STANDARDS

The status of the IAEA safety standards derives from the IAEA's Statute, which authorizes the IAEA to establish or adopt, in consultation and, where appropriate, in collaboration with the competent organs of the United Nations and with the specialized agencies concerned, standards of safety for protection of health and minimization of danger to life and property, and to provide for their application.

With a view to ensuring the protection of people and the environment from harmful effects of ionizing radiation, the IAEA safety standards establish fundamental safety principles, requirements and measures to control the radiation exposure of people and the release of radioactive material to the environment, to restrict the likelihood of events that might lead to a loss of control over a nuclear reactor core, nuclear chain reaction, radioactive source or any other source of radiation, and to mitigate the consequences of such events if they were to occur. The standards apply to facilities and activities that give rise to radiation risks, including nuclear installations, the use of radiation and radioactive sources, the transport of radioactive material and the management of radioactive waste.

Safety measures and security measures[1] have in common the aim of protecting human life and health and the environment. Safety measures and security measures must be designed and implemented in an integrated manner so that security measures do not compromise safety and safety measures do not compromise security.

The IAEA safety standards reflect an international consensus on what constitutes a high level of safety for protecting people and the environment from harmful effects of ionizing radiation. They are issued in the IAEA Safety Standards Series, which has three categories (see Fig. 1).

Safety Fundamentals

Safety Fundamentals present the fundamental safety objective and principles of protection and safety, and provide the basis for the safety requirements.

Safety Requirements

An integrated and consistent set of Safety Requirements establishes the requirements that must be met to ensure the protection of people and the environment, both now and in the future. The requirements are governed by the objective and principles of the Safety Fundamentals. If the requirements are not met, measures must be taken to reach or restore the required level of safety. The format and style of the requirements facilitate their use for the establishment, in a harmonized manner, of a national regulatory framework. Requirements, including numbered 'overarching' requirements, are expressed as 'shall' statements. Many requirements are not addressed to a specific party, the implication being that the appropriate parties are responsible for fulfilling them.

Safety Guides

Safety Guides provide recommendations and guidance on how to comply with the safety requirements, indicating an international consensus that it

---

[1] See also publications issued in the IAEA Nuclear Security Series.

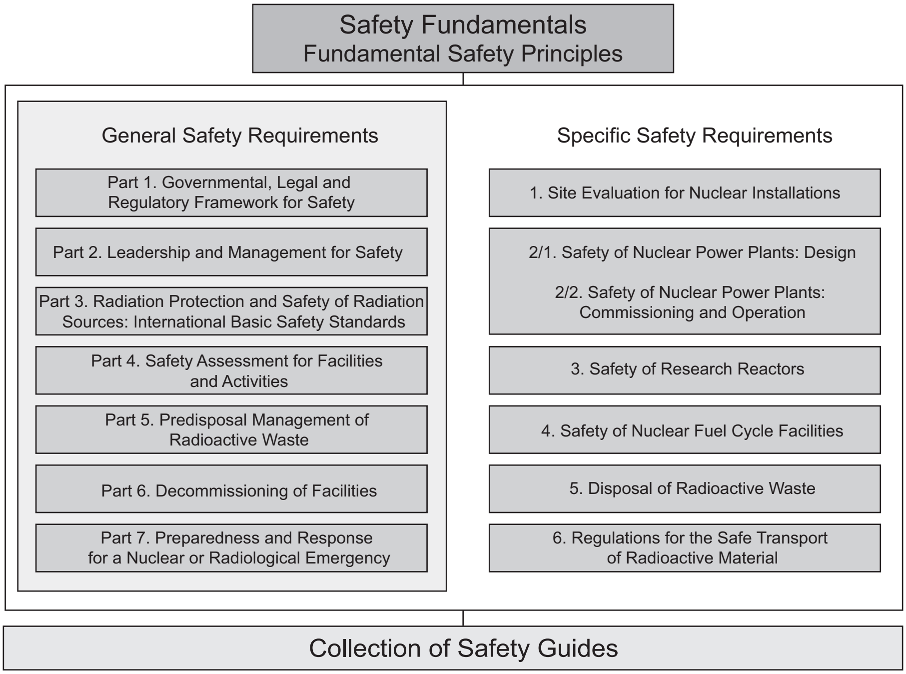

FIG. 1. The long term structure of the IAEA Safety Standards Series.

is necessary to take the measures recommended (or equivalent alternative measures). The Safety Guides present international good practices, and increasingly they reflect best practices, to help users striving to achieve high levels of safety. The recommendations provided in Safety Guides are expressed as ‘should’ statements.

APPLICATION OF THE IAEA SAFETY STANDARDS

The principal users of safety standards in IAEA Member States are regulatory bodies and other relevant national authorities. The IAEA safety standards are also used by co-sponsoring organizations and by many organizations that design, construct and operate nuclear facilities, as well as organizations involved in the use of radiation and radioactive sources.

The IAEA safety standards are applicable, as relevant, throughout the entire lifetime of all facilities and activities — existing and new — utilized for peaceful purposes and to protective actions to reduce existing radiation risks. They can be used by States as a reference for their national regulations in respect of facilities and activities.

The IAEA's Statute makes the safety standards binding on the IAEA in relation to its own operations and also on States in relation to IAEA assisted operations.

The IAEA safety standards also form the basis for the IAEA's safety review services, and they are used by the IAEA in support of competence building, including the development of educational curricula and training courses.

International conventions contain requirements similar to those in the IAEA safety standards and make them binding on contracting parties. The IAEA safety standards, supplemented by international conventions, industry standards and detailed national requirements, establish a consistent basis for protecting people and the environment. There will also be some special aspects of safety that need to be assessed at the national level. For example, many of the IAEA safety standards, in particular those addressing aspects of safety in planning or design, are intended to apply primarily to new facilities and activities. The requirements established in the IAEA safety standards might not be fully met at some existing facilities that were built to earlier standards. The way in which IAEA safety standards are to be applied to such facilities is a decision for individual States.

The scientific considerations underlying the IAEA safety standards provide an objective basis for decisions concerning safety; however, decision makers must also make informed judgements and must determine how best to balance the benefits of an action or an activity against the associated radiation risks and any other detrimental impacts to which it gives rise.

DEVELOPMENT PROCESS FOR THE IAEA SAFETY STANDARDS

The preparation and review of the safety standards involves the IAEA Secretariat and five Safety Standards Committees, for emergency preparedness and response (EPReSC) (as of 2016), nuclear safety (NUSSC), radiation safety (RASSC), the safety of radioactive waste (WASSC) and the safe transport of radioactive material (TRANSSC), and a Commission on Safety Standards (CSS) which oversees the IAEA safety standards programme (see Fig. 2).

All IAEA Member States may nominate experts for the Safety Standards Committees and may provide comments on draft standards. The membership of the Commission on Safety Standards is appointed by the Director General and includes senior governmental officials having responsibility for establishing national standards.

A management system has been established for the processes of planning, developing, reviewing, revising and establishing the IAEA safety standards.

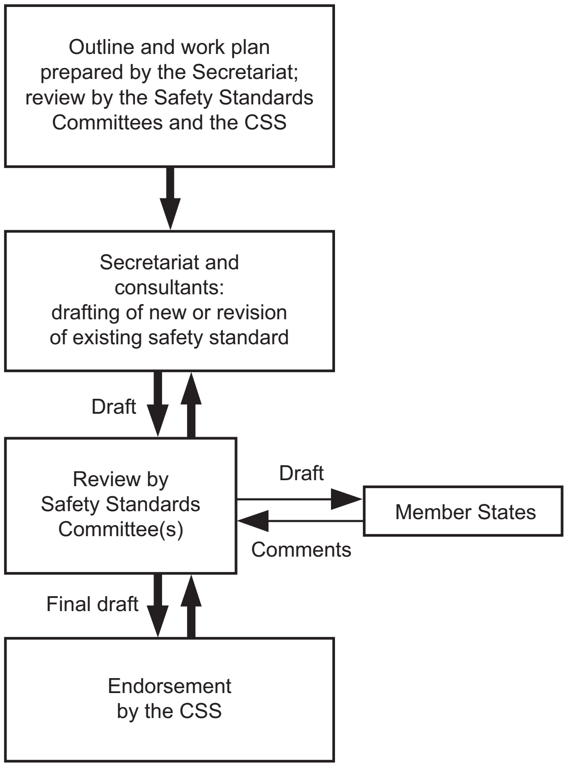

FIG. 2. The process for developing a new safety standard or revising an existing standard.

It articulates the mandate of the IAEA, the vision for the future application of the safety standards, policies and strategies, and corresponding functions and responsibilities.

INTERACTION WITH OTHER INTERNATIONAL ORGANIZATIONS

The findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the recommendations of international expert bodies, notably the International Commission on Radiological Protection (ICRP), are taken into account in developing the IAEA safety standards. Some safety standards are developed in cooperation with other bodies in the United Nations system or other specialized agencies, including the Food and Agriculture Organization of the United Nations, the United Nations Environment Programme, the International Labour Organization, the OECD Nuclear Energy Agency, the Pan American Health Organization and the World Health Organization.

INTERPRETATION OF THE TEXT

Safety related terms are to be understood as they appear in the IAEA Nuclear Safety and Security Glossary (see https://www.iaea.org/resources/publications/iaea-nuclear-safety-and-security-glossary). Otherwise, words are used with the spellings and meanings assigned to them in the latest edition of The Concise Oxford Dictionary. For Safety Guides, the English version of the text is the authoritative version.

The background and context of each standard in the IAEA Safety Standards Series and its objective, scope and structure are explained in Section 1, Introduction, of each publication.

Material for which there is no appropriate place in the body text (e.g. material that is subsidiary to or separate from the body text, is included in support of statements in the body text, or describes methods of calculation, procedures or limits and conditions) may be presented in appendices or annexes.

An appendix, if included, is considered to form an integral part of the safety standard. Material in an appendix has the same status as the body text, and the IAEA assumes authorship of it. Annexes and footnotes to the main text, if included, are used to provide practical examples or additional information or explanation. Annexes and footnotes are not integral parts of the main text. Annex material published by the IAEA is not necessarily issued under its authorship; material under other authorship may be presented in annexes to the safety standards. Extraneous material presented in annexes is excerpted and adapted as necessary to be generally useful.

CONTENTS

1. INTRODUCTION

BACKGROUND

1.1. Requirements for the chemistry programme for the operation of nuclear power plants are established in IAEA Safety Standards Series No. SSR-2/2 (Rev. 1), Safety of Nuclear Power Plants: Commissioning and Operation [1]. This Safety Guide provides recommendations on meeting those requirements in water cooled nuclear power plants.

1.2. Implementing a chemistry programme is essential to ensure the safe operation of a nuclear power plant. It contributes to the integrity, reliability and availability of structures, systems and components (SSCs) in accordance with their intended design and functions. The chemistry programme is based on a detailed rationale usually provided by the designer of the plant, but ownership of the content and proper implementation of the chemistry programme ultimately rests with the plant operating organization. The main goals of the chemistry programme (covering both chemistry and radiochemistry) are (a) to contribute to reactivity management, (b) to minimize the potentially harmful effects of radiolytic decomposition of water and all forms of corrosion of SSCs affected by the chemistry regime, (c) to preserve the integrity of the fuel, and (d) to reduce the buildup of radioactive material, enabling lower radiation doses to personnel. Additional goals are to limit the discharge of chemicals and radioactive material to the environment and to minimize the generation of radioactive waste. These goals fulfil the fundamental safety objective to protect people and the environment from harmful effects of ionizing radiation established in IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [2].

1.3. Recommendations on the chemistry programme from the point of view of ageing management of SSCs are provided in IAEA Safety Standards Series No. SSG-48, Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants [3].

1.4. The chemistry programme comprises the following three basic elements: the chemistry regime, chemistry control and chemistry measurements. The chemistry regime is defined by the reactor type and design, the construction materials used, and any requirements placed on the operating chemistry in the safety analysis of the plant. Chemistry control confirms that the plant is operated in accordance with the requirements of the chemistry regime and defines the parameters to be measured, their measurement frequencies, expected measurement values when deemed necessary, graded limit values, and corrective actions to be taken if necessary. Chemistry measurements provide information on the actual chemistry conditions in the systems, which in turn serve as the basis for all further operational and safety related decisions.

1.5. This Safety Guide supersedes IAEA Safety Standards Series No. SSG-13, Chemistry Programme for Water Cooled Nuclear Power Plants[1].

OBJECTIVE

1.6. The objective of this Safety Guide is to provide recommendations on water chemistry for nuclear power plants to meet the requirements of SSR-2/2 (Rev. 1) [1], in particular Requirement 29, which states that "**The operating organization shall establish and implement a chemistry programme to provide the necessary support for chemistry and radiochemistry.**" These recommendations aim at mitigating the degradation of SSCs and ensuring their integrity and availability, while adhering to a commitment to minimizing the generation of radioactive waste and reducing radiation doses and limiting discharges of radioactive material and chemicals to the environment to levels that are as low as reasonably achievable and are within national regulations.

1.7. The recommendations provided in this Safety Guide are aimed primarily at managers of operating organizations for the oversight of the nuclear power plant chemistry programme, and at regulatory bodies for the fulfilment of their external oversight responsibilities and development of national regulatory requirements for water chemistry.

1.8. The recommendations provided in this Safety Guide can also be used by technical support organizations and research organizations when they provide support for operating organizations or regulatory bodies.

1.9. This Safety Guide can also be useful for nuclear power plant chemistry personnel for continuously improving existing chemistry programmes, supporting the development of new chemistry activities, and assisting in the development of corrective actions to eliminate identified weaknesses in existing programmes.

---

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Chemistry Programme for Water Cooled Nuclear Power Plants, IAEA Safety Standards Series No. SSG-13, IAEA, Vienna (2011).

SCOPE

1.10. This Safety Guide provides recommendations on the chemistry programmes that should be established in all types of water cooled nuclear power plant. These programmes ensure that SSCs important to safety, SSCs whose failure might prevent SSCs important to safety from fulfilling their intended function, and SSCs that are credited in the safety analyses can operate reliably throughout the original design life of the plant, including construction, commissioning, all operational states and accident conditions, and decommissioning.

1.11. This Safety Guide provides a basis for the development of an effective plant chemistry programme for various types of water cooled nuclear power plant, including the main activities involved. It also provides recommendations on chemistry and radiochemistry monitoring to ensure compliance with the plant’s operational limits and conditions.

1.12. This Safety Guide does not provide detailed technical advice on the water chemistry regimes of specific water cooled nuclear power plants. The intentions and expectations for chemistry programmes are only described to the extent necessary to understand the scope of chemistry control and chemistry measurements, because the details of each programme are plant specific.

STRUCTURE

1.13. Section 2 provides recommendations on the functions and responsibilities of organizations involved in the chemistry programme and the interfaces between them. Section 3 provides recommendations on the training and qualification of personnel involved in chemistry activities. General recommendations on the chemistry programme are provided in Section 4. Recommendations on the process of chemistry control are given in Section 5. Section 6 provides recommendations on the optimization of chemistry aspects of radiation exposure. Recommendations on chemistry and radiochemistry measurements are provided in Section 7. Section 8 provides recommendations on the management of chemistry data. Recommendations on the quality control of chemicals and other substances are given in Section 9. The Annex provides information on the preservation of SSCs in nuclear power plants during outages.

2. FUNCTIONS AND RESPONSIBILITIES IN RELATION TO THE IMPLEMENTATION OF THE CHEMISTRY PROGRAMME

2.1. The operating organization is required to develop, implement, assess and continuously improve an integrated management system, in accordance with the requirements established in IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [4] and with Requirement 2 of SSR-2/2 (Rev. 1) [1].

2.2. Requirement 3 of SSR-2/2 (Rev. 1) [1] states that "**The structure of the operating organization and the functions, roles and responsibilities of its personnel shall be established and documented.**" Under the integrated management system, clear functions and responsibilities should be defined in accordance with the requirements established for all chemistry activities, such as management of resources, chemistry and radiochemistry control and measurements, management of the buildup of radioactive material, chemistry and radiochemistry surveillance, chemistry and radiochemistry data management, quality control, reviews of results and training and qualification of personnel. Recommendations on the management system for nuclear installations are provided in IAEA Safety Standards Series No. GS-G-3.5, The Management System for Nuclear Installations [5].

2.3. Paragraph 7.13 of SSR-2/2 (Rev. 1) [1] states:

> "The chemistry programme shall be developed prior to normal operation and shall be in place during the commissioning programme. The chemistry programme shall provide the necessary information and assistance for chemistry and radiochemistry for ensuring safe operation, long term integrity of structures, systems and components, and minimization of radiation levels."

Managers should ensure that the chemistry programme contributes to the following:

(a) Ensuring reactivity control of the reactor core;
(b) Preserving the integrity of the fuel cladding;
(c) Minimizing all forms of corrosion of SSCs caused by the chemistry regime;

(d) Minimizing the buildup of radionuclides to reduce dose rates at the plant and hence reduce radiation doses to personnel;
(e) Reducing the amount of chemical and radioactive waste and planned discharges to the environment.

2.4. The operating organization should ensure that the chemistry programme enables the reliable and continued operation of SSCs in the long term and does not compromise design assumptions or manufacturer requirements throughout the operating lifetime of the plant and the decommissioning stage.

2.5. Requirement 4 of SSR-2/2 (Rev. 1) [1] states that "**The operating organization shall be staffed with competent managers and sufficient qualified personnel for the safe operation of the plant.**" For normal day-to-day operations, the operating organization should provide sufficient funds and the necessary number of qualified chemistry personnel at all levels, including technical support personnel, supervisors and managers for the chemistry programme.

2.6. The managers of the chemistry programme should ensure that sufficient numbers of chemistry personnel are always available at the nuclear power plant or can come to the plant quickly when needed.

2.7. The operating organization should provide sufficient resources for the development of chemistry control methodologies. In addition, the operating organization should provide adequate facilities and sampling and measurement equipment (including laboratory and on-line monitoring instruments) for chemistry measurements. The operating organization should also ensure that the chemistry equipment and related systems are ready to return to service after maintenance and modifications, in accordance with predefined acceptance criteria. Further recommendations are provided in IAEA Safety Standards Series No. SSG-74, Maintenance, Testing, Surveillance and Inspection in Nuclear Power Plants [6].

2.8. The operating organization is required to assess its own safety performance and enable continuous improvement in accordance with Requirement 13 of GSR Part 2 [4] and Requirement 9 of SSR-2/2 (Rev. 1) [1]. The plant management should set clear targets for the continuous improvement of safety performance in the chemistry area, periodically reinforcing its expectations on the chemistry programme. Targets and management expectations should be described in the plant or corporate documentation.

2.9. The plant management should ensure that any measures to shorten scheduled shutdown periods and to accelerate plant startup activities will not compromise compliance with chemistry control procedures. For example, water purification systems should be used efficiently during the shutdown and startup stages and suitable wet or dry preservation conditions for equipment should be maintained during shutdown. As stated in GSR Part 2 [4], safety is an overriding priority and is not to be compromised by other priorities.

2.10. Changes to a plant's organizational structure that could affect the existing chemistry programme should be brought to the attention of the managers of the programme at an appropriate level for advice, comments and approval, as necessary.

2.11. Managers and supervisors of the chemistry programme should routinely observe chemistry activities to ensure adherence to plant policies and chemistry procedures. Such observations should also include human factors (e.g. workload, performance, job stress).

2.12. Information flow within the chemistry department should be well organized. Relevant information should be properly distributed and archived, and should be easily retrievable.

2.13. Paragraph 4.34 of SSR-2/2 (Rev. 1) [1] states:

> "Self-assessment by the operating organization shall be an integral part of the monitoring and review system. The operating organization shall perform systematic self-assessments to identify achievements and to address any degradation in safety performance. Where practicable, suitable objective performance indicators shall be developed and used to enable senior managers to detect and to react to shortcomings and deterioration in the management of safety."

The chemistry programme should be included in the operating organization's self-assessment programme. Internal audits, other self-assessments and independent reviews of the chemistry programme should be conducted regularly. Self-assessment of the chemistry programme should include participation in both intralaboratory and interlaboratory comparisons that should include both chemistry and radiochemistry measurements. Paragraph 6.3 of GSR Part 2 [4] states that "The corrective actions necessary for eliminating the causes of non-conformances, and for preventing the occurrence of, or mitigating the consequences of, similar safety related events, shall be determined, and corrective actions shall be taken in a timely manner." Identified non-conformances of the chemistry programme should be reported and included in the plant's corrective action programme with the proper significance level, and the status of corrective actions should be regularly evaluated.

2.14. Performance indicators for the chemistry programme, including relevant operational indicators, should be established to monitor the effectiveness of the programme. Performance indicators for the chemistry programme should be regularly communicated to chemistry personnel. Relevant indicators should also be brought to the attention of other departments and senior management. Chemistry performance indicators should be analysed for trends, and preventive and/or corrective measures should be undertaken when necessary in a timely manner.

2.15. Requirement 24 and paras 5.27–5.33 of SSR-2/2 (Rev. 1) [1] establish requirements for the feedback of operating experience. The managers of the chemistry programme should regularly collect operating experience from operating organizations at a national and international level to ensure that the chemistry programme is kept up to date with best industry practices. Lessons identified from operating experience relating to the chemistry programme should be appropriately taken into account in the procedures of the chemistry programme or other types of plant documentation, and should be brought to the attention of chemistry personnel.

2.16. If design changes relevant to chemistry are planned, the managers of the chemistry programme should be included in the plant's design change process. The managers should understand the changes and the consequences of these changes for the chemistry programme and approve the changes in the design basis documents relevant to the water chemistry programme. The operating organization should own, or have easy access to, the design basis documents. After the implementation of changes, the managers should revise the chemistry programme, if necessary, and update relevant documentation (see para. 4.42 of SSR-2/2 (Rev. 1) [1]).

2.17. For any plant modifications, the managers of the chemistry department should provide all relevant chemistry data to the other plant departments, as necessary. Further recommendations on controlling activities relating to modifications to nuclear power plants are provided in IAEA Safety Standards Series No. SSG-71, Modifications to Nuclear Power Plants [7].

2.18. Information relating to chemistry should be shared at meetings that are held to review activities relating to, for example, ageing management, corrosion, leakages, outage planning, emergency preparedness and response planning, reduction of dose rates at the plant and reduction of the activity and amount of liquid radioactive waste.

2.19. Chemistry personnel should have a clear understanding of their functions and responsibilities. Proper organizational arrangements should be established for managing the interfaces between the chemistry department and other departments contributing to chemistry activities to ensure that responsibilities are clearly defined and chemistry results are efficiently used. If a corporate chemistry function is established, the roles and responsibilities of the operating organization and the corporate organizations should be clearly communicated to, and understood by, all personnel.

2.20. The interface arrangements established between the chemistry department and other departments (e.g. operations, maintenance, instrumentation and control or technical support departments) should ensure that necessary repairs to chemistry systems and equipment are made in a timely manner, that repair backlogs are avoided, and that equipment remains available to meet any relevant requirements defined by the safety analysis of the plant. If issues involving other departments are identified, then these should be brought to the attention of the senior management in a timely manner.

2.21. Water chemistry and radiochemistry reports should be shared with other relevant departments in the operating organization. The content and the frequency of these reports, as well as the relevant departments with which they are shared, should be based on the needs of the operating organization.

2.22. Methods for delivering analytical results to other departments (e.g. the operations and maintenance departments) should be well established and communicated to all relevant personnel. When follow-up actions are needed, responsibility for their implementation should be clearly assigned to the relevant department.

2.23. Well defined interfaces should be established with the regulatory body, the design organization, and internal and external technical support organizations. Expectations regarding reporting to the regulatory body should be clearly stated in plant documentation and properly understood by all managers of the chemistry programme.

2.24. Qualified external contractors and consultants should be made available as necessary to meet the needs of the chemistry programme. The operating organization may delegate certain tasks of the chemistry programme to other organizations, but the operating organization is required to retain overall responsibility for these tasks, in accordance with Requirement 1 of SSR-2/2 (Rev. 1) [1] and para. 4.33 of GSR Part 2 [4]. The operating organization should ensure that the chemistry department provides sufficient support to, and control of, contractors working within the chemistry area.

2.25. All contractors of the chemistry department should be subject to the same expectations as chemistry personnel, particularly with respect to their skills and competences, adherence to procedures, reporting of results, safety culture and performance evaluation. Further recommendations on the management of contractors are provided in SSG-74 [6].

2.26. The chemistry department and the training department should provide all the information that contractors need to ensure that they understand the relevant plant procedures.

3. QUALIFICATION AND TRAINING OF CHEMISTRY PERSONNEL AT A NUCLEAR POWER PLANT

3.1. Requirement 7 of SSR-2/2 (Rev. 1) [1] states that **"The operating organization shall ensure that all activities that may affect safety are performed by suitably qualified and competent persons."** The recruitment, qualification and training of chemistry personnel should be conducted in accordance with the recommendations provided in IAEA Safety Standards Series No. SSG-75, Recruitment, Qualification and Training of Personnel for Nuclear Power Plants [8], and should follow the safety culture principles described in GS-G-3.5 [5]. Chemistry personnel should have a sufficient and relevant educational degree in accordance with the local education system. Job descriptions for chemistry personnel should be included in the plant documentation.

3.2. The managers of the chemistry programme should ensure that chemistry personnel are qualified. The necessary qualifications should be clearly defined for each position. The managers should ensure that sufficient supervision is performed and that chemistry personnel demonstrate a commitment to high standards of safety performance.

3.3. All chemistry activities should be performed by qualified chemistry personnel, but trainees may be assigned to perform such activities under the supervision of qualified personnel.

3.4. A systematic approach to training for chemistry personnel should be applied in accordance with the recommendations provided in SSG-75 [8]. Training facilities and methods should be used that have been proven to be effective in achieving the training objectives. During all steps of the training programme, the level of knowledge and experience of the chemistry personnel should be taken into account.

3.5. The managers of the chemistry programme should develop and implement basic chemistry training for all relevant nuclear power plant personnel, as well as initial, ongoing and refresher training for chemistry personnel as appropriate.

3.6. Initial training for chemistry personnel should include on the job training in areas relating to the chemistry programme, chemistry control and chemistry measurements (e.g. work in laboratories, how to operate equipment at sampling points, how to handle chemicals in laboratories and storage areas, knowledge of injection points of chemicals in operating systems, chemistry in the safety analysis report). The managers of the chemistry programme or a qualified trainer should confirm the successful completion of initial training by personnel.

3.7. Ongoing training in routine tasks should be given to all chemistry personnel, and should have clear goals. This training should also cover chemistry specific areas during startup, normal operation and outages and during the most probable transients and emergency scenarios. Periodic refresher training should also be considered for infrequent tasks (e.g. access to and use of the post-accident sampling system, if not used for regular sampling).

3.8. On the job training should be provided in the laboratory, workshop or other locations where chemistry activities take place.

3.9. On the job training for activities such as taking samples, using on-line chemistry stations, fixing deficiencies in on-line and off-line equipment, performing regular minor maintenance on on-line equipment and laboratory instruments, and using the post-accident sampling system should be conducted in accordance with the written operating procedures for these activities.

3.10. On the job training activities should include techniques for recognizing unusual conditions during sampling, insufficient radiation protection, malfunction of measurement equipment and adverse trends in measurement results.

3.11. The theoretical training of chemistry personnel should include the chemistry regime, chemistry control, chemistry measurements and the potential impact of changes in chemistry on the safety of the nuclear power plant (including for different operational states).

3.12. Chemistry laboratory supervisors should be familiar with equipment used by chemistry personnel and know how to operate it, even if they are not the ones responsible for executing the related tasks on a regular basis.

3.13. The training programme should be modified to include training in new technologies and analytical methods prior to their introduction in the plant.

3.14. Chemistry personnel and other plant personnel who deal with chemicals should be trained in the following specific areas:

(a) The classification, labelling and packaging of hazardous and radioactive substances;
(b) The proper storage, handling and disposal of specific chemicals, their mixtures and other substances;
(c) The use, availability, provision and location of material safety data sheets;
(d) The use and maintenance of personal protective equipment.

3.15. Chemistry personnel should receive training on all relevant plant requirements for nuclear, radiation and industrial safety.

3.16. The plant management should support the participation of the plant's chemistry personnel in relevant national and international workshops, conferences and meetings, and should facilitate their access to networks or forums for the exchange of operating experience.

3.17. Chemistry personnel should take part in training programmes or emergency exercises simulating the release of chemicals or radioactive materials (see paras 5.5 and 5.6 of SSR-2/2 (Rev. 1) [1]). Emergency chemistry procedures, emergency equipment and expected chemistry values should be used in these programmes and exercises to ensure that chemistry personnel are able to use them in an emergency.

3.18. As part of their training, chemistry personnel should become familiar with various routes to reach post-accident sampling points, in case the usual routes are inaccessible during accident conditions.

4. CHEMISTRY PROGRAMME AT A NUCLEAR POWER PLANT

4.1. In accordance with para. 7.13 of SSR-2/2 (Rev. 1) [1], the chemistry programme is required to contribute to ensuring the safe operation of the plant, the long term integrity of SSCs and the minimization of radiation levels at the plant. In fulfilment of other requirements established in SSR-2/2 (Rev. 1) [1], the chemistry programme should also contribute to ensuring the integrity of fuel and limiting all planned discharges to the environment to levels that are as low as reasonably achievable and within national regulations.

4.2. The operating organization should conduct assessments of the characteristics of the expected source term and public exposure scenarios. Recommendations on the conduct of such assessments are provided in IAEA Safety Standards Series No. GSG-10, Prospective Radiological Environmental Impact Assessment for Facilities and Activities [9].

4.3. The principle of optimization of protection and safety should be applied when setting discharge limits, and the regulatory body should evaluate whether the processes established by the operating organization to protect workers and the public are optimized. The operating organization should establish procedures to monitor the source term and the environment in order to control effluents and verify compliance with the discharge limits. Further recommendations on establishing discharge limits and on the process for optimizing the protection of members of the public, as well as workers who manage radioactive effluents, are provided in IAEA Safety Standards Series No. GSG-9, Regulatory Control of Radioactive Discharges to the Environment [10]. The source term for a release of radioactive material to the environment should be evaluated for all operational states and accident conditions as recommended in IAEA Safety Standards Series No. SSG-2 (Rev. 1), Deterministic Safety Analysis for Nuclear Power Plants [11].

4.4. The integrated management system should include the responsibilities of the managers of the chemistry programme regarding implementation of the programme. The organizational structure of the company (e.g. fleet, corporate, single site, multi-unit facilities) and the safety analysis of the plant should be taken into account when defining these responsibilities.

4.5. The chemistry programme should include documentation to serve as a basis for the selection, monitoring and analysis of the chemistry parameters. The instructions for the chemistry programme should be aligned with the operational limits and conditions (see also IAEA Safety Standards Series No. SSG-70, Operational Limits and Conditions and Operating Procedures for Nuclear Power Plants [12]). These instructions should explicitly define graded limit values for specific chemistry parameters enabling the efficient implementation of the chemistry programme. Plant documentation should describe potential corrective actions relating to water chemistry to be applied at various operational stages.

4.6. The chemistry programme should cover at least the following aspects:

(a) The chemistry programme documentation should clearly identify the SSCs that are within the scope of the chemistry programme.
(b) A plant specific chemistry regime should be developed in accordance with the plant's design and safety analysis to contribute to the safe operation of the plant during all operational states, design basis accidents and design extension conditions. The managers of the chemistry programme should understand any proposed design changes and the consequences of these changes for the chemistry programme, updating the programme accordingly if necessary. Any changes in the design basis documents relevant to the water chemistry programme should be approved by the managers.
(c) The chemistry programme should be regularly reviewed to take into account operating experience, including good practices, from other plants and from other States (e.g. feedback on operating events, research results, revised standards). The conclusions of the review should be documented and the improvements incorporated into the chemistry programme, when considered beneficial. Managers and supervisors of the chemistry programme should regularly review available internal and external information on operating experience. The information on operating experience and the results of these reviews should be made available to relevant chemistry personnel.
(d) New nuclear power plants should benefit from the experience of other similar plants in the selection of materials, equipment and water chemistry programmes, for example to minimize the source term during plant operations and subsequently during the decommissioning phase.

(e) The primary water chemistry regime should take into account its potential impact on the following:
   (i) Plant specific corrosion mechanisms of materials in the primary system;
   (ii) Fuel cladding corrosion;
   (iii) Activation and transport of corrosion products;
   (iv) Dose rates;
   (v) Crud induced power shifts (where applicable);
   (vi) Crud induced localized corrosion.
(f) The secondary side chemistry regime should:
   (i) Minimize corrosion in the systems and in the components;
   (ii) Minimize deposits in the steam generators;
   (iii) Minimize concentration of deleterious impurities in bulk water and more importantly in crevice areas with restricted flow;
   (iv) Minimize leaks in both the water and air parts of the condenser;
   (v) Ensure the effective purification of steam generator blowdown water and water from condensers.
(g) Condenser tube leakages should be properly controlled and minimized to avoid the ingress of harmful impurities.
(h) The chemistry regime for auxiliary and supporting systems should be compatible with the construction materials to preserve their full integrity and availability.
(i) For chemistry control in semi-closed cooling systems with cooling towers, the following aspects should be taken into account:
   (i) The system design and the types of material present in the system;
   (ii) The regulatory requirements regarding microbiological growth;
   (iii) The discharge of effluents to the environment;
   (iv) The quality of the raw water;
   (v) The supply of chemical compounds needed to operate the system.
(j) Appropriate chemistry control and diagnostic parameters should be used to ensure safe and reliable operation (see paras 5.9 and 5.10).
(k) The chemistry programme data should be communicated in a timely manner to relevant managers and to those parts of the organization that need such information (e.g. operators, maintenance personnel, system engineering group, technical support organizations).
(l) Any deviations (e.g. deficiencies, adverse trends, fast transients) from normal operational limits should be addressed in a timely manner, and the effectiveness of methodologies used for the identification of such deviations should be regularly evaluated and improved, if necessary.

(m) On-line instruments and equipment in the laboratory should be regularly inspected, calibrated, maintained and kept up to date. The necessary redundancy and/or diversity for this equipment should be ensured.

(n) The chemistry department should provide information on the plant ageing management programme to ensure the safe and long term operation of the SSCs.

(o) The in-service inspection results should be used to confirm whether the chemistry programme is effective.

(p) Procedures and practices should be established to ensure that representative sampling with relevant frequencies can be performed from necessary process systems. The proper alignment of graded limit values and measurement frequencies should be carefully evaluated.

(q) A process to avoid the ingress of impurities from chemicals and substances should be implemented. The selection of new construction materials for modernization or refurbishment activities should be carefully considered to minimize the generation and subsequent dissolution of corrosion products and their subsequent activation in the reactor core.

(r) Radiochemistry measurements should be performed for closed cooling water circuits in boiling water reactors and high-power channel-type reactors, and in the primary and secondary sides of pressurized water reactors and pressurized heavy water reactors to detect leaks in pressure boundaries.

(s) Discharges of radioactive substances and chemicals should be kept as low as reasonably achievable and within national regulations. The chemistry department should carefully evaluate, thoroughly understand and properly document the potential impact of any changes in the chemistry regime on the safe operation of the nuclear power plant, including in relation to radioactive and chemical discharges.

(t) The operating organization should make arrangements to ensure that, after being transferred to holding tanks, liquid effluents are analysed before being discharged. The total amount of discharged effluents should be known and their overall impact on the environment should be assessed.

(u) Radioactive discharges to the environment should be measured on-line before their discharge to ensure that national and plant limits are not exceeded.

(v) The chemistry programme should provide adequate support to identify, characterize and minimize radioactive waste generated at the nuclear power plant (including waste from decontamination).

(w) Hazardous chemicals should be stored and handled properly, and material safety data sheets should be readily available to all plant personnel.

(x) The chemistry programme should include guidance on the selection of suitable decontamination techniques, when necessary.

(y) The plant documentation should define the necessary cleanliness and storage conditions for SSCs during construction and commissioning to ensure the safe and reliable operation of SSCs throughout the lifetime of the plant.
(z) The chemistry programme should include clear expectations and instructions for SSC preservation during outages (see the Annex).

5. CHEMISTRY CONTROL AT A NUCLEAR POWER PLANT

5.1. The purpose of chemistry control is to ensure that systems within the scope of the chemistry programme are operated in accordance with the appropriate chemistry regime. The chemistry regime depends on the design of the plant and on the construction materials used. Chemistry control should be continuously improved by taking into account up-to-date knowledge, research results and operating experience.

5.2. Paragraph 7.14 of SSR-2/2 (Rev. 1) [1] states:

> "Chemistry surveillance shall be conducted at the plant to verify the effectiveness of chemistry control in plant systems and to verify that structures, systems and components important to safety are operated within the specified chemical limit values."

The effectiveness of chemistry control in relevant plant systems should be regularly evaluated by establishing and implementing sufficiently extensive chemistry and radiochemistry measurements.

5.3. To achieve effective chemistry control, the managers of the chemistry programme should define detailed chemistry parameters to be followed in all water cooled reactor types. These parameters should be developed taking into consideration their potential safety importance. All parameters should be based on adequate technical knowledge and international nuclear industry experience.

5.4. The control parameters should be those parameters that have a negative impact on material integrity, fuel cladding corrosion or fuel design performance, or that have a direct impact on reactivity control, radiation fields or the environment.

5.5. The control parameters should have clear graded limit values, which should be strictly followed. If deviations from these limit values occur, corrective actions should be initiated within a predefined period of time, and progressively significant actions should continue to be applied until plant shutdown, if deemed technically necessary.

5.6. To enable the implementation of corrective actions in a timely manner, the chemistry department should use sufficiently sensitive and accurate analytical techniques and should select appropriate monitoring frequencies of control parameters. If continuous monitoring is unavailable, sufficient sampling should be implemented.

5.7. Plant specific, expected control parameter values should be specified in the chemistry documentation to avoid unintentionally exceeding graded limit values.

5.8. To avoid the long lasting accumulation of detrimental impurities in low concentrations, integrated limit values for these impurities should be defined, where relevant, and timely actions should be taken if these integrated limit values are exceeded.

5.9. Records of the chemistry control parameters should be maintained and assessed, and any values exceeding the limit values or any deviations from the chemistry programme should be treated in conformance with the management system of the operating organization.

5.10. Diagnostic parameters should be defined to provide further information on the chemistry control status of the plant. The parameters chosen should enable the chemistry department to react proactively to chemistry variations.

5.11. The chemistry department should continuously analyse trends in control and diagnostic parameters and react proactively if adverse trends are identified. Trend analysis should be performed to identify deviations in both short and long term perspectives.

5.12. Normal operational values should also be defined for the activity concentrations of the most important fuel-originated radionuclides present in the primary coolant. The detection limits and threshold values for fuel defects and suspected fuel leakage should also be specified.

5.13. Radiochemistry parameters should be systematically monitored, analysed for trends, evaluated and, in the case of deviation, correlated with chemical and operational data and in relation to occupational exposure and environmental discharges, such as pH at operating temperature (pH_T) and thermal power in the following stages:

(a) Power operation (primary and secondary coolant);
(b) Transients (primary coolant);
(c) Shutdown (primary coolant);
(d) Outages (primary coolant).

Radiochemistry parameters should be taken into account when occupational exposure and environmental discharges are evaluated. Tools should be available to enable the detection of fuel leakage and provide information about its severity.

5.14. Chemistry parameters and their corresponding graded limit values, when applicable, should be clearly defined in chemistry procedures or other relevant plant documentation in the following stages:

(a) Transition from construction to commissioning;
(b) Commissioning;
(c) Startup;
(d) Power operation;
(e) Transients;
(f) Shutdown;
(g) Outages;
(h) Transition from operation to decommissioning;
(i) Decommissioning.

5.15. During outages, equipment and systems should be maintained under adequate lay-up conditions and in accordance with Requirement 32 of SSR-2/2 (Rev. 1) [1]. Information on the preservation of SSCs is provided in the Annex. Lay-up parameters should be monitored and documented, and corrective actions should be implemented, if needed.

5.16. The water chemistry regime of active and passive safety systems that contain liquid neutron absorbers (e.g. boric acid tanks, containment sprinkler systems, bubble stacks, reservoirs containing gadolinium) should be maintained in accordance with each system's technical specifications.

5.17. Appropriate water chemistry control should be applied to minimize the consequences of a loss of coolant accident resulting in the release of iodine radionuclides to the containment building.

5.18. The quality of lubricant oil for systems important to safety should be regularly monitored and controlled.

5.19. The quality of diesel fuel should be verified before its transfer into the diesel fuel tanks. The quality of diesel fuel in the storage tanks for the diesel generators should be checked in accordance with plant documentation. The monitoring results should be analysed for trends to allow for the early detection of potential deterioration of the expected properties.

5.20. Tanks and unventilated spaces containing gases should be strictly monitored and properly maintained to prevent explosions caused by the simultaneous buildup of oxygen and hydrogen and because of the potential presence of gaseous fission products and iodine species.

5.21. The concentrations of the chemical inhibitors that are added to cooling systems and other systems that might have microbiological growth and microbiologically induced corrosion should be adequately controlled and monitored. Potential impacts on industrial safety and the environment should also be assessed.

WATER CHEMISTRY CONTROL IN BOILING WATER REACTORS

5.22. During operation, chemistry control in a boiling water reactor should be focused on decreasing the concentration of harmful impurities in the reactor coolant to the lowest practicable level in order to avoid or minimize intergranular stress corrosion cracking of core components and parts of pressure vessel penetrations, to minimize fuel performance risks and to reduce radiation levels on surfaces of SSCs.

5.23. To avoid or minimize stress corrosion cracking of specific components, appropriate mitigating chemicals should be injected into the coolant, and their concentration should be carefully measured. If mitigating chemicals are not used, the basis for the applied chemistry regime should be clearly documented.

5.24. Dissolved hydrogen and oxygen levels should be maintained within the boiling water reactor specifications.

5.25. During startup, the oxygen concentration in the boiling water reactor water should be controlled and it should be maintained at a low enough level to minimize intergranular stress corrosion cracking.

5.26. Steam humidity should be kept as low as possible to reduce the spread of contamination and degradation of the steam lines.

5.27. The conductivity and concentrations of chlorides, fluorides and sulphates in the boiling water reactor coolant should be controlled and kept below the graded limit values. The concentrations of iron, nickel, silica, copper (in the case of components containing copper) and zinc (in the case of zinc injections) should be adequately controlled in the feedwater system to minimize fuel performance risks.

5.28. The origin of corrosion products entering the boiling water reactor coolant should be understood in order to implement necessary mitigation actions to minimize their impact on fuel cladding and on the amount of activated corrosion products (e.g. corrosion products from feedwater sources, reactor internal materials, carbon steel surfaces in the reactor water cleanup system).

5.29. The boiling water reactor shutdown and startup procedures should be strictly followed to control the release of corrosion products and to effectively remove them using coolant purification system filters and demineralizers, as well as to minimize corrosion. Any deliberate deviation from the procedures should be carefully evaluated by the operating organization and the justification for the deviation clearly documented for future assessments.

5.30. In preparation for shutdown, at those plants where it is possible, the flow rate of the boiling water reactor water cleanup system should be maximized to the extent possible to minimize the inventory of activated corrosion products in the reactor water. Similarly, during a plant shutdown for refuelling, the flow rate in the cleanup system should be as high as possible during the crud and corrosion product release phase.

5.31. The capacity of the boiling water reactor's cleanup system should be based on the amount of fission products released into the coolant as a result of the maximum allowable fuel leakage during power operation. The capacity should also be high enough to efficiently remove corrosion products dissolved from the circuit surfaces and impurities introduced into the coolant.

5.32. The concentration of activated corrosion products in the boiling water reactor water and the transport of those products should be minimized. During normal operation, the continuous injection of zinc into the feedwater should be optimized for this purpose, when applicable.

5.33. If a boiling water reactor has a probe installed in pipelines to recombine radiolysis gases, its availability to fulfil its function should be ensured.

WATER CHEMISTRY CONTROL IN HIGH-POWER CHANNEL-TYPE REACTORS

5.34. For a nuclear power plant with a graphite moderated reactor and water cooling by forced circulation circuit, a chemistry regime that keeps the pH close to a neutral value (i.e. in the range of 6.5–8.0) without chemical additions should be adopted. Graphite moderated reactors should have high purity feedwater, obtained using a full flow condensate and bypass purification system for reactor coolant.

5.35. Chemistry control at a graphite moderated reactor should ensure that:

(a) The deposition of corrosion products on fuel assemblies, heat exchanger surfaces and pipelines is minimized;
(b) The corrosion phenomena of materials is minimized;
(c) Moisture separators produce high quality steam for turbines, as specified by the turbine manufacturer.

5.36. The chemistry parameters, in particular the concentration of dissolved hydrogen and oxygen, should be maintained within specified limits to reduce the risk of corrosion.

5.37. To minimize the level of activated corrosion products in deposits on component surfaces in the forced circulation circuit of a graphite moderated reactor, flushing with or without reagents should be performed both at the beginning of and after shutdown periods.

PRIMARY WATER CHEMISTRY CONTROL IN PRESSURIZED WATER REACTORS (INCLUDING WATER COOLED, WATER MODERATED POWER REACTORS)

5.38. The concentration of dissolved ^{10}B in the pressurized water reactor coolant system for controlling core reactivity should be regularly monitored to prevent deviation from normal isotopic depletion. The concentration of boric acid should be monitored using either on-line measurements or grab sample measurements conducted frequently to support control of pH_T of the primary coolant. The concentration of ^{10}B should be verified before the preparation of the borated solution to ensure that the necessary percentage of ^{10}B is present in the boric acid.

5.39. The addition or removal of alkaline compounds should be used to maintain the optimum pH_T value throughout the fuel cycle to reflect the continuous decrease of boron concentration in the primary coolant. In pressurized water reactors, either lithium hydroxide (enriched in ^{7}Li to minimize tritium generation) or potassium hydroxide and ammonia are used to adjust the pH_T. When potassium hydroxide is used, the total alkali mixture (i.e. potassium injected, lithium produced by neutron reaction on boron, and possibly sodium as an impurity) should be monitored using available techniques.

5.40. The concentration of hydrogen should be kept within specified limits during power operation to minimize the concentration of oxygen and other oxidizing species in the primary coolant. In addition, if make-up water is de-aerated, the oxygen concentration of the make-up water should be monitored and oxygen should be degassed or chemically scavenged, when necessary, to be within specifications.

5.41. Corrosive impurities should be kept below specified limits to avoid corrosion of the primary system components. The most important stressors are oxygen, chlorides, fluorides and sulphates.

5.42. The concentrations of chemical compounds with a low solubility should be kept within specifications to reduce their deposition on fuel cladding surfaces. Such chemical compounds include calcium compounds, magnesium compounds, aluminium compounds and, possibly, silica compounds.

5.43. The pressurized water reactor shutdown and startup procedures should be strictly followed to minimize corrosion and to control the release of corrosion products and to effectively remove them using coolant purification system filters and demineralizers. Any deliberate deviation from the procedures should be carefully evaluated by the operating organization and the justification for the deviation clearly documented for future assessments.

5.44. No specific lay-up conditions are needed for drained primary systems during outages since the materials are selected to minimize susceptibility to corrosion at ambient temperature and atmosphere.

5.45. To further optimize chemistry control, additional chemical compounds may be used in the primary circuit water of a pressurized water reactor. The use of depleted zinc or electrocatalysts should be evaluated to better control the source terms of the corrosion products and the stress corrosion cracking of nickel based alloys. The conclusions of such evaluations should be clearly documented.

5.46. An upper limit for zinc should be specified where applicable, to comply with fuel vendor guidance. Limits for silica and nickel concentrations should also be specified in the case of zinc injection, because these might form low solubility compounds that could deposit on fuel cladding surfaces.

PRIMARY AND MODERATOR WATER CHEMISTRY CONTROL IN PRESSURIZED HEAVY WATER REACTORS

5.47. A management system for heavy water (D_2O) should be established in pressurized heavy water reactors to account for the D_2O inventory and to control the level of tritium activity. Throughout the heavy water management system, D_2O should be segregated on the basis of its tritium content and isotopic composition.

5.48. The isotopic purity of D_2O in the heat transport system should not be permitted to decrease below a value that ensures that excessive positive reactivity will be prevented in the event of voiding in the heat transport system. Additionally, the isotopic purity of D_2O in the heat transport system should not be permitted to increase beyond the isotopic purity of the moderator at the equilibrium of the fuel cycle.

5.49. The concentration of soluble reactivity agents (e.g. poisons such as boron or gadolinium) should be based on the negative reactivity necessary to ensure that the pressurized heavy water reactor will remain subcritical in the event of a serious process failure. The poison concentration that could lead to an over-poisoned guaranteed shutdown state is specific to each nuclear power plant and should be documented in the safety analysis report.

5.50. The isotopic concentrations of boron (^{10}B) and gadolinium (^{155}Gd to ^{157}Gd) salts intended for use as neutron poisons should be verified prior to their introduction into the reactor system, to ensure that their isotopic concentrations are equal to, or higher than, their natural isotopic abundance.

5.51. Upper and lower limits for deuterium or hydrogen and oxygen concentrations in cover gas systems should be established to eliminate the possibility of the formation of an explosive gas mixture.

5.52. The concentration of dissolved deuterium in the primary circuit of a pressurized heavy water reactor should be such that radiolysis is suppressed and the system components are not impacted by hydrogenation.

5.53. The concentrations of chloride, fluoride and sulphate, and of corrosion products should be kept below specified limits. Deviations from the measured theoretical value of conductivity should trigger actions to investigate the potential ingress of ionic impurities or potential problems with the system sampling techniques.

5.54. During shutdown of a pressurized heavy water reactor, efforts should be made to maintain optimal chemistry specifications, despite the limited availability of purification and chemical addition systems. Hydrogen should not be added when the reactor is cold and depressurized. During shutdown for maintenance, the empty part of the primary system should be filled with nitrogen gas, to the extent possible, to minimize air ingress.

5.55. During shutdown of a pressurized heavy water reactor, normal chemistry specifications should be maintained for the moderator system, except in the following scenarios:

(a) When the moderator contains gadolinium as a result of poison injection by the shutdown safety system, as a result of being in a guaranteed shutdown state, or as a result of xenon simulation;
(b) When the cover gas is being purged;
(c) When the moderator is being drained.

SECONDARY WATER CHEMISTRY CONTROL IN PRESSURIZED WATER REACTORS (INCLUDING WATER COOLED, WATER MODERATED POWER REACTORS AND PRESSURIZED HEAVY WATER REACTORS)

5.56. Special attention should be paid to the integrity of the parts of secondary and auxiliary systems that might be significantly affected by various forms of corrosion or deposited corrosion products. The secondary and auxiliary systems and their water chemistry control should be designed to minimize the ingress of corrosive impurities.

5.57. The selected water chemistry regime for secondary and auxiliary systems:

(a) Should further minimize the flow accelerated corrosion of construction materials, particularly in components made of carbon steels;
(b) Should be compatible with all secondary side materials;
(c) Should reduce the amount of corrosion products in the steam generator feedwater to minimize their deposition on steam generator tubes, between tubes and tube sheets, and on and within tube support plates and collectors;
(d) Should be compatible with the plant's purification systems;
(e) Should minimize the discharge of liquid and solid radioactive substances and other materials to the environment;
(f) Should be achieved by selecting appropriate chemicals to avoid causing unnecessary health risks to personnel.

5.58. The secondary circuit should be operated with a high pH value, which should be obtained using volatile alkaline reagents such as ammonia and/or amines (e.g. morpholine, 2-aminoethan-1-ol, dimethylamine, hydrazine). The pH value of the secondary side water is plant specific and should be such that an appropriate pH_T value is ensured throughout the secondary circuit. The concentration of alkaline chemicals should be specified and verified.

5.59. A reducing agent should be added when necessary to scavenge oxygen in the water in order to minimize susceptibility to stress corrosion cracking in steam generators. The chemical injection strategy (e.g. injection points, rate, frequency) should be carefully evaluated to ensure maximum effectiveness.

5.60. The primary to secondary circuit leakage rate in the steam generator tubes should be calculated on the basis of on-line activity measurements and should be strictly controlled within predefined limits. Leaks from the primary to secondary circuit should be limited to minimize the production of radioactive waste (e.g. liquid effluents, resins, filters, sludge) and the potential release of radionuclides into the environment.

5.61. The levels of deleterious impurities (e.g. sodium ions, chloride ions, sulphate ions, lead ions, copper ions, total suspended solids, suspended iron) in the steam generator water should be measured and kept as low as possible. As impurities accumulate in the steam generators during steady state operation, blow-down limits should be established either for each impurity or through a representative indicator (e.g. cation conductivity).

5.62. The use of lead-containing equipment or materials such as certain greases in the secondary systems during operation or maintenance should be avoided to the extent possible.

5.63. The potential impact of chemistry parameters on the integrity of the steam generator should be regularly evaluated and the results should be analysed for trends. The main inputs for such an evaluation should be the following:

(a) Evaluation of the results of non-destructive testing (during in-service inspections) of the integrity of the steam generator tubes, at least for degradation relating to the chemistry control of primary and secondary circuits;
(b) Measurement of hideout return to obtain an estimate of the impurity levels in crevices and in flow restricted areas (e.g. sludge piles, deposits);
(c) Evaluation of the quality and quantity of sludge removed from steam generators during outages;
(d) Evaluation of the amount of hard deposits in the steam generators that can cause clogging.

5.64. If necessary (i.e. on the basis of a safety assessment), an effective cleaning procedure should be conducted to remove deposits from steam generators to mitigate the effects of various forms of corrosion. However, the need to perform cleaning should first and foremost be avoided by implementing effective chemistry control and/or other related measures, such as effective material selection and compatibility. If cleaning becomes necessary, an adequate safety justification should be provided.

5.65. To further optimize the control of corrosion products in the steam generators, the use of dispersant compounds and film-forming products in the secondary water should be considered and assessed. The results of the assessments should be clearly documented for future work.

5.66. Inorganic and organic impurity concentrations in the demineralized make-up water should be controlled to ensure compliance with technical specifications.

5.67. Auxiliary systems should be operated in accordance with a specific chemistry regime to minimize corrosion risks.

6. OPTIMIZATION OF THE CHEMISTRY ASPECTS OF RADIATION EXPOSURE

6.1. The optimization of the chemistry regime should contribute to reducing radiation exposure by the following means:

(a) Continuous reduction of dose rates in the plant over time;
(b) Reduction of discharges of radioactive material to the environment;
(c) Reduction of the generation of radioactive waste and its radioactivity.

6.2. Specifications for all important radiochemistry parameters should be established and applied during different operating modes to ensure that doses to personnel comply with the dose limits, are as low as reasonably achievable and are in compliance with regulatory requirements. During an outage and, if possible, during operation, dose rates from systems and components should be measured regularly to allow for trends to be analysed. These data should be complemented by nuclide specific measurements to identify which nuclides are the main contributors to the dose rates.

6.3. To reduce the radiation dose to personnel, the chemistry programme should include the following:

(a) The application of a suitable chemistry regime to minimize the generation and subsequent dissolution of corrosion products, deposition of corrosion products in the reactor core and their subsequent transport to surfaces of SSCs;
(b) The use of high quality make-up water to avoid the ingress of easily activated chemical species and suspended materials into the process streams;
(c) The effective use of primary and secondary water cleanup systems for removing dissolved and suspended, activated and non-activated substances;
(d) Quality control of the chemicals used in the coolant systems to avoid the ingress of impurities that could have a negative impact on SSCs or increase activity levels;
(e) The regular discharging of systems to reduce the level of tritium, if applicable.

6.4. The deposition of corrosion products in the reactor core should be minimized by keeping the chemistry parameters of the primary water coolant as constant as possible and at an optimal value during steady state operation. Particular attention should be given to preparations for shutdown. Plans should be established to enable the purification of reactor coolant during refuelling outages.

6.5. The dissolution of elemental cobalt (^{59}Co) in the reactor water coolant should be controlled through engineering modifications and an optimized chemistry regime. The use of materials containing ^{59}Co that come into contact with the primary coolant should be avoided to the extent possible to reduce dose rates due to ^{60}Co. For some reactor designs, this should include, where reasonably practicable, specifying low cobalt-containing grades of stainless steel for some SSCs. To avoid the unnecessary dissolution of inactive cobalt ions in the primary coolant, all large replacement or heavily decontaminated components should be properly pre-passivated, if technically possible, before their surfaces are exposed to the operating environment.

6.6. Chemistry control should minimize the deposition of nickel into the reactor core during steady state operation and efficiently dissolve ^{58}Co during shutdown periods. The purification system should have a suitable configuration to implement the efficient removal of ^{58}Co from the water, particularly during the shutdown period.

6.7. Programmes for the replacement of stellite (typically 57% cobalt) and other cobalt-containing hard-facing alloys, as well as silver and materials containing antimony, should be considered, where practicable. The chemistry department should be part of the process for the approval of new equipment and materials for use in plant systems.

6.8. The presence of easily activated elements should be minimized in SSCs and, if necessary and possible, specifically removed from the coolant during reactor shutdown by a proper shutdown chemistry regime with an adequate purification system. In graphite moderated reactor units, ^{95}Zr could also be an important contributor to radiation fields and should therefore be eliminated if possible.

6.9. During the commissioning stage, surfaces should be pre-passivated prior to initial startup in order to produce a protective oxide layer on component surfaces to minimize the release of corrosion products. The chemistry conditions to be maintained during this period should be aligned with the materials used in the system, and should be considered and justified in the safety analysis of the plant.

6.10. The successful completion of hot conditioning should be verified. Acceptance criteria for the completion of this process (e.g. relating to the chemicals used, duration and temperature) should be established. Material samples could be taken and analysed as an additional step to confirm the quality of the oxide film formed on the sample surfaces. The injection of zinc during this period should be considered; if zinc is not used, the justification for not using it should be clearly documented.

6.11. Harmful chemical species (e.g. oxygen, halogens, corrosion products) and chemical additives (e.g. hydrogen, alkalis, zinc) should be strictly controlled to minimize fuel cladding deterioration and thereby optimize protection and safety with regard to occupational exposure and environmental discharges. The amount of low solubility species should be minimized to keep the buildup of deposits on the cladding surfaces as low as possible and thus avoid the risk of fuel cladding failures.

6.12. The normal level of fission product activity in the primary coolant should be measured during the initial period of reactor operation following startup, in order to define a reference background level value for use in trend analysis. This value should be included in the radiochemistry procedures and used to evaluate fuel leakage or fission product contamination in the reactor core.

6.13. The activities of fuel-originated radionuclides in the primary coolant and in other systems should be kept below their specified values. These activities should be checked by continuous monitoring and/or periodic sampling, and the measurement results should be analysed for trends and assessed to identify potential fuel cladding defects.

6.14. The plant management should agree on levels for fission product concentrations in the coolant, beyond which no load following actions should be taken. These levels should be clearly based on the plant's safety analysis. If there is significant fuel failure, the management should order the shutdown of the unit within a reasonable period of time to remove the defective fuel element.

CHEMISTRY ASPECTS OF DECONTAMINATION

6.15. The need to undertake decontamination at the nuclear power plant should be reduced as far as reasonably achievable. Comprehensive decontamination procedures (e.g. using chemical, electrochemical or mechanical techniques) should be developed and validated for applications for which decontamination is necessary. When choosing the decontamination technique, the potential long term impact on plant materials, the minimization of recontamination rates and the generation of nuclear waste should be taken into consideration.

6.16. Chemical decontamination should be complemented by optimized chemistry control for a net reduction of occupational doses at the plant. The recontamination of surfaces should be minimized by reducing the source terms to the extent practicable.

6.17. Extensive chemical decontamination processes should be avoided in order to prevent too high a dissolution rate of the protective oxide films on the primary circuit. After chemical decontamination of larger primary circuit components or the full system, proper rinsing and/or re-passivation of system surfaces should be performed to avoid extensive deposits of corrosion products on fuel surfaces that could increase the risk of fuel cladding failure and potential power shifts. Water should be purified to remove corrosion products.

CHEMISTRY ASPECTS OF RADIOACTIVE WASTE STORAGE

6.18. Operating procedures and chemistry control practices should ensure that the generation of radioactive waste is kept as low as possible in terms of both activity and volume, taking into consideration doses to workers and discharges to the environment.

6.19. The treatment and interim storage of radioactive waste arising from plant operation are required to be conducted in accordance with the requirements established in IAEA Safety Standards Series No. GSR Part 5, Predisposal Management of Radioactive Waste [13], in particular Requirement 12 on radioactive waste acceptance criteria. The chemistry programme should be applied for the treatment and interim storage of radioactive waste. Further recommendations on waste management in the operation of nuclear power plants are provided in IAEA Safety Standards Series No. SSG-40, Predisposal Management of Radioactive Waste from Nuclear Power Plants and Research Reactors [14].

6.20. In order to minimize liquid and gaseous waste and/or activity, and thus facilitate disposal and reduce on-site and off-site exposure in a cost-effective manner, the operating organization:

(a) Should monitor and quickly identify leakages in the primary systems and take corrective actions in a timely manner;
(b) Should optimize the handling and transport of liquids to reduce the potential amount of liquid waste collected;

(c) Should segregate liquids from different sources to avoid dilution and mixing of chemically incompatible substances and liquids that have a significant difference in activity levels;
(d) Should reduce the amount of chemicals used, and recycle chemical substances (particularly boric acid) if possible and reasonable;
(e) Should establish appropriate chemistry control to prevent primary to secondary coolant leakages;
(f) Should reduce the amount of gas introduced into the system to the minimum quantity practicable;
(g) Should use ion exchange resins and selective sorbents;
(h) Should use filters to separate suspended radioactive substances from the liquids;
(i) Should use hold-up tanks and other delay systems (e.g. charcoal beds) to allow radioactive decay before material is discharged to the environment;
(j) Should use effective filters to separate aerosols from gaseous discharges;
(k) Should use systems for the volume reduction of gases (e.g. recombiners, absorbers, vapour recovery system, pressurized storage), which also serve as delay systems;
(l) Should optimize liquid waste management.

7. CHEMISTRY AND RADIOCHEMISTRY MONITORING AT A NUCLEAR POWER PLANT

7.1. Paragraph 7.15 of SSR-2/2 (Rev. 1) [1] states:

> "The chemistry programme shall include chemistry monitoring and data acquisition systems. These systems, together with laboratory analyses, shall provide accurate measuring and recording of chemistry data and shall provide alarms for relevant chemistry parameters. Records shall be kept available and shall be easily retrievable."

The scope and frequency of chemistry and radiochemistry monitoring activities during commissioning, various operating modes (e.g. startup, shutdown, operation at stable power levels) and outages, as well as in transient conditions, should be specified by the chemistry department in the relevant plant documentation and procedures. The same applies to accident conditions and decommissioning.

7.2. The frequency with which chemistry and radiochemistry measurements are taken should be defined taking into consideration the rate of change of parameters compared with the time scales for actions associated with graded limit values, the safety importance of SSCs, the aggressiveness of the measured impurities, and operating modes.

7.3. The chosen analytical method should provide sufficient sensitivity in the concentration ranges of expected values and graded limit values. The 'matrix effect' (i.e. the effect of other ingredients in the sample) should be determined and corrections should be made, if necessary.

7.4. The chemistry and radiochemistry measurements should be used to detect trends in the chosen parameters, to discover and eliminate undesirable effects and to minimize the consequences of deviations in chemistry parameters. The measurements should be taken at all stages in the lifetime of a plant, including commissioning, startup and shutdown periods, and when systems are taken out of operation for long periods or during decommissioning.

7.5. Chemistry and radiochemistry measurements:

(a) Should provide timely chemistry and radiochemistry results allowing the operating organization to run the plant according to the specifications;
(b) Should verify compliance with chemistry control parameters, diagnostic parameters and radiochemistry limits and conditions;
(c) Should detect any abnormal conditions and enable the implementation of corrective actions;
(d) Should ensure compliance with the discharge limits.

7.6. Computer programs used to calculate chemistry parameters should be verified and validated in accordance with the recommendations provided in IAEA Safety Standards Series No. SSG-39, Design of Instrumentation and Control Systems for Nuclear Power Plants [15].

7.7. The most important control parameters should be measured using on-line monitoring techniques. For these parameters, the chemistry department should implement redundant and independent verification.

7.8. The chemistry programme should include provisions for the comparison of data from different sampling points or the comparison of measurements of different parameters from the same sampling point (e.g. intercomparison of grab sample results and measurements of cation conductivity in the steam generator blowdown system) in order to evaluate the plausibility of the data measured.

7.9. Paragraph 7.16 of SSR-2/2 (Rev. 1) [1] states that "Laboratory monitoring shall involve the sampling and analysis of plant systems for specific chemical parameters, concentrations of dissolved and suspended impurities, and radionuclide concentrations."

All on-line and laboratory analysis procedures:

(a) Should describe the intended use of the procedure;
(b) Should reference information sources used for the development of the procedure;
(c) Should provide a summary of relevant information on the analysis methods to be used, indicating the accuracy, linearity and range of the methods, possible interferences and the precision of the measurements;
(d) Should state the equipment, reagents and control standards needed to perform the analyses;
(e) Should provide step by step instructions for performing the analyses and calculating the results;
(f) Should indicate the quality control requirements;
(g) Should describe the measures for industrial safety and radiation protection;
(h) Should provide information on instrument calibration;
(i) Should give instructions for unplanned situations;
(j) Should prove a limit of detection and a limit of quantification.

7.10. The monitoring equipment and methods to be used should be validated before commissioning. The validation process should demonstrate that the instruments, equipment and methods are suitable for the task. The validation data should be properly documented and recorded so that they are easily retrievable and traceable.

7.11. A calibration and maintenance programme should be established and applied to all on-line and laboratory monitoring instruments. The responsibilities for calibration and maintenance should be clearly defined.

7.12. Calibration strategies should be chosen in such a way that the range of calibration points includes the values that are expected to be measured and the calibration points are as close as possible to the expected measurement values.

7.13. Monitoring equipment should be calibrated at regular intervals, at a frequency decided on the basis of the manufacturer specifications, plant experience or equipment control charts. The calibration should be checked regularly with a control standard. The concentration of the control standards should be close to the expected value. The results of the calibration checks should be analysed against appropriate control and warning limits. Depending on the analytical method applied, calibration control measurements should be performed before and/or after each analytical run.

7.14. Reagents and sources used for calibration and control should be validated (e.g. all control standards used should be traceable to certified standard solutions or reagents). Calibration and control standards should be prepared from different reference materials to avoid common failures.

7.15. On-line chemistry monitoring and data acquisition systems should be used to accurately measure and record data and provide alarms for key chemistry parameters. The measurement ranges of analytical instruments should extend beyond the operating ranges and safety limits of the plant.

7.16. Typical physical conditions (e.g. temperature, pressure, flow rate) at the measuring location should be taken into account. Although some instruments have temperature compensation for calibration purposes, the temperature of the measurement media should be controlled as some instruments might have limited temperature ranges.

7.17. The activity of fission products should be measured to confirm the fuel integrity, identify fuel cladding leaks and obtain an estimate of the severity of the leaks. The following should be taken into consideration for performing these tasks:

(a) The gamma spectrometry equipment should be well maintained and calibrated, and various measurement geometries should be used for calibration.
(b) Sufficient sensitivity should be ensured to allow the early detection of fuel leaks.
(c) Power transients accompanied by ‘spiking phenomena’ for fission products should be adequately monitored.
(d) Depending on the type of fuel, a selection of both volatile and non-volatile radionuclides should be measured to enable the detection of both small and large cladding defects.
(e) Appropriate radionuclide activity ratios should be applied to assess the burnup of leaking fuel rods in order to facilitate their identification during operation or outages, depending on the type of reactor.

(f) To detect potential fuel leaks, the radioactivity of the primary circuit should be monitored using fixed on-line analysers. Otherwise, an adequate frequency for grab sampling should be defined.

7.18. Radiochemistry measurements should also be taken during spent fuel handling operations (e.g. during reactor pool storage, transport operations and interim storage), in order to monitor fuel integrity and the possible propagation of defects after the removal of the fuel from the reactor. These measurements, together with proper sampling arrangements, should also be part of the process to identify leaking fuel rods.

7.19. Measurements of the primary coolant activity of activated corrosion products should be taken to evaluate chemistry control performance and to understand and minimize radioactive material transport. Such measurements should be taken at various sampling points.

7.20. Measurements of other activated species (e.g. radioisotopes of argon, tungsten, sodium, potassium and chlorine) should be performed to cross-check the results of chemical analyses and to provide an early warning of low concentrations of potential ingresses of foreign material.

7.21. Radiochemistry methods should be used to evaluate barrier leak rates that cannot be monitored by other measurement techniques, especially when the leak rate is very low (e.g. in steam generator tube leaks or leaks to intermediate cooling systems).

7.22. Radiochemistry measurements should be taken to monitor the performance of purification systems, especially when the removal of radioactive material is the main purpose of the purification system.

7.23. The activities of relevant radionuclides should be measured when monitoring the efficiency of decontamination processes, especially in the decontamination of large components, in order to optimize treatment time and minimize radioactive waste generation. Monitoring practices should be in accordance with the optimization of protection and safety.

7.24. Radiochemistry methods should be used to characterize radioactive waste with regard to its treatment, conditioning and disposal. The following should be taken into consideration for the characterization of waste:

(a) Effective and validated radiochemical separation methods should be developed for the activity measurement of difficult-to-measure radionuclides (e.g. pure alpha or beta emitters, low energy gamma emitters).
(b) For the radionuclides specified for each disposal facility, and as defined in the safety analysis report, the activities should be determined repeatedly in a defined set of waste streams, so that sufficient data are accumulated from which mathematical correlations between difficult-to-measure radionuclides and key (reference) radionuclides can be derived (so-called ‘fingerprinting’).
(c) The correlations described in (b) should be used for the calculation-based characterization of newly generated waste, but periodic checks of their correctness should be performed through new radiochemical analyses.

7.25. The activity of radioactive effluents, both liquid and gaseous, should be monitored regularly by appropriate activity fractioning and monitoring methods.

7.26. Methods that rely on radiochemical separation should be applied in monitoring releases of tritium and ^{14}C, as these are particularly low energy beta emitters.

7.27. The radioisotopes on the inner surfaces of the primary circuit should be performed using in-situ gamma spectrometry at carefully selected points in the primary circuit, or other techniques such as wipe sampling, oxide layer scraping or electrochemical sampling. The data obtained should be analysed for trends and correlated with chemical and operational data, such as pH_T and thermal power.

CHEMISTRY FACILITIES AND EQUIPMENT

7.28. Laboratories should be suitably secured and should have adequate space, supplies and equipment.

7.29. Redundancy of laboratory analysis (on the site or at other locations or organizations) for the most important parameters should be provided either on the site or at other locations or organizations, to ensure that analytical services can be provided at all times, including during design basis accidents and design extension conditions.

7.30. Adequately redundant equipment should be made available for performing analyses of given types and at given frequencies of the most important chemistry and radiochemistry parameters. If any analyses are outsourced, the chemistry department should ensure that the necessary redundancy is also provided by the relevant external organization.

7.31. Laboratories should implement good general housekeeping and ensure orderliness and cleanliness in work areas and at sampling points. These areas should comply with the criteria for contamination levels defined in plant procedures. Eating, drinking and smoking should not be allowed in the laboratories. Proper environmental conditions should be maintained in the laboratories. Radiochemistry laboratories should be regularly controlled by the radiation protection department to avoid buildup of radiation fields.

7.32. Industrial safety (including through fume hoods for ventilation, appropriate storage of flammable solvents and hazardous materials, tools to deal with spilled chemicals, flammables and other gases, provision of safety showers for personnel, personal protective equipment and first aid kits) and radiation safety (including through radiation shielding and contamination control facilities) should be ensured during all chemistry and radiochemistry related activities.

7.33. Fume hoods should be periodically checked in accordance with industry standards. The malfunction of active safety systems (e.g. the ventilation system of a fume hood) should be promptly indicated and repaired. All laboratory and work practices should be conducted in accordance with plant procedures and industrial safety standards.

7.34. All laboratory equipment should be in good condition in order to provide accurate and reliable analytical data for monitoring purposes. The condition of such equipment should be ensured by a documented maintenance plan, a regular calibration plan, and a long term plan for equipment renewal. Instruments currently undergoing validation or maintenance should be clearly labelled.

7.35. Instrumentation manuals, logbooks and calibration and control records should be available in the laboratory.

7.36. For relevant parameters, the adequacy and the accuracy of chemistry and radiochemistry measurements should be checked regularly by means of intralaboratory and interlaboratory tests to identify potential analytical interferences, incorrect calibration, errors in the selection or implementation of the analytical technique, and issues in instrument operation. The results of these tests should be evaluated to determine the cause of unexpected deviations, taking into account both the short and long term effects of such deviations. If necessary, corrective actions should be taken to further improve laboratory performance.

7.37. If instrument performance shows significant irregularities, an investigation should be conducted to determine the cause and to identify suitable actions to restore measurements with the appropriate quality.

7.38. Representative grab samples should be ensured by appropriate flushing of sampling lines, proper determination of the sample flow rate, cleanness of containers, and minimization of the risk of chemical contamination and loss of dissolved gases or volatile substances during sampling. A written procedure on the sampling process should be made available.

7.39. Account should be taken of delays in obtaining samples (e.g. owing to the volume of the sampling line for liquid samples) and of specific sampling issues associated with obtaining representative samples of soluble and particulate corrosion products.

POST-ACCIDENT SAMPLING SYSTEM

7.40. A post-accident sampling system should be ready to operate when needed, in accordance with accident or emergency procedures, to obtain chemistry and radiochemistry samples from the reactor coolant or from the sumps and fission products in the containment. If a post-accident sampling system does not exist, other means of post-accident sampling should be available.

7.41. For post-accident sampling, the following should be available:

(a) Procedures for post-accident sampling.
(b) Radiation protection measures (e.g. shielding of the sampling tube) for the personnel who perform sampling, transport the samples to the laboratory and perform the measurements in the laboratory. These measures should be evaluated in advance.
(c) A programme for preventive maintenance.
(d) Regular checks of the operability of post-accident sampling.
(e) Regular training of personnel designated to perform post-accident sampling (i.e. personnel taking grab samples and performing subsequent activities).
(f) A list of the chemistry parameters to be monitored.

7.42. Radiochemistry equipment should be available to measure post-accident samples having high activity levels, or suitable techniques should be used to dilute reliable samples.

8. MANAGEMENT OF CHEMISTRY DATA AT A NUCLEAR POWER PLANT

8.1. The results of on-line measurements, grab samples and quality control measurements should be recorded (e.g. in laboratory logs, plant process computers, data sheets or databases containing periodic on-line measurements). The results should be supplemented with information necessary for their interpretation, assessment and communication, as appropriate.

8.2. Chemistry data should be stored in a database and be easily retrievable, in accordance with chemistry department documentation and the requirements of the quality assurance programme. The database should be appropriately secured so that only authorized personnel have access to it. If stored data need to be corrected for any reason, the corrections and their justifications should be traceable.

8.3. Analytical data should be reviewed to verify their completeness, accuracy and consistency. To identify actual and potential deviations in chemistry parameters, the assessment of chemistry data should be performed promptly after the data have been recorded. Depending on the significance and potential consequences of any deviation, the chemistry personnel should inform relevant operating personnel in accordance with plant procedures.

8.4. Significant deviations in chemistry analysis results should be promptly reported to the appropriate level of management. The chemistry department should establish effective communication with other relevant departments at the nuclear power plant when analytical data indicate the need for prompt action to correct chemistry related problems.

8.5. In the case of deviations or anomalies in the measurement results, analyses should be checked and verified by a qualified member of the chemistry personnel and appropriate corrective actions should be taken in a timely manner and documented.

8.6. The primary responsibility for the review of deviations or anomalies in chemistry data should be assigned to chemistry personnel. The chemistry personnel should compare the current data with those previously obtained and should investigate why the results obtained are outside the expected range of the existing system operating conditions. The chemistry personnel should regularly evaluate the results of the laboratory quality control tests.

8.7. Trends in chemical data should be correlated with operational parameters such as thermal power and changes in chemical injection rates.

8.8. Data should be compared with operational limits, and an evaluation and trend analysis of the data should be performed to assess the efficiency of chemistry control, to identify inconsistencies in analytical data and adverse trends in chemistry conditions, and to help in optimizing chemistry control in plant systems.

8.9. Trends in relevant chemistry parameters should be analysed to obtain an adequate picture of plant chemistry conditions and to facilitate the correlation between the chemistry parameters and the status of the systems.

8.10. The trends should be reviewed soon after the data have been recorded to identify problems that might necessitate the implementation of corrective actions before a parameter exceeds its specified limit. The expected values should be used to detect a parameter approaching its specified limit and there should be sufficient margins between these values and the control limits, to the extent possible. Trend analysis should also be used to evaluate transients of a short duration caused by plant operational changes, and slower long term changes occurring during steady state operation.

9. QUALITY CONTROL OF CHEMICALS AND OTHER SUBSTANCES AT A NUCLEAR POWER PLANT

9.1. Paragraph 7.17 of SSR-2/2 (Rev. 1) [1] states:

> "The use of chemicals in the plant, including chemicals brought in by contractors, shall be kept under close control. The appropriate control measures shall be put in place to ensure that the use of chemical substances and reagents does not adversely affect equipment or lead to its degradation."

A policy should be established to prevent the use of unapproved chemicals or other substances in or on the plant's SSCs. The responsibility for coordinating the control of chemicals and other substances on the site should be clearly established in accordance with the plant's integrated management system.

9.2. The operating organization should be responsible for ensuring the use of appropriate chemicals and their specified quality.

9.3. The use of chemicals and other substances at the plant, including those brought to the plant by contractors, should be controlled in accordance with clearly established plant procedures.

9.4. A list of approved chemicals and other substances that are allowed to be used at the plant should be readily available. All personnel working at the plant should know where to find this list.

9.5. Chemicals and other substances should not be used in SSCs that are within the scope of the chemistry programme if they contain corrosion inducing components above the specified limits or if they might increase the activity on the SSC surfaces. If the use of such chemicals and substances cannot be rejected, a risk assessment should be performed and documented before accepting their use.

9.6. Procedures should be established for the procurement, storage, replacement and ordering of chemicals and other substances, including hazardous chemicals. These procedures should align with or be more stringent than national regulations.

9.7. Prior to the use of operational chemicals and other substances (e.g. boric acid, ion exchange resins, diesel fuel), a sample should be taken and analysed to ensure compliance with the relevant specifications, and the results should be compared with the supplier's certificate. If the results are not in compliance with the specifications, use of the chemicals or other substances should be rejected, or a risk assessment should be performed and documented before accepting their use.

9.8. The batch or container of chemicals or other substances should be labelled in accordance with plant procedures, for easy verification that the relevant department has approved its use in a specific area. Chemicals and other substances in storage areas should have a label indicating their shelf life. Tanks containing chemicals should also be appropriately labelled.

9.9. When a chemical is transferred from a stock container to a smaller container, the latter should be labelled with the name of the chemical, the date of transfer and pictograms to indicate the risk and application area. The contents of the smaller container should not be transferred back into the stock container.

9.10. If a sealed stock container has been opened, the date of opening should be documented. The quality of chemicals in open stock containers should be checked periodically. Residues of chemicals and substances should be disposed of in accordance with plant procedures.

9.11. The number of new chemicals and other substances in the plant should be minimized. However, the replacement of harmful (from the point of view of personnel safety, environmental protection and material compatibility) chemicals or other substances with harmless ones should be encouraged.

9.12. Personnel involved in receiving, storing, transporting and using chemicals and other substances should be trained in storage compatibility, labelling, handling and related safety requirements.

9.13. The plant management should periodically perform walkdowns at the plant to evaluate whether the control and storage of chemicals and other substances is effective and to check for insufficient storage practices of chemicals and other substances.

9.14. Material safety data sheets for all approved chemicals and other substances should be available and easily accessible to everyone on the site (e.g. in an electronic database). These data sheets should be in accordance with the relevant national legislation and should include, at a minimum, the possible hazards of the material, preventive measures for its handling, and medical recommendations in case of its improper use.

9.15. Chemicals should be stored appropriately, for example in a cabinet that is fire resistant and that catches spillages. The chemical storage area should have a safety shower, in accordance with national regulatory requirements and plant design and documentation, and waste disposal procedures. Oxidizing and reducing chemicals, flammable solvents and concentrated acid and alkaline solutions should be stored separately. Reasonably small amounts of approved and properly labelled chemicals can be stored in other controlled environments.

9.16. When storing chemicals, account should be taken of the reduced shelf life of opened containers. Unsealed and partly emptied containers should be stored in such a manner that the remaining product meets the certified specifications.

REFERENCES

[1] INTERNATIONAL ATOMIC ENERGY AGENCY, Safety of Nuclear Power Plants: Commissioning and Operation, IAEA Safety Standards Series No. SSR-2/2 (Rev. 1), IAEA, Vienna (2016).

[2] EUROPEAN ATOMIC ENERGY COMMUNITY, FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS, INTERNATIONAL ATOMIC ENERGY AGENCY, INTERNATIONAL LABOUR ORGANIZATION, INTERNATIONAL MARITIME ORGANIZATION, OECD NUCLEAR ENERGY AGENCY, PAN AMERICAN HEALTH ORGANIZATION, UNITED NATIONS ENVIRONMENT PROGRAMME, WORLD HEALTH ORGANIZATION, Fundamental Safety Principles, IAEA Safety Standards Series No. SF-1, IAEA, Vienna (2006),
https://doi.org/10.61092/iaea.hmxn-vw0a

[3] INTERNATIONAL ATOMIC ENERGY AGENCY, Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants, IAEA Safety Standards Series No. SSG-48, IAEA, Vienna (2018).

[4] INTERNATIONAL ATOMIC ENERGY AGENCY, Leadership and Management for Safety, IAEA Safety Standards Series No. GSR Part 2, IAEA, Vienna (2016),
https://doi.org/10.61092/iaea.cq1k-j5z3

[5] INTERNATIONAL ATOMIC ENERGY AGENCY, The Management System for Nuclear Installations, IAEA Safety Standards Series No. GS-G-3.5, IAEA, Vienna (2009).

[6] INTERNATIONAL ATOMIC ENERGY AGENCY, Maintenance, Testing, Surveillance and Inspection in Nuclear Power Plants, IAEA Safety Standards Series No. SSG-74, IAEA, Vienna (2022).

[7] INTERNATIONAL ATOMIC ENERGY AGENCY, Modifications to Nuclear Power Plants, IAEA Safety Standards Series No. SSG-71, IAEA, Vienna (2022).

[8] INTERNATIONAL ATOMIC ENERGY AGENCY, Recruitment, Qualification and Training of Personnel for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-75, IAEA, Vienna (2022).

[9] INTERNATIONAL ATOMIC ENERGY AGENCY, UNITED NATIONS ENVIRONMENT PROGRAMME, Prospective Radiological Environmental Impact Assessment for Facilities and Activities, IAEA Safety Standards Series No. GSG-10, IAEA, Vienna (2018).

[10] INTERNATIONAL ATOMIC ENERGY AGENCY, UNITED NATIONS ENVIRONMENT PROGRAMME, Regulatory Control of Radioactive Discharges to the Environment, IAEA Safety Standards Series No. GSG-9, IAEA, Vienna (2018).

[11] INTERNATIONAL ATOMIC ENERGY AGENCY, Deterministic Safety Analysis for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-2 (Rev. 1), IAEA, Vienna (2019).

[12] INTERNATIONAL ATOMIC ENERGY AGENCY, Operational Limits and Conditions and Operating Procedures for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-70, IAEA, Vienna (2022).

[13] INTERNATIONAL ATOMIC ENERGY AGENCY, Predisposal Management of Radioactive Waste, IAEA Safety Standards Series No. GSR Part 5, IAEA, Vienna (2009).
[14] INTERNATIONAL ATOMIC ENERGY AGENCY, Predisposal Management of Radioactive Waste from Nuclear Power Plants and Research Reactors, IAEA Safety Standards Series No. SSG-40, IAEA, Vienna (2016).
[15] INTERNATIONAL ATOMIC ENERGY AGENCY, Design of Instrumentation and Control Systems for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-39, IAEA, Vienna (2016).

Annex

PRESERVATION OF STRUCTURES, SYSTEMS AND COMPONENTS IN A NUCLEAR POWER PLANT

A–1. The scope of this Annex is to provide information based on international best practice on the preservation of structures, systems and components (SSCs) in order to maintain their integrity during the different stages of a nuclear power plant's lifetime. If preservation actions are not sufficient, the impact of various forms of corrosion and potential oxide deposition from the coolant can lead to overall equipment failure, equipment unavailability or the need for extensive inspections, repairs or replacement programmes.

A–2. It is common for many plant systems and components to be open and exposed to air when they are inspected, maintained or repaired during outages. Depending on the actions taken by plant personnel, the internal surfaces of plant systems and components will be exposed to different types of environment for various lengths of time.

A–3. When deciding on preservation conditions during an outage, the operating organization needs to consider the materials used in the SSCs as well as the length of time of the lay-up. Their susceptibility to corrosion is typically defined in various types of plant documentation that are based on international knowledge and guidelines. High alloyed steels will generally need fewer preservation actions than materials such as carbon steels. Therefore, SSCs made of austenitic stainless steel are in most cases left as they are, though the existing water chemistry specifications continue to be strictly observed. For systems composed of carbon steel, the preservation actions needed are more demanding owing to the material's lower corrosion resistance to moisture and oxidizing conditions.

A–4. The length of the preservation period will affect the type of lay-up selected to mitigate corrosion in the system in question. For example, if a plant is going to be shut down for a short period of time, it may be acceptable to leave the system as it is in wet lay-up and maintain recirculation if necessary and possible. The addition of lay-up chemicals to the system will help to minimize corrosion during longer outages. However, plant systems need to be reviewed carefully to identify possible dead ends that these lay-up chemicals might not reach, and for which additional actions might therefore be needed. If dry lay-up is selected, the systems need to be drained when the components are hot to promote the removal of moisture. The use of corrosion inhibitors, such as film-forming products, can help to control corrosion during extended outages and refurbishments. If such inhibitors are used, the appropriate application and control of chemicals is of the utmost importance.

PRESERVATION STRATEGY

A–5. The purpose of preservation is to maintain the integrity of SSCs by mitigating corrosion phenomena. The implementation of a proper lay-up strategy is not only of utmost importance for nuclear power plants in the commissioning stage but also for those already in operation. Preservation measures have an impact on the lifetime of plant SSCs and are therefore an important part of ageing management and asset management programmes. If preservation measures are properly implemented, they can help ensure availability of SSCs and reduce maintenance costs in the long term. The measures selected need to take into account the industrial and radiation safety measures of the operating organization and ensure that the amounts of liquid and solid waste generated, and the amounts of chemicals discharged to the environment, are limited.

A–6. The designers' specifications, operating experience and any operational constraints need to be taken into account in the preservation strategy. The strategy covers all SSCs that are within the scope of the chemistry programme and other systems that are susceptible to degradation when they are not being operated (e.g. gaskets, seals). Plant documentation needs to clearly describe the functions and responsibilities of the personnel involved in preservation.

A–7. The preservation strategy is adapted to the outage type (i.e. planned or unplanned); the outage duration; the equipment, materials and coatings used in SSCs; and the relevant regulatory requirements. The strategy also takes into consideration aspects such as personnel health and safety policies (including chemical hazard and risk of anoxia), the need for radiation protection, and outage related operational constraints. For example, to limit chemical discharges to the environment, dry lay-up of the secondary system feedwater train may be preferable to using alkaline wet lay-up.

A–8. The operating organization needs to have established not only a clear preservation strategy, but also a documented process to ensure that all steps of preservation are adequate, correctly implemented and recorded. The following aspects need to be taken into account in the development of the documented process:

(a) The preservation of the steam generators is to be considered as a high priority.
(b) If the system is to be drained, it can be performed under vacuum and in hot conditions to speed up drying. However, how and when the draining can be performed is plant and system specific.
(c) If dryers are used, they are to be of sufficiently high capacity to handle the system volumes.
(d) All valves that are not pressure barrier valves are to be operated regularly (e.g. once every two weeks).
(e) An evaluation is needed to determine whether special measures are necessary for preservation of the SSCs (e.g. dismantling of equipment such as valves, pumps, heat exchangers, u-tube air blows).
(f) The wet lay-up concept has higher monitoring demands and involves the use of potentially carcinogenic chemicals that might result in hazardous waste.
(g) Preservation methods may be interrupted (e.g. for inspections). Therefore, plans are to include a process to re-establish preservation conditions, when necessary.
(h) Encapsulation and/or maintenance activities after dry tests or wet tests are to be included in the plans, in particular for the commissioning stage.
(i) When selecting the preservation types, demineralized water production capacity is to be considered in relation to outage length as part of the water management plan.
(j) Hazards associated with the application of chemicals are to be clearly spelled out in the plans and procedures.
(k) Any other relevant changes in environmental and climate conditions, such as increasing humidity or danger of freezing, are to be considered.

A–9. The operating organization can also establish more detailed plans for preservation. These plans can be easily converted into a plant work planning process at short notice, if needed. If a decision is taken not to implement preservation, the basis for this decision needs to be justified and documented.

TYPES OF PRESERVATION

A–10. At room temperature, general corrosion usually appears on susceptible metal surfaces and spreads over all parts of the system that are in contact with water or air with high humidity. However, in certain conditions, different types of localized corrosion can also occur. One of the most important aims of preservation is to minimize the possibility of defect initiation during longer lay-up periods. Therefore, plans and procedures for preservation in different operational conditions need to be established at the plant.

A–11. The starting point for selecting a preservation type is to know the following:

(a) The construction materials used in the systems;
(b) The duration of the planned preservation period;
(c) The scope of the preservation (e.g. whole system, components, only large components).

A–12. If a system contains components made of high alloyed steel (e.g. austenitic stainless steel), no specific lay-up actions are typically needed. If the lay-up period is extensively long, this type of system can be drained and, if necessary, flushed with demineralized water and dry air. If a system contains components made of low alloyed steel (e.g. carbon steel), when dry lay-up is not feasible, wet alkaline lay-up is usually selected, in particular if the preservation time is long. If a system contains components made of a combination of both high and low alloyed steel, wet alkaline lay-up methods are preferred. Quite often, system overpressure is needed to avoid air ingress. Venting, filling and draining may be used to ensure that the selected preservation method reaches all locations, including dead ends and branches.

A–13. The maximum delay for implementing the most suitable preservation method is defined in the preservation strategy. Typically, preservation activities are initiated if the planned outage is longer than a predetermined amount of time (e.g. one or two weeks). In some cases, flushing of the system or large components is necessary as a pre-emptive action.

A–14. One of the following lay-up approaches may be selected, taking into account the duration of preservation, the system layout and the materials used:

(a) Dry lay-up. The equipment and/or system needs to be completely drained for this method. The operating organization may consider using inert gas or dry air to ensure the effectiveness of the preservation. The operating organization may also consider using film-forming products before shutdown to facilitate subsequent dry lay-up.
(b) Wet lay-up. For boiling water reactors, wet lay-up generally means that the water chemistry conditions are similar to the plant operating conditions,

specifically for the reactor vessel, recirculation piping and control rod drive system. For feedwater heaters, feedwater, condensate piping and moisture separators and reheaters, inter alia, the systems have to be filled with demineralized water and are not generally open to the atmosphere. If possible, the systems should be in recirculation mode. For pressurized water reactors, wet lay-up is considered mainly to limit the corrosion of less corrosion resistant materials and for steam generators. When large quantities of chemicals are needed to ensure adapted wet lay-up conditions, this type of preservation could be limited to situations where radiation protection measures need to be implemented, or to specific maintenance operations, long outages or to the secondary side of steam generators.

(c) Maintaining systems and equipment in the conditions they are in at shutdown. This is to be considered when the outage duration is short and the system and equipment materials are not susceptible to corrosion in the existing conditions. This is the most practical lay-up method for closed cooling water systems if no maintenance work is planned inside the equipment. However, several forms of localized corrosion are more likely to occur when cooling water systems are left stagnant or are improperly drained and dried during a long outage.

A–15. Paragraph 3.131 of IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [A–1], states:

> "Registrants and licensees, in cooperation with suppliers, as appropriate:
>
> (a) Shall ensure that any radioactive waste generated is kept to the minimum practicable in terms of both activity and volume".

Independent of the chosen lay-up method, the volume of contaminated waste generated as a result needs to be compatible with the capacity of the plant's radioactive waste processing system.

A–16. When starting up the plant after a long lay-up, the highest capacity of water purification is used to remove corrosion products that have formed in the coolant.

A–17. As part of the preservation strategy, the operating organization may prepare in advance a table or list containing information on the typical materials used in the system that are to be preserved, the length of the planned lay-up and the type of preservation method that is to be used.

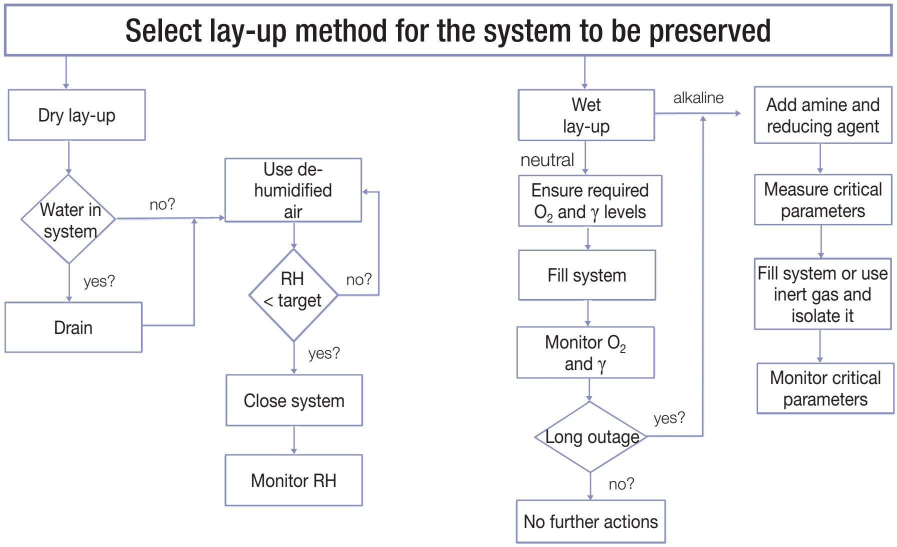

FIG. A–1. Generic flow chart showing the potential steps in a preservation process. RH — relative humidity; γ — conductivity; critical parameters — the chemistry parameters needed for successful lay-up.

A–18. The preservation strategy can be supported by a flow chart providing information on the various steps within the process. An example of a generic flow chart is shown in Fig. A–1. In practice, a more detailed flow chart is needed that includes information such as a list of measurements to be performed, acceptance criteria for the relevant parameters and the reporting needs. A separate flow chart could be created to provide information on what needs to be considered when the system is restarted.

FLUSHING

A–19. For nuclear power plants in operation, the flushing of SSCs prior to preservation activities might not be necessary if the quality of the coolant meets the plant's operating chemistry guidelines. If flushing is needed, paras A–20 to A–24 describe the general practices applicable to a nuclear power plant in operation.

A–20. Flushing is typically performed either by blow-out or by recirculating the coolant through the system. Independent of the method, it is important to have an adequate flow rate to remove any particulates or chemicals that might reside in the system. The flushing media need to have a water quality that is similar to or better than that used during normal operation. If the system is an in-line system, the water purification equipment needs to be lined up with the flushing media and optimized for the effective removal of expected impurities.

A–21. When flushing is necessary, especially during the commissioning of SSCs, or when SSCs are returned to operation after preservation, the composition of the flushing media has to be appropriate for the materials. At a minimum, demineralized water needs to be used and, depending on the corrosion resistance of the materials, the flushing media may need to be conditioned to reach an optimum pH value to mitigate potential corrosion phenomena.

Acceptance criteria for flushing media

A–22. The media used for flushing need to have predefined properties that in many cases are plant specific. At a minimum, the following parameters can be defined:

(a) If only demineralized water is used, the maximum acceptable conductivity value for the flushing media or for the cation conductivity value (if the solution contains air) needs to be defined. It might be useful to measure the cation conductivity after degasification of the solution and to also set a limit value for oxygen.
(b) If amine, ammonia, or hydrazine or any other reducing agent is used with demineralized water, its concentration needs to be given and other relevant chemistry parameters (e.g. pH, conductivity) need to be measured. In addition, the acceptance levels of impurities in the lay-up chemicals need to be defined.

A–23. The flushing plan needs to contain a criterion to indicate when flushing can be stopped. Typically, the pH value and the total level of impurities (which is usually estimated using conductivity measurement results) are used for the specification of acceptance criteria to ensure that the expected cleanliness has been achieved.

A–24. Depending on the preservation strategy, corrosion products and corrosion inducing ions may need to be measured.

DRY LAY-UP

A–25. A prerequisite for dry lay-up is that the system can be dried in a reasonably short time. Systems containing high alloyed steel components do not typically need any additional actions after drainage. For systems containing low alloyed steel components, however, additional arrangements are needed to ensure that there is no residual water on the surfaces.

A–26. Prior to dry lay-up, the systems and components are drained as effectively as possible to minimize the amount of water on the surfaces and to meet the expected relative humidity criteria. This is followed by dehumidification using dry air. If the surrounding air is dry enough, the use of dehumidified air might not be needed. Components such as valves and pumps may also need to be dismantled; once properly dried, these components can be reassembled and reinstalled in the system.

A–27. Hot draining and/or draining under vacuum speeds up the dry lay-up process. In some cases, conditioning the atmosphere of entire rooms or parts of buildings can be more cost effective than providing protection for a system or a single component. When necessary, overpressure of an inert gas (e.g. nitrogen) can be used to avoid the ingress of air and moisture into the system.

A–28. The use of corrosion inhibitors such as film-forming products has been reported by the operators of some pressurized water reactors to control corrosion during extended outages and refurbishments. Film-forming products can be added for a short period of time just prior to a scheduled outage to enhance component protection during lay-up and to provide optimized startup conditions for the subsequent fuel cycle.

Acceptance criteria for dry lay-up

A–29. Air quality is checked during dry lay-up. Air that is dry, clean and free of oil and dust needs to be used throughout the process. Humidity criteria are established and humidity is monitored to ensure that residual moisture on surfaces remains at acceptable levels.

A–30. Relative humidity criteria (e.g. relative humidity below 40% at 20°C when room temperature is higher than 10°C) need to be achieved within a few days after drainage and maintained at the desired level. If relative humidity is above the defined criteria, the reason for the deviation is identified, corrective actions are taken to restore relative humidity to acceptable levels, and all relevant information is properly documented.

A–31. When a dry lay-up is complemented by the use of inert gas overpressure, measurements are taken to ensure that overpressure is maintained. If desiccants (i.e. substances able to adsorb water) are used, they need to be handled carefully to reduce the risk of introducing impurities or foreign materials into the systems and the equipment. Consideration needs be given to the material compatibility of the desiccant (or desiccant bag) with metal surfaces.

Monitoring of dry lay-up

A–32. The following steps could be taken to ensure effective dry lay-up:

(a) Checking the quality of the last flushing media including checking parameters such as pH, concentration of corrosion inducing ions (e.g. fluoride, chloride, sulphate), conductivity and concentration of relevant corrosion products (e.g. iron ions, suspended solids).
(b) Documenting the temperature of the media when draining the system.
(c) Visually checking that the system is fully drained.
(d) Checking that there are no residues from desiccants or other contamination, either visually or by using swipe samples.
(e) If condensers are used to dry the air:
   (i) Checking that condensers are installed correctly;
   (ii) Checking and analysing the trends in the amount of condensate in the condenser regularly (e.g. once per day).
(f) If air dryers are used to reduce humidity:
   (i) Checking that air dryers are installed correctly;
   (ii) Checking that the air does not contain dust and oil;
   (iii) If dust filters are installed in the dryers, checking the differential pressure of the filter (e.g. once per day at the beginning and once per week after a steady state is reached);
   (iv) Checking the relative humidity at the identified dryer inlet and outlet openings (e.g. once per day at the beginning and once per week after a steady state is reached);
   (v) Checking the air flow at the dryer outlet openings (e.g. once per day at the beginning and once per week after a steady state is reached);
   (vi) Checking that the dryer temperature does not fall below the dew point locally.

(g) If overpressurized inert gas is used to prevent air ingress:
   (i) Checking and analysing the trend in overpressure using a manometer (e.g. once per day at the beginning and once per week after a steady state is reached);
   (ii) Checking the availability of inert gas.

(h) If a vacuum is used to decrease humidity, checking and analysing the trends in underpressure using a manometer (e.g. once per day at the beginning and once per week after a steady state is reached).

WET LAY-UP

A–33. Wet lay-up without any changes to the water chemistry parameters after the outage is typically used for pressurized water reactor vessels, boiling water reactor vessels, reactor coolant system piping, boiling water reactor recirculation systems, control rod drive hydraulic systems, refuelling water storage tanks and the primary side of the steam generators. The secondary side of the steam generators is usually preserved using demineralized water containing a high enough concentration of alkaline chemicals to reach the target pH value and an appropriate reducing agent to scavenge oxygen.

A–34. Alkaline wet lay-up is most effective if the coolant does not contain oxygen. This condition is typically achieved by using oxygen scavengers or by completely filling up the system, including the dead ends, as well as by venting the air from potential air pockets and not having the system open to the atmosphere. An effective way to mitigate the ingress of oxygen into the system is to have system overpressure or to have a nitrogen or inert gas blanket inside the system.

A–35. The length of the preservation period needs to be carefully evaluated. If preservation using demineralized water without additives in a system made of low alloyed materials is selected, the basis for the decision needs to be documented. In plants where dispersants are injected into the coolant, the amount injected could be increased at the end of cycle, and injections could continue until zero percent power is reached. This will increase the amount of dispersant in the solution and help control the transport of corrosion products. When preservation is over, plans are needed for the treatment of any chemicals added and their discharge into the environment.

Acceptance criteria for wet lay-up

A–36. For wet lay-up, two media can be used: demineralized water or water conditioned with chemicals to obtain the necessary pH and reducing conditions. The method is chosen on the basis of the type of material present in the system and on the length of the preservation.

A–37. For neutral wet lay-up (i.e. without chemicals), low enough (precisely defined) conductivity conditions need to be achieved prior to preservation. For alkaline wet lay-up, ammonia and/or an amine as well as a reducing agent are added to the demineralized water. Clear acceptance values need to be defined for selected impurities in these chemicals, and attention needs to be paid to the management of the chemicals used in the lay-up.

A–38. During neutral wet lay-up, a programme for monitoring conductivity and the concentration of predefined ions and iron needs to be implemented. During alkaline wet lay-up, the pH as well as the concentration of reducing chemicals, predefined ions and iron need to be checked regularly. In addition, target values and limit values for those parameters need to be defined, taking into account the analytical performance of the monitoring equipment. For representative sampling, sufficient recirculation of the lay-up medium needs to be ensured when possible.

A–39. Oxygen also needs to be monitored. If inert gas overpressure is used to avoid air ingress, a criterion for the overpressure of this gas needs to be defined, and controls need to be implemented to ensure that the criterion is met. Deviations of the relevant parameters during lay-up need to be addressed in a timely manner and properly documented.

Monitoring of wet lay-up

A–40. The following steps could be taken to ensure effective wet lay-up without additives:

(a) Checking the quality of demineralized water before filling the system, including checking the concentration of corrosion inducing ions (e.g. fluoride, chloride, sulphate, cation conductivity at 25ºC, sodium) and measuring conductivity and oxygen concentration;
(b) Ensuring the continuous availability of demineralized water and checking its quality;
(c) Checking that the system is fully filled (e.g. once per day at the beginning and once per week after a steady state is reached);

(d) Checking that the system is sealed from the atmosphere;
(e) Checking and analysing the trends in the quality of the lay-up medium, for example checking the concentration of corrosion inducing ions (e.g. fluoride, chloride, sulphate) and measuring the conductivity and oxygen concentration (e.g. once per day at the beginning and once per week after a steady state is reached);
(f) Checking and analysing the trends in the concentration of relevant corrosion products such as iron and suspended solids (e.g. once per day at the beginning and once per week after a steady state is reached);
(g) Checking and analysing the trends in overpressure (using a manometer) if the system is under inert gas (e.g. once per day at the beginning and once per week after a steady state is reached).

A–41. The following steps could be taken to ensure effective alkaline wet lay-up:

(a) Checking the quality of demineralized water before filling the system, including checking the concentration of corrosion inducing ions (e.g. fluoride, chloride, sulphate) and measuring conductivity and oxygen concentration;
(b) Ensuring the continuous availability of demineralized water and checking its quality;
(c) Checking that the correct amount of lay-up chemicals is added (depending on the materials used in the system);
(d) Checking that the system is filled up to the specified level (e.g. once per day at the beginning and once per week after a steady state is reached);
(e) Checking and analysing the trends in overpressure (using a manometer) if the system is under inert gas (e.g. once per day at the beginning and once per week after a steady state is reached);
(f) Checking and analysing the trends in the quality of the lay-up medium, for example checking the pH and/or the concentration of additives, corrosion inducing ions (e.g. fluoride, chloride, sulphate) and measuring the oxygen concentration (e.g. once per day at the beginning and once per week after a steady state is reached);
(g) Checking and analysing the trends in the concentration of relevant corrosion products such as iron and suspended solids (e.g. once per day at the beginning and once per week after a steady state is reached).

DOCUMENTATION AND EVALUATION OF THE EFFECTIVENESS OF THE PRESERVATION

A–42. A process needs to be implemented at the plant to ensure that suitable documentation and data relating to preservation are available. This process ensures that all the administrative approval practices necessary during preservation are properly followed. Once the system is put back in operation, plant documentation is needed to verify that the preservation was done in such a way that there has been no decrease in equipment reliability or increase in release rates of corrosion products that could result in their subsequent transport into the core.

A–43. The preservation documentation includes, to a reasonable extent, not only the SSCs in wet or dry lay-up but also the connected systems, because these might challenge the lay-up conditions. This documentation clearly defines the basis for selecting the preservation method. The documentation also contains analysis reports and trend analyses of the relevant parameters. An example of a simplified form displaying lay-up data is shown in Fig. A–2.

A–44. Deviations from the relevant parameters during lay-up — and any corrective actions taken to address these deviations — need to be well documented. If there is a significant deviation during the preservation process, the relevant parties (e.g. the commissioning and operating organizations) need to be informed.

A–45. When corrective actions are needed, a cause analysis is performed and properly documented. The plant's corrective action plan ensures that necessary corrective actions are implemented and completed in a timely manner.

Alkaline wet lay-up with ammonia							Document I.D.:	
Measurement results for lay-up parameters (target values, except for total iron)								
Date	pH ≥10.3	Fluoride (mg/kg) <0.15	Chloride (mg/kg) <0.15	Sulphate (mg/kg) <0.15	Oxygen (mg/kg) <0.5	Total iron (mg/kg)	Deviation	Verified by:
20.2.2021	10.3	0.03	0.14	0.05	0.5	6	None	valkmek
21.2.2021	10.4	0.07	0.2	0.06	0.4	5	High Cl^-	makelkar
22.2.2021	10.3	0.06	0.5	0.03	0.5	6	Increasing Cl^-	pekkjlak

FIG. A–2. Example of a simplified form displaying lay-up data.

A–46. A review of the actions taken during preservation needs to be conducted and documented, with a view to preventing the re-occurrence of the same transients. The collective documentation of each system preserved needs to be shared with the plant's ageing management personnel or experts once the preservation period is over.

A–47. The operating organization may consider including a dedicated indicator for preservation in its key performance indicator programme. This indicator would be useful in evaluating the effectiveness of actions taken during lay-up and would provide a tool to compare actions taken during different outages. The indicator could include measurements of carefully selected chemistry parameters and any disturbances that occurred during preservation (e.g. malfunction of the air drying system, accidental drainage of the system under preservation).

REFERENCE TO THE ANNEX

[A–1] 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), https://doi.org/10.61092/iaea.u2pu-60vm

CONTRIBUTORS TO DRAFTING AND REVIEW

Bolz, M.	Consultant, Germany
Clinard, M.-H.	Framatome, France
Kameswaran, R.	Canadian Nuclear Safety Commission, Canada
Kvarnström, R.	Fortum Power and Heat Oy, Finland
Maekelae, K.	International Atomic Energy Agency
McGregor, E.	Office for Nuclear Regulation, United Kingdom
Miyashige, Y.	Tokyo Electric Power Company Holdings, Japan
Morgan, H.	International Atomic Energy Agency
Mura, M.	Electric Power Research Institute, United States of America
Nishiura, H.	Kansai Electric Power Company, Japan
Stoll, T.	Kernkraftwerke Lippe-Ems GmbH, Germany
Tompuri, K.	Teollisuuden Voima Oy, Finland
Viricel, L.	Électricité de France, France
Yamano, D.	Kansai Electric Power Company, Japan
Yuya, K.	Tokyo Electric Power Company Holdings, Japan

IAEA
International Atomic Energy Agency

No. 27

ORDERING LOCALLY

IAEA priced publications may be purchased from our lead distributor or from major local booksellers.

Orders for unpriced publications should be made directly to the IAEA.

Orders for priced publications

Please contact your preferred local supplier, or our lead distributor:

Eurospan
1 Bedford Row
London WC1R 4BU
United Kingdom

Trade orders and enquiries:
Tel: +44 (0)1235 465576
Email: trade.orders@marston.co.uk

Individual orders:
Tel: +44 (0)1235 465577
Email: direct.orders@marston.co.uk
www.eurospanbookstore.com/iaea

For further information:
Tel. +44 (0) 207 240 0856
Email: info@eurospan.co.uk
www.eurospan.co.uk

Orders for both priced and unpriced publications may be addressed directly to

Publishing Section
International Atomic Energy Agency
Vienna International Centre
PO Box 100
1400 Vienna, Austria
Telephone: +43 1 2600 22529 or 22530
Email: sales.publications@iaea.org
www.iaea.org/publications

24-02710E-T

Safety through international standards

International Atomic Energy Agency
Vienna, 2024
www.iaea.org