IAEA SAFETY STANDARDS

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Step 8

Soliciting comments by Member States

Chemistry Programme for Water Cooled Nuclear Power Plants

DS525

DRAFT SAFETY GUIDE

Revision of IAEA Safety Standards Series No. SSG-13

CONTENTS

1. INTRODUCTION

BACKGROUND

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

1.2. This Safety Guide provides recommendations on water chemistry in water-cooled nuclear power plants.

1.3. 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. The chemistry programme is based on a detailed rationale usually provided by the manufacturer of the plant, but ultimately ownership of the contents and proper implementation of the chemistry programme rests with the plant operator/licensee. The main goals of the chemistry programme (both chemistry and radiochemistry) are to contribute to the reactivity management, to minimize all forms of corrosion of SSCs influenced by the chemistry regime, to preserve the integrity of the fuel and to reduce the buildup of radioactive material enabling lower occupational radiation exposure. In addition, the goal is to limit the discharges of chemicals and radioactive material to the environment as well as minimize the generation of radioactive waste. These goals fulfil the fundamental safety objective to protect people and the environment from the harmful effects of ionizing radiation established in IAEA Safety Standards Series No. SF-1, Fundamental Safety Principles [2].

1.4. Further recommendations on SSCs included in the chemistry programme from the point of view of ageing management 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].

1.5. The chemistry programme comprises of three basic elements, the chemistry regime, chemistry control and chemistry measurements. The chemistry regime is defined by the reactor type, its design,the construction materials used and any requirements placed on the operating chemistry in the plant's safety analysis. The chemistry control assures that the plant is operated in accordance with the chemistry regime and defines the parameters to be measured, their measurement frequencies, limit values and corrective actions to be taken if necessary. The chemistry measurements provide information about the actual chemistry conditions in the systems, which in turn serve as the basis for all further decisions.

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

OBJECTIVE

1.7. The objective of this Safety Guide is to provide recommendations on water chemistry for nuclear power plants to meet the requirements in SSR-2/2 (Rev. 1) [1], in particular Requirement 29. These recommendations aim at mitigating the degradation of SSCs and ensuring their availability, adhering to a commitment to reduce radiation doses and limit discharges of radioactive material and chemicals to the environment to levels that are as low as reasonably achievable and to reduce the generation of radioactive waste.

1.8. The recommendations provided in this Safety Guide are aimed primarily at managers of operating organizations to effectively oversee the plant chemistry programme and at regulatory bodies when fulfilling their external oversight responsibilities and during development of national regulatory requirements for the water chemistry.

1.9. The recommendations provided in this Safety Guide can also be used by technical support organizations and research organizations when they are providing support for licensees or regulatory bodies.

1.10. This Safety Guide can also be useful to plant chemistry personnel to continuously improve existing chemistry programmes, support the development of new chemistry activities within the programme and to assisting the development of corrective actions for eliminating identified weaknesses in the current programme.

SCOPE

1.11. This Safety Guide covers all types of water-cooled nuclear power plants This Safety Guide provides Member States with recommendations and guidance on the chemistry programme the plant should have in place. This programme should ensure that SSCs important to safety, those SSCs whose failure may prevent SSCs important to safety from fulfilling their intended function and those SSCs that are credited in the safety analyses can operate reliably throughout the original design lifetime including the construction, commissioning and operation as well as the decommissioning stage.

1.12. This Safety Guide addresses the main activities of the plant chemistry programme for various types of water-cooled nuclear power plants and gives a basis for an effective plant chemistry

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

programme. It also contains recommendations on chemistry and radiochemistry monitoring to ensure compliance with the plant operational limits and conditions.

1.13. This Safety Guide does not provide detailed technical advice related to particular chemistry regime of water-cooled nuclear power plants. The intentions and expectations of the chemistry programme are only described in-so-far as is necessary to understand the scope of chemistry control and chemistry measurements, because each programme is plant specific. The information in the Annex can be used for planning the preservation of SSCs during different stages of the plant lifetime and in preparation for decommissioning.

1.14. Recommendations on meeting the safety requirements applicable to decommissioning are outside the scope of this Safety guide and are provided in IAEA Safety Standards Series No. SSG-47, Decommissioning of Nuclear Power Plants, Research Reactors and Other Nuclear Fuel Cycle Facilities [2].

STRUCTURE

1.15. 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 the 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 chemistry aspects of radiation exposure optimization. Recommendations on chemistry and radiochemistry measurements are provided in Section 7. Section 8 provides recommendations on the management of chemistry data. Recommendations on 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 the different stages of the plant lifetime.

2. FUNCTIONS AND RESPONSIBILITIES FOR THE MANAGEMENT OF THE CHEMISTRY PROGRAMME

2.1. The operating organization is required to develop, implement, assess and continuously improve a management system, in accordance with the requirements established in IAEA Safety Standards Series No. GSR Part 2, Leadership and Management for Safety [5] 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.” The integrated management system should define clear functions and responsibilities at the plant in accordance with the requirements established for all chemistry activities, such as management of resources, chemistry and radiochemistry control and measurements, dose management, chemistry and radiochemistry surveillance, chemistry and radiochemistry data management, quality control, reviews of results and staff training and qualification. Recommendations on the management system for a nuclear power plant are provided in IAEA Safety Standards Series No. GS-G-3.5, The Management System for Nuclear Installations, [6]. Job descriptions of chemistry personnel should be included in plant documentation.

2.3. Requirement 29 of SSR-2/2 (Rev. 1) [1] states that **"The operating organization shall establish and implement a chemistry programme to provide the necessary support for chemistry and radiochemistry."**

2.4. 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."

2.5. The chemistry programme should contribute to the following:

(a) Ensuring reactivity control of the reactor core;

(b) Preserving the integrity of the fuel cladding and pressure boundary components;

(c) Minimizing the buildup of radioactive nuclides to reduce dose rates at the plant and hence radiation doses to personnel;

(d) Reducing the amount of chemical and radioactive waste and planned discharges to the environment.

2.6. The operating organization should ensure that the chemistry programme supports the reliable and continued operation of SSCs in the long term and does not compromise design assumptions during the entire operating lifetime of the plant and the decommissioning stage.

2.7. 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."**

2.8. 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 chemistry management

2.9. The operating organization should provide sufficient resources for the development of chemistry control methodologies. The operating organization should provide adequate facilities, sampling and equipment (including laboratory and on-line instruments) for chemistry measurements. The operating organization should ensure that the chemistry equipment and related systems are ready to return to service after maintenance and modifications according to predefined acceptance criteria. Further recommendations are provided in IAEA Safety Standards Series No. SSG-74, Maintenance, Testing, Surveillance and In-service Inspection in Nuclear Power Plants [7]

2.10. The operating organization is required to assess performance and enable its continuous improvement in accordance with Requirement 13 of GSR Part 2 [5] and Requirement 9 of SSR-2/2 (Rev. 1) [1]. Plant management should set clear targets for continuous improvement of operational safety performance in the chemistry area. Plant management should periodically reinforce its expectations on the chemistry programme. Targets and management expectations should be described in the plant or fleet documentation. Continuous improvement of chemistry programme should be an established practice among the chemistry personnel and the challenges relating to long term operation of the plant should be addressed.

2.11. Plant management should ensure that any measures to shorten the scheduled shutdown period and to accelerate plant startup activities will not compromise the compliance with chemistry control procedures (e.g. efficient use of water purification systems during the shutdown and startup stages, maintaining suitable wet or dry conservation conditions in equipment during shutdown). In accordance with GSR Part 2 [5], safety is an overriding priority and safety is not to be compromised by other priorities.

2.12.

Changes in a plant’s organizational structure that could affect the existing chemistry programme should be brought to the attention of the chemistry management at an appropriate level for advice, comments or approval if necessary.

2.13. Chemistry managers and supervisors 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 measures, job stress) with regard to the working environment.

2.14. Information flow within the chemistry department should be well organized. Relevant information should be distributed in written form on paper or in electronic form, properly archived and easily retrievable.

2.15. Requirement 9 of SSR-2/2 (Rev. 1) [1] states that **“The operating organization shall establish a system for continuous monitoring and periodic review of the safety of the plant and of the performance of the operating organization.”**

2.16. 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."

2.17. The chemistry programme should be included in the plant self-assessment programme. Audits and other self-assessments, and independent reviews of the chemistry programme should be conducted regularly. The self-assessment programme for the chemistry programme should also include participation in both intra and interlaboratory comparison programme which should include both chemistry and radiochemistry measurements. Identified non-conformances should be reported, should be included in the plant's corrective action programme with proper significance level and the status of corrective actions should be regularly evaluated (see para. 6.3 of GSR Part 2 [5]).

2.18. Performance indicators for the chemistry programme (both chemistry and radiochemistry), 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 the chemistry personnel. Relevant indicators should also be brought to the attention of other departments and senior management. Chemistry performance indicators should be analyzed for trends, and preventive and/or corrective measures should be undertaken when necessary in a timely manner.

2.19. Requirement 24 and paras 5.27–5.33 of SSR-2/2 (Rev. 1) [1] establish requirements on feedback of operating experience. The chemistry management should regularly collect operating experience from national and international utilities and organizations to ensure information exchange and that the chemistry programme is kept up to date with best industry practices. Lessons identified from the operating experience relating to the chemistry programme should be appropriately implemented in the procedures of the chemistry programme or other types of plant documentation and should be brought to the attention of the chemistry personnel.

2.20. If design changes relevant to chemistry are planned, members of the chemistry personnel should be included in the plant's design authority process. As part of the process, chemistry management 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 design basis documentation or have an easy access to it. After the implementation of changes, the chemistry management should revise the chemistry programme, if necessary, and update relevant documentation (see para. 4.42 of SSR-2/2 (Rev. 1) [1]).

2.21. For any plant modifications, the chemistry department should provide all necessary data to the other plant departments, if needed. 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 [8].

2.22. Information relating to chemistry should be shared with the meetings reviewing activities relating to, for example, ageing management, corrosion, leakages, outage planning, emergency preparedness and response planning, reducing dose rates at the plant and reducing liquid radioactive waste.

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

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

2.25. 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 match the need of the operating organization. These reports should also enable to deliver irregularly provided information, if necessary.

2.26. A method 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 need to be implemented, the responsibilities should be clearly assigned to the relevant department.

2.27. Well-defined interfaces should be established with the regulatory body, the design organization, and internal and external technical support organizations. Reporting expectations to the regulatory body should be clearly stated in the plant documentation and properly understood by all chemistry managers.

2.28. Qualified external contractors and consultants should be made available as necessary to meet the needs of the chemistry programme. The operating organization may delegate to other organizations some tasks of the chemistry programme, but the operating organization should retain overall responsibility for such delegated work (see Requirement 1 of SSR-2/2 (Rev. 1) [1] and para. 4.33 of

GSR Part 2 [5]). The operating organization should ensure that the chemistry department provides sufficient support to and control of contractors working within the chemistry area.

2.29. All contractors and suppliers of the chemistry department should be made subject to the same expectations as chemistry personnel, particularly with respect to the chemistry skills and competences, adherence to procedures, result reporting, safety culture and performance evaluation. Further recommendations on the management of contractors are provided in SSG-74 [7].

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

3. TRAINING AND QUALIFICATION OF THE CHEMISTRY PERSONNEL

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."** Recruitment, qualification and training of the chemistry personnel should be conducted in accordance with the recommendations provided in IAEA Safety Standard Series No. SSG-75, Recruitment, Qualification and Training of Personnel for Nuclear Power Plants, [9] and follow safety culture principles as described in [5]. Chemistry personnel should have a sufficient and relevant educational degree in accordance with the local education system.

3.2. The chemistry management should ensure that chemistry personnel are qualified. For each position the necessary qualifications should be clearly defined. The chemistry management should ensure that sufficient supervision is done and that chemistry personnel demonstrate commitment to high safety performance [1].

3.3. All chemistry activities should be performed by authorized chemistry personnel, but trainees may be assigned to carry out chemistry activities while supervised by qualified personnel.

3.4. A systematic approach to training for chemistry personnel should be applied in accordance with the recommendations provided in SSG-75 [9]. Training facilities and methods should be used which have been proven to be effective in attaining the training objectives. During all steps of the training programme, the level of education of staff should be taken into account.

3.5. The chemistry management should develop and implement basic (i.e. general training for all personnel), initial, ongoing and refresher training for the chemistry personnel as appropriate.

3.6. Initial training for chemists should include on the job training in those areas which are related to chemistry programme, control and measurements (e.g. chemistry in safety analysis report, laboratories, sampling points, chemical handling, storage areas, and injection points of chemicals in operating systems). Initial training for chemists should cover chemistry-specific areas during startup, normal operation, outages, most probable transients and likely emergency scenarios. The chemistry management or a qualified trainer should approve the successful completion of the initial training.

3.7. Continues training for routine tasks should be carried out for all chemistry personnel and it should have clearly written goals. Periodic refresher trainings should also be considered for infrequent tasks (e.g., access to and use of 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 or at the premises of the instrument supplier.

3.9. On the job training should be conducted in accordance with written operating procedures 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.

3.10. 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. Chemists at a nuclear power plant should have sufficient knowledge in their areas of responsibility to be able to communicate effectively with and to support the operating personnel. The theoretical part of their training should include the chemistry regime, the chemistry control, the chemistry measurements, the potential impact of changes in chemistry on the safety of the nuclear power plant including operational events, and the appropriate rationale.

3.12. Chemists should be familiar with equipment used by chemistry personnel and have the knowledge how to operate it, even if they are not the ones responsible for executing the related tasks on a daily 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 when applicable.

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

(a) The storage, handling and proper disposal of hazardous, flammable and poisonous chemicals as well as radioactive substances;

(b) The labelling of chemicals stored and used inside and outside the laboratory;

(c) The use of material safety data sheets and where they can be found;

(d) The use and maintenance of personal protective equipment.

3.15. After the training the chemistry personnel should be knowledgeable of all relevant plant requirements for nuclear, radiation and industrial safety.

3.16. The plant management should support participation of plant chemistry representatives at national and international workshops, conferences and meetings and should facilitate access to networks or forums for exchange of operating experience relevant to the nuclear industry.

3.17. Paragraph 5.5 of SSR-2/2 (Rev. 1) [1] states:

> "A training programme for emergencies shall be established and implemented to ensure that plant staff and, as required, staff from other participating organizations possess the essential knowledge, skills and attitudes required for the accomplishment of non-routine tasks under stressful emergency conditions."

3.18. Paragraph 5.6 of SSR-2/2 (Rev. 1) [1] states:

> "The emergency plan shall be tested and validated in exercises before the commencement of fuel loading. Emergency preparedness training, exercises and drills shall be planned and conducted at suitable intervals, to evaluate the preparedness of plant staff and staff from external emergency response organizations to perform their tasks, and to evaluate their cooperation in coping with an emergency and in improving the efficiency of the response."

3.19. Chemistry personnel should take part in training programmes or emergency exercises simulating possible release of chemicals or radioactive materials. Emergency chemistry procedures, emergency equipment and expected chemistry values should be used in training and exercises to ensure correct responses by chemistry personnel.

3.20. Chemistry personnel should regularly train different routes to reach the post-accident sampling arrangement, if normal ways will not be accessible during accident conditions.

4. CHEMISTRY PROGRAMME

4.1. The chemistry programme should contribute to ensuring safe operation, long term integrity of SSCs and integrity of fuel, minimizing buildup of radioactive material, and limiting all discharges to the environment to levels as low as reasonably achievable [1].

4.2. The integrated management system should define the accountabilities and responsibilities of the chemistry management regarding the implementation of the chemistry programme. Implementation and responsibilities of the chemistry programme should be organized and documented in such a way that takes into account the organizational structure of the company (e.g. fleet, corporate, single site, multi-unit facilities) and plant's safety analysis.

4.3. The chemistry programme should include documentation to serve as a basis for the selection, monitoring and analysis of the chemistry parameters and it should be in place prior to normal operation. The chemistry instructions should be aligned with operational limits and conditions (see also IAEA Safety Standards Series No. SSG-70, Operational Limits and Conditions and Operating Procedures for Nuclear Power Plants [10]). The chemistry instructions should explicitly define graded limit values for specific chemistry parameters enabling efficient implementation of the chemistry programme. The plant documentation should describe potential corrective actions to be applied in various operational stages.

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

(a) The chemistry department should clearly document the SSCs which are within the scope of the chemistry programme.

(b) A plant specific chemistry regime should be in place and it should be developed in accordance with the original plant design and safety analysis. Potential design changes should take into account the existing chemistry regime and, if needed, the existing chemistry programme should be updated to reflect any structural changes to the SSCs that are part of the chemistry programme.

(c) The chemistry programme should be regularly reviewed to take into account: the operating experience, including good practices, from other utilities and Member States (e.g. appropriate feedback on operating events, research results, revised standards); and the documented conclusions and the improvements incorporated into the chemistry programme, when considered beneficial. Chemistry managers and supervisors 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) The primary water chemistry regime should take into account its potential impact on: (i) plant specific corrosion mechanisms of construction materials, (ii) fuel cladding corrosion, (iii) activation and transport of corrosion products, (iv) dose rates, (v) crud induced power shifts and (vi) crud induced localized corrosion.

(e) The secondary side chemistry regime should minimize: (i) corrosion in the systems and in the components, (ii) deposits in the steam generators, (iii) concentration of deleterious impurities in bulk water and more importantly in crevice areas with restricted flow and (iv) leaks in both water and air parts in condenser. The secondary side chemistry programme should ensure effective purification of steam generator blowdown water and water from condensers.

(f) Condenser tube leakages should be properly controlled and minimized to avoid ingress of harmful impurities.

(g) The chemistry regime for auxiliary systems should be in accordance with the used materials to preserve their full integrity and availability.

(h) For chemistry control in semi-closed cooling systems with cooling towers the following points should be taken into account:

  (i) The system design and the type of materials 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 for chemical compounds needed to operate the system.

(i) Appropriate chemistry control and diagnostic parameters should be used to ensure safe and reliable operation (see 5.9. and 5.10).

(j) The results of the chemistry programme should be communicated in a timely manner to relevant chemistry managers and to those parts of the organization that need such information (e.g. operators, maintenance personnel, the system engineering group, technical support organizations).

(k) The chemistry management should ensure that sufficient number of staff is always available at the plant or can quickly come to the plant when needed.

(l) Any deviations (e.g. deficiencies, adverse trends, fast transients) from normal operational limits should be addressed in a timely manner, and effectiveness of used methodologies 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 redundancies for this equipment should be ensured.

(n) The chemistry department should provide plant ageing management programme information needed to ensure safe and long term operation of the SSCs. Recommendations on ageing management are provided in SSG-48 [3].

(o) The in-service inspection results should be used to confirm whether the chemistry program is effective or not.

(p) Procedures and practices should be in place 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 impurity ingress from chemicals and substances should be in place. Selection of new construction materials due to modernization or refurbishment activities should be carefully evaluated to minimize the dissolution of corrosion products and their subsequent activation in the reactor core.

(r) Radiochemistry measurements should be carried out for closed cooling water circuits in boiling water reactors (BWRs) and graphite moderated reactors (RBMKs) and in the primary and secondary sides of pressurized water reactors (PWRs) and pressurized heavy water reactors (PHWRs) to detect leaks in pressure boundaries.

(s) Discharges of radioactive species and chemicals should be kept as low as reasonably achievable and within national regulations. Chemistry departments should carefully evaluate, thoroughly understand and properly document the potential impact of any changes in the chemistry regime on safe operation of the nuclear power plant including aspects of radioactive and chemical discharges. Radioactive discharges to the environment should be measured on-line before their discharge to ensure that national and plant limits are not exceeded and to evaluate potential impacts on the environment.

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

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

(v) The chemistry programme should include guidance documentation to select suitable decontamination techniques, when necessary.

(w) The lear cleanliness requirements and storage conditions should be defined for SSCs in plant documentation during construction and commissioning stages to ensure safe and reliable operation of SSCs throughout the lifetime of the plant.

(x) The chemistry programme should include clear chemistry expectations and instructions for SSC preservation periods (see the Annex).

5. CHEMISTRY CONTROL

5.1. Chemistry control should 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. The chemistry control should be continuously improved by taking into account up-to-date knowledge and operating experience.

5.2. Paragraph 7.14 of SSR-2/2 (Rev. 1) [1] states that “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 the chemistry control should be regularly evaluated.

5.3. To achieve effective chemistry control, 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 which are known to have a negative impact on material integrity, fuel cladding corrosion, fuel design performance, or have a direct impact on reactivity control, radiation fields or the environment.

5.5. The control parameters should have clear graded limit values and it should be ensured that these values are strictly followed. If deviations from these limit values occur, corrective actions should be initiated progressively within a predefined period of time and more significant actions should continue to be applied until plant shutdown, if technical justification deems it 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.

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

5.8. To avoid 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 the limit values are exceeded.

5.9. Records of the chemistry control parameter 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 chemical status of the plant. These parameters should be chosen in such a way to enable the chemistry department to react proactively on chemistry variations.

5.11. The chemistry department should continuously analyze trends in control and diagnostic parameters and proactively react if adverse trends are identified.

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

5.13. Radiochemistry parameters should be systematically monitored, analysed for trends, evaluated and in case of deviation they should be correlated with chemical and operational data, such as pH_T (pH at operating temperature) and thermal power [8]. Tools should be available to enable detection of the fuel leakage as well as to 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) Normal operation;

(e) Transients;

(f) Shutdowns, both short and extended ones;

(g) Outages;

(h) Accident conditions;

(i) Transition from operation to decommissioning;

(j) Decommissioning.

5.15. During outages, equipment and systems should be maintained under adequate layup conditions and in accordance with safety requirements. Further information on layup conditions is provided in the Annex. Preservation parameters should be monitored, documented and corrective actions should be implemented, if needed.

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

5.17. The quality of lubricant oil for safety related systems (e.g. emergency pumps, emergency diesel generators) should be regularly monitored and controlled by the operating organization.

5.18. The quality of diesel fuel should be verified before transferring into the diesel fuel tanks. The quality of diesel fuel in the storage tanks for the emergency diesel generators should be checked in accordance with plant documentation. The monitoring results should be analyzed for trends to allow for the detection of early indications of potential deterioration of the expected properties.

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

5.20. The concentrations of the chemical inhibitors that are added to cooling and other systems that might have microbiological growth and microbiologically induced corrosion, should be adequately controlled and monitored. If a biocide containing chlorine is added to the system, the chemistry department should perform a risk assessment. Potential impacts on industrial safety and the environment should also be assessed

WATER CHEMISTRY CONTROL IN BOILING WATER REACTORS

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

5.22. To avoid or minimize stress corrosion cracking of specific components, mitigating chemicals should be injected into the coolant, if applicable and their concentration should be carefully measured. The basis for the applied chemistry regime should be clearly documented.

5.23. Dissolved hydrogen and oxygen levels should be maintained within specifications.

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

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

5.26. The conductivity and concentrations of chlorides, fluorides and sulphates in the 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.

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

5.28. 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 and explosion risks. Any deliberate deviation from the procedures should be carefully evaluated by operating organizations and the basis clearly documented for future assessments.

5.29. In preparation for shutdown, at those plants where it is possible, the flow rate of the 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 a refueling outage, the flow rate in the cleanup system should be as high as possible during the crud and corrosion product release phase.

5.30. The capacity of the purification 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 to the coolant.

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

5.32. If a plant has installed a catalyst recombiner probe inline at dead ends of pipes to recombine radiolysis gases, its availability should be ensured.

WATER CHEMISTRY CONTROL AT GRAPHITE MODERATED REACTORS (RBMK):

5.33. For a nuclear power plant with a graphite moderated and water cooled primary circuit, the chemistry regime should be applied without the use of any acids or alkalizing chemicals. Graphite moderated reactor plants should have high purity feedwater and effective purification systems for condensate and reactor coolant.

5.34. Chemistry control at a graphite moderated reactor should ensure the following:

(a) The deposition of corrosion products on heat exchanger surfaces and on piping surfaces should be minimized;

(b) Corrosion (e.g. intergranular stress corrosion cracking, flow accelerated corrosion) of the materials of the main steam–water circuits should be minimized;

(c) Moisture separators should produce high quality steam for turbines.

5.35. The chemistry parameters, particularly dissolved hydrogen and oxygen should be maintained within specified limits to reduce the risk of corrosion.

5.36. To minimize the level of ^{95}Zr and other activated corrosion products within the oxide films on component surfaces, flushing (washing) of the primary circuit should be performed at the beginning of shutdown.

PRIMARY WATER CHEMISTRY CONTROL AT PRESSURIZED WATER REACTORS (INCLUDING WWERs)

5.37. The concentration of dissolved ^{10}B in the reactor coolant system for controlling core reactivity should be regularly monitored to prevent deviation from abnormal 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.

5.38. 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 the tritium generation) or potassium hydroxide and ammonia are used to adjust 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.

5.39. 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 deaerated, the oxygen concentration of make-up water should be monitored and oxygen should be degassed or chemically scavenged, when necessary, to be within specifications.

5.40. 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.

5.41. 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, aluminum compounds and possibly silica compounds.

5.42. 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 and explosion risks. Any deliberate deviation from the procedures should be carefully evaluated by operating organizations and the basis clearly documented for future assessments.

5.43. No specific layup conditions are needed for drained primary systems during the outages since the materials are not supposed to be susceptible to corrosion at ambient temperature and atmosphere.

5.44. To further optimize chemistry control, additional chemical compounds may be used in the primary circuit water. 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.

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

PRIMARY AND MODERATOR WATER CHEMISTRY CONTROL AT PRESSURISED HEAVY WATER REACTORS (PHWR)

5.46. A management system for heavy water (D_2O) should be established 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 and isotopic composition.

5.47. 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 heavy water 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.

5.48. The concentration of soluble reactivity agents (poisons such as boron or gadolinium) should be based on the negative reactivity necessary to ensure that the 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 the nuclear power plant and should be documented in the safety analysis.

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

5.50. Upper and lower limits for deuterium/ hydrogen and oxygen concentrations in cover gas systems should be adequately established to eliminate the possibility of creating an explosive gas mixture.

5.51. The concentration of dissolved deuterium in the primary circuit should be such that radiolysis is suppressed and the system components are not impacted by hydrogenation.

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

5.53. During reactor shutdown, 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, to the extent possible, the empty part of the primary system should be filled with nitrogen gas to minimize air ingress.

5.54. During reactor shutdown, normal chemistry specifications should be maintained for the moderator system, except for the following occasions:

(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 drained.

SECONDARY WATER CHEMISTRY CONTROL AT PRESSURIZED WATER REACTORS (INCLUDING PWRs, WWERs AND PHWRs)

5.55. Special attention should be paid to the integrity of the various parts of the 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.

5.56. The selected water chemistry regime:

(a) Should 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 onto steam generator tubes, between tubes and tube sheets, 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 waste to the environment;

(f) Should be achieved by selecting appropriate chemicals to avoid causing unnecessary health risks to the operating organization.

5.57. 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). The pH value of the secondary side water is plant specific and should be such that an appropriate pH_T value is ensured in various parts of the secondary system. Concentration of alkaline chemicals should be specified and verified.

5.58. 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 most effective injection points of chemicals should be carefully evaluated.

5.59. The primary to secondary circuit leakage rate in the steam generator tubes should be calculated based on 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.

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

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

5.62. The potential impact of chemistry parameters on the integrity of the steam generator should be regularly evaluated and related results should be analyzed for trends. The main tools 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 primary and secondary water chemistry control;

(b) Measurement of hideout return to get an estimation of 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 able to cause clogging.

5.63. If necessary, an effective cleaning procedure should be applied 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, i.e., materials selection/compatibility, etc. If cleaning becomes necessary, an adequate safety justification should be performed.

5.64. To further optimize corrosion product control in the steam generators, the use of dispersant compounds and film forming products should in the secondary water should be assessed. The results of these monitoring activities should be clearly documented for future work.

5.65. Impurity concentrations (inorganic and organic) in the demineralized make-up water should be controlled to ensure compliance with technical specifications.

5.66. Auxiliary systems should be operated according to specific chemistry regime to address e.g. microbiologic induced corrosion and specific chemistry control to minimize corrosion risks.

6. OPTIMIZATION OF THE CHEMISTRY ASPECTS OF RADIATION EXPOSURE

6.1. The optimization of the chemistry regime should contribute to the following:

(a) Continuous reduction of dose rates in the plant over time;

(b) Reduction of any 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 compliance of doses to the personnel with the dose limits and maintain radiation exposures of personnel as low as reasonably achievable. During an outage, and if possible, also during operation, dose rates from systems and components should be measured regularly to allow for trends to be analyzed. 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 exposure of personnel to radiation, the chemistry programme should include the following:

(a) The application of a suitable chemical regime to minimize dissolution of corrosion products, deposition of corrosion products in-core and their subsequent transport on surfaces of SSCs;

(b) The use of high quality make-up water to avoid 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 ingress of impurities which 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 into the core should be minimized by keeping the chemistry parameters of the primary water coolant as constant as possible and at an optimal value during normal power operation. Particular attention should be placed on preparations for shutdown. Plans should be in place to enable the purification of reactor coolant during refueling outages.

6.5. The dissolution of elemental cobalt to the reactor water coolant should be controlled through engineering modifications and an optimized chemistry regime. The use of materials containing cobalt (^{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 Co-containing grades of stainless steel for some SSCs. To avoid unnecessary dissolution of inactive cobalt ions into 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 procedures. The existing purification system should have a suitable configuration to implement efficient removal of ^{58}Co from the water, particularly during the shutdown period.

6.7. Programmes for the replacement of Stellite™ (typically 57% Co), silver and materials containing antimony should be considered, where practicable. The chemistry department should be part of the approval process when new equipment and materials are being approved 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 the selection of 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 be eliminated if possible.

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

6.10. Successful completion of the hot conditioning should be verified (e.g. chemicals used, duration, temperature). Acceptance criteria for completion of this process should be established. Material samples could be used as an additional step for further surface analysis to confirm the quality of the oxide film formed on the sample surfaces. Injection of zinc during this period should be considered and if not used, the basis for not using zinc should be clearly documented.

6.11. Harmful chemical species (e.g. oxygen, hydrogen, alkalis, corrosion products and additives such as zinc) should be strictly controlled to minimize fuel cladding deterioration and thereby optimize occupational radiation 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 to avoid 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, which value should be used for 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 radionuclides in the primary coolant and in other systems should be kept below their specified control values. The activity should be checked by continuous monitoring and/or periodic sampling, and the measurement results should be trended 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 the plant should not participate in load follow actions or, if the fuel failure is significant enough, the management should order the shutdown of the unit within a reasonable period of time to remove the defective fuel element. There should be a clear link between relevant fission product concentrations/limits and the plant’s safety analysis.

6.15. Comprehensive decontamination procedures (e.g. chemical, electrochemical, mechanical) should be developed and validated for different applications. When choosing the decontamination technique, potential long term impacts to plant materials should be considered along with minimizing the re-contamination rates as well as the generation of nuclear waste. The need to undertake decontamination should be reduced so far as is reasonably achievable.

6.16. Chemical decontamination followed by optimized chemistry control should result in a net reduction of occupational doses at the plant. The re-contamination of the surfaces should be minimized by reducing the source terms to the extent practical.

6.17. Extensive chemical decontamination processes should be avoided in order to avoid high corrosion dissolution rates. After chemical decontamination of larger primary circuit components or the full system, proper rinsing and/or re-passivation of system surfaces should be carried out to avoid extensive deposits of corrosion products on the fuel surfaces that could have increased risk of fuel cladding failure and potential power shifts. Purification of the water should ensure the removal of corrosion products.

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 but also considering doses to the workers and discharges to the environment.

6.19. In accordance with chemistry programme, treatment and interim storage of radioactive waste arising from plant operation should be strictly controlled in a manner consistent with the requirements for safe disposal of waste established in IAEA Safety Standards Series No. SSR-5, Disposal of Radioactive Waste [11]. During treatment and interim storage, the requirements defined by waste acceptance criteria should be followed. 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 [12].

6.20. In order to minimize liquid and gaseous waste and/or activity, the operating organization:

(a) Should monitor and quickly identify leakages in the primary systems and should take corrective actions in timely manner;

(b) Should optimize 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 having significant difference in activity levels;

(d) Should reduce the amounts of chemicals 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 (charcoal beds) to allow radioactive decay before material is discharged into the environment;

(j) Should use effective filters to separate aerosols from gaseous discharges;

(k) Should use treatment for volume reduction (e.g. recombiners, absorbers, vapor recovery system, pressurized storage), which also serves as a delay system;

(l) Should optimize liquid waste management in order to minimize liquid waste generation, facilitate disposal and reduce on-site and off-site exposure in a cost-effective manner.

6.21. Discharges of liquid and gaseous radioactive effluents arising from plant operations should be authorized by the regulatory body. The operating organization should conduct assessments on 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 [13].

6.22. The principle of optimization of protection 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 the optimization of the protection of workers managing radioactive effluents and the members of the public are provided in IAEA Safety Standards Series No. GSG-9, Regulatory Control of Radioactive Discharges [14].

6.23. The operating organization should make arrangements to ensure that liquid effluents are analyzed after being transferred to holding tanks before being discharged. The total amount of discharged effluents should be known and their overall impact on the environment should be assessed. Requirement 12 of IAEA Safety Standards Series No. SSR-2/1 (Rev. 1), Safety of Nuclear Power Plants: Design [15] states that **"Special consideration shall be given at the design stage of a nuclear power plant to the incorporation of features to facilitate radioactive waste management and the future decommissioning and dismantling of the plant.**

6.24. New nuclear power plants should benefit from prior experience on the selection of materials and should apply a reactor chemistry regime that can minimize the source term during plant operations to as low as practicable to significantly minimize the decommissioning source term.

6.25. 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.

7. CHEMISTRY AND RADIOCHEMISTRY MEASUREMENTS

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.”

7.2. The operating organization should establish and implement chemistry and radiochemistry measurements to verify the effectiveness of chemistry control in relevant plant systems. The scope and frequency of chemistry and radiochemistry monitoring activities for commissioning, operating modes (startup, shutdown, operation at stable power levels, outages) as well as transient conditions should be specified by the chemistry department in relevant plant documentation and procedures.

7.3. The frequency of the measurements should be defined taking into consideration the rate of change of parameters, the safety importance of the SSCs and the aggressiveness of the measured impurities.

7.4. The chosen analytical method should provide sufficient sensitivity in the expected and graded limit values concentration ranges. The ‘matrix effect’ (the effect of other components in the sample) should be determined and corrected if necessary.

7.5. The measurements should be used to detect trends in the chosen parameters, to discover and eliminate undesirable effects and minimize consequences of out-of-range chemistry parameters. The chemistry and radiochemistry measurements should be carried out through all stages of the lifetime of a plant, including commissioning, shutdown and startup periods, and when systems are taken out of operation for prolonged periods.

7.6. Chemistry and radiochemistry measurements:

(a) Should provide timely chemistry and radiochemistry results to 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 should enable the implementation of corrective actions;

(d) Should ensure compliance with the discharge limits.

7.7. Computer programs used to calculate chemistry parameters should be verified and validated according to guidance in IAEA Safety Standards Series No. SSG-39, Design of Instrumentation and Control Systems for Nuclear Power Plants [16].

7.8. 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.

7.9. Plant documentation should include data to allow the comparison of data from different sampling points or the comparison of measurements of different parameter 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.

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

7.11. All on-line and laboratory analyses procedures should do the following:

(a) Describe the intended use of the procedure;

(b) Reference information sources used for development of the procedure;

(c) Provide a summary of information on the methods used, indicating the accuracy, linearity and range of the methods, possible interference between different methods and the precision of the measurements;

(d) State equipment, reagents and standards needed to perform the analyses;

(e) Provide step by step instructions for performing the analyses and calculating the results;

(f) Indicate the quality control requirements;

(g) Describe the measures for industrial safety and radiological protection;

(h) Provide information on instrument calibration;

(i) Give instructions on how to proceed if something unexpected happens.

7.12. The instruments, equipment and methods to be applied should be validated before commissioning. The validation process should demonstrate that instruments, equipment and methods are suitable for the task. The validation data should be properly documented and recorded so that it is easily available and retraceable.

7.13. 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. Calibration should be performed at regular intervals and the frequency should be decided on the basis of equipment manufacturers' specifications, plant experience or as result of the control charts.

7.14. Calibration strategies should be chosen in such a way that the range of the calibration points includes the values that are expected to be measured and the calibration points are as close as possible to the expected measurement value. The calibration should be checked regularly with a control solution (control standard).

7.15. Depending on the analytical method applied, calibration control measurements should be performed before and after each analytical run. The concentration of the control solution should be close to the expected value. These results should be graphically displayed in control charts with appropriate control and warning limits.

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

7.17. 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.

7.18. 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, temperature of the measurement media should be controlled as some instruments might have limited temperature ranges.

7.19. The activity of fission products should be measured to confirm the fuel integrity, identify fuel cladding leaks and get an estimation of severity of the leaks. The following should be taken into consideration for the conduct of these measurements:

(a) The gamma spectrometry equipment should be well maintained and calibrated, and different measurement geometries should be used for calibration;

(b) Sufficient sensitivity with respect to activity measurements of fission products should be ensured to allow 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) Properly selected 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 be able to detect potential fuel leaks, the radioactivity of the primary circuit of a pressurized water reactor should be monitored using fixed on-line analyzers. Otherwise, an adequate frequency for grab sampling should be defined.

7.20. Radiochemistry measurements should be part of the spent fuel handling operations, starting from reactor pool storage throughout any transport operations to interim storage facilities, in order to monitor the 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.

7.21. Measurements of the primary coolant activity of the activated corrosion products should be carried out to evaluate chemistry control performance, and to understand and minimize radioactive material transport processes. Such measurements should be carried out at different sampling points (e.g. upstream and downstream from the steam generators).

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

7.23. Radiochemical methods should be used to evaluate barrier leak rates which cannot be monitored by other measurement techniques, especially when the leak rate is very small (e.g. steam generator tube leaks, leaks to intermediate cooling systems).

7.24. Radiochemistry measurements should be applied in monitoring the performance of purification systems, especially when removal of radioactive material is the main purpose of operation of the purification system.

7.25. Measurement of the activities of relevant radionuclides should be carried out while 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 as low as reasonably possible principles and objectives.

7.26. 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 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 can be derived between difficult-to measure radionuclides and key (reference) radionuclides (so-called ‘fingerprinting’).

(c) Such correlations should be used for the calculation-based characterization of newly generated waste, but periodic checks of their correctness should be carried out by new radiochemical analyses.

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

7.28. Methods that rely on radiochemical separation and properly calibrated instruments should also be applied to monitor releases of tritium and ^{14}C speciation as these are particularly low energy beta emitters, especially in their gaseous form.

7.29. Determination of the radioisotopes on the inner surfaces of primary circuit should be done by using in-situ gamma spectrometry at carefully selected parts of the primary circuit. Other techniques could be the use of wipe sampling, oxide layer scraping or electrochemical sampling. These data should be analyzed for trends and correlated with chemical and operational data, such as pH_T and thermal power.

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

7.31. Redundancy of laboratory analysis on site or in other location or organization for most important parameters should be provided to ensure that analytical services can be provided at all times, including design basis accidents and beyond design basis accident conditions.

7.32. Adequately redundant instruments and equipment for performing analyses of given types and at given frequencies should be made available for the most important chemistry and radiochemistry parameters. If some of these analyses are outsourced, the chemistry department should ensure the necessary redundancy is also available by service providers or other organization.

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

7.34. Industrial safety (including 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 radiological safety (proper radiation shielding and contamination control facilities) should be ensured during all chemistry and radiochemistry related activities.

7.35. The fume hoods should be periodically checked according to the industry standards. The malfunction of active safety systems like the ventilation system of fume hoods should be promptly indicated and repaired. All laboratory and work practices should be carried out in accordance with plant procedures and industrial safety standards.

7.36. All laboratory instruments and equipment should be in good condition in order to provide accurate and reliable analytical data for monitoring purposes. The condition of such instruments and equipment should be ensured by a documented maintenance plan and a regular calibration plan as well as by having a long-term equipment renewal plan. Instruments under validation or maintenance should be clearly labelled.

7.37. Instrumentation manuals, well-maintained logbooks and calibration records should be made available in the laboratory.

7.38. For relevant parameters, the adequacy and accuracy of chemistry and radiochemistry measurements should be checked regularly by means of intra-laboratory and interlaboratory tests to identify potential analytical interferences, improper calibration, errors in the selection or the implementation of the analytical technique and issues in instrument operation. These test results should be evaluated to determine the cause of unexpected differences and deviations, with account taken of both short- and long-term effects. If necessary, corrective actions should be taken to further improve laboratory performance.

7.39. If the instrument performance shows significant deviation from the expected values, an investigation should be performed to determine the cause of the deviation. Repair or recalibration of an analytical instrument should be done, as appropriate, to restore the necessary accuracy.

7.40. 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.

7.41. Account should be taken of delays in obtaining samples (owing to, for example, the volume of the ‘sampling line’ for liquid samples) and of specific sampling issues associated with obtaining representative sampling of soluble and particulate corrosion products.

7.42. A post-accident sampling system facility should be ready to operate when needed in accordance with accident or emergency procedures to provide the chemistry and radiochemistry samples from the reactor coolant or the sumps in the containment and fission products in the containment. If a post-accident sampling system does not exist, it should be ensured that other approaches are available.

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

(a) Procedures for post-accident sampling.

(b) Radiation protection measures for personnel who carry out sampling, while transporting the samples to the laboratory and during the measurements. Such measures should be evaluated in advance and applied when the post-accident sampling is being performed (e.g. shielding of the sampling tube).

(c) A programme for preventive maintenance.

(d) Regular checks of the operability of post-accident sampling.

(e) Regular training of personnel designated for operation of post-accident sampling (i.e. personnel taking grab samples and performing subsequent activities).

(f) Specification of the chemistry parameters to be monitored.

7.44. Radiochemistry equipment should be available to measure samples having high activity levels or suitable techniques should be used to dilute reliable samples.

8. MANAGEMENT OF CHEMISTRY DATA

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, registered data sheets, databases containing periodic on-line measurements). The results should be supplemented with complementary information necessary for their interpretation, assessment and communication, if needed.

8.2. The data relating to chemistry should be suitably archived, stored and easily retrievable, in a database in accordance with the chemistry department documentation and the quality assurance programme expectations. The database should be appropriately secured so that only authorized personnel have access to it. If stored and approved data need to be corrected due to any reason, these modifications 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, assessment of chemistry data should be performed promptly after the data have been recorded. Depending on the importance and potential consequences of any deviation, the chemistry personnel should inform relevant operating personnel in accordance with the plant procedures.

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

8.5. The primary responsibility for review of chemistry data should be assigned to the 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. Chemistry personnel should regularly evaluate the results of the laboratory quality control tests.

8.6. Trends in chemical data should be correlated to operational parameters such as thermal power, and changes in chemical injection rates.

8.7. Data should be compared with operational limits and the evaluation and trend analysis of the data should be carried out 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 in the plant systems.

8.8. Trends of relevant chemistry parameters should be analyzed to obtain an adequate picture of the plant chemistry conditions and to facilitate the correlation between the related chemistry parameters and the status of the systems.

8.9. 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 these should have sufficient margins to the control limits, to the extent possible. Trend analysis should also be used to evaluate transients of short duration caused by plant operational changes and slower, long term changes occurring during steady state operation.

8.10. Significant deviations in chemistry analysis results should be proactively reported to the appropriate level of management. Effective communication with other relevant groups at the power plant should be established when analytical data indicate the need for prompt action to correct chemistry related problems.

9. QUALITY CONTROL OF CHEMICALS AND OTHER SUBSTANCES

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."

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

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

9.4. 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.

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

9.6. Chemicals and other substances should not be used in in-scope SSCs if they contain corrosion inducing components above the specified limits or if they might increase the activity on plant surfaces. If the rejection of such chemicals and substances is not possible, a risk assessment should be performed and documented.

9.7. Procedures should be in place 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.

9.8. Prior to the use of operational chemicals and substances (e.g. boric acid, ion exchange resins, diesel fuel), a sample should be taken and analyzed to ensure compliance with given specifications and the results should be compared with the supplier certificate. If the results do not match the given specifications, the substance should be rejected, or a risk analysis should be performed and properly documented to accept its use.

9.9. The batch or container should be labelled according to the plant procedures for easy verification that the relevant department has approved the use in a specific area. Chemicals and substances in storage areas should have a label indicating the shelf life of the material.

9.10. 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. If a sealed stock container has been opened, the date of opening has to be documented.

9.11. The contents of the smaller container should not be transferred back into the stock container. Residues of chemicals and substances should be disposed of in accordance with plant procedures. The quality of chemicals in open stock containers should be checked periodically. Tanks containing chemicals should be appropriately labelled.

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

9.13. Personnel involved in receiving, storing, transporting and using chemical substances should be trained to understand storage compatibility, labelling, handling and related safety requirements.

9.14. Management should periodically carry out walkdowns at the plant to evaluate that the control of chemicals and substances is effective and to check for insufficient storage practices of chemicals and substances.

9.15. Material safety data sheets for all approved chemicals and substances should be available and easily accessible to everyone on site (e.g. in an electronical databank). These data sheets should be in accordance with the relevant national legislation and should include, at a minimum, possible dangers to staff health, preventive measures for handling the materials and medical recommendations in case of accidental use.

9.16. Chemicals should be stored in an appropriate cabinet which is, for example, fire protected and captures spillages and a safety shower should be in place in accordance with plant documentation. Waste disposal procedures should be established. 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 in the workshops or in the operational department.

9.17. 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. .

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Annex

PRESERVATION OF STRUCTURES, SYSTEMS AND COMPONENTS IN A NUCLEAR POWER PLANT DURING DIFFERENT STAGES OF THE PLANT LIFETIME

A–1. It is common to have many plant systems and components open and exposed to air when they are inspected, maintained and 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 environments for various lengths of time.

A–2. When deciding on preservation conditions, the operating organization needs to consider the materials used in structures, systems and components (SSCs) as well as the length of time for the layup. The susceptibility of the components and systems to corrosion and their performance against degradation are typically defined in various types of plant documentation which are based on international knowledge and guidelines. High alloyed steels will generally have fewer preservation requirements than materials such as carbon steels. Therefore, SSCs made of austenitic stainless steel are in most cases left as they are. However, the existing water chemistry specifications have to be strictly adhered to. For systems composed of carbon steel, the requirements are more demanding due to the material’s lower corrosion resistance to moisture and oxidizing conditions.

A–3. The length of the shutdown period will impact the options of how to select and maintain proper layup to mitigate corrosion. 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 layup and keep, when necessary and possible, ongoing recirculation to minimize corrosion. The addition of preservation chemicals to the system will help to minimize corrosion during longer outages. However, plant systems have to be carefully reviewed to identify possible dead legs that would not be exposed to the preservation chemicals using normal application methods. For these systems, additional actions may be needed. In a case of dry layup, the systems need to be drained when components are hot to help 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 used, appropriate application and control of chemicals is of utmost importance.

A–4. The scope of this annex is to provide information based on best international practice to assure that the preservation of SSCs is done properly to maintain their integrity during the different stages of a 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 failures, equipment unavailability or to the need for extensive inspections, repairs or replacement programmes.

PRESERVATION STRATEGY

A–5. The purpose of preservation is to mitigate corrosion phenomena of SSCs and maintain their integrity. The implementation of a proper layup strategy is not only of utmost importance for plants in the commissioning stage but also for nuclear power plants already in operation. Preservation measures impact the lifetime of the plant components and are hence an important part of the ageing management or the asset management programmes. If the preservation measures are properly implemented, they can assist in ensuring the systems' availability and help reduce maintenance costs in the long term. The measures taken have to take into account the industrial and radiation safety of the operational organization and limit both the amount of liquid and solid wastes generated, and the amount of chemicals discharged to the environment.

A–6. The preservation strategy has to consider both the designers' specifications as well as the operating experience and any operational constraints. The strategy has to cover all SSCs that are within the scope of the chemistry programme and needs to include other systems which are susceptible to undergo degradation when they are not being operated (e.g. gaskets, seals). The plant documentation needs to clearly describe the functions and responsibilities of the personnel involved in preservation.

A–7. The preservation strategy has to be adapted to the outage type (planned or unplanned), outage duration, equipment, materials and coatings used in SSCs as well as to the regulatory requirements. It also needs to consider different aspects such as staff 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 layup of the secondary system feedwater train could be preferred instead of using alkaline wet preservation.

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

(a) Preservation of the steam generators needs to be considered as a high priority.
(b) If the system is to be drained, it can be done in hot conditions to speed up drying and under vacuum. However, how and when this can be done is plant and system specific.
(c) The capacity of dryers, if used, has to be sufficiently high to take into account the system volumes.
(d) All valves, which are not pressure barrier valves, are to be operated regularly (e.g. once every two weeks).
(e) Plants need to include an evaluation if special measures are needed (e.g. dismantling of equipment like valves, pumps, heat exchangers u-tube air blows.).

(f) The wet layup concept has higher monitoring demands and involves the use of potentially carcinogenic chemicals which might result in hazardous waste.
(g) Preservation methods may be interrupted (e.g. for inspections). Therefore, plans have to include a process to re-establish the necessary preservation conditions.
(h) Particularly during the commissioning stage, encapsulation and/or maintenance activities after dry tests or wet tests need to be included in the plans.
(i) When selecting the preservation types, utilities have to also consider their demineralized water production capacity in relation to outage length as part of the water management plan.
(j) Hazards associated with the application of chemicals need 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, need to be considered.

A–9. The operating organization can also have more detailed plans in place for preservation. These plans can be easily converted to the plant work planning process in short notice, if needed. If preservation cannot be implemented, the basis for this decision needs to be justified and documented.

AVAILABLE PRESERVATION TYPES

A–10. At room temperature general corrosion usually appears on metal surfaces and is spread over the entire system which is in contact with water or air with high humidity. However, if conditions are suitable, different types of localized corrosion can also occur. One of the most important aspects of preservation is to minimize the possibility of defect initiation during longer layup periods. Therefore, the plant needs to have plans and procedures in place for preservation in different operational conditions.

A–11. The starting point in preservation is to know the following:

(a) The construction materials used in the systems;
(b) The length of the planned period of time which might be available for layup;
(c) The scope of the preservation (e.g. whole system, components, only large components).

A–12. If the components are made of high alloyed steels, like austenitic stainless steels, typically no specific preservation actions are needed. If the layup period is extensively long, such systems can be drained and, if necessary, flushed with demineralized water and dry air. For systems made of low alloyed steels, such as carbon steels, when dry preservation is not feasible, wet alkaline preservation is selected in most cases, particularly if the layoup time is longer. In some systems and components both types of material may exist, in which case wet alkaline preservation modes are preferred. Quite often system overpressure is needed to avoid air ingress. Venting and fill and drain approaches need to be considered to ensure that the selected preservation method reaches all locations, including dead legs and branches.

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

A–14. The following approaches may be considered for selecting the layup method, taking into account the duration of the preservation, the systems layout and the materials used:

(a) Dry layup: Equipment and/or system need to be completely drained. The operating organization may consider using inert gas or dry air to ensure the effectiveness of the preservation. The operating organization could also consider using film forming products before shutdown to facilitate subsequent dry preservation.

(b) Wet layup: For boiling water reactors, wet layup 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 separator and reheaters, for example, the systems have to be filled with demineralized water and are not generally open to atmosphere. If possible, systems should be in a recirculation mode. For pressurized water reactors, wet layup is considered mainly to limit corrosion of less corrosion resistant materials and for steam generators. When large quantities of chemicals are needed to ensure adapted wet layup conditions, this type of preservation could be limited to situations when radiation protection measures need to implemented, or to specific maintenance operations, long outages and to the secondary side of steam generators.

(c) Maintaining systems and equipment in the same conditions as they are after shutdown when outage duration is short enough and materials are not susceptible to corrosion in those particular conditions. This to the best layup practice for closed cooling water systems if no maintenance work is planned inside the concerned 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. Independent of the chosen layup method, the generated contaminated waste cannot be incompatible with the plant's radioactive waste processing system and cannot result in waste volumes that the system was not designed to process. The generated waste is also required to meet the regulatory requirements applying to the plant. Paragraph 3.131(a) of IAEA Safety Standards Series No. GSR Part 3, Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards [A–1]) states that: “radioactive waste generated is kept to the minimum practicable in terms of both activity and volume”.

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

The operating organization could prepare beforehand, as part of the strategy, a table or list which contains information on the typical materials used in the system to be preserved, the length of the planned layout and the kind of preservation method that is to be considered.

A–17. The preservation strategy can be supported by a flowchart providing information on the various steps within the process. An example of such a generic flowchart is shown in Fig. A–1. In practice, a more detailed flow chart is needed including more detailed information such as a list of measurements to be carried out, acceptance criteria for the relevant parameters and the reporting needed. A separate flowchart could be created to provide information on what needs to be considered when the system is taken back into operation.

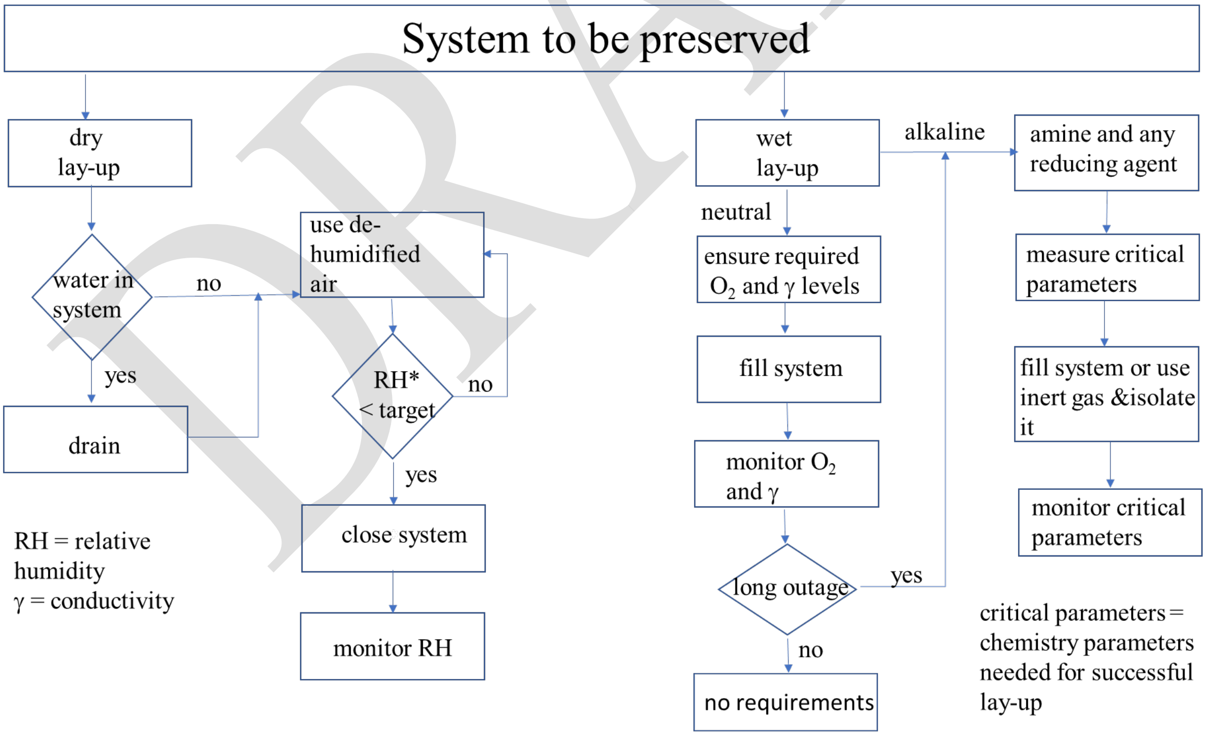


Fig A–1. Generic flowchart describing the potential steps in preservation process.

FLUSHING

A–18. For operating nuclear power plants, flushing of SSCs prior to preservation activities might not be necessary as long as the quality of the coolant meets the plant operating chemistry guidelines. If flushing is needed, paras A–19–A–22 describe the general practices applicable to a nuclear power plant in operation.

A–19. Flushing is typically done 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 similar or better water quality than the one used during normal operation. If the system is an in-line system, then it needs to be lined up to water purification equipment which has to be optimized to remove effectively the impurities expected to exist in the flushing media.

A–20. When flushing is necessary, especially during commissioning of components or systems, or when components or systems are returned to operation after they have been preserved, the composition of the flushing solution has to be appropriate to the materials. At a minimum, demineralized water needs to be used and, depending on the corrosion resistance of the materials, the flushing water may need to be conditioned to reach an optimum pH value to mitigate potential corrosion phenomena.

Acceptance criteria for flushing media

A–21. The water solution used for flushing needs to have predefined properties which 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 solution or 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 and hydrazine or any other relevant reducing agent is used with demineralized water, their concentrations have to be given, and other relevant chemistry parameters (e.g. pH, conductivity) have to be measured. In addition, the acceptance levels of impurities in the preservation chemicals have to be well-defined.

A–22. The flushing plan needs to contain a criterion to indicate when flushing can be completed. 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.

Depending on the preservation strategy measurement of relevant corrosion products and corrosion inducing ions is recommended.

DRY PRESERVATION

A–23. A prerequisite for dry preservation is that the system can be dried in a reasonably short time. High alloyed systems do not typically need any additional actions after the drainage but for low alloyed systems additional arrangements are needed to ensure that the surfaces do not contain residual water.

A–24. Prior to dry preservation, the components and systems have to be drained as efficiently 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. In practice this may additionally involve dismantling components such as valves and pumps. Once properly dried these components can be re-assembled and re-installed back to the system.

A–25. Hot draining and draining under vacuum speeds up the dry preservation process. If the site location is such that the surrounding air is dry enough, the use of dehumidified air might not be needed. In some cases, conditioning the atmosphere of entire rooms or parts of buildings can be more cost effective than providing protection for a single component or a system. When necessary, overpressure of an inert gas (e.g. nitrogen) can be used to avoid ingress of air and moisture into the system.

A–26. The use of corrosion inhibitors such as film-forming products have been reported by the operators of some pressurized water reactors to control corrosion during extended outages and refurbishments. For layup protection application, film-forming products can be added during a short period of time just prior to the scheduled outage to establish a protective film to enhance component protection during layup and to provide optimized startup conditions for the subsequent fuel cycle.

Acceptance criteria for dry preservation

A–27. When implementing dry layup, the air quality has to be checked. Dry and clean air, free of oil and dust has to be used throughout the process. Humidity criteria need to be established and humidity has to be monitored to ensure that residual moisture on surfaces remains at acceptable levels.

A–28. Relative humidity (RH) criteria (e.g. relative humidity below 40% at 20 ºC when room temperature is higher than 10 ºC) 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 needs to be identified, corrective actions need to be taken to restore relative humidity to acceptable levels and all relevant information needs to be properly documented.

A–29. When a dry layup is complemented by the use of inert gas overpressure, the necessary measurements are needed to ensure that overpressure is maintained. Desiccants (i.e. substances able to adsorb water) have to be carefully used to reduce the risk of introducing impurities or foreign materials into the systems and the equipment.

Monitoring of dry preservation

A–30. The following steps could be taken to ensure efficient dry preservation:

(a) Checking the quality of the last flushing water, including checking parameters such as pH, corrosion inducing ions (e.g. fluoride, chloride, sulphate), conductivity and relevant corrosion products (e.g. iron ions, suspended solids).

(b) Documenting the temperature of the medium 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 analyzing the trend 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, checking the differential pressure of the filter (e.g. once per day at the beginning and later on when a steady state is reached once per week);

  (iv) Checking the relative humidity at the identified inlet and outlet openings (e.g. once per day at the beginning and later on when a steady state is reached once per week);

  (v) Checking the air flow at the outlet openings (e.g. once per day at the beginning and later on when a steady state is reached once per week);

  (vi) Checking that the temperature doesn’t fall below the dew point locally.

(g) If over-pressurized inert gas is used to prevent air ingress:

  (i) Checking and analyzing the trend in the overpressure (using a manometer) once per day and after a steady state is reached, once per week;

  (ii) Checking the availability of inert gas.

(h) If vacuum is used to decrease humidity, checking and analyzing the trend in the under-pressure (using a manometer) once per day and after a steady state is reached, once per week.

WET PRESERVATION

A–31. Wet layup without any changes to the water chemistry parameters after the shutdown is carried out typically for pressurized water reactor vessels, boiling water reactor vessels, reactor coolant system piping, boiling water reactor recirculation system, control rod drive hydraulic system, refueling water storage tanks and the primary side of the steam generator. For example, the secondary side of the steam generator is in most cases 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–32. The alkaline wet preservation is most efficient if the coolant does not contain oxygen. This condition is typically achieved either by using oxygen scavengers or by completely filling up the system including the dead ends. Equally important is to vent the air from potential air pockets and not have the system open to the atmosphere. An effective way to mitigate ingress of oxygen into the system is to have system overpressure or have a nitrogen or inert gas blanket inside the system.

A–33. The length of the preservation period needs to be carefully evaluated and the basis accurately documented if preservation is carried out using demineralized water without additives in a system made of low alloyed materials. Plants that inject dispersants could increase the amount of dispersant injected to the coolant at the end of cycle and continue injecting to zero percent power. This will increase the amount of dispersant in the solution and help control the transport of corrosion products. When preservation is finished, plans have to be in place on how to treat the chemicals if they are added and provide instruction to determine if they can be discharged into the environment.

Acceptance criteria for wet preservation

A–34. For wet preservation, the plant can use demineralized water or water conditioned with chemicals to obtain the required pH and reducing conditions. The chosen method has to be based on the type of material present in the system and on the length of the layup.

A–35. For wet preservation without chemicals, the plant has to ensure that low enough (precisely defined) conductivity conditions are achieved prior to preservation. For alkaline wet preservation, amine and any reducing agent is added to the demineralized water. The plant needs to define clear acceptance values for selected impurities in these chemicals. The plant needs to pay attention to the management of the chemicals used in the preservation.

A–36. During the neutral wet preservation, the plant needs to implement a monitoring programme for conductivity and for the concentration of predefined anions and iron. Regarding alkaline treatments, the pH, as well as the concentration of reducing chemicals, predefined anions 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 layup medium needs to be ensured when possible.

A–37. Monitoring of oxygen is also recommended. If an inert gas overpressure is used to avoid air ingress, a criterion for the overpressure of this gas needs be defined and controls need to be implemented to ensure that the criterion is met. Deviations of the relevant parameters during the preservation have to be addressed in a timely manner and have to be properly documented.

Monitoring of wet preservation

A–38. The following steps could be taken to ensure efficient wet preservation 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) and measuring conductivity and oxygen concentration;

b) Ensuring continuous availability of demineralized water and checking its quality;

c) Checking that the system is fully filled (e.g. once per day and later on when a steady state is reached once per week);

d) Checking that the system is sealed from the atmosphere;

e) Checking and analyzing the trend in the quality of the preservation medium, for example checking corrosion inducing ions (e.g. fluoride, chloride, sulphate) and measuring the conductivity and oxygen concentration (e.g. once per day and later on when a steady state is reached once per week);

f) Checking and analyzing the trend in the concentration of relevant corrosion products (e.g. iron, suspended solids) once per day and after a steady state is reached once per week;

g) Checking and analyzing the trend in over-pressure (using a manometer) if the system is under inert gas, once per day and, after a steady state is reached once per week.

A–39. The following steps could be taken to ensure efficient wet preservation with additives:

a) Checking the quality of demineralized water before filling the system, for example, checking the concentration of corrosion inducing ions (e.g fluoride, chloride, sulphate) and measuring the conductivity and oxygen concentration;

b) Ensuring continuous availability of demineralized water and checking its quality;

c) Checking that the correct amount of preservation chemicals is added (depending on the materials of the system);

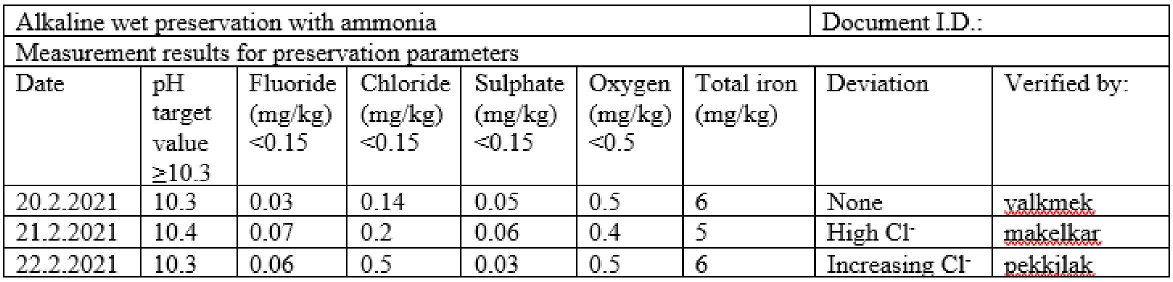
d) Checking that the system is filled up to the specified level once per day and after a steady state is reached, once per week;

e) Checking and analyzing the trend in over-pressure (using a manometer) when the system is under inert gas, once per day and after a steady state is reached, once per week;

f) Checking and analyzing the trend in the quality of the preservation 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 once per day and after a steady state is reached once per week;

g) Checking and analyzing the trend in the concentration of relevant corrosion products (e.g. iron, suspended solids) once per day and after a steady state is reached check once per week.

TABLE A–2: SIMPLIFIED EXAMPLE OF PRESERVATION DOCUMENTATION



Alkaline wet preservation with ammonia							Document I.D.:	
Measurement results for preservation parameters								
Date	pH target value ≥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	yalkmek
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^-	pekkilak

RECORD KEEPING AND EVALUATION OF THE EFFECTIVENESS OF THE PRESERVATION

A–40. The plant needs to have in place a process ensuring that suitable record keeping, and data collection relating to preservation is available. This process needs to guarantee that all necessary approval practices and administrative approvals during the preservation are properly followed. Once the system is put back in operation, there need to exist plant documents verifying that the preservation was done in such a way that the actions taken have not resulted in the decrease of equipment reliability nor in an increase in corrosion product release rates that could result in their subsequent transport into the core region.

A–41. The preservation documentation has to include to a reasonable extent not only the systems and components to be in wet or in dry layup but also connecting systems, because these might challenge the conditions under preservation. This documentation needs to clearly define the basis for the selected preservation method. The preservation documentation has to contain all analysis reports and trend analyses of the relevant parameters.

A–42. Deviations of the relevant parameters during preservation and any countermeasures taken to address deviations have to be well documented. If deviation is significant during the preservation process, relevant parties such as commissioning and licensee organizations, need to be informed.

A–43. When corrective actions are needed, a cause analysis needs to be performed and properly documented. The plant's corrective action plan should ensure that necessary corrective actions are implemented and completed in a timely manner.

A–44. An effectiveness review of the actions taken should be documented so that reoccurrence of the same transient is prevented. 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–45. The plant may consider including a dedicated indicator for preservation in their key performance indicator programme. This indicator would be useful in evaluating the effectiveness of actions taken during layup and would provide a tool to compare actions taken during different outages. The indicator could consist of carefully selected chemistry parameters and any disturbances that occurred during preservation (e.g. malfunction of air drying system, accidental drainage of system under preservation).

REFERENCES 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).

CONTRIBUTORS TO DRAFTING AND REVIEW

Bolz, M.	Consultant, Germany
Clinard, M-H.	Framatome, France
Daisuke, Y.	The Kansai Electric Power Co., Inc, Japan
Kameswaran, R.	Canadian Nuclear Safety Commission, Canada
Kvarnström, R.	Fortum Power and Heat Oy, Finland
Maekelae, K.	International Atomic Energy Agency
Miyashige, Y.	Tokyo Electric Power Company Holdings, Japan
Morgan, H.	International Atomic Energy Agency
Mura, M.	Electric Power Research Institute, USA
Nishiura, H.	The Kansai Electric Power Co., Inc, Japan
Stoll, T.	Kernkraftwerke Lippe-Ems GmbH, Germany
Tompuri, K.	Teollisuuden Voima Oy, Finland
Viricel, L.	Électricité de France, France
Yuya, K.	Tokyo Electric Power Company Holdings, Japan