

IAEA SAFETY STANDARDS

for protecting people and the environment

Step 6

Preparing the draft publication

**Chemistry Programme for Water Cooled Nuclear Power
Plants
DS525**

DRAFT SAFETY GUIDE

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1. INTRODUCTION

BACKGROUND

1.1. This Safety Guide covers all types of water-cooled nuclear power plants and provides more detailed guidance on those water chemistry related safety requirements given in IAEA Specific Safety Requirement publication on Safety of Nuclear Power Plants: Commissioning and Operation, IAEA Safety Standards Series No. SSR-2/2 (Rev.1) [1] and in IAEA Specific Safety Guide on Decommissioning of Nuclear Power Plants, Research Reactors and Other Nuclear Fuel Cycle Facilities, IAEA Safety Standards Series No. SSG-47 [2].

1.2. A chemistry programme is essential for the safe operation of a nuclear power plants. It contributes to the integrity, reliability and availability of structures, systems and components (SSCs) in accordance with their intended design. The scope of the SSCs which should at least be included within the chemistry programme from the point of view of ageing management is given in the IAEA Specific Safety guide on Ageing Management and Development of a Programme for Long Term Operation of Nuclear Power Plants, IAEA Safety Standards Series No. SSG-48 [3]. The chemistry programme is based on a detailed rationale usually provided by the manufacturer of the plant. The main goals of the chemistry programme 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 build-up 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 IAEA Fundamental Safety objective to protect people and the environment from the harmful effects of ionizing radiation.

1.3. The chemistry programme is built on three pillars, the chemistry regime, chemistry control and chemistry measurements. The chemistry regime is defined by the reactor type, its design and construction materials used. Chemistry control should assure that the plant is operated in accordance with the chemistry regime. It defines the parameters to be measured, their measurement frequencies, limit values and corrective actions to be taken if necessary. Chemistry measurements provide information about the actual chemistry conditions in the systems, which provides the basis for all further decisions.

1.4. This Safety Guide is intended to be useful for plant chemistry personnel to continuously improve existing chemistry programmes. It should also be used to support the development of new chemistry activities within the programme as well as to assist in the development of corrective actions for eliminating identified weaknesses in the current programme.

1.5. This Safety Guide should be used by responsible managers of operating organizations to effectively oversee the plant chemistry programme and by regulatory bodies not only when fulfilling

their external oversight responsibilities and but also during development of national regulatory requirements in water chemistry area. The guidance given in this Safety Guide should be used by technical support and research organizations when they are providing support for licensees or regulatory bodies.

OBJECTIVE

1.6. The objective of this Safety Guide is to provide Member States with chemistry guidance based on best international practices. The objective is achieved by providing recommendations which mitigate degradation of SSCs and ensure their availability, adhere 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 liquid radioactive waste.

SCOPE

1.7. 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, life extension periods as well as the decommissioning phase.

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

1.9. This Safety Guide does not provide detailed technical advice related to particular chemistry regimes 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. The information in Annex A can be used for planning the preservation of SSCs during different phases of plant lifetime and in preparation for decommissioning.

STRUCTURE

1.10. Section 2 provides recommendations on the functions and responsibilities of organizations involved in the chemistry programme and the interfaces between them. Section 3 gives guidance on the training and qualification of personnel involved in the chemistry activities. General recommendations on the chemistry programme are addressed in Section 4. Recommendations on the process of chemistry control are given in Section 5. Section 6 describes recommendations on the chemistry aspects of radiation exposure optimization. Guidance for chemistry and radiochemistry measurements are

addressed 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. Annex A provides guidance on preservation of SSCs in nuclear power plants during the different phases of the plant lifetime.

2. FUNCTIONS, RESPONSIBILITIES IN ORGANISATION

2.1. 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 as described in IAEA Safety Guide publication on The Management System for Nuclear Installations, IAEA Safety Standard Series No. GS-G-3.5, IAEA, Vienna (2016) [4]. Detailed job descriptions of chemistry staff should be available in plant documentation.

2.2. Plant management should periodically reinforce its expectations on the chemistry programme. Plant management should set clear targets for continuous improvement of operational safety performance in the chemistry area. Targets and management expectations should be described in plant documentation.

2.3. Plant management should ensure that any measures to shorten the scheduled shutdown period and to accelerate plant start-up activities will not compromise the compliance with chemistry control procedures (e.g. efficient use of water purification systems during shutdown and start-up phases, maintaining suitable wet or dry conservation conditions in equipment during shutdown periods, etc.). Safety should always be prioritized over production as strongly emphasized in IAEA General Safety Requirement publication on Leadership and Management for Safety, IAEA Safety Standards Series No. GSR Part 2, IAEA, Vienna (2018) [5].

2.4. The operating organization should establish and implement a chemistry programme to:

- a) ensure criticality control of the reactor core;
- b) preserve the integrity of SSCs within the scope of the water chemistry programme;
- c) preserve the integrity of the fuel cladding;
- d) minimize the build-up of radioactive nuclides to reduce dose rates at the plant and hence radiation doses to personnel;

- e) reduce amount of chemical and radioactive waste and to reduce planned discharges to the environment.

2.5. 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 decommissioning period.

2.6. 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 chemistry and technical support staff, supervisors and chemistry management. Management resources should be proportionate with operational requirements.

2.7. The operating organization should provide sufficient resources for the development of chemistry control methodologies. Continuous improvement should be an established practice among staff in the chemistry group and the challenges related to long-term operation of the plant should be addressed.

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

2.9. 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 and specifications.

2.10. 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, etc.) with regard to the working environment.

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

2.12. 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 should also include participation in an interlaboratory comparison programme which should include both chemistry and radiochemistry measurements. Identified non-conformances should be reported, included in the plant's corrective action programme with proper significance level and the status of corrective actions should be regularly evaluated [5].

2.13. Performance indicators including relevant operational indicators for the chemistry programme (both chemistry and radiochemistry) should be established to monitor the effectiveness of the programme. Performance indicators should be regularly communicated to the staff. Relevant indicators

should also be brought to the attention of other departments and senior management. Chemistry performance indicators should be trended, and preventive and/or corrective measures undertaken when necessary.

2.14. The representatives of the chemistry department should regularly obtain operating experience from national and international organizations to ensure information exchange and the chemistry programme being kept up to date with best industry practices. Lessons learnt should be appropriately implemented in plant's procedures or other types of plant documentation and brought to the attention of staff.

2.15. If design changes relevant to chemistry are planned, personnel from the chemistry department should be included in the plant's design authority process. As part of the process, chemistry management should understand and approve the changes in those design basis documents relevant to the water chemistry programme, and they should own this information or have an easy access to it. The chemistry programme should be revised if necessary.

2.16. For any plant modifications required, the chemistry department should provide all necessary data to the plant departments.

2.17. The chemistry department should be represented in all relevant plant meetings to assure appropriate and timely information flow. Chemistry information should also be represented in plant committees which are related to, for example, ageing management, corrosion issues, leakages, dose rate and liquid radwaste reduction and outage planning.

2.18. Chemistry personnel should have a clear understanding of their roles and responsibilities. Proper organizational interface arrangements should be established 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 between operating and corporate organizations should be clearly communicated and understood.

2.19. 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 kept to a minimum. Issues involving other departments should be brought to the attention of senior management in a timely manner.

2.20. Water chemistry and radiochemistry reports should be shared with other relevant departments in the operating organization. The contents of these reports, how frequently and to which organization they are sent, should be clearly defined in plant documentation. However, these reports should leave

place to report also non-routine events. A method for delivering analytical results to other departments (e.g. the operations department) should be well established and communicated. When actions are required, the responsibilities should be clearly assigned.

2.21. Well-defined interfaces should be established with the regulatory body, design 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.

2.22. Qualified external contractors and consultants should be made available as necessary. 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 [5]. The operating organization should ensure that chemistry department provides sufficient support and control of contractors working within the chemistry area.

2.23. All contractors and suppliers should be made subject to the same expectations as plant staff, particularly with respect to required chemistry skills and competences, adherence to procedures, result reporting, safety culture and performance evaluation. Further recommendations on the management of contractors are provided in IAEA Safety Guide publication on Maintenance, Surveillance and In-service Inspection in Nuclear Power Plants, IAEA Safety Standards Series No. SSG-74, IAEA, Vienna (2022) [6].

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

3. TRAINING AND QUALIFICATION

3.1. Recruitment, training and qualification of the chemistry staff should be organized in accordance with the recommendations provided in IAEA Safety Guide publication on Recruitment, Qualification and Training of Personnel for Nuclear Power Plants, IAEA Safety Standard Series No. SSG-75, IAEA, Vienna (2022) [7]. Chemistry staff should have a sufficient and related educational degree according to the local education system.

3.2. During all steps of the training programme, the level of pre-education should be taken into account.

3.3. The chemistry management should ensure that chemistry personnel are qualified, and that sufficient number of staff is always available at the plant or can quickly come to the plant when needed. For each position the required qualification should be described. The qualification programme should ensure that sufficient supervision is done by the chemistry management and that chemistry staff demonstrate commitment to high safety performance [1, 4].

3.4. A systematic approach to training for chemistry staff should be applied in accordance with the recommendations provided in Ref. [7]. Basic training (i.e. general training for all personnel), initial, ongoing and refresher training should be developed and implemented.

3.5. Initial training for chemists should include on the job training in those areas which are related to chemistry control and measurements (e.g. in 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 start-up, normal operation, shutdown and most probable transient situations. Line management or a qualified trainer should approve the successful completion of the training.

3.6. Ongoing training for routine tasks should be carried out regularly for all chemistry staff and it should have clearly written goals. Refresher trainings should also be considered at plants in which there is a large chemistry staff that does not perform certain tasks on a regular basis (e.g. yearly safety training, use of post-accident sampling system if not used for regular sampling etc.).

3.7. Training facilities and methods should be used which have been proven to be effective in attaining the training objectives. 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.

3.8. On the job training should be conducted in accordance with written operating procedures for activities such as taking samples, using an on-line chemistry station, 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.

3.9. All chemistry activities should be performed by authorized chemistry staff, but trainees may be assigned to carry out chemistry activities while 'shadowing' (supervised by) authorized staff.

3.10. Training courses should include techniques for recognizing unusual conditions during sampling, 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 operations group. The theoretical part of the training should include the chemistry regime, the chemistry control and the chemistry measurements, impact of change in chemistry on safety of the NPP, and the appropriate rationale.

3.12. Chemists should know the equipment used by chemistry staff and have the knowledge how to operate them, even if they are not the ones responsible for executing the 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 staff should take part in training programmes or emergency exercises where internal or external releases of chemicals or radioactive materials are involved. Emergency chemistry procedures, emergency equipment and expected chemistry values should be used in training and exercises to ensure correct responses by chemistry staff.

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

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

- a) the storage and handling of hazardous, flammable and poisonous chemicals;
- 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.

3.17. After the training the chemistry staff should be knowledgeable of all relevant plant requirements for nuclear and industrial safety.

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

4. CHEMISTRY PROGRAMME

4.1. The chemistry programme should contribute to ensure safe operation, long term integrity of SSCs, integrity of fuel, minimize build-up of radioactive material and limit all discharges to the environment to levels as low as reasonably achievable [1].

4.2. The integrated management system should define the responsibilities of the chemistry organization regarding the implementation of the chemistry programme. The related chemistry department accountabilities and responsibilities should be clearly communicated to the operating organization. Implementation and responsibilities of the chemistry programme should be organized and documented in such a way that it takes into account the organizational structure of the company (fleet, corporate, single site, etc.).

4.3. The chemistry programme should include plant documentation providing a basis for selection, monitoring and analysis of the chemistry parameters. The chemistry instructions should be aligned with operational limits and conditions as addressed in IAEA Safety Guide publication on Operational Limits

and Conditions and Operating Procedures for Nuclear Power Plants, IAEA Safety Standard Series No. SSG-70, IAEA, Vienna (2022) [8]. The chemistry instructions should explicitly define graded limit values for specific chemistry parameters enabling efficient implementation of the chemistry programme. In addition to the graded limit values, the plant documents should describe potential remedial actions to be applied in various operational phases.

4.4. Generic chemistry programme expectations should include at least the following attributes:

- a) The chemistry department should have a clearly documented scope of SSCs which are part of the chemistry programme;
- b) A plant specific chemistry regime should exist and be in accordance with the original plant design. Potential design changes should take into account the existing chemistry regime and if needed the existing chemistry programme should be updated to reflect the structural changes done to the SSCs;
- 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, and revised standards), conclusions documented and improvements incorporated into the chemistry programme, when considered beneficial. Chemistry managers and supervisors should regularly review available internal and external operating experience information. Operating experience information and results of these reviews should be made available to the whole chemistry staff;
- 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. regulatory requirements regarding microbiological growth;
 - iii. 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;
 - j) Results of the chemistry programme should be communicated in timely manner to relevant chemistry managers and to those parts of the organization who need such information (operators, maintenance staff, the system engineering group, technical support organizations, etc.);
 - k) 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;
 - l) On-line instruments and equipment in the laboratory should be regularly inspected, calibrated, maintained and kept up to date. The necessary redundancies for these equipment should be ensured;
 - m) The chemistry department should provide plant ageing management programme information needed to ensure safe and long-term operation of the SSCs;
 - n) The in-service inspection results should be used to confirm whether the chemistry program is effective or not;
 - o) 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;
 - p) 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;
 - q) Radiochemistry measurements should be carried out for closed cooling water circuits in BWRs and RBMKs and in the primary and secondary sides of PWRs and PHWRs to detect leaks in pressure boundaries;
 - r) Discharges of radioactive species and chemicals should be kept ALARA 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 NPP

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 (e.g. for production of tritium and ^{14}C);

- s) The chemistry programme should provide adequate support to identify and characterize radioactive waste generated at the nuclear power plant (including waste from decontamination);
- t) Hazardous chemicals should be stored and handled properly, and material safety data sheets should be readily available to all plant personnel;
- u) The chemistry programme should define clear cleanliness requirements and storage conditions for SSCs during construction and commissioning phases to ensure safe and reliable operation of SSCs throughout the plant lifetime;
- v) The chemistry programme should include clear chemistry expectations and instructions for SSC preservation periods (more in Annex 1).

5. CHEMISTRY CONTROL

5.1. Chemistry control should ensure that systems within the scope of chemistry programme are operated according to the appropriate chemistry regimes. The chemistry regime depends on the design of the plant and on construction materials used. The chemistry control should be continuously improved by taking into account up-to-date knowledge and operating experience. The effectiveness of the chemistry control should be regularly evaluated.

5.2. To achieve effective chemistry control, the chemistry programme should define detailed chemistry parameters to be followed in all reactor types. These parameters should be addressed according to their potential safety importance. All parameters should be based on adequate technical knowledge and international industry experience.

5.3. The control parameters should be those which are known to result in a negative impact on materials integrity, fuel rod corrosion, fuel design performance and radiation fields or directly have an impact on reactivity control or on the environment.

5.4. Control parameters should be strictly followed and should have clear graded limit values. 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.

5.5. The chemistry department should ensure that the monitoring frequencies of control parameters are selected in such a way that actions can be implemented in timely manner. The analytical techniques used should be sufficiently sensitive and accurate to enable implementation of corrective actions in a timely manner.

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

5.7. 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.

5.8. The chemistry control parameter records should be assessed and any values exceeding any limit values or any deviation from the chemistry programme should be treated in conformance with the management system of the operating organization.

5.9. 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 that they enable the chemistry department to react proactively on chemistry variations.

5.10. The chemistry department should regularly trend control and diagnostic parameters and proactively react on adverse trends.

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

5.12. Radiochemistry should be systematically monitored, trended, evaluated and correlated with chemical and operational data, like pH_T (pH at operating temperature) and thermal power [8]. Tools should be available to enable detection and estimation of the type and amount of the fuel leakage as well as to provide information about the burn-up of the fuel rod.

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

- a) Transition from construction to commissioning;
- b) commissioning;
- c) start-up;
- d) normal operation;
- e) transients;

- f) shutdown;
- g) outages;
- h) accident conditions;
- i) transition from operation to decommissioning;
- j) decommissioning.

5.14. During outages, equipment and systems should be maintained under adequate lay-up conditions (see Annex A) and in accordance with safety requirements. Preservation parameters should be monitored and documented. Corrective actions should be implemented if needed.

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

5.16. The quality of lubricant oil for safety related systems like emergency pumps, emergency diesel generators etc., should be regularly monitored and controlled by the plant operating organization.

5.17. The quality of diesel fuel should be verified before unloading 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 trended for early indication of potential deterioration of the expected properties.

5.18. Tanks and unventilated spaces containing gases should be strictly monitored and properly maintained not only to prevent potential explosions caused by the simultaneous build-up of oxygen and hydrogen but also because of the potential presence of gaseous fission products and iodine.

5.19. The concentrations of the chemical inhibitors that are added to cooling and other systems that may 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 environment should also be assessed. The chemistry parameters that indicate proper treatment should be selected, monitored and controlled.

WATER CHEMISTRY CONTROL IN BOILING WATER REACTORS (BWRs)

5.20. During operation, the chemistry control at a BWR 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 (IGSCC) of core components and parts of

pressure vessel penetrations, minimizing fuel performance risks and reducing radiation levels on SSC surfaces.

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

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

5.23. During start-up, the oxygen concentration in the reactor water should be controlled and should be maintained at a low enough level to minimize IGSCC.

5.24. Steam humidity should be kept as low as possible to reduce spread of contamination and erosion corrosion of the steam lines.

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

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

5.27. In preparation for shutdown, at those plants where it is possible, the flow rate of the reactor water clean-up 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 this system should be as high as possible during the crud and corrosion product release phase.

5.28. 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.

5.29. 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.

5.30. 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):

5.31. For a nuclear power plant with a graphite moderated nuclear power reactor (RBMK), the chemistry regime should be applied without the use of any acids or alkalinizing chemicals. RBMK plants should have high purity feedwater and effective purification systems for condensate and reactor coolant.

5.32. Chemistry control at a RBMK should ensure that:

- a) deposition of corrosion products on heat exchanger surfaces and piping is minimized;
- b) corrosion (e.g. IGSCC, flow accelerated corrosion) of the materials of the main steam–water circuits is minimized;
- c) moisture separators produce high quality steam for turbines.

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

5.34. 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. Flushing may be conducted without special reagents or by the use of a combined procedure (chemical and without chemical).

PRIMARY WATER CHEMISTRY CONTROL AT PRESSURIZED WATER REACTORS (PWR AND WWER)

5.35. The concentration of dissolved ^{10}B in the reactor coolant system for controlling core reactivity should be regularly controlled to prevent deviation from abnormal isotopic depletion. Boric acid should be measured either by using on-line measurements or by having sufficiently frequent results from grab sample measurements to support control of pH_T of the primary coolant.

5.36. Addition or removal of alkaline compounds should be used in order 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 ^7Li 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 (potassium injected, lithium produced by neutron reaction on boron, and possibly sodium as an impurity) should be monitored using available techniques.

5.37. The concentration of hydrogen should be kept within specified limits during power operation to minimize the concentration of oxygen and other oxidizing species in primary coolant. In addition, the

oxygen concentration of make-up water should be monitored and degassed or chemically scavenged to be within specifications.

5.38. 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.

5.39. 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 silicon dioxide.

5.40. Shutdown and start-up procedures should be strictly followed to control the release of corrosion products and to effectively remove them by 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 relevant plant organizations and the basis clearly documented for future assessments.

5.41. No specific lay-up conditions are required for drained primary systems during the outages since the materials are not supposed to be susceptible to corrosion at ambient temperature.

5.42. In order 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 corrosion products' source terms and the stress corrosion cracking of nickel-based alloys. The conclusions of such evaluations should be clearly documented.

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

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

5.44. A management system for heavy water (D₂O) should be established to account for the D₂O inventory and to control the level of tritium activity. Throughout the heavy water management system, D₂O should be segregated on the basis of its tritium and isotopic composition.

5.45. The isotopic purity of D₂O 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.

5.46. The concentration of soluble reactivity agents (poisons such as boron and/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 required to achieve an over poisoned guaranteed shutdown state is specific to the nuclear power plant and should be documented in the safety analysis.

5.47. 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.

5.48. Graded limit values for deuterium and hydrogen concentrations in cover gas systems should be adequately established in order to eliminate the possibility of creating an explosive gas mixture.

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

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

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

5.52. During reactor shutdown, normal chemistry specifications should be maintained for the moderator system, except when:

- a) 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) the cover gas is being purged;
- c) the moderator is drained.

SECONDARY WATER CHEMISTRY CONTROL AT PRESSURIZED WATER REACTORS (PWR, WWER AND PHWR)

5.53. Special attention should be paid to the integrity of the various parts of the secondary and auxiliary systems that may be significantly affected by various forms of corrosion or deposited corrosion

products. The secondary circuit and its water chemistry control should also be designed to minimize the ingress of corrosive impurities.

5.54. The selected water chemistry regime should:

- a) minimize the flow accelerated corrosion of construction materials, particularly in components made of carbon steels;
- b) be compatible with all secondary side materials;
- c) reduce the amount of corrosion products in the steam generator feedwater to minimize their deposition onto SG tubes, between tubes and tube sheets, on and within tube support plates and collectors;
- d) be compatible with the plant's purification systems;
- e) minimize the discharge of liquid and solid waste to the environment;
- f) be achieved without causing the unnecessary health risks to the operating organization by selecting inappropriate chemicals.

5.55. The secondary circuit should be operated with high enough pH obtained using volatile alkaline reagents such as ammonia and/or amines (e.g. morpholine, ethanolamine, 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 alkalizing substances should be specified and verified.

5.56. 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.

5.57. The primary to secondary circuit leakage rate in the steam generator tubes should be calculated based on on-line activity measurements and strictly controlled within predefined limits. Such leaks 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.

5.58. The levels of deleterious impurities (e.g. sodium, chloride, sulphate, lead and copper ions) in the steam generator water should be measured and kept as low as possible. These 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).

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

5.60. The potential impact of chemistry parameters on the integrity of the steam generator should be regularly evaluated and related results should be trended. The main tools for such an evaluation should be:

- a) evaluation of the results of non-destructive testing (in-service inspection) of the integrity of the steam generator tubes, at least due to degradation that is related to the primary and secondary water chemistry control;
- b) the measurement of 'hideout return' to get an estimation of impurity levels in crevices and areas with restricted flow areas (sludge piles, deposits, etc.).
- 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.

5.61. If necessary, an effective cleaning procedure should be applied to remove deposits from steam generators to mitigate the effects of various forms of corrosion.

5.62. In order to further optimize corrosion product control in the steam generators, dispersant compounds and film forming products should be considered in the secondary water. The conclusions of these evaluations should be clearly documented for future work.

5.63. Impurity concentrations in the demineralized make-up water should be controlled to ensure compliance with technical specifications.

5.64. Auxiliary systems should be operated according to specific chemistry regimes and control with the aim to minimized corrosion risks.

6. CHEMISTRY ASPECTS OF RADIATION EXPOSURE OPTIMISATION

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

- 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.

6.2. Specifications for all important radiochemistry parameters should be established and applied during different operational modes to fulfill dose limits and maintain radiation exposures ALARA. During an outage, and if possible, also during operation, dose rates from systems and components should be measured regularly for trending purposes. 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 to radiation, the chemistry programme should include:

- a) Application of a suitable chemical regime to minimize corrosion product dissolution, deposition of corrosion products in-core and their subsequent transport on SSC surfaces;
- 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 clean-up systems for removing dissolved and suspended activated as well as non-activated substances;
- d) Quality control of the chemicals used in the coolant systems to avoid ingress of impurities which could have 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 corrosion product deposition into the core should be minimized by keeping primary water coolant chemistry parameters 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 comes in contact with primary coolant should be avoided to the extent possible to reduce dose rates due to ^{60}Co . To avoid unnecessary dissolution of inactive cobalt ions into the primary coolant, all large replacement or heavily decontaminated components should be properly pre-passivated before their surfaces are exposed to the operating environment.

6.6. Chemistry control should minimize the deposition of Ni 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 StelliteTM (typically 57% Co), antimony and silver 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 RBMK units, ^{95}Zr could also be an important contributor to radiation fields and should be eliminated if possible.

6.9. During the commissioning phase, surfaces should be pre-passivated (hot conditioning) prior to initial start-up 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.

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

6.11. Harmful chemical species (oxygen, hydrogen, alkalis, corrosion products and additives such as zinc) should be strictly controlled to minimize fuel cladding deterioration and thereby optimize occupational radiation exposures and environmental discharges. The amount of low solubility species should be minimized to keep the build-up 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 start-up, in order to provide a reference background level. This level 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 should define 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, should require shutdown of the unit within a reasonable period of time to remove the defective fuel element.

6.15. Comprehensive decontamination procedures (e.g. chemical, electrochemical and 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 generation of nuclear waste.

6.16. Chemical decontamination followed by optimized chemistry control should result in a net reduction of occupational dose of 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, the proper re-passivation of system surfaces should be carried out to avoid extensive corrosion product deposits on the fuel surfaces with increased risk of fuel cladding failure and potential power shifts.

6.18. Operational procedures and chemistry control practices should ensure that generation of radioactive waste is kept as low as possible in terms of both activity and volume but also considering both doses to the workers and discharges to the environment.

6.19. Treatment and interim storage of radioactive waste should be strictly controlled in a manner consistent with the requirements for safe disposal of waste given in IAEA Specific Safety Requirement publication on Disposal of Radioactive Waste, IAEA Safety Standards Series No. SSR-5 [9]. 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 the IAEA Specific Safety guide on Predisposal Management of Radioactive Waste from Nuclear Power Plants and Research Reactors, IAEA Safety Standards Series No. SSG-40 [10].

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

- a) Monitor and quickly identify leakages in the primary systems and take immediate corrective actions;
- b) Optimize handling and transport of liquids to reduce the potential amount of liquid waste collected;
- c) Implement segregation liquids to avoid dilution and mixing of chemically incompatible substances and liquids having significant difference in activity levels;
- d) Reduce the amounts of chemicals and recycle chemical substances (particularly boric acid) if possible and reasonable;
- e) Establish appropriate chemistry control to prevent primary to secondary coolant leakages;
- f) Reduce the amount of gas introduced into the system to the minimum quantity practicable;
- g) Use ion exchange resins and selective sorbents;
- h) Use filters to separate suspended radioactive substances from the liquids;
- i) Use hold-up tanks and other delay systems (charcoal beds) to allow radioactive decay before material is discharged into the environment;
- j) Use effective filters to separate aerosols from gaseous discharges;

- k) Use treatment for volume reduction (recombiners, absorbers, vapor recovery system, pressurized storage), which also serves as a delay system;
- l) 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 should be authorized by the regulatory body. Operators should present assessments on the characteristics of the expected source term and the public exposure scenarios. Guidance on this assessment is given in IAEA Prospective Radiological Environmental Impact Assessment for Facilities and Activities, IAEA Safety Standards Series No. GSG-10 [11]. Regarding the discharge limits, the regulatory body should evaluate whether the processes to protect workers and the public were optimized to keep radiation exposures ALARA. There should be established procedures to monitor the source term and the environment in order to control effluents and verify the compliance of limits. IAEA Regulatory Control of Radioactive Discharges IAEA General Safety Guide GSG-9 [12] provides guidance for establishing and controlling discharge limits and for the process for the optimization of the protection of workers managing radioactive effluents and the members of the public.

6.22. Liquid effluents should be 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.

6.23. Decommissioning should be considered already in the design phase of a plant. New builds should learn from prior materials selection experience and apply a reactor chemistry regime that will minimize the source term during plant operations to as low as practicable to significantly minimize the decommissioning source term. Designs should also consider layout and ease of decommissioning tasks.

6.24. 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. 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 plant commissioning, plant operational modes (start-up, shutdown, operation at stable power levels, outages) as well as transient conditions should be specified by the chemistry department in relevant plant documents and procedures.

7.2. The measurement frequencies should be aligned with the rate of change of parameters. They should also relate to the safety importance of the SSCs and to the aggressiveness of measured impurities.

7.3. 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.

7.4. The measurements should be used to detect trends in 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 start-up periods, and when systems are taken out of operation for prolonged periods.

7.5. Chemistry and radiochemistry measurements should:

- a) Provide timely chemistry and radiochemistry results to operating organization to run the plant according to the specifications;
- b) Verify compliance with chemistry control and diagnostic parameters and radiochemistry limits and conditions;
- c) Detect and thus enable implementation of corrective actions for any abnormal conditions;
- d) Ensure compliance with discharge limits.

7.6. Programmes used to calculate chemistry parameters should be verified and validated according to guidance in the IAEA Specific Safety Guide on Design of Instrumentation and Control Systems for Nuclear Power Plants, IAEA Safety Standards Series No. SSG-39 [13].

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

7.8. Plant documentation to compare data from different sampling points or comparison of different parameter measurements from the same sampling point (e.g. intercomparison of grab sample results and measurements of cation conductivity in the steam generator blowdown system) should be in place for evaluating the plausibility of the data measured.

7.9. All on-line and laboratory analyses procedures should:

- a) Describe the intended use of the procedure;
- b) Reference information sources used for development of the procedure;
- c) Provide a summary of characteristic information on the methods used, indicating possible interference, accuracy, linearity and range of the methods and the precision of the measurements;
- d) State equipment, reagents and standards required to perform the analysis;
- e) Provide step by step instructions for performing analysis and calculating the results;

- f) Indicate quality control requirements;
- g) Describe industrial safety and radiological protection measures;
- h) Provide information on instrument calibration;
- i) Give instructions on how to proceed if something unexpected happens.

7.10. Instrumentation, equipment and the methods to be applied should be validated. The validation process should show 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.

7.11. A calibration and maintenance programme should be established and applied to all on-line and laboratory monitoring instrumentation. The responsibilities for calibration and maintenance should be clearly defined. Timely calibration should be performed either on the basis of equipment manufacturers' recommendations, plant experience or as result of the control charts.

7.12. Calibration strategies should be chosen in such a way that the calibration points are lower and higher than the expected value and that they are as close as possible to the expected measurement value. The calibration should be checked regularly with a control solution (control standard).

7.13. Depending on the method applied, such 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.

7.14. Reagents and sources used for calibration and control should be valid (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.

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

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

7.17. Measurement of fission product activity should be carried out to confirm the fuel integrity, identify fuel cladding leaks and get an estimation of number of leaking fuel elements:

- a) For this purpose, good quality, well-maintained and calibrated gamma spectrometry instrumentation, and a sufficient variety of calibrated measurement geometries should be applied;

- b) Sufficient sensitivity with respect to activity measurements of fission products should be ensured for the early detection of fuel leaks;
- c) Power transients accompanied by 'spiking phenomena' for fission products should be adequately monitored;
- d) As part of these actions, and 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.

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

7.19. Measurement of primary coolant activity of the activated corrosion products should be carried out to evaluate chemistry control performance, 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).

7.20. Measurement of other activated species (e.g. radioisotopes of argon, tungsten, sodium, potassium and chlorine) should be performed as a useful means of verifying or cross-checking the results of chemical analyses and for early warning of low concentrations of potential foreign material ingress.

7.21. 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).

7.22. 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.

7.23. 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 ALARA principles and objectives.

7.24. Radiochemistry methods should be used to characterize radioactive waste with regard to its treatment, conditioning and disposal:

- 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 and 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') activity characterization done by radionuclide vectors/distributions;
- 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.

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

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

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

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

7.29. Redundancy of laboratory facilities for most important analyses should be provided to ensure analytical services at all times including design basis accidents and beyond design basis accident conditions.

7.30. Adequately redundant instrumentation and equipment for performing analyses of given types and frequencies should be made available for the most important chemistry and radiochemistry parameters.

If some of these activities are outsourced, the chemistry department should ensure the necessary redundancy is also available by service providers.

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

7.32. Industrial safety (including and considering but not limited to fume hoods for ventilation, appropriate storage of flammable solvents and hazardous materials as well as tools to deal with spilled chemicals, flammable and other gases, provision of safety showers for personnel, as well as 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 measurements.

7.33. The fume hoods should be periodically checked according to 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.

7.34. 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.

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

7.36. 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 analytical interference and improper calibration, analytical technique and 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 action should be taken to further improve laboratory performance.

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

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

7.39. Account should be taken of delays in obtaining samples (due 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.

7.40. A post-accident sampling system facility should be ready to operate when required by 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, other approaches should be available.

7.41. For proper post-accident sampling, the following should exist:

- a) Procedures for the 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 to sampling tube);
- c) A programme for preventive maintenance;
- d) Regular checks of the operability of the post-accident sampling;
- e) Regular training of personnel designated for operation of the post-accident sampling (i.e. personnel taking grab samples and performing subsequent activities);
- f) Specification of the chemistry parameters to be monitored.

7.42. 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 properly (e.g. laboratory logs, plant process computer, 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 accordance with the chemistry department documentation and the quality assurance programme expectations. The database should be appropriately secured so that only authorized personnel has 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 staff should inform relevant operation personnel according to the plant procedures.

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

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

8.6. Trends in chemical data should be correlated to operational parameters like thermal power, changes in chemical injection rates, etc.

8.7. Data should be compared with operational limits and the evaluation and trending of 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. Trending of relevant chemistry parameters should be carried out to obtain an adequate picture of plant chemistry conditions and to facilitate correlation between related chemistry parameters and the status of systems.

8.9. Trends should be reviewed soon after data have been recorded, in order to identify problems that may need corrective action before a parameter exceeds its specified limit. The expected values should be used to detect a parameter approaching its specified limit. These expected values should have sufficient margins to control limits. Trending 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. 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.

9.2. The operating organization should be responsible for the use of the proper chemicals and their correct quality.

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

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

9.5. Chemicals and other substances should not be used in SSCs if they contain corrosion inducing components above specified limits or may increase activity on plant surfaces. If this is not possible, a risk assessment should be performed and documented.

9.6. Procedures should be in place for the procurement, storage, replacement and ordering of chemicals and other substances, including hazardous chemicals.

9.7. Prior to the use of operational chemicals and substances like boric acid, ion exchange resins, diesel fuel, etc., a sample should be taken and analyzed to ensure compliance with given specifications. The results should be compared with the supplier certificate. If the results do not match the required specification, the substance should be rejected, or a risk analysis should be performed and properly documented in order to accept their use.

9.8. The batch/container should be labelled according to the plant procedures for easy verification that the relevant department has approved the use in a particular area. In addition, chemicals and substances in storage areas should also have a label indicating the shelf life of the material.

9.9. When a chemical is transferred from a stock container to a smaller container, the latter should be labelled with the name of the chemical, the date of transfer and pictograms to indicate the risk and application area. All the chemical containers should have an expiration date.

9.10. 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.

9.11. The 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. The number of new chemicals and substances in the plant should be minimized.

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

9.13. 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.

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

9.15. Chemicals should be stored in an appropriate cabinet which is, for example, fire protected and captures spillages and in a room which is equipped with a safety shower in accordance with plant documentation. Waste disposal procedures should be established. Oxidizing and reducing chemicals, flammable solvents and concentrated acid and alkali 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 operational department.

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

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ANNEX

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

INTRODUCTION

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 staff, the internal surfaces of plant systems and components will be exposed to different type of environments for various lengths of time.

A-2. When deciding on preservation conditions, a plant needs to consider the materials used in structures, systems and components (SSCs) as well as the length of time for the layup. The component's and system's susceptibility to corrosion and their performance against degradation are defined typically in various types of plant documentation which are based on international knowledge and guidelines. High alloyed steels will generally have less preservation requirements than materials like 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. 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, recirculation ongoing to minimize corrosion. The addition of preservation chemicals to the system will help 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 locations, 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 used chemicals is of utmost importance.

A-4. The scope of this annex is to give guidance based on the best international practices to assure that the preservation is done properly to maintain the integrity of SSCs during the different phases 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 programs.

PRESERVATION STRATEGY

A-5. As mentioned previously, 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 phase but also for NPPs already in operation. Preservation measures impact the lifetime of the plant components and are hence an important part of the ageing/asset management program. If properly implemented, they assist in ensuring systems' availability and help reduce maintenance costs in the long term. The actions taken have to also take into account 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' requirements as well as operator experience and constraints. The plant documentation needs to clearly describe the functions and responsibilities of staff involved in preservation. The strategy has to cover all SSCs within the scope of the chemistry programme. It needs to also include other systems which are susceptible to undergo degradation when they are not being operated (e.g. gaskets, seals, etc.).

A-7. The preservation strategy has to be adapted to outage type (planned or unplanned), outage duration, equipment, materials and coatings used in SSCs as well as to the regulatory requirements. It must also consider staff health and safety policies (including chemical hazard and risk of anoxia), need for radiation protection and outage related operating constraints. In many cases, multiple different aspects have to be taken into consideration. For example, in order to limit chemical discharges to the environment, dry layup of the secondary system feedwater train could be preferred instead of using alkalized wet preservation.

A-8. The operating organization needs to have in place not only a clear strategy but also a documented process to ensure that all steps of preservation are adequate, correctly implemented and documented. The operating organization can also have more detailed plans in place for preservation which can be easily converted to the plant work planning process in short notice, if needed. The following issues are to be considered:

- a) Preservation of the steam generators is to be considered 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) 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/2 weeks);
- e) Plants must include an evaluation if special measures are needed (e.g. dismantling of equipment like valves, pumps, heat exchangers u-tube air blows, etc.);

- f) The wet layup concept requires more monitoring and the use of potentially carcinogenic chemicals which may result in hazardous waste;
- g) Preservation methods may be interrupted, e.g. for inspections. Therefore plans have to include process to re-establish the required preservation conditions;
- h) Particularly during the commissioning phase, encapsulation and/or maintenance activities after dry tests / wet tests need to be included in the plans;
- i) When selecting 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 application of chemicals need to be clearly spelled out in the plans/procedures;
- k) Any other relevant changes in environment and climatic conditions, like increasing humidity or danger of freezing, are to be considered.

A-9. In case preservation cannot be implemented, the basis needs to be justified and documented.

DIFFERENT PRESERVATION TYPES AVAILABLE

A-10. At room temperature general corrosion usually appears on metal surfaces and is spread over the entire system in contact with water or air having 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, as mentioned previously, 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:

- a) the construction materials used in the systems;
- b) what is the length of the planned period of time;
- c) the scope of the preservation (whole system vs components or 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 like carbon steels when dry preservation is not feasible, wet alkaline preservation is selected in most cases, particularly if the layout time is longer. In some systems and components both type of materials may exist, in which case wet alkaline preservation modes are preferred. Quite often system overpressure is needed to avoid air ingress. Venting and fill & 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 is to be defined in the preservation strategy. Typically, preservation activities start if the planned outage is longer than for example one or two weeks. In some cases, flushing of the system or large component is necessary as a pre-emptive action. The following approaches may be considered, taking into account preservation duration, systems lay-out and materials used:

- a) Dry layup: Equipment/system completely drained. Plants may consider using inert gas or dry air to ensure the effectiveness of the preservation. Plants could also consider using film forming products before shutdown to facilitate subsequent dry preservation;
- b) Wet layup: For BWRs wet layup generally means that the water chemistry conditions are similar to plant operating conditions specifically for the reactor vessel, recirculation piping and control rod drive system. For feedwater heaters, feedwater/condensate piping, and moisture separator/reheaters, for example, the systems should be filled with demineralized water and not generally open to atmosphere. If possible, systems should be in a recirculation mode. For PWRs 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 requiring radiation protection, and/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. Many plants have found this to be 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-14. Independent of the chosen layup method, the generated contaminated waste cannot be incompatible with the plant's radwaste processing system or result in waste volumes that the system was not designed to process. The generated waste must also meet the regulatory requirements applying to the plant. In general, the radwaste production is to be kept as low as possible.

A-15. 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.

It is also recommended to prepare beforehand, as part of the strategy, a table or list which contains typical materials used in the system to be preserved, the length of the planned layout and what kind of preservation method is to be considered.

A-16. The strategy can be supported by a flowchart which provides more detailed information about various steps within the process as shown in Fig. A-1. In practice, a more detailed flow chart is needed. The actual flowchart can also include the following type of information: a list of measurements to be carried out and acceptance criteria for the relevant parameters and 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.

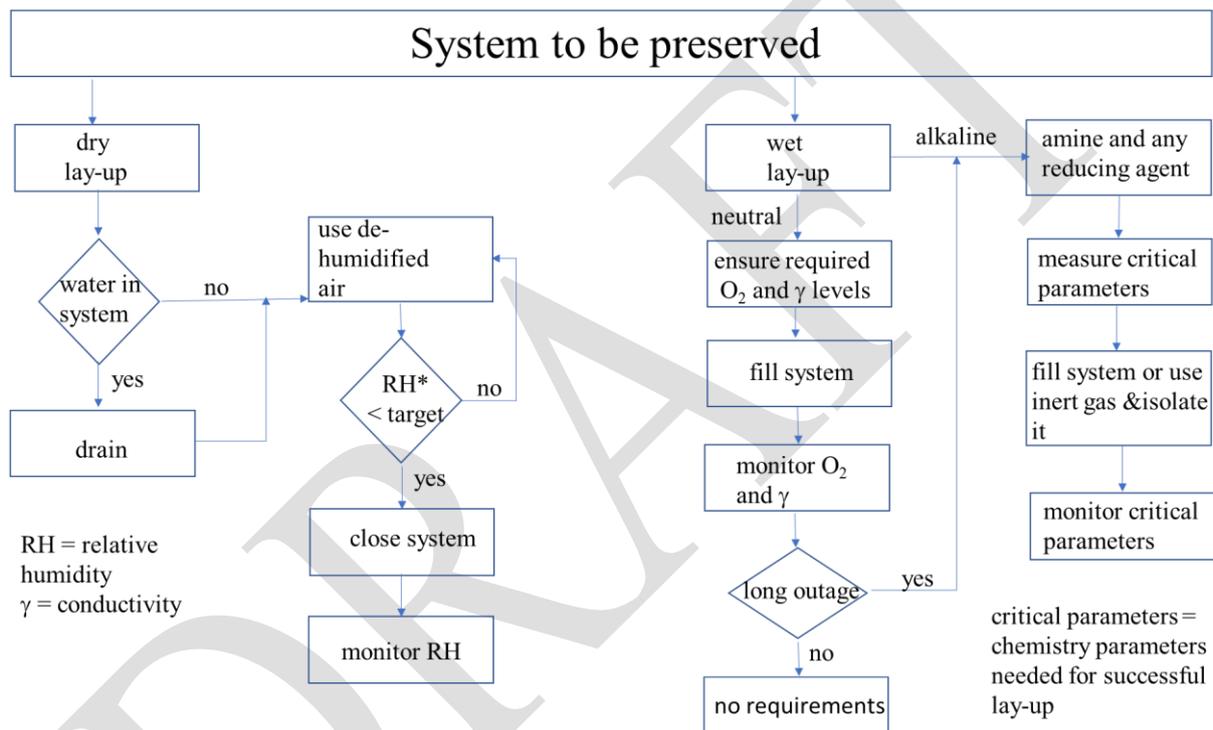


Fig A-1. Generic flowchart describing the potential steps in preservation process.

FLUSHING

A-17. For operating nuclear power plants, flushing of SSCs prior to preservation activities may not be necessary as long as the quality of the coolant meets the plant operating chemistry guidelines. But if needed, the general practices described below are also applicable for an NPP in operation. The 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 a proper flow rate to remove any particulates or chemicals that may reside in the system. As a general guidance 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 is to be optimized for the impurities expected to exist in the flushing media.

A-18. 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 must be appropriate to the materials used. 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-19. The water solution used for flushing must have predefined properties. These in many cases are plant specific. However, at least the following general requirements can be followed:

- a) If only demineralized water is used, define the maximum acceptable conductivity value for the flushing solution or the cation conductivity value if the solution contains air. It might be useful to measure 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 must be given, and other relevant chemistry parameters (e.g. pH, conductivity, etc.) have to be measured. In addition, the acceptance levels of impurities in the preservation chemicals have to be well-defined.

A-20. The flushing plan must also have a criterion when flushing can be completed. Typically, some of the following parameters are used for such acceptance criteria to ensure that expected cleanliness has been achieved:

- a) pH value and total level of impurity levels which are typically estimated using conductivity measurement results. In some Member States plants also measure relevant corrosion products like iron and/or suspended solids and especially corrosion inducing ions like fluoride, chloride and sulphate.

DRY PRESERVATION

A-21. 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. Prior to dry preservation, the components and systems must be drained as efficiently as possible to minimize the amount of water on the surfaces to meet the expected relative humidity criteria. This is

followed by dehumidification using dry air. In practice this may additionally require dismantling components such as valves and pumps. Once properly dried these components can be re-assembled and re-installed back to the system. 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 inert gas like nitrogen can be used to avoid ingress of air and moisture into the system. The use of corrosion inhibitors such as film-forming products have been reported by some PWR operators to control corrosion during extended outages and refurbishments. For lay-up protection application, film-forming products can be added during a short period of time just prior to the scheduled outage in order to establish a protective film to enhance component protection during layup and to provide optimized start-up conditions for the subsequent fuel cycle.

Acceptance criteria for dry preservation

A-22. When implementing dry layup, the air quality must be checked. Dry and clean air as well as air free of oil and dust have to be used throughout the process. Humidity criteria need be established and monitored to ensure that residual moisture on surfaces will remain at an acceptable level. Relative Humidity (RH) criteria (e.g. below 40% at 20 °C when room temperature is >10 °C) needs to be achieved within a few days after drainage and maintained at the desired level. If RH is above the defined criteria, the reason for the deviation needs to be identified, corrective actions need to be taken to restore RH and all relevant information must be properly documented. When a dry layup is complemented by the use of inert gas overpressure, the necessary measurements are needed to ensure that overpressure is maintained. The use of desiccants (i.e. substances able to adsorb water) have to be carefully implemented to reduce the risk of introducing impurities or foreign materials into the systems and equipment.

Monitoring of dry preservation

A-23. The following steps are recommended to be taken to ensure efficient dry preservation:

- a) Check quality of the last flushing water (e.g. pH, corrosion inducing ions like fluoride, chloride, sulphate, conductivity, relevant corrosion products like iron, suspended solids);
- b) Document temperature of the medium when draining the system;
- c) Visually check that the system is fully drained;
- d) Check that there are no residues from desiccants or other contamination either visually or by using swipe samples.

If condensers are used to dry the air:

- a) Check that condensers are installed correctly;
- b) Check and trend the amount of condensate in the condenser regularly, e.g. 1/day.

If air dryers are used to reduce humidity:

- a) Check that air dryers are installed correctly;
- b) Check that the air does not contain dust and oil;
- c) If dust filters are installed, check differential pressure of the filter, e.g. 1/day later on when a steady state is reached 1/week;
- d) Check the relative humidity at the identified inlet and outlet openings, e.g. 1/day later on when a steady state is reached 1/week;
- e) Check air flow at the outlet openings, e.g. 1/day later on when a steady state is reached 1/week;
- f) Check that the temperature doesn't fall below the dew point locally.

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

- a) Check and trend overpressure (manometer) once per day. After a steady state is reached check once per week;
- b) Check the availability of inert gas.

If vacuum is used to decrease humidity :

- a) Check and trend under-pressure (manometer) once per day. After a steady state is reached check once per week.

WET PRESERVATION

A-24. Wet layup without any changes to the water chemistry parameters after the shutdown is carried out typically for PWR and BWR reactor vessels, RCS piping, BWR recirculation system, control rod drive hydraulic system, refueling water storage tanks and the primary side of the steam generator. Whereas, for example, the secondary side of the steam generator is in most cases preserved using demineralized water containing a high enough concentration of alkalizing agent to reach the target pH value and a proper reducing agent to scavenge oxygen. 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. 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 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 solution and help control corrosion product transport. When preservation is finished plans have to exist 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-25. 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 must be based on materials present in the system of concern and on the length of the lay-up.

A-26. 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-27. During the neutral wet preservation, the plant must put a monitoring programme in place to follow conductivity and concentration of predefined anions and iron. Regarding alkalized treatments, pH as well as concentration of reducing chemicals, predefined anions and iron content needs to be checked regularly. In addition, target as well as limit values for those parameters must be defined taking into account analytical performance of monitors. For representative sampling, sufficient recirculation of the layup medium needs to be ensured when possible.

A-28. 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 to be defined and controlled. Deviations of the relevant parameters during the preservation should be addressed in a timely manner and properly documented.

Monitoring wet preservation without additives:

- a) Check quality of demineralized water before filling the system, e.g. concentration of corrosion inducing ions like fluoride, chloride, sulphate and measure conductivity and oxygen concentration;
- b) Ensure continuous availability of demineralized water and check its quality;
- c) Check that the system is fully filled e.g. 1/day, later on when a steady state is reached 1/week;
- d) Check that the system is sealed from atmosphere;

- e) Check and trend quality of the preservation medium, e.g. corrosion inducing ions like fluoride, chloride, sulphate and measure conductivity and oxygen concentration, 1/day, later on when a steady state is reached 1/week;
- f) Check and trend concentration of relevant corrosion products, e.g. iron, suspended solids once per day. After a steady state is reached check once per week;
- g) Check and trend over-pressure (manometer) if the system is under inert gas, once per day. After a steady state is reached check once per week.

Monitoring wet preservation with additives:

- a) Check quality of demineralized water before filling the system, e.g. concentration of corrosion inducing ions like fluoride, chloride, sulphate and measure conductivity and oxygen concentration;
- b) Ensure continuous availability of demineralized water and check its quality;
- c) Check that correct amount of preservation chemicals are added (depending on the materials of the system);
- d) Check that the system is filled up to specified level once per day. After a steady state is reached check once per week;
- e) Check and trend over-pressure (manometer) when the system is under inert gas, once per day. After a steady state is reached check once per week;
- f) Check and trend quality of the preservation medium, e.g. pH and/or concentration of additive, corrosion inducing ions like fluoride, chloride, sulphate and measure oxygen concentration once per day. After a steady state is reached check once per week;
- g) Check and trend concentration of relevant corrosion products, e.g. Fe, suspended solids once per day. After a steady state is reached check once per week.

TABLE A-2: SIMPLIFIED EXAMPLE OF PRESERVATION DOCUMENT

Alkaline wet preservation with ammonia							Document I.D.:	
Measurement results for preservation parameters								
Date	pH target value	Fluoride (mg/kg)	Chloride (mg/kg)	Sulphate (mg/kg)	Oxygen (mg/kg)	Total iron (mg/kg)	Deviation	Verified by:
20.2.2021	≥10.3	<0.15	<0.15	<0.15	<0.5	6	None	<u>valmek</u>
21.2.2021	10.4	0.07	0.2	0.06	0.4	5	High Cl ⁻	<u>makelkar</u>
22.2.2021	10.3	0.06	0.5	0.03	0.5	6	Increasing Cl ⁻	<u>pekkilak</u>

RECORD KEEPING AND EFFECTIVENESS EVALUATION OF THE PRESERVATION

A-29. The plant must have in place a process ensuring that suitable record keeping, and data collection related to preservation is available. In addition, the 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, plant documents must exist verifying that the preservation was done in such a way that actions taken have not resulted in the decrease of equipment reliability nor an increase in corrosion product release rates that could result in their subsequent transport into the core region.

A-30. 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 may challenge the conditions under preservation. This documentation needs to clearly define the basis for the selected preservation method. The preservation documentation must contain all analysis reports and trending of the relevant parameters. Deviations of the relevant parameters during preservation and countermeasures taken have to be addressed and well documented. If deviation is significant during the preservation process, relevant parties need to be informed. 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. An effectiveness review of the actions taken should be documented so that reoccurrence of the same transient is mitigated. The collective documentation of each system preserved needs to be shared with the plant's ageing management staff or experts once the preservation period is over.

A-31. The plant may consider including a dedicated indicator for preservation in their key performance indicator programme. The 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 different chemistry parameters mentioned in the previous chapters and any disturbances that occurred during preservation (e.g. malfunction of air drying system, accidental drainage of system under preservation, etc.).

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