Use of C-188 Sources in Wet Source Storage Gamma Irradiators

The purpose of this document is to provide guidance on best practices to achieve proper operating conditions for Nordion's C-188 sources used in wet source storage irradiators.

SCOPE

This document is applicable to all C-188 sealed sources used in wet source storage gamma irradiators and addresses the following aspects:

- Background information about stainless steel and its corrosion
- Basic requirements for all sources present in the irradiator
- Requirements for source holders used for securing these sources in the irradiator
- Requirements related with the quality of water in the source storage pool
- General requirements for the overall irradiator facility
- Guidelines for a simple management system for maintaining proper operating conditions

Stainless Steel and its Corrosion

Nordion's C-188 sources are made of a particular grade of stainless steel known as 316L. If they are used in accordance with proper operating conditions they are resistant to corrosion, and can withstand 20 years of operating in underwater storage, high temperatures, frequent quenching and high radiation fields which are typically found in wet source storage gamma irradiators.

Under certain conditions; however, these sources can be affected by some forms of localized corrosion, which may lead to their rapid deterioration, possible loss of integrity and leakage of small amounts of Cobalt-60 into the storage pool. It is essential; therefore, that owners and operators of wet source storage irradiators have some understanding of the mechanisms that can lead to corrosion or damage of sources, and knowledge of how to maintain proper operating conditions in their facilities. More information on the main forms of corrosion which affect stainless steel can be found in Annex A.

Operating Conditions

The following sections specify appropriate operating conditions for Nordion's C-188 sources used in wet source storage irradiators. Establishment and proper maintenance of these conditions are essential for maintaining the integrity of the source over its useful life.

These operating conditions should be met continuously and documented throughout the entire life of the sources.

SOURCES

Wet storage of the sources combined with their high temperature, frequent quenching and high radiation levels create a harsh operating environment which can lead to various forms of corrosion and under some circumstances even to loss of source integrity. Corrosion products from any item in a storage pool may have detrimental effect on sources present in the same pool and therefore it is essential that all sources in a storage pool containing C-188s meet the specifications defined in this table:

All sources from all manufacturers contained in the same irradiator pool shall:
1. Have an outer encapsulation fabricated from Type 316L stainless steel or an equivalent grade of stainless steel.
2. Meet the performance requirements of ISO 2919 or ANSI N43.6 classification E53424 or E43424.[1]
3. Be certified leak tight to ISO 9978.
4. Be fabricated, transported, stored and used at all times in a manner that prevents sensitization of their stainless steel encapsulation. *For Nordion's C-188 sources this means that their maximum surface temperature shall never exceed 482°C (900°F).*
5. Be arranged in such a way, that when in the irradiate position, their maximum surface temperature does not exceed the maximum temperature specified by their manufacturer. *For Nordion's C-188 sources this means that their maximum surface temperature in the irradiate position shall not exceed 260°C (500°F).*
6. Show no signs of corrosion throughout the entire period of use of the sources.

The requirements defined in this section are met by Nordion's C-188 sources at the time of delivery and installation. An irradiator operator is responsible for continual compliance with these requirements throughout the entire lifetime of their sources.

Additional recommendations intended to minimize the risk and to limit the impact of sensitized or otherwise corroding sources on the facility:

1. If sensitization is suspected, the manufacturer of the sources in question should be contacted to evaluate the situation and to determine the extent of the problem.
2. Sensitized sources should be removed from the pool as soon as possible and extensive water analysis should be completed at that time (see Pool Water Monitoring and Testing).
3. If any sources present in the pool are found to be sensitized, corroded or leaking, the manufacturer of any sources present should be contacted immediately to assess the situation, provide assistance and evaluate risk to the sources that they have manufactured.

[1] The performance classification E43424 was defined in earlier versions of the referenced standards and is acceptable for older legacy sources which were certified in accordance with these older revisions.

SOURCE HOLDERS

Proper design of source holders is essential for ensuring appropriate corrosion protection for radioactive sources. A poor source holder design can lead to localized concentration of impurities in the water such as halides, which in turn may cause rapid corrosion of sources through pitting and crevice corrosion as well as development of stress corrosion cracking (see Annex A).

The design of source holders shall meet the following requirements:

1. Any parts in contact with the source are made of austenitic type stainless steel.
2. The only contact between the source holder and sealed sources occurs at the larger diameter end caps. The central tubing section of the source must not be contacted.
3. Adequate clearances exist at source holding locations to allow for temperature expansion of both the holder and the sources in the irradiate position (raised above the pool).
4. When submerged in the pool, the natural, convective flow of water around each of the sources in the holder is maintained at all times and no areas of stagnation shall exist.
5. When raised above the pool, all water drains quickly from the source holder and no water shall be retained around the sources. The drainage must be such that it could not be restricted by sediment or other debris present in the pool.
6. Sediment shall not accumulate around the sources.

POOL WATER QUALITY

Pool water quality is critical for maintaining corrosion resistance and ensuring trouble free operation of radioactive sources in wet source storage irradiators.

Pool water quality specifications:

1. Conductivity shall be maintained below 10.0 microsiemens per centimeter (μS/cm).

   Conductivity measurements serve as an indicator of potentially high halide levels (e.g., bromide, chloride and fluoride), which are known to be corrosive to stainless steel.

2. Total chlorine[2] shall be maintained below 1 part per million (ppm).

   Chlorine (as well as other halogens) has the ability to locally penetrate and damage the protective passive film on stainless steel and thus allow various forms of corrosive attack to occur.

3. Total of three halide ions (Br^-, Cl^- and F^-), shall be less than 1 ppm.

   The effect of halide ions is the same as that described for chlorine. Halides have the ability to locally penetrate and damage the protective passive film on stainless steel and thus allow various forms of corrosive attack to occur.

4. Pool water pH shall be maintained between 4.5 and 8.5.

   Various modes of corrosion which affect stainless steel are accelerated and/or triggered by either low or high pH solutions. In order to avoid these, the pH of pool water should be maintained within the middle range specified above.

5. Total silicon (Si) shall be below 5 ppm.

   Silica (SiO_2) in pool water is a concern due to its ability to form thick deposits on sealed sources used in wet storage irradiators. Accumulation of such deposits restricts access of fresh pool water to capsule's material, and thus creates potential for development of crevice corrosion underneath.

   Silicon on its own should not affect the integrity of the source, but may accelerate and aggravate the damage associated with a failure in factors such as conductivity, chlorine and halides.

6. Pool water shall be maintained in a state of good optical clarity which is sufficient to allow for reading source numbers on capsules – with use of optical aids.

   Sediment shall not be allowed to accumulate in any part of the pool.

   Good optical clarity of pool water is necessary for manipulating sources in the pool during source replenishments and adjustments. Sediments accumulating anywhere in the pool create conditions favourable for crevice corrosion. This is especially critical if sediment is allowed to accumulate around sources which, by their nature, become hot and are frequently cycled in and out of the pool. Such conditions tend to locally concentrate halides present in pool water in trace amounts and can lead to rapid development of localized pitting or crevice corrosion of the sources.

Any water added to the pool to compensate for evaporation should be deionized and should meet the same criteria defined above. Topping up with untreated tap water and waiting for the deionizer system to bring the whole pool back to the required levels is not acceptable. Under such circumstances water in the pool may not meet the specifications outlined and can lead to premature deterioration of the sources.

[2] Total chlorine = free chlorine plus combined chlorine.
Free chlorine = residual chlorine existing in water as hypochlorous acid and hypochlorite ions.
Combined chlorine = residual chlorine existing in water in chemical combination with ammonia or organic nitrogen compounds, i.e. chloramines.

POOL WATER MONITORING AND TESTING

In order to ensure that pool water quality is maintained in accordance with the conditions specified above, it needs to be monitored and tested on a regular basis. Listed below are the requirements for such testing including test methods, their sensitivity, testing frequency, laboratory accreditation and record keeping.

Pool water monitoring and testing requirements:

1. **Conductivity and pH of pool water shall be monitored continuously.**

   The monitoring system should alarm automatically when a set threshold is exceeded. The threshold should be outside the expected range of operation but within the allowed limits for pH and conductivity.

   Any excursions beyond the threshold limits shall be formally recorded investigated and addressed.

   Daily verification of the conductivity and pH reading by staff with a formal log book record is acceptable as an alternate or a backup method.

   NOTE – unusual pH changes are often the earliest indication of pool water deterioration.

2. **Pool water analysis for total chlorine shall be carried out and recorded quarterly.**

   The test method used should have a method detection limit (MDL[3]) of 0.1 ppm (mg/L) or better and be accepted for compliance monitoring of total chlorine by the US EPA. Total chlorine measurements should be taken within 15 minutes of collecting the water sample since it dissipates rapidly. For this reason, measurements of total chlorine are typically performed on site with use of a portable test kit.

3. **Laboratory analysis of pool water samples for conductivity, halide[4] ions (Br^-, Cl^- and F^-), silicon and pH shall be performed quarterly.**

   All testing shall be performed by a laboratory accredited by a national accreditation body which is recognized by the International Laboratory Accreditation Cooperation (ILAC).

   Determination of conductivity shall be in accordance with ASTM 1125 or equivalent and have the MDL of 1 µS/cm or better.

   Determination of halides shall be in accordance with EPA method 300.0 (inorganic anions) or equivalent and have the MDL of 0.1 ppm (mg/L) or better for each halide ion.

   Determination of silicon shall be in accordance with EPA method 200.7 (silicon[5], total), SM 3120B or equivalent and have the MDL of 0.1 ppm (mg/L) or better.

   Determination of pH shall be in accordance with ASTM D1293 or equivalent.

4. **It is recommended that a more extensive analysis of pool water be performed once per year.**

   The following additional elements should be included in this analysis: sulphate, nitrate, calcium, chromium, cobalt, copper, iron, magnesium, molybdenum, nickel, sodium, zinc.

   There are no specific maximum allowable concentrations for these additional elements. The additional data, however, will enable trending of water quality and may help answer questions regarding occasional pool water imbalances.

5. **Any failures to meet the above specifications shall be documented, investigated and corrected as soon as possible.**

   Failures to meet the above specifications increase the likelihood of corrosion attack and if corrosion has already started, increase its severity and progression speed. When such failures are left unchecked or uncorrected for extended periods of time, they can lead to localized corrosion severe enough to cause perforation and loss of integrity of any sealed sources. It is essential, therefore, that all failures to meet the above specifications are investigated and corrected in a timely fashion. Maintaining good record of all such events will allow for assessment of their cumulative effect.

6. **Records demonstrating compliance with this specification shall be maintained on site and should be available to Nordion staff upon request.**

   Nordion may occasionally request a copy of such records in order to verify that operating conditions are being met. Lack of such records, their incompleteness or poor quality may mean that the operating conditions cannot be verified over the life of the sources.

NOTE – Water samples for the above testing must be taken from the pool itself and not from the output of the water treatment system.

MINOR EXCURSIONS

During normal operation of wet source storage, the irradiator's water quality may deteriorate slightly for short periods of time. This occurs typically during maintenance and source loading activities. Under such circumstances minor excursion up to the limits specified below are acceptable, providing that their total accumulated duration does not exceed 90 days per year.

1. Conductivity - up to 20 µS/cm.
2. Total Chlorine - up to 3 ppm.
3. Total Halides - up to 3 ppm.
4. Total Silicon - up to 15 ppm.

[3] Method Detection Limit (MDL) – is the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero.

[4] A halide ion is a halogen atom bearing a negative charge. The halide anions are: fluoride (F^-), chloride (Cl^-), bromide (Br^-), iodide (I^-) and astatide (At^-). Chloride, fluoride and bromide are the most common halides found in pool water and under most circumstances it is acceptable to test for these three halides only.

[5] The compound of concern in pool water is silica (SiO_2) due to its propensity to form thick deposits on sealed sources. Silica can be present in water in two forms: as dissolved silica and as colloidal silica. Some test methods detect only the dissolved portion and not the colloidal form. Testing for total silicon (Si) with test methods specified in this document will detect both forms of silica.

POOL AND FACILITY

Other factors could have negative effect on the sealed sources used in wet source storage irradiators, including the following:

Irradiator pool and overall facility requirements:
1. Pool liner and all parts and components used in the pool shall be made of corrosion resistant materials that are compatible with each other and with other components that will be in the pool, including the sources. Under no circumstances shall mild steel or sensitized stainless steel be present in the pool.
2. Sources shall be protected with a mechanical barrier to prevent interference from items such as product boxes or carriers.
3. Atmosphere inside the irradiation chamber shall be maintained in a way that prevents formation of an environment which is corrosive to the austenitic stainless steel material of the sources or in any way diminishes their inherent corrosion resistance.
4. Sufficient air exchange rates must be maintained to expel ozone generated by gamma radiation interacting with the atmosphere and to vent any chemicals released by the product during its irradiation.

Recommendations for Documentation of Conditions of Use

The purpose of this section is to provide guidelines for records management of operating conditions defined in this document.

ESTABLISHING RECORD OF INITIAL CONDITIONS OF USE

Prior to installing Nordion C-188 sources in a wet storage irradiator all of the requirements for conditions of use defined in this document must be met.

- If the irradiator has been designed, installed and commissioned by Nordion, all these requirements will be met and an "Industrial Irradiator Acceptance Certificate" will be issued to attest to this fact.
- If the irradiator has not been designed, installed and commissioned by Nordion then a design review report should be prepared that specifically addresses each design requirement and describes in detail how each has been met. This report should be reviewed and approved by the customer's Quality Assurance Lead and Senior Management. A copy of the design report and evidence of its review and approval should be maintained as quality records.

ONGOING RECORDS OF CONDITIONS OF USE

After the initial conditions have been established and documented, they need to be maintained, for as long as the facility remains in operation. In order to ensure proper ongoing maintenance of conditions several key aspects must be addressed.

Design Changes

Any changes to the irradiator should be documented and subjected to a formal review and approval with special attention paid to continuing compliance with conditions of use defined in this document.

- If such changes are made by Nordion they will be documented and the design review will be completed within the scope of the work.
- If such changes are made by the customer or third party, they should be documented and subjected to a design review and approval by the customer's Quality Assurance Lead and Senior Management. A copy of the design change report and evidence of its review and approval should be maintained as quality records.

Introduction of New Sources

Any sources introduced to the irradiator must meet all of the requirements specified in this document.

- For C-188 sources supplied and installed by Nordion all of these requirements will be met at the time of installation and certificates confirming this compliance can be provided if requested.
- For non-Nordion supplied sources all relevant certificates should be obtained from the suppliers and/or service providers to confirm compliance with these requirements.

A formal review should be conducted and documented to confirm that all requirements set out in this document have been addressed. This report should be reviewed and approved by the customer's Quality Assurance Lead and Senior Management and a copy should be maintained as a quality record.

Monitoring Pool Water Quality

There should be a detailed procedure describing the activities undertaken and the equipment used to ensure that pool water quality is maintained and that testing requirements specified in this document are met. This procedure should address the following aspects:

1) Overview of the water quality monitoring program
2) Responsibilities – person responsible for which aspects of the program
3) Pool water sampling plan including the frequency and method of sampling
4) Test plan for each of the specified pool water quality parameters
5) Requirements for review, approval and filing of test results
6) Description of all in-house equipment used for testing and monitoring
7) Calibration plans for all of the above equipment
8) Training plan for all employees responsible for aspects of the program
9) Remediation plan to be invoked in the event that one or more of the pool water quality requirements is determined to be out of specification

Deviation Reports

All deviations and their associated remediation activities should be captured in a formal deviation report that captures the following:

1) Description of the deviation from specified conditions of use
2) Evidence of the deviation (e.g., a test report)
3) The date it was discovered
4) How it was discovered
5) Initial risk assessment
6) Initial corrective action taken
7) Remediation action taken to prevent recurrence
8) Result of remediation action
9) The date that conditions of use specified in this document were re-established (with evidence; e.g., a test report)
10) The length of time sources were exposed to non-compliant conditions
11) Review and approval by the customer's Quality Assurance Lead and Senior Management

Records

Records provide evidence of ongoing compliance and should be maintained for the life of the irradiator. Records include, but are not limited to:

1) The pool water quality monitoring procedure and previous versions of it
2) Pool water test results
3) Review and approval of test results
4) Calibration certificates for all equipment used
5) Certification of all external testing service providers
6) Training
7) Deviation reports

Glossary

Austenitic Stainless Steel

Austenitic stainless steel is the most common and familiar type of stainless steel. It is non-magnetic, extremely formable and weldable and can be successfully used in both cryogenic and high temperature applications. Austenitic stainless steels have a face centered cubic crystal structure.

Corrosion

Corrosion is the deterioration of materials, usually metals, by chemical interaction with their environment.

Halides

Halides are chemical compounds in which one of the elements is a halogen

Halogens

Halogens are a group of five chemically related non-metallic elements – fluorine, chlorine, bromine, iodine and astatine.

Sensitization

Sensitization is a process by which austenitic stainless steel, when exposed to temperatures between 450°C – 850°C, becomes sensitized. Sensitized austenitic stainless steel loses part of its corrosion resistance and becomes susceptible to one particular form of corrosion – intergranular attack.

Annex A – Forms of Corrosion Which Affect Stainless Steel

PITTING CORROSION

Pitting is a localized form of corrosion which can occur as a result of exposure to specific environments, most notably those containing chlorides. In most structural applications, the extent of pitting is likely to be superficial and the reduction in section of a component is negligible. However, in applications such as ducting, piping and containment structures, pitting corrosion can result in localized wall perforation and loss of containment. Pitting corrosion develops and progresses more rapidly in elevated temperatures.

CREVICE CORROSION

Crevice corrosion is a localized form of attack which is initiated by the extremely low availability of oxygen in a crevice. It is only likely to be a problem in stagnant solutions where a build-up of chlorides can occur. The severity of crevice corrosion is very dependent on the geometry of the crevice; the narrower and deeper the crevice, the more severe the corrosion. Crevices typically occur between nuts and washers or around the thread of a screw or the shank of a bolt. Crevices can also occur under deposits accumulated on the surface of stainless steel.

BIMETALLIC (GALVANIC) CORROSION

Bimetallic (galvanic) corrosion may occur when dissimilar metals in electrical contact are immersed in a common electrolyte (e.g., rain, condensation, pool water) resulting in the exchange of electrons between them. As a result of this galvanic current which flows between the two metals, the less noble metal (the anode) corrodes at a faster rate than would have occurred if the metals were not in contact.

The rate of galvanic corrosion also depends on the relative size of the areas of the metals in contact, the temperature and the composition of the electrolyte. In particular, the larger the area of the cathode (more noble) in relation to that of the anode (less noble), the greater the rate of attack will be. Adverse area ratios are likely to occur with fasteners and at joints. Carbon steel bolts in stainless steel members should be avoided because the ratio of the area of the stainless steel to the carbon steel is large and the bolts will be subject to aggressive attack. Conversely, the rate of attack of a carbon steel member by a stainless steel bolt is much slower.

STRESS CORROSION CRACKING (SCC)

The development of SCC requires the simultaneous presence of tensile stresses and specific environmental factors such as the presence of chlorides. The stresses do not need to be very high in relation to the proof stress of the material and may be due to loading, thermal cycling or residual effects from manufacturing processes such as welding or bending. Caution should be exercised when stainless steel members with high residual stresses are used in chloride rich environments.

GENERAL (UNIFORM) CORROSION

General corrosion is much less severe in stainless steel than in other steels. It only occurs when the stainless steel is at a pH value <1.0. Reference should be made to tables in the manufacturer's literature, or the advice of a corrosion engineer should be sought, if the stainless steel is to come into contact with chemicals.

SENSITIZATION AND INTERGRANULAR ATTACK

When austenitic stainless steels are subject to prolonged heating between 450-850°C, the carbon in the steel diffuses to the grain boundaries and precipitates as chromium carbide. This removes chromium from the solid solution and leaves a lower chromium content adjacent to the grain boundaries. As chromium is the element providing corrosion resistance to stainless steels, the grain boundaries become prone to preferential attack on subsequent exposure to a corrosive environment. Steels in this condition are termed 'sensitized.'

REFERENCES:

British Stainless Steel Association (www.bssa.org.uk) – "Corrosion mechanisms in stainless steel."

If you have questions regarding this information, best practices in adhering to the conditions of use, or testing methods, we invite you to contact Nordion at www.nordion.com.