Water Activation in ProteusONE Facility

Document type/sub-type	Other Internal Document
Process	Design and Develop
Metadoc ID + version	Metadoc ID 115244 Version 0
Version changes	First Version
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Effective date	07 March 2023
Purpose	This document summarizes the risk and observations related to the water activation of a ProteusONE facility.
Scope: Boundaries	ProteusONE Facility
Scope: Depth	This document is applicable to the water cooling system and ground water underneath the ProteusONE bunker.

*cf MID 79703: Classification Policy

The interactions of secondary neutrons with water may result in the production of unstable isotopes such as:

- Tritium (^{3}H) with an half-life $T_{1/2}$ = 12.3 years;
- ^{7}Be with $T_{1/2}$ = 53.3 days;
- PET isotopes such as ^{13}N ($T_{1/2}$ = 9.96 min.), $^{15}0$ ($T_{1/2}$ = 2.03 min.) and ^{11}C ($T_{1/2}$ = 20.38 min.).

Neutrons can interact either with the water used to cool down the equipment (S2C2, magnets) or the ground water surrounding the PT building.

1 Cooling Water Activation

As the cooling water is circulating inside a closed circuit, it is exposed all the time to the neutron fluxes coming from the equipment. Therefore, there is some risk to observe a build-up with time of the long-lived isotopes ^{3}H and ^{7}Be. In order to evaluate that risk, measurements of Tritium and ^{7}Be activities were performed in cooling water samples taken in the ProteusONE system installed at Centre Antoine Lacassagne (CAL) in Nice, France. After one full year of operation, searches for ^{3}H and ^{7}Be contamination were performed by an accredited laboratory in France. As summarized in Table 1, both measurements were below the detection limit. Those results indicate that the ^{3}H and ^{7}Be concentration levels in cooling water are below the IAEA Clearance Levels [2] by factors 8 10^{-5} and 6 10^{-4}, respectively.

Table 1: Measurements of ^{3}H and ^{7}Be activities in cooling water

Isotope	Method	Detection Limit (DL)	Result	Clearance Level (IAEA)	Result / CL
^{3}H	Scintillation counting (ISO 9698)	8 Bq/L	< DL	100 Bq/g	< 8 10^{-5}
^{7}Be	Gamma spectrometry (ISO 10703)	6 Bq/L	< DL	10 Bq/g	< 6 10^{-4}

The cooling water samples were coming from the cyclotron vault as this is the area where the largest neutron fluxes are generated by protons lost inside the accelerator and protons impinging on the energy degrader. In case of the treatment room, beam intensities are reduced by a factor 10 to 100 compared to cyclotron room and thus, the risk to generate some activation in water is also totally negligible.

Other measurements were performed at the PARTICLE facility (UZ Leuven, Belgium) using the deionization bottles of the cooling water system [3].

Activity levels of 3H, 14C and 32P in the liquid part of the bottles (i.e. cooling water) were evaluated using the LSC (Liquid Scintillation Counting) method and are presented in Table 2 for 11 bottles.

Solid material contained inside the bottles was also sampled and the activity levels of 3H, 7Be and 14C were measured using LSC. The activity level of 7Be was also determined by gamma spectroscopy and the results obtained in 3 samples are presented in Table 3.

The comparison of the measurements performed both at CAL and PARTICLE to the Clearance Levels defined by IAEA [2] clearly shows that the activity levels generated in the cyclotron cooling water remain far below the limits defined for exemption.

Table 2: Measurements of ^{3}H, ^{14}C and ^{32}P activities in cooling water (UZ Leuven)

Sample	Date of Sample	Results in ^{3}H region (Bq/ml)	Results in ^{14}C region (Bq/ml)	Results in ^{32}P region (Bq/ml)
Bottle 1	20-11-2019	0.08	0.04	0.03
Bottle 2	20-11-2019	0.03	0.03	0.01
Bottle 3	20-11-2019	0.06	0.05	0.01
Bottle 4	20-11-2019	0.25	0.17	0.03
Bottle 5	20-11-2019	0.03	0.03	0.01
Bottle 6	20-11-2019	0.07	0.05	0.02
Bottle 7	20-11-2019	0.13	0.05	0.03
Bottle 8	20-11-2019	0.05	0.04	0.01
Bottle 9	20-11-2019	0.02	0.03	0.02
Bottle 10	20-11-2019	0.01	0.01	0.01
Sample cooling water	16-02-2020	0.03	0.04	0.02
Bottle 11	07-05-2020	0.41	0.09	0.05
Reference sample cooling water	07-05-2020	0.07	0.07	0.02

Table 3: Measurements of ^{3}H, ^{7}Be and ^{14}C activities in solid material (UZ Leuven)

Sample	Results ^{3}H (Bq/kg)	Results ^{7}Be (Bq/kg)	Results ^{10}Be (Bq/kg)	Results ^{14}C (Bq/kg)
#1	< 16	< 3.2	< 210	< 40
#2	< 15	< 6	< 210	< 40
#3	< 15	< 7	< 210	< 21

Table 4: IAEA Clearance Levels for radionuclides of artificial origin in bulk [2]

Radionuclide	Clearance level (Bq/g)
^{3}H	100
^{7}Be	10
^{14}C	1
^{32}P	1000

2 Ground Water Activation

The ProteusONE facility might be build in proximity from groundwater and neutrons escaping from the biological shielding might interact with this groundwater. However, the floor slab has a minimal thickness of 50 cm for structural reasons and thus the neutron fluxes coming from the equipment are strongly attenuated before reaching the ground water.

To evaluate the risk of generating ^{3}H or ^{7}Be in groundwater, a Monte Carlo study was performed using the MCNPX radiation transport code. Assuming a floor slab thickness of 100 cm below the S2C2, we determined the production yields of various isotopes in water located right below the floor slab. All the details of the study are described in IBA document M-ID 74630 [4] and the final results are summarized in Table 5. For all isotopes, the saturated activities are several orders of magnitude below the Clearance Levels defined by IAEA. Therefore, there is no risk of groundwater activation below a ProteusONE facility.

Table 5: Saturated activities of unstable isotopes produced in ground water below the S2C2 floor slab

Isotope	Saturated Activity (Bq/cm³)
^{3}H	$6.8\ 10^{-6}$
^{7}Be	$9.6\ 10^{-4}$
^{11}C	$2.4\ 10^{-3}$
^{14}O	$9.8\ 10^{-4}$
^{15}O	$7.7\ 10^{-3}$

3 References

[1] “Rapport d’essais n° 18-00709-04918”, Eichrom Laboratories, February 2018.

[2] “Application of the Concepts of Exclusion, Exemption and Clearance”, IAEA Safety Guide RS-G-1.7 (2004).

[3] “Clearance Measurements Deionization Bottles Clinical Bunker PARTICLE”, M-ID 115112, March 2023.

[4] “ProteusONE at IEO – Water Activation”, M-ID 74630, September 2018.

[1] “Rapport d’essais n° 18-00709-04918”, Eichrom Laboratories, February 2018.

[2] “Application of the Concepts of Exclusion, Exemption and Clearance”, IAEA Safety Guide RS-G-1.7 (2004).

[3] “Clearance Measurements Deionization Bottles Clinical Bunker PARTICLE”, M-ID 115112, March 2023.

[4] “ProteusONE at IEO – Water Activation”, M-ID 74630, September 2018.

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