Technical University of Denmark

DTU

Radiation challenges of primary cooling return water at the ESS
Paper

Klinkby, Esben Bryndt; Muhrer, Günter; Carlsson, H.; Eriksson, Björn

DTU Library
Technical Information Center of Denmark

PAPER • OPEN ACCESS

Radiation challenges of primary cooling return water at the ESS

View the article online for updates and enhancements.

IOP ebooks™

Bringing you innovative digital publishing with leading voices to create your essential collection of books in STEM research.

Start exploring the collection - download the first chapter of every title for free.

Radiation challenges of primary cooling return water at the ESS

Esben Klinkby[1,2]**, Günter Muhrer**[1]**, H. Carlsson**[1] **and Björn Eriksson**[1]

1) European Spallation Source ESS, Box 176, S-221 00 Lund, Sweden
2) DTU Nutech, Technical University of Denmark, Frederiksborgvej 399, DK-4000 Roskilde, Denmark

E-mail: `esbe@dtu.dk`

Abstract. At ESS water is used both as thermal moderators and to cool the beryllium- and steel reflectors, the shielding and plugs. This means that the water, in separate loops, will be subject to a significant proton and neutron irradiation which will activate the water. After irradiation, the water is led to delay tanks situated in one of the triangular rooms downstream from the target.This paper aims at determining the shielding required to ensure that the biological dose-rate requirements in the target building and instrument halls are met during operation of facility.

1. Introduction
The construction of the European Spallation Source (ESS) is ongoing in Lund, Sweden. At ESS it is necessary to operate water loops for the thermal moderators and for the cooling of the beryllium- and the steel reflectors as well shielding blocks and plugs. The water in each of these circuits is exposed to a very high level of radiation. This causes activation of the water and impurities therein. In this work the measures for safe handling of the return water are investigated. In particular the consequences in terms of shielding requirements of moving the delay tanks from their baseline location in the triangular room, to the adjacent Connections cell are investigated.

2. Methods and Modelling
The radiation shielding calculations are performed following the ESS Procedure for designing shielding for safety [1]. Monte Carlo radiation transport calculations are performed with the MCNPX-2.7 code [2]. Using a this tool, a model is prepared describing in detail the target, moderators and reflectors as shown in figure 1.
To determine the neutron flux in the water of the moderators and reflectors, the interactions of one million 2 GeV protons on target are simulated. The resulting neutron flux is recorded and handed to CINDER'90 (v. 1.05)[4, 5] for an activation calculation using as irradiation scenario the expected ESS operations schedule for two years of full power operations (5 MW).
As seen in figure 2 the piping leading the water through the various systems is complex, and is not modelled in detail in this study. Instead, a simplified MCNPX model is prepared (see figure 3 (left)), in which the approximate water volume of various fractions of the pipe circuits
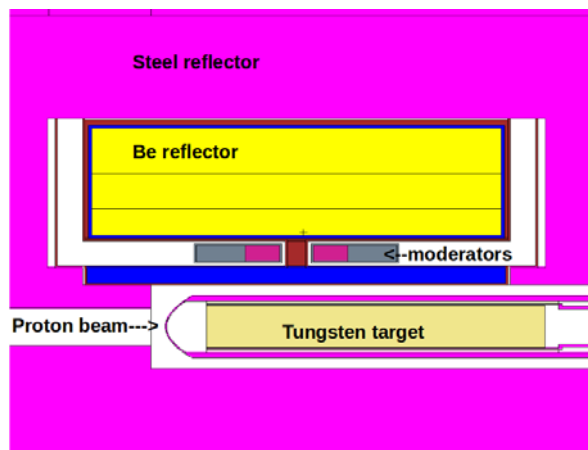
Figure 1: MCNPX geometry used in the proton on target simulations which are performed to evaluate the neutron flux at the location of the cooling water.

is used to define volumetric source terms (scaling the full source term), at various cooling times to account for the water flow.
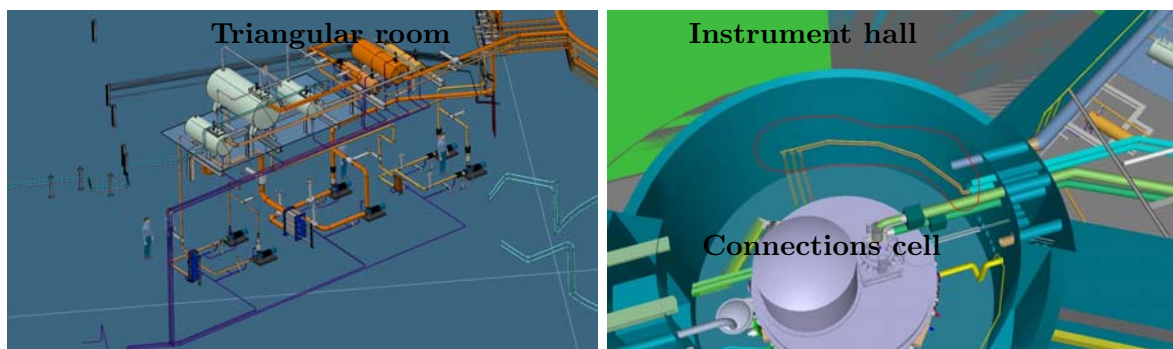

Figure 2: Left: CAD drawing of triangular rooms. The orange pipes and orange delay tanks contain the irradiated water under study. Right: The connections cell, located directly above the target-moderator-reflectors. The orange pipes, carrying the irradiated water the toward the Connections cell, are encircled in red.

3. Results
Table 1 lists the isotopes giving the largest contribution to the total activity at selected cooling times. As expected ^{16}N (^{16}O$(n,p) \rightarrow ^{16}$N) is the main contributer at short cooling times whereas ^{7}Be plays this role at longer cooling times.

3.1. Inlet pipe shielding
To describe the irradiation due to the cooling water as it pass through the delay tank inlet pipe, a simplified MCNPX model is prepared describing only the Connections Cell, triangular rooms, delay tanks and inlet- and outlet pipes - (see figure 3). A volumetric source term is defined using that the 5 m long pipe results in a total water volume of about 1.5 L, or approximately 1/6 of the total water inventory. Thus, as a conservative approximation the source at zero cooling

Isotope	Half-life [s] [s]	Decay mode	Time step [0s]	Time step [90s]
^{3}H	3.89E8	β	621.3	621.3
^{7}Be	4.61E6	$EC\beta + \gamma[477keV]$	445.1	445.1
^{11}C	1223	β	1473	1400
^{14}O	70.6	$\beta + \gamma[2.3MeV]$	92.3	38.5
^{15}O	122	β	4511	2723
^{16}N	7.1	$\beta + \gamma[6.1MeV]$	4462	0.8
Total			12380	7161

Table 1: Total activity in Curies. Only isotopes contributing in excess of 10Ci at 60 s cooling are listed, but all are included in the total sum.

time is used with a weight reduced by a factor of 1/6. This source is placed in the delay tank inlet pipe and a gamma transport simulation is carried out using MCNPX. Using ICRP-116 gamma flux-to-dose conversion factors [6], the resulting biological dose-rate map is shown in figure 3(left). In this figure 12 cm lead shielding surrounds the pipe.
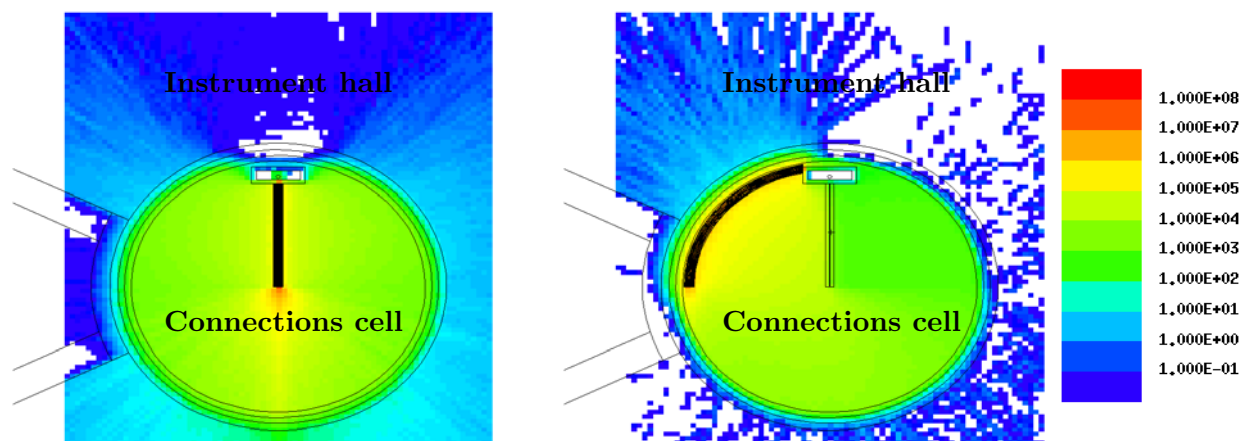

Figure 3: Left: Biological dose-rate in μSv/h due to the delay tank inlet pipe (central in the figure). Shielding thickness: 12 cm lead. Right: Biological dose-rate in μSv/h due to the delay tank outlet pipe (following the circumference of the wall). Shielding thickness: 2 cm lead.

3.2. Delay tank shielding
The water circuits, of course, are not exactly steady. Moreover the timescales relevant to the water flow are similar to the half-life of ^{16}N, which according to table 1 is main contributer to the activity on a few seconds timescale. To accurately model the source term to be used for delay tank shielding calculations, the following observations are made:

- Moderator water content: 9L
- Moderator exhaust speed: 0.6 L/s (or 2 m/s) so the average cooling time, at the time of exiting the moderator: 7.5 s.
- Pipes: 10 m. 5 m vertical and 5 m horizontal

Thus, source terms are prepared corresponding to cooling times between $7.5\text{s} + \frac{10\text{ m}}{2\text{m/s}} \approx 13$ s and 37 s in 9 equidistant steps - see table 2.

Cooling time [s]	13	16	19	22	25	28	31	34	37
Source weight [%]	12	12	12	12	12	12	12	12	4

Table 2: Source definitions used to model the delay tank.

Several limits of biological dose-rate apply at various locations in the target building and the surrounding buildings. Focusing to the connections cell the most stringent limit driving the shielding is that of the neighbouring instrument hall: 3μSv/h - see figure 2.

The resulting dose-rate map due to the presence of activated primary coolant water in the delay tank is shown in figure 4. The dose-rate requirements in the instrument hall are met only after introducing 18 cm of lead shielding. It should be noted that the delay tank need shielding on all horizontal directions, though the shielding requirements on the side facing the center of the room, can be reduced by approximately two orders of magnitude due to the geometrical dilution between the delay tank and the instrument hall on the opposite side of the connection cell.
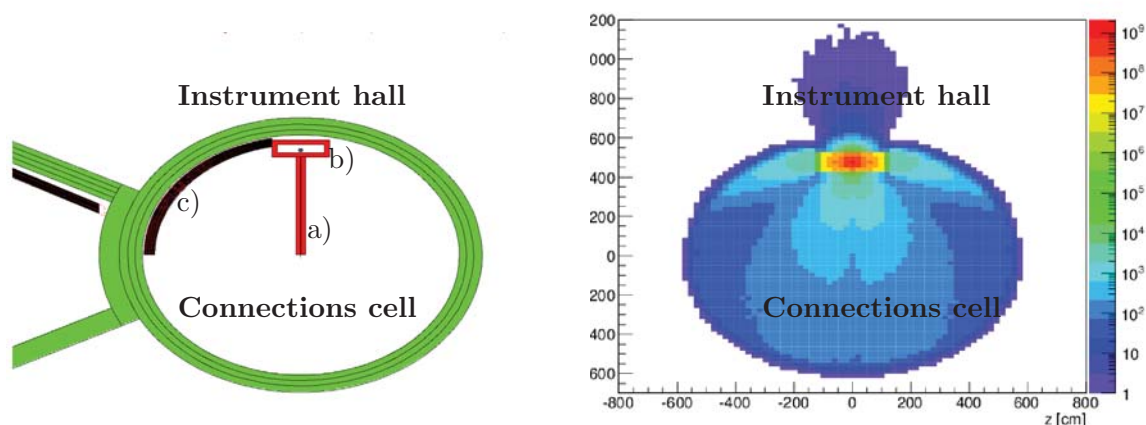

Figure 4: Left: simplified MCNPX geometry used throughout this study for calculations of biological dose rate. The source is placed either in the delay tank inlet pipe: $a)$, in the delay tank: $b)$ or in the delay outlet pipe $c)$. The green structure is regular concrete (density 2.35 g/cm^3, thickness of circular wall: 80 cm). Right: Biological dose-rate in μSv/h due to the delay tank, which is located inside the Connections cell. Shielding thickness: 18 cm lead.

3.3. Outlet pipe shielding

A delay tank size of 90 s is assumed for calculations of the outlet pipe.

The outlet pipe is modelled as a 2 cm diameter pipe placed along the inner circumference of the Connections cell. Its volume correspond to about 30% of the moderator volume, which is applied to the source weight. The pipe shielding required to reach satisfactory dose-rate levels in the neighbouring instrument hall is 2 cm of lead - the resulting dose-rate maps are shown in figure 3(right).

4. Conclusions

The shielding requirements of the primary coolant return water are studied using MCNPX neutron and gamma transport calculations in combination with CINDER'90. Immediately after returning from the moderators/reflectors ^{16}N is the most challenging isotope, while after the cooling for 90 s in the delay tanks, ^{7}Be claims this role. For irradiated water present in the connections cell, the most challenging biological dose-rate limit to be met is that of the instrument hall. To meet the 3μSv/h limit, the following shielding must be installed:

- 12cm lead around delay tank inlet pipe
- 18cm lead between delay tanks and instrument hall
- 2cm lead around 90s delay tank outlet pipe

The above assumes that the delay are moved from the present baseline location in the triangular room to the Connections cell. In the opposite case, where the delay tanks remain in the triangular rooms, the 12 cm shielding requirement of the delay tank inlet pipe must be maintained throughout the length of the inlet.

References

[1] ESS Procedure for designing shielding for safety, ESS-0019931
[2] Waters L. S. and others . The MCNPX Monte Carlo radiation transport code. *AIP Conf.Proc.* **896**, 81-90 (2007)
[3] ESS-0045043. Sheet: 2.Input and output data
[4] W. B. Wilson, S. T. Cowell, T. R. England, A. C. Hayes & P. Moller, A Manual for CINDER'90 Version 07.4 Codes and Data, LA-UR-07-8412 (December 2007, Version 07.4.2 updated March 2008).
[5] Franz X. Gallmeier and Michael Wohlmuther, ACTIVATION SCRIPT VERSION 1.0 USER GUIDE, ORNL/TM-2008/031 (August 18, 2008).
[6] Conversion Coefficients for Radiological Protection Quantities for External Radiation Exposures. ICRP Publication 116. Ann. ICRP 40(2-5), 2010