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ACTIVATION OF THE HEAVY WATER COOLANT OF THE ISIS TARGET

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1. Introduction

During operation the D_2O coolant of the target becomes highly active. The production rates of radionuclides from interactions in the water have been calculated by Atchison [1] using the HETC Monte Carlo package [2]. These production rates have been used to calculate the buildup and decay of activity, and associated radiation levels using a simple model of the water circuit.

Measurements of the short lived components have been made with a high resolution gamma detector and the results are compared with the predictions.

2. Activation Calculation

The production rates of the radionuclides from [1], together with mean lifetimes and decay modes, are shown in Table 1.

The specific activity, α_T, of an individual nuclide in the target cooling water is given by

$$\alpha_T = \alpha_o \frac{(1 - e^{-t_i/\lambda})\, e^{-t_c/\lambda}\, (1 - e^{-T/\lambda})}{V\,(1 - e^{-T_c/\lambda})}$$

where α_o is the production rate

V is the volume of water in the target

t_i is the time for volume V of water to pass through the target

λ is the mean lifetime

T is the time from startup of the proton beam

T_c is the circulation time for the water around the circuit

These quantities are illustrated on the schematic diagram of the water circuit in Figure 1.

The specific activities in the target coolant for various irradiation and decay times are shown in Table 2.

3. Radiation Levels Around the Cooling Plant

The water cooling system comprising pipes, pumps, filters, heat exchanges etc, are mounted on one of the trolleys in the Target Station services area (see Figures 2 and 4).

To estimate the radiation levels in this area from the active target, moderator and reflector water circuits the pipes were treated as line gamma sources and the dose rate at 1 m from each pipe was calculated.

For a 200 μA beam of 800 MeV protons this procedure predicts a dose rate of 1 Sv/h on the trolley.

The main contribution to the dose is from the β^+ emitters which are relatively short lived. The decay of the dose rate is shown in Figure 3 and after about 3 hours the level becomes fairly constant and is dominated by ^7Be. Ion exchange columns in the circuit collect all the ^7Be and on this basis it was predicted that entry to the services area for work on the water plant would be possible after about 3 hours when the dose rate would be less than 100 μSv/h. At the present ~ 10% intensity a cooldown period of about 30 min has been found to be necessary before entry. This is somewhat shorter than calculated and the faster fall off of the dose rate is probably a result of the ion exchange columns collecting some of the shorter lived activity in addition to the ^7Be.

The high radiation levels around the plant require substantial shielding, 1 m of concrete, and the 6 MeV gammas from ^{16}N dominate this requirement.

4. Measurements of Water Activation

A Lithium drifted Germanium detector is installed outside the Services Area viewing a delay reservoir on a bleed line in the target cooling circuit through a hole in the shielding. The position of this detector is shown in Figure 4 and schematic detail in Figure 5.

The primary purpose of this device is to act as an on-line fission product monitor to detect any failure of the zircalloy cladding on the uranium target discs. The principle of the method is to detect gammas from fission products, for example ^{95}Nb, ^{97}Nb, ^{132}I, ^{124}Sb, which have energies in a region of relatively low background from the normal activity of the water. Calculations [3] indicate that a failure of the cladding will be detected within a few minutes.

Much work needs to be done in commissioning and evaluating this equipment. The water activity measurements described below whilst interesting in their own right are a crucial step in establishing the background counting rate environment in which fission product activity needs to be detected.

4.1 Long lived activity in the ion exchange resin

Samples of the ion exchange resin from the target cooling circuit after 2 months decay time were placed 20 cm from the shielded GeLi detector and the gamma spectra measured. The dominant nuclide present was ^{7}Be and small concentrations (relative to ^{7}Be) of other nuclides were identified which are listed below together with the likely production mechanism.

Nuclide	Half life	Probable target nucleus
Na 22	2.6 y	Many possibilities
Sc 46	84 d	Stainless Steel
Mn 54	312 d	Stainless Steel
Co 56	79 d	Stainless Steel
Co 58	71 d	Stainless Steel
Co 60	5.3 y	Stainless Steel

Nuclide	Half life	Probable target nucleus	
Zn 65	244 d		
Se 75	120 d		
Rb 83	86 d		
Sr 85	65 d	}	Zircalloy Cladding
Y 88	107 d		
Zr 88	85 d		
Zr 99	66 d		
Nb 95	35 d		
Ag 110M	233 d	Ag	Silver plated seals

Note that the presence of ^{95}Nb as a spallation product makes the use of this nuclide problematic for the fission product monitor.

The nuclides detected are much as expected and provide very useful information for the backgrounds to be expected for fission product detection.

4.2 Short lived activity in the cooling water

The decay of the intensity of the 511 keV annihilation gammas from the β^+ emitters was measured as a function of time after beam turn off. The decay curve is shown in Figure 6.

The relative contributions of ^{15}O, ^{13}N and ^{14}O were calculated by fitting the decay curve with three exponential functions. Figure 5 shows the relative contribution together with the theoretical prediction. Bearing in mind the detail being required of the Monte Carlo program the agreement in relative contributions is excellent. ^{11}C was predicted at a rate of 13% of ^{15}O. This was not evident in the measurements and the discrepancy may well be due to a partial or complete removal of ^{11}C by the ion exchange column.

5. Conclusion

The detection system has performed well and initial operating experience gives confidence that it will provide the required rapid detection of cladding failure in the target.

The agreement between detailed Monte Carlo calculations of activity and measurements is good.

References

[1] F Atchison A Theoretical Study of a Target REflector and Monderator Assembly for SNS - RL-81-006.

[2] HETC RSIC computer code collection No CCC-178.

[3] G H Eaton Proposal for an on-line clad failure detector system for the SNS target station using high-resolution γ-ray spectroscopy - SNS/TS/N10/82.

Nuclide	Mean Life	Production Rate nuclei/proton	Decay Mode (branching ratio)*	Gamma Energy Mev (Branching Ratio)
^{18}F	158.29m	1.06×10^{-5}	β^+	
^{17}N	6.02s	5.00×10^{-5}	β^-(0.05) β^-n(0.95)	0.87 (0.03)
^{16}N	10.29s	1.60×10^{-3}	β^-	6.13 (0.69)
^{15}O	176.15s	1.00×10^{-2}	β^+	
^{15}C	3.53s	7.70×10^{-5}	β^-	5.30 (0.68)
^{14}O	101.84s	3.20×10^{-4}	β^+	2.31 (0.99)
^{14}C	8267y	1.20×10^{-3}	β^-	
^{13}N	14.37m	2.60×10^{-3}	β^+	
^{11}C	29.40m	1.10×10^{-3}	β^+	
^{11}Be	19.92s	1.10×10^{-4}	β^-(0.97) $\beta^-\alpha$(0.03)	2.13 (0.33) 4.67 (0.02 5.85 (0.02) 6.79 (0.04) 7.97 (0.02)
^{10}C	27.63s	2.20×10^{-4}	β^+	0.718 (0.99)
^{10}Be	2.31×10^{6}y	1.00×10^{-4}	β^-	
^{7}Be	76.88d	1.70×10^{-3}	EC	0.478 (0.1035)
^{3}H	17.51y	1.00×10^{-2}	β^-	

(* Branching ration 1.0 unless shown in brackets).

Table 1. Production rates and decay modes of radionuclides produced in the Target Coolant.

	Irradiation times					
	1s	60s	1h	1d	7d	∞
18F	7.46E+06	4.46E+08	2.23E+10	7.08E+10	7.08E+10	7.08E+10
17N	3.75E+09	2.45E+10	2.45E+10	2.45E+10	2.45E+10	2.45E+10
16N	2.46E+11	2.65E+12	2.65E+12	2.65E+12	2.65E+12	2.65E+12
15O	3.54E+11	1.80E+13	6.25E+13	6.25E+13	6.25E+13	6.25E+13
15C	9.04E+08	3.66E+09	3.66E+09	3.66E+09	3.66E+09	3.66E+09
14O	1.86E+10	8.45E+11	1.90E+12	1.90E+12	1.90E+12	1.90E+12
14C	3.08E+01	1.85E+03	1.11E+05	2.66E+06	1.86E+07	8.03E+12
13N	1.99E+10	1.15E+12	1.69E+13	1.72E+13	1.72E+13	1.72E+13
11C	4.14E+09	2.44E+11	6.36E+12	7.31E+12	7.31E+12	7.31E+12
11Be	1.85E+10	3.60E+11	3.78E+11	3.78E+11	3.78E+11	3.78E+11
10C	3.28E+10	8.17E+11	9.23E+11	9.23E+11	9.23E+11	9.23E+11
10Be	9.18D-03	5.51E-01	3.31E+01	7.94E+02	5.56E+03	6.69E+11
7Be	1.71E+06	1.03E+08	6.17E+09	1.47E+11	9.91E+11	1.14E+13
3H	1.19E+05	7.14E+06	4.29E+08	1.03E+10	7.20E+10	6.69E+13
Totals	6.98E+11	2.41E+13	9.16E+13	9.30E+13	9.39E+13	1.80E+14

Table 2a. Build-up of specific activity of target plate coolant Bq m^{-3}.

The decay of activity, from its saturation value, after beam has been switched off, is shown below.

	Cooling times					
	1m	5m	1h	8h	1d	7d
18F	7.04E+10	6.86E+10	4.85E+10	3.41E+09	7.93E+06	0.0
17N	1.15E+06	0.0	0.0	0.0	0.0	0.0
16N	7.79E+09	5.78E-01	0.0	0.0	0.0	0.0
15O	4.44E+13	1.14E+13	8.31E+04	0.0	0.0	0.0
15C	1.52E+02	0.0	0.0	0.0	0.0	0.0
14O	1.05E+12	9.98E+10	8.44E-04	0.0	0.0	0.0
14C	8.03E+12	8,03E+12	8.03E+12	8.03E+12	8.03E+12	8.03E+12
13N	1.60E+13	1.21E+13	2.64E+11	5.34E-02	0.0	0.0
11C	7.07E+12	6.17E+12	9.50E+11	5.93E+05	0.0	0.0
11Be	1.86E+10	1.09E+05	0.0	0.0	0.0	0.0
10C	1.05E+11	1.78E+07	0.0	0.0	0.0	0.0
10Be	6.69E+11	6.69E+11	6.69E+11	6.69E+11	6.69E+11	6.69E+11
7Be	1.14E+13	1.14E+13	1.14E+13	1.13E+13	1.12E+13	1.04E+13
3H	6.69E+13	6.69E+13	6.69E+13	6.69E+13	6.69E+13	6.68E+13
Totals	1.56E+14	1.17E+14	8.82E+13	8.69E+13	8.68E+13	8.59E+13

Table 2b. Decay of specific activity target plate coolant Bq m^{-3}.

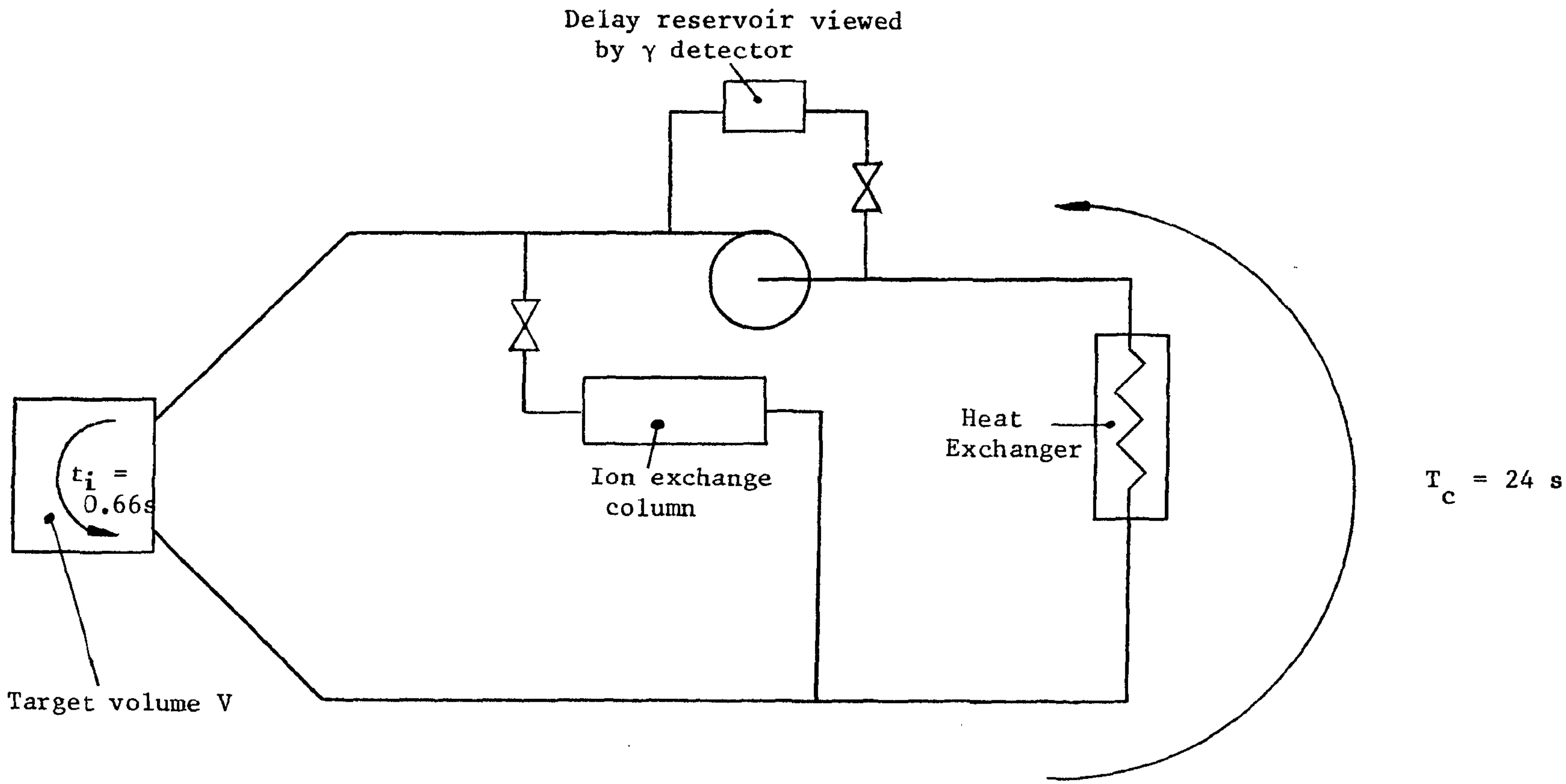

Figure 1. Schematic diagram of the target cooling circuit.

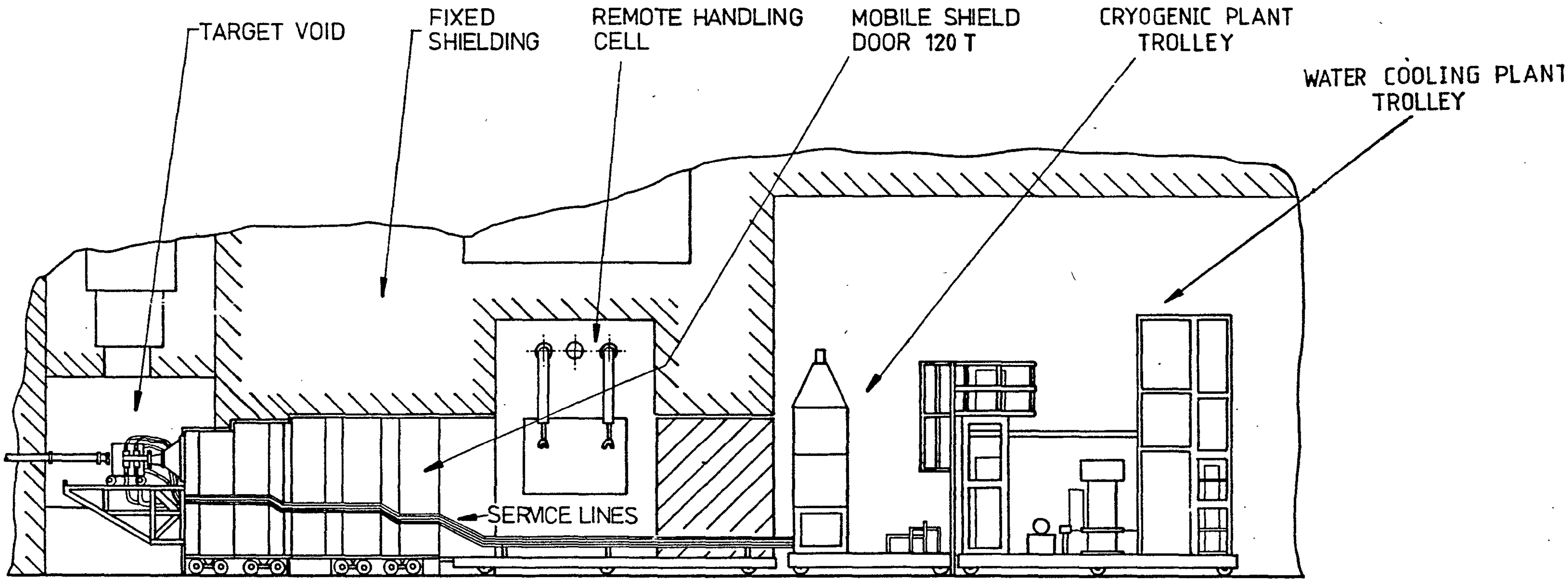

Figure 2. Target station and services area trolleys.

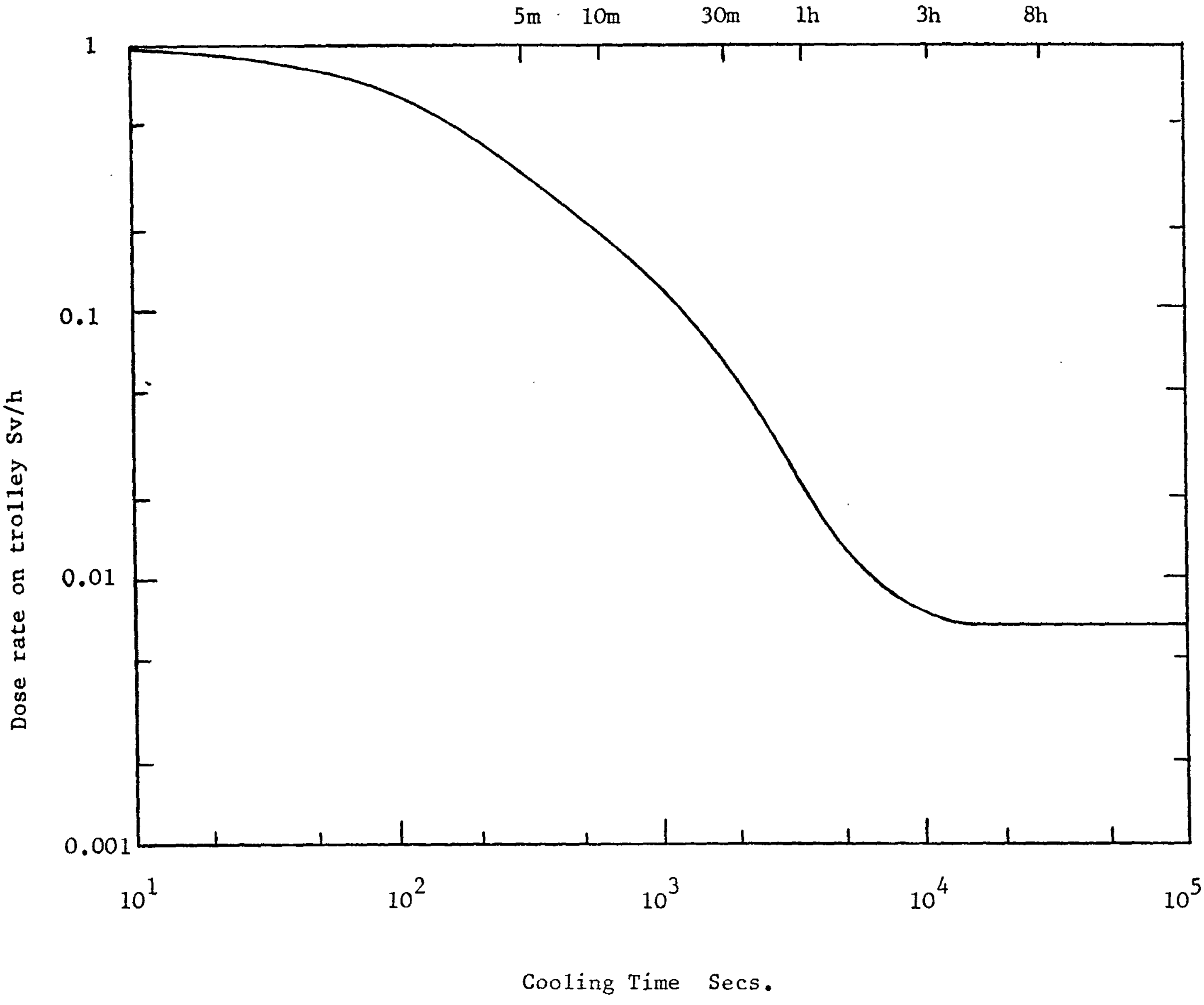

Figure 3. Calculated decay of radiation level on the water services trolley when proton beam is turned off.

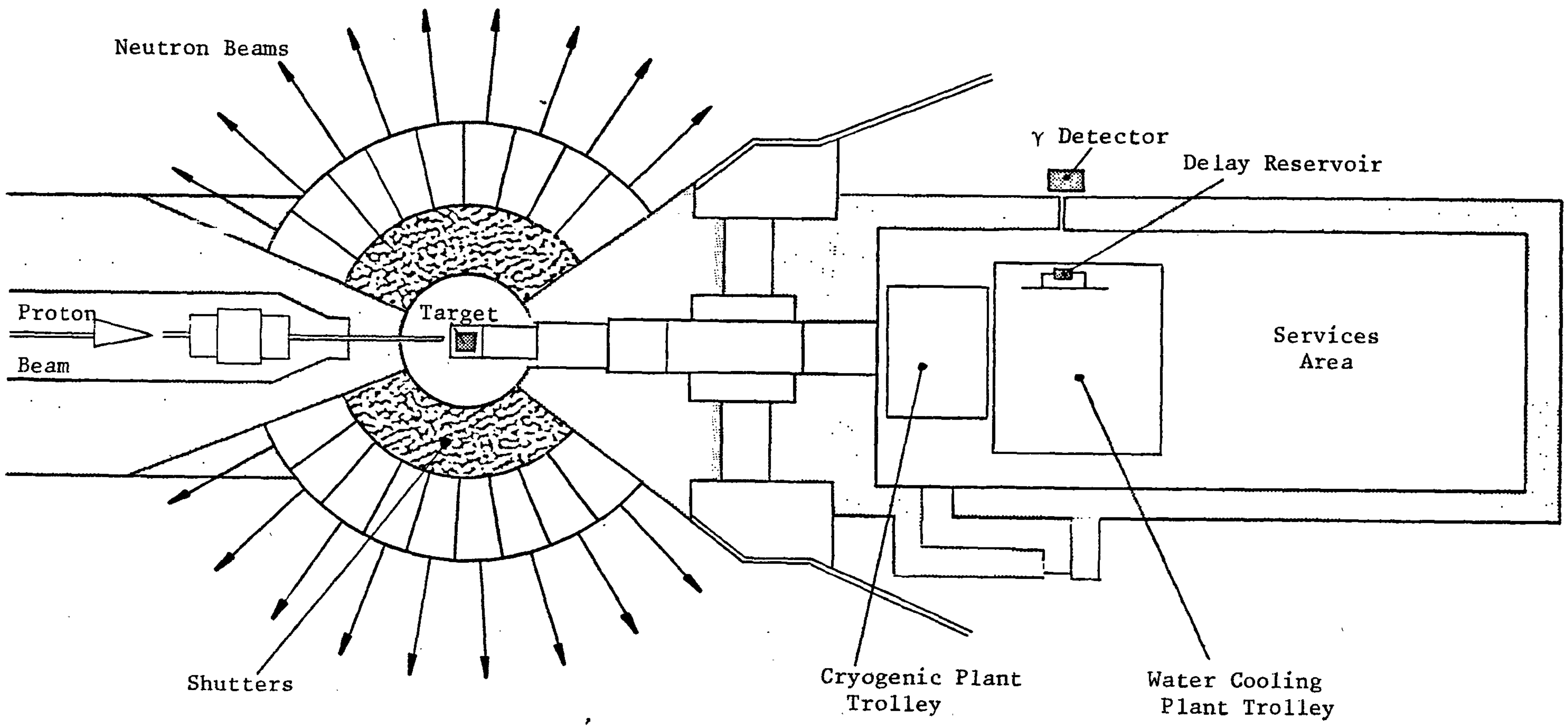

Figure 4. Overall Layout of Target Station.

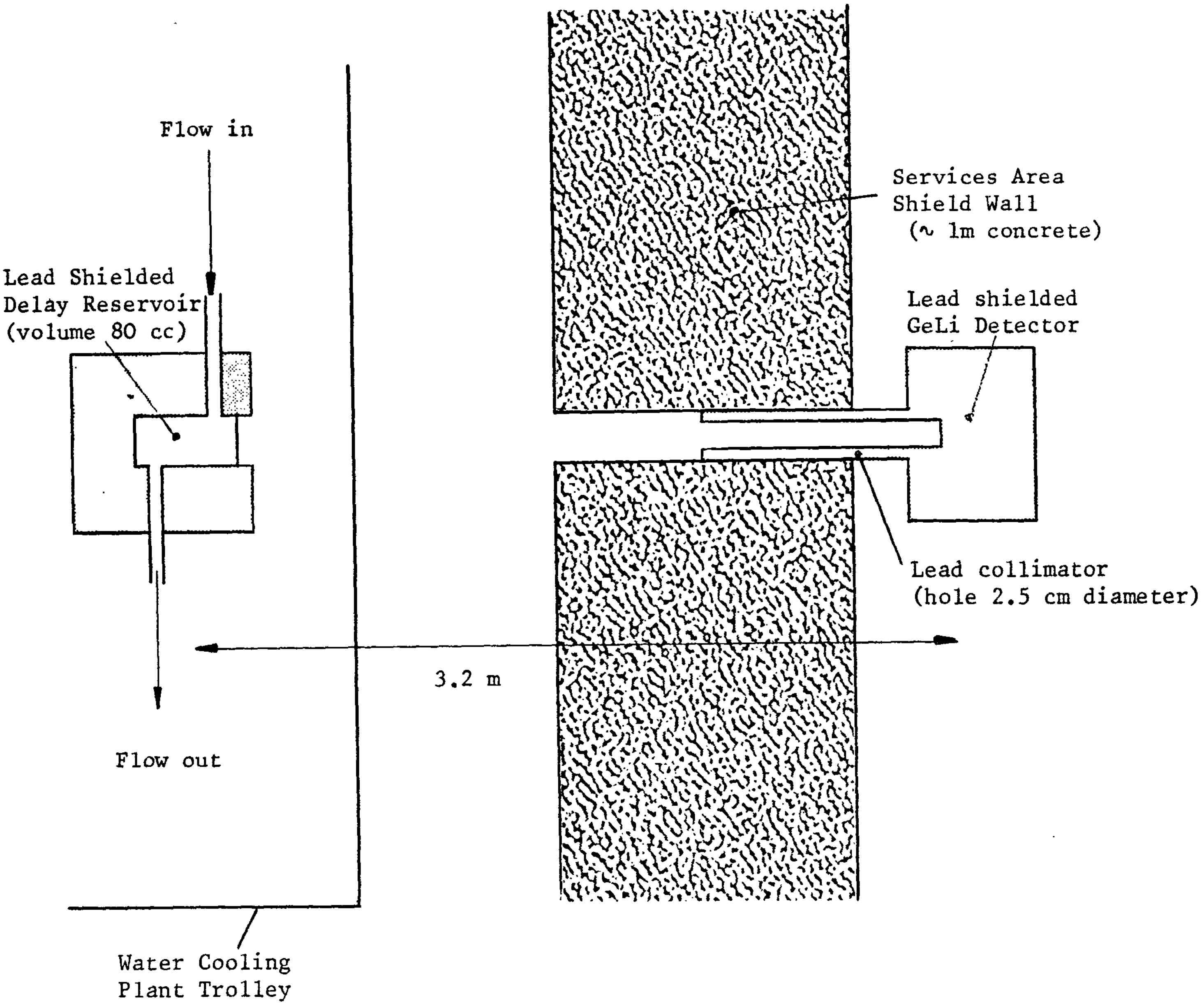

Figure 5. Schematic detail of the arrangement of the delay reservoir and GeLi detector.

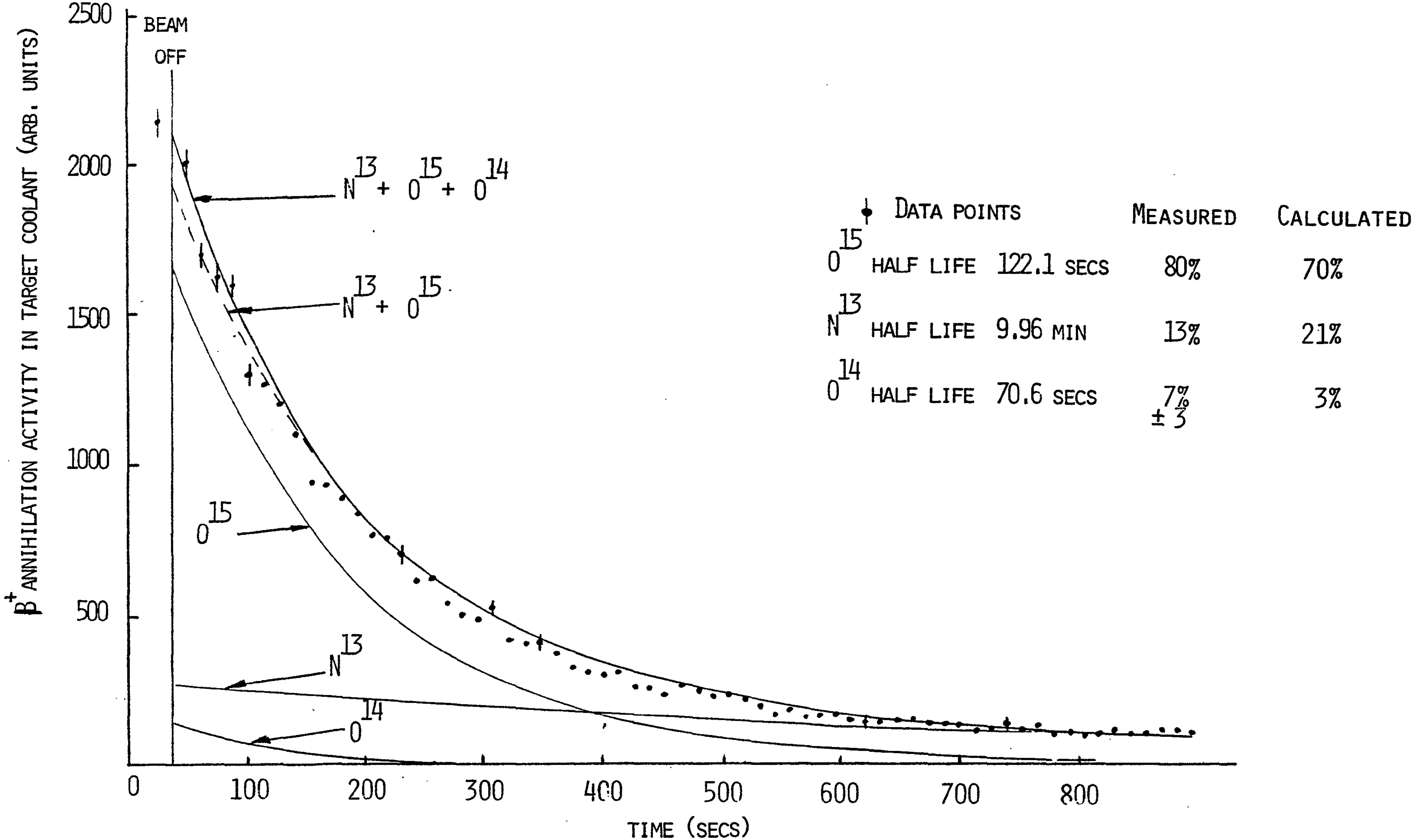

Figure 6. Decay of β^+ annihilation gammas in the target coolant.