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^{7}Be BUILD-UP IN A LARGE WATER BEAM DUMP SYSTEM AT THE STANFORD LINEAR ACCELERATOR CENTER*

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ABSTRACT

The production of ^{7}Be in the 20 GeV accelerator cooling water systems has given rise to some unexpected operational problems concerned with handling the mixed bed resins used to maintain water quality in these systems. The mixed bed resins must be periodically recharged. The vendor performing this service is not licensed to handle radioactive materials, and SLAC is not equipped to handle Curie quantities of radioactive materials in the form of a loose powder.

An experiment was performed to determine the efficiency of a mechanical filter for removing ^{7}Be. A 16 GeV, 24-100 kW electron beam going into a large water dump was used. A fraction of the water flow was diverted through a mechanical filter and resin bed in series. Sampling techniques, counting equipment, and calibration methods are briefly described. The production rate of ^{7}Be is compared with theory.

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I. INTRODUCTION

The production of ^{7}Be in water by high energy electron irradiation is principally from photo spallation of oxygen. Coward based on DeStaebler's calculation predicted that 280 Ci of ^{7}Be would be produced, at saturation, by the absorption of a 1 MW high energy electron beam in a large volume of water.[1,2] ^{7}Be decays by electron capture emitting a 477 keV γ 10.3% of the time to ^{7}Li. The decay scheme appears in Fig. 1.[3]

The purity of primary cooling water is maintained by a mixed bed cation and anion exchange resin. This resin bed is contained in a stainless steel column through which a portion of the primary cooling water is constantly circulated. During the early phases of accelerator operation ^{7}Be was detected in a resin bed servicing a small copper water-cooled beam dump which absorbed 1 - 10 kW's of electrons.[4]

Following completion of the BSY and experimental areas, use of the large water beam dumps became increasingly frequent. Initially electron beam power was limited to a few kW's for brief periods. Since then, higher power runs for longer periods of time have become commonplace. Electron beam power ranging between 20 - 100 kW's for 100 - 200 hours at energies of 5 to 20 GeV have been experienced.

The accelerator tube, beam scrapers, targets and beam dumps are water cooled. This water is low conductivity water and circulates in a primary cooling loop. Heat is removed at a heat exchanger supplied by a secondary cooling water loop from one of four cooling towers. There are thirty sectors each with three separate cooling systems: e.g., klystron, accelerator and waveguide systems. Of the three, the accelerator and waveguide systems provide cooling water to areas where activation products may be produced. The Beam Switchyard (BSY) and

research areas have six major cooling-water systems which provide cooling water for magnets, collimators, targets and beam dumps.

Each individual water system has a 1.5 ft^3 mixed bed ion exchange resin solumn in line to maintain water purity at 0.5 - 1.0 megohm-cm. There are ~70 of these resin beds which must be regenerated periodically. Of those radionuclides produced by the absorption of an e^- beam in water only ^7Be and ^3H have sufficiently long half-lives to create a disposal or handling problem. Of the water systems mentioned, 10 absorb sufficient beam power to produce enough ^7Be to present a handling and disposal problem. It is these latter systems where the greatest beam absorption occurs and therefore where the largest production of ^7Be is found.

The resin beds require regeneration periodically. We are not prepared to perform this task at SLAC. The beds are therefore sent out to a commercial firm for regeneration. Those resin beds which contain ^7Be in detectable quantities are processed at SLAC. We do not regenerate the beds but dispose of them as radioactive waste. Initially at low power levels we were seeing a few mCi's of ^7Be per column. When high power runs were sustained for several hours to days we began seeing fractions of curies of ^7Be in those resin columns used on the large copper and water beam dumps. This level of radioactivity resulted in dose rates of 200 - 800 mR/hr at the surface of these resin columns.

Water samples were taken immediately after beam shutdown and the ^7Be activity in the water ranged between 10^{-4} to 10^{-3} $\mu Ci/cc$. The ^7Be activity seemed to disappear from a second water sample taken 48 hours later.

It was apparent from the measured activity in the resin columns and the disappearance of the ^7Be in water that the resin beds were acting as very efficient filters.

This discussion will deal with the production and measurement of ^{7}Be in a large e^{-} beam water dump and the ultimate absorption of this isotope on a typical mixed bed resin column.

II. DISCUSSION

Since it is apparent that the resin beds are very efficient filters for ^{7}Be in water, it follows that some sort of equilibrium should exist; and that the time to reach equilibrium should be much sooner than the physical decay constant of this isotope would indicate.

Assuming a filtering efficiency of near unity, the removal rate can be described by the following equation:

$$\lambda_e = \frac{F}{V} \tag{1}$$

where

λ_e = removal constant

F = flow rate through resin bed

V = total volume of water in the primary system .

Equation (1) would indicate that 50% of equilibrium would occur in a few hours rather than 54 days as the physical half-life would indicate for steady state beam conditions.

The actual removal rate of ^{7}Be by the resin bed was determined by removing water samples from the primary cooling system of A-Beam Dump (ABD) at various times following beam turnoff and upstream of the resin bed. These samples were then counted for ^{7}Be activity. Figure 2 shows the removal of ^{7}Be as a function of time from ABD primary water. Approximately 10 hours of recirculating time at ~ 7.5 gpm through the resin bed was required to remove 1/2 of the ^{7}Be from

the primary water. Equation (1) would predict that 1/2 of the activity in water would be removed in ~ 4 hours.

The production rate of ^{7}Be can be calculated by using the predicted saturation activity of ^{7}Be for a given beam power.

$$\frac{(R)\,(k)}{k_1 P} = \mu Ci/MW\text{-}sec \qquad (2)$$

where

R = saturation activity, Ci

k = disintegrating atoms per second per Ci, d/Ci-sec

k_1 = number of atoms ^{7}Be per μCi

P = power in MW.

If the removal rate of ^{7}Be in the resin column and the production rate are known then the ^{7}Be activity in water for steady beam conditions can be predicted.

$$C_{(t)} = \frac{BP}{F}\left(1 - e^{-\lambda_e t}\right) \qquad (3)$$

where

$C_{(t)}$ = concentration of ^{7}Be in water, $\mu Ci/cc$

B = production constant, $\mu Ci/kW\text{-}sec$

P = electron beam power, kW

F = flow rate through resin bed, cc/sec

λ_e = removal rate in resin bed, min^{-1}

t = irradiation time, min .

The saturation activity is simply

$$C_{(sat)} = \frac{BP}{F} \qquad (4)$$

Figure 3 is a plot of activity vs irradiation time and absorbed electron beam power. Figure 4 is simply the saturation activity for various steady state conditions. The physical decay constant is not considered due to ^{7}Be's 54 day physical half-life.

Figure 3 demonstrates the build-up of ^{7}Be concentration as a function of beam power and irradiation time using the removal constant (λ_e) due to the filtering action of the resin column. It is this factor alone which causes saturation activity to be reached long before the predicted time based on ^{7}Be's physical half-life. The original calculation of DeStaebler and Coward did not include the filtering action of the resin beds. This means that for a 1 MW beam absorbed in water instead of having a maximum of 28 μCi/cc (or 280 Ci in 10^7 cc of water) the maximum concentration in water will be $\leq 1 \times 10^{-1}$ μCi/cc ($\sim$ 1 Ci) of ^{7}Be as long as the resin beds are being used in the system.

III. EXPERIMENT

The dump used for this experiment was A-Beam Dump (ABD) which is composed of a large water and copper dump containing $\sim$ 2000 gal. of water. ABD was designed to absorb a 2 MW electron beam. It is a 58" diameter by 15' long stainless steel tank. Copper plates located at the back are cooled by the same water which ultimately becomes the primary beam absorber. Flow-through the dump is $\sim$ 400 gal/min.

The heat exchanger is located outside the BSY and is cooled by cooling-tower water in a secondary loop. A second loop carrying a small fraction of the primary water through a resin column is located near the heat exchanger. Flow rate in this loop is normally 7-8 gal/min.

Two resin columns were placed in series in the resin column loop with water sampling points. The upstream column contained spent resin, while the downstream column contained new resin. Water samples were removed at arbitrary times while the e^- beam was dumped into ABD. A schematic is shown in Fig. 5. Beam current was monitored continuously and displayed on a chart providing a continuous record of beam current entering ABD.

Water samples were counted with a 400-channel analyzer and a 5" × 4" NaI well crystal. The well crystal will accept samples of 60 ml. Activity was calculated by integrating under the ^{7}Be photo peak and applying the necessary calibration factors. The data is reported in μCi/cc.

Following each experiment (48 hours) the absorbed activity was measured for each of the two resin columns (see Table 1). A factor of 2000 - 3000 difference in activity was noted. This infers a removal efficiency of near unity for the spent bed resin column. The depleted resin bed activity was measured with an ion chamber and assumed point source; the regenerated bed with a NaI crystal and associated 400-channel analyzer and an assumed distributed source.

TABLE 1

^{7}Be RESIN COLUMN ACTIVITY FOLLOWING EXPERIMENTS

Date	Depleted Bed			Regenerated Bed	Ratio
	mr/hr		mCi	mCi	
	Surface	1 meter			
1/12/68	200	10	170 ± 20%	0.06 ± 5%	2800
3/4/68	400	20	700 ± 20%	0.240 ± 5%	3000
3/19/68	600	34	1200 ± 20%	0.560 ± 5%	2000

The experimental results appear in Fig. 6 and clearly demonstrate that 50% of equilibrium does occur in ~ 10 hours. The power levels fluctuated during this experiment between 24 and 100 kW. The average power during this run was ~ 30 kW. The beam energy was 16 GeV.

Figure 7 shows the results of a second experiment. Note that the data points are scattered badly. The curve at the bottom shows the variation in beam power at the approximate time samples were removed from the water system. The solid lines describe the theoretical curve for a 30 kW and 50 kW steady state beam if it had existed. The average power for this run is estimated to be 40 kW.

Figure 8 shows a plot of the gamma spectrum from one of the water samples. This is a portion of a 0 - 3 MeV scan by a Ge(Li) crystal. The only peaks observed were from ^{7}Be (477 keV) and the 511 keV peak from ^{11}C.

IV. CONCLUSION

The resin beds currently used at SLAC are very efficient filters for ^{7}Be in water. The concentration of this isotope in water will not reach difficult proportions even at 1 MW due to the presence of the resin beds in the primary system.

Also, the resin beds will become convenient sources of easily recovered Curie quantities of ^{7}Be. Presently SLAC is treating the beds as radioactive waste. This isotope is costly to produce in Curie quantities by other means and would seem to be a useful isotope for research due to its uncomplicated decay scheme. For example, if a 1 MW electron beam is absorbed in ABD for 1 week ~ 4 Ci of ^{7}Be would be absorbed in a single resin column.

The fact that the ^{7}Be was absorbed efficiently by a spent resin bed would indicate that any high cross-sectional area mechanical filter would do as well in its place. Smith and Miller at UCRL found that ordinary Whatman 41 (541) filter

paper removed 50% of the ^{7}Be found in water samples as long as the pH remained very slightly acid.

DeStaebler's predicted production of ^{7}Be seems to be in agreement with the values reported. However, uncertainties (± 50%) concerned with the measurement of beam power over several hours make it difficult to measure the production constant precisely. These experiments were performed parasitically and the electron beam was adjusted to the needs of the primary experiment. Therefore, beam power was increased or decreased or turned off as needed. The water cooling system remained on at all times thus altering the concentration of ^{7}Be in water due to the resin column which continued to remove the isotope.

The resin beds used at SLAC have a demonstrably high filtering efficiency for ^{7}Be in the form that we produce at SLAC. Equation (1) should, therefore, describe within a few percents the removal rate. However, the calculated effective half-life is ~ 0.4 of the measured half life. Also, water samples collected during the two experiments and following beam turn-off revealed the presence of ^{7}Be in the samples both upstream and downstream of the resin beds. However, the downstream column contained less than 0.05 of the activity found in the upstream or depleted resin column.

Obviously the ^{7}Be is getting through the first bed but is not absorbing on the second bed. This would suggest some chemical change in the form of this isotope which affects filtration and perhaps is due to the resin bed itself. This condition even though unexplained does not alter the basic conclusions in this report.

REFERENCES

1. DeStaebler, H., "Photon Induced Residual Activity," Report No. SLAC-TN-63-92, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1963).
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3. Lederer, C. M., Hollander, J. M. and Perlman, I., Table of Isotopes, 6th Edition, (John Wiley and Sons, Inc., New York, 1967).
4. McCall, R. C., "Activation of Water During Beam Tests," Report No. SLAC-TN-66-4, Stanford Linear Accelerator Center, Stanford University, Stanford, California (1966).

PROPERTIES OF $^{7}_{4}Be$

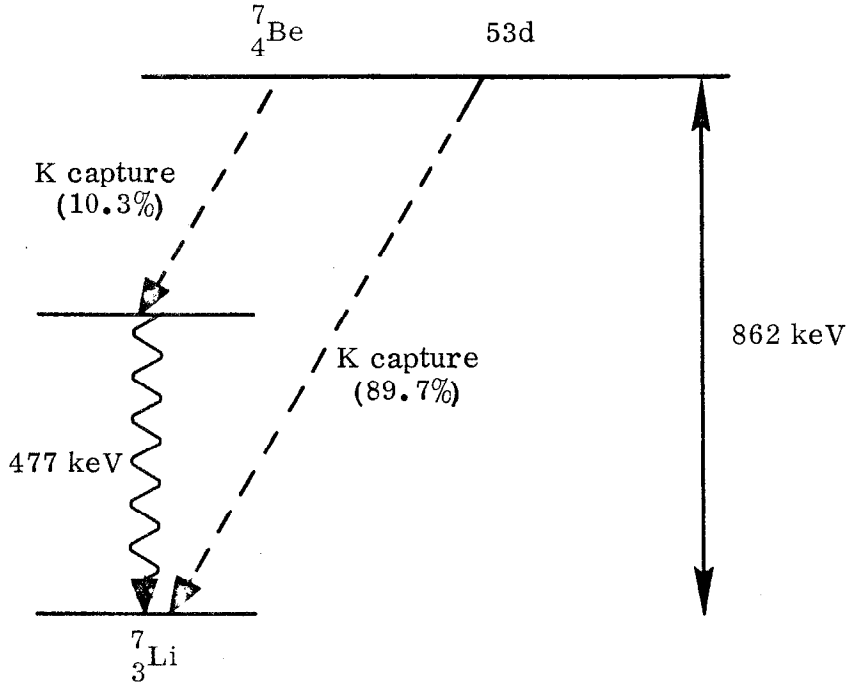

Fig. 1

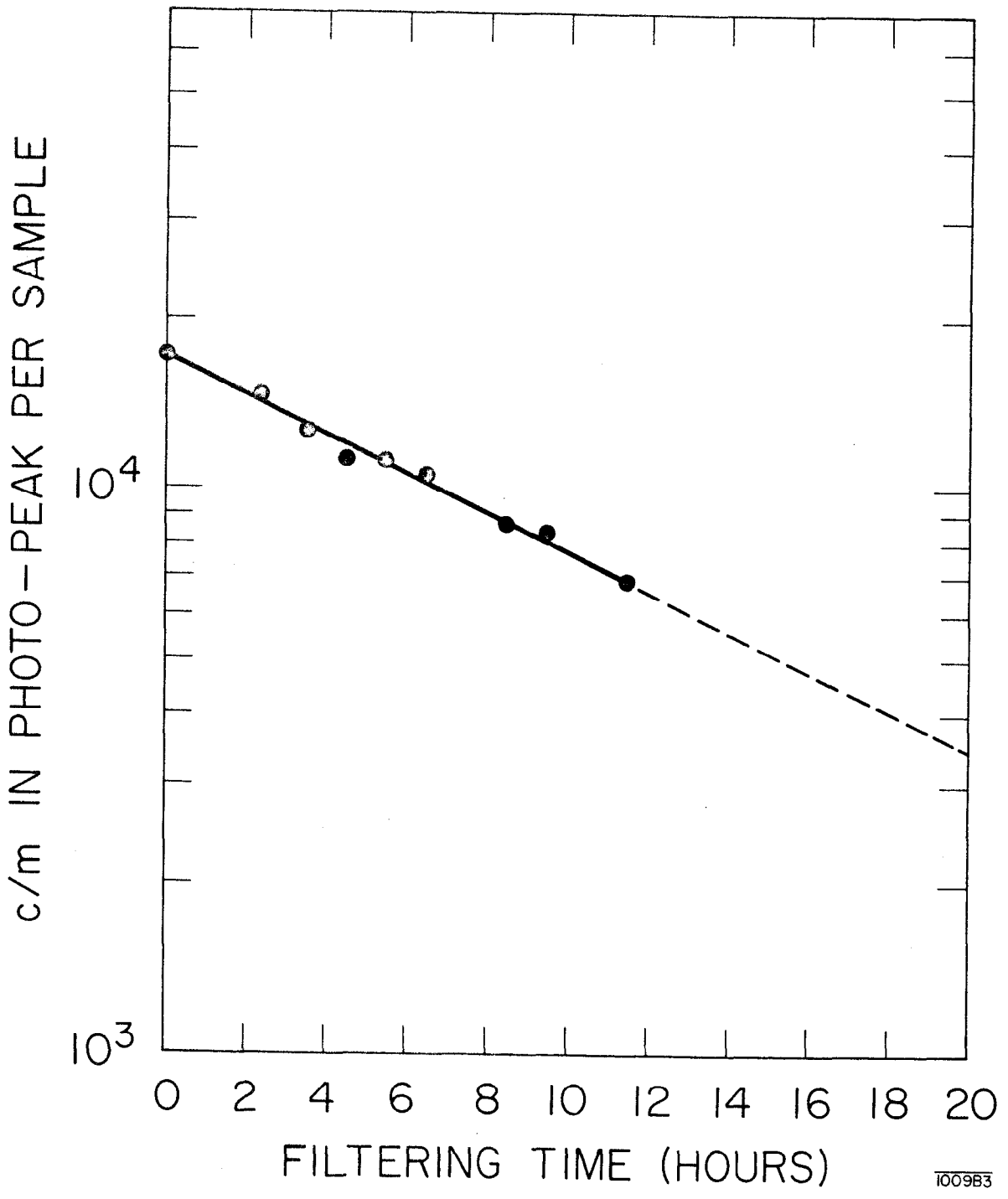
c/m IN PHOTO-PEAK PER SAMPLE
10^4
10^3
0 2 4 6 8 10 12 14 16 18 20
FILTERING TIME (HOURS)
1009B3

Fig. 2

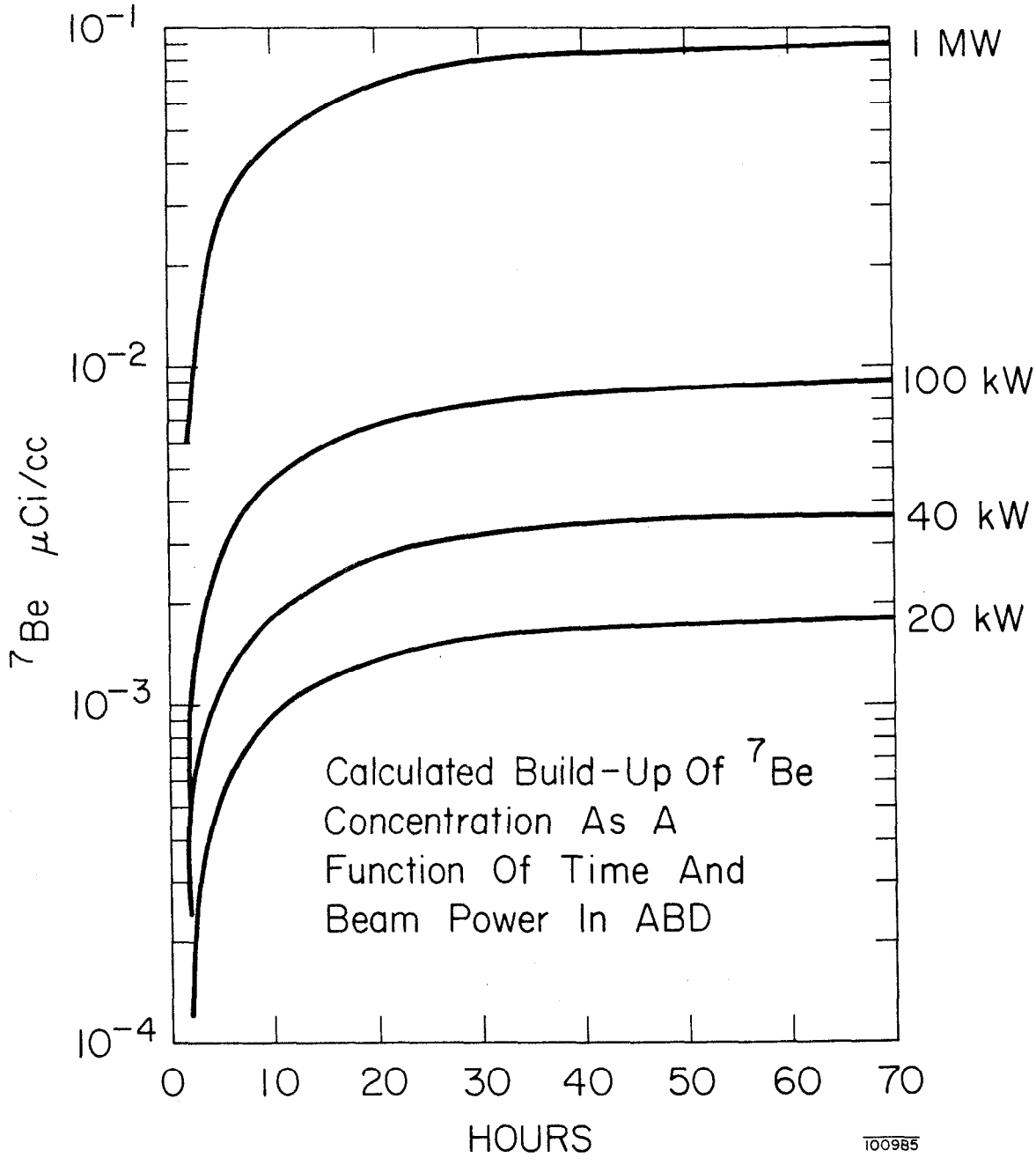
10^{-1}
10^{-2}
10^{-3}
10^{-4}
^{7}Be μCi/cc
1 MW
100 kW
40 kW
20 kW
Calculated Build-Up Of ^{7}Be Concentration As A Function Of Time And Beam Power In ABD
0
10
20
30
40
50
60
70
HOURS
100985

Fig. 3

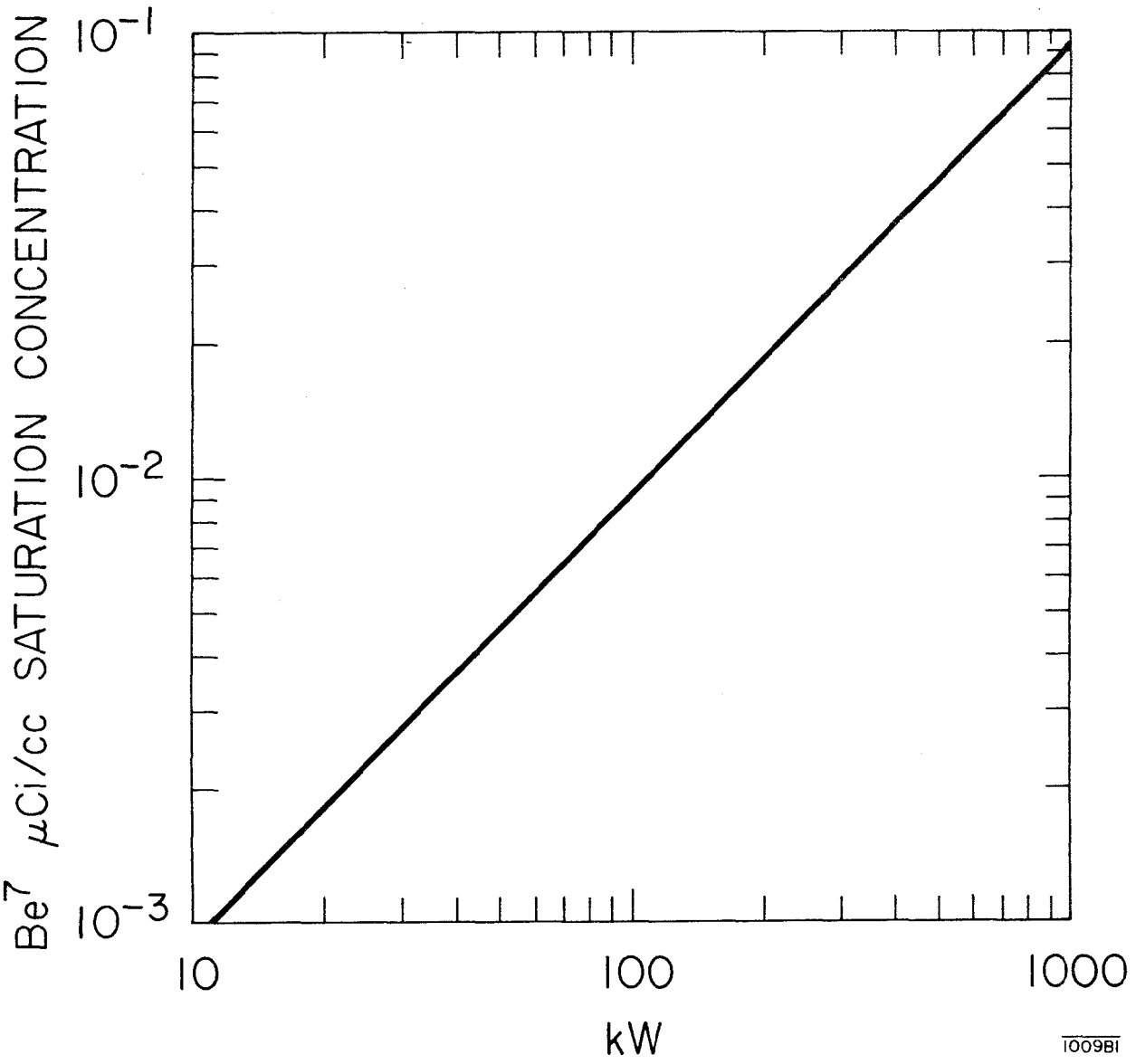
Be^7 μCi/cc SATURATION CONCENTRATION
10^{-1}
10^{-2}
10^{-3}
10
100
1000
kW
1009BI

Fig. 4

DIAGRAM OF WATER COOLING SYSTEM

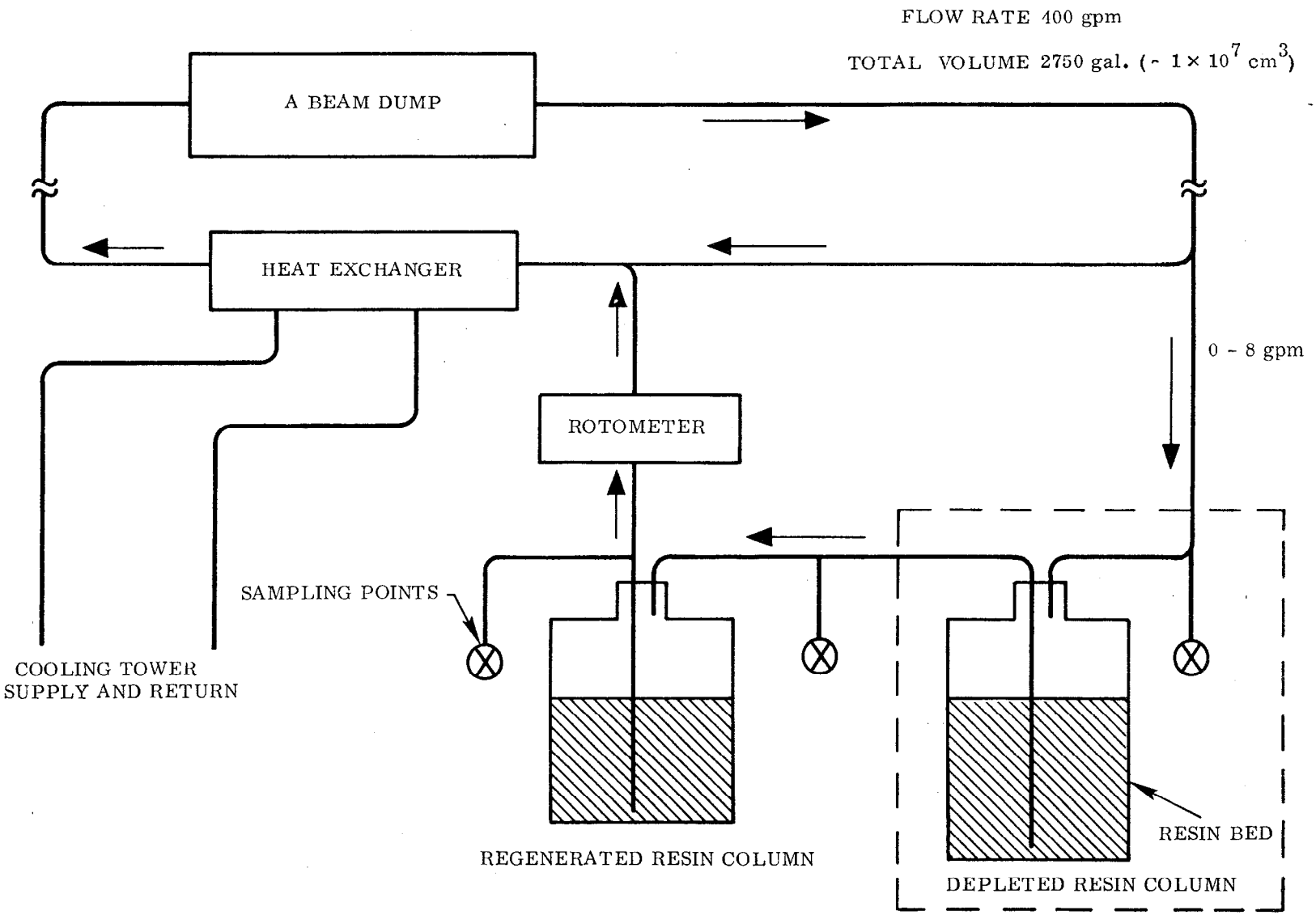

Fig. 5

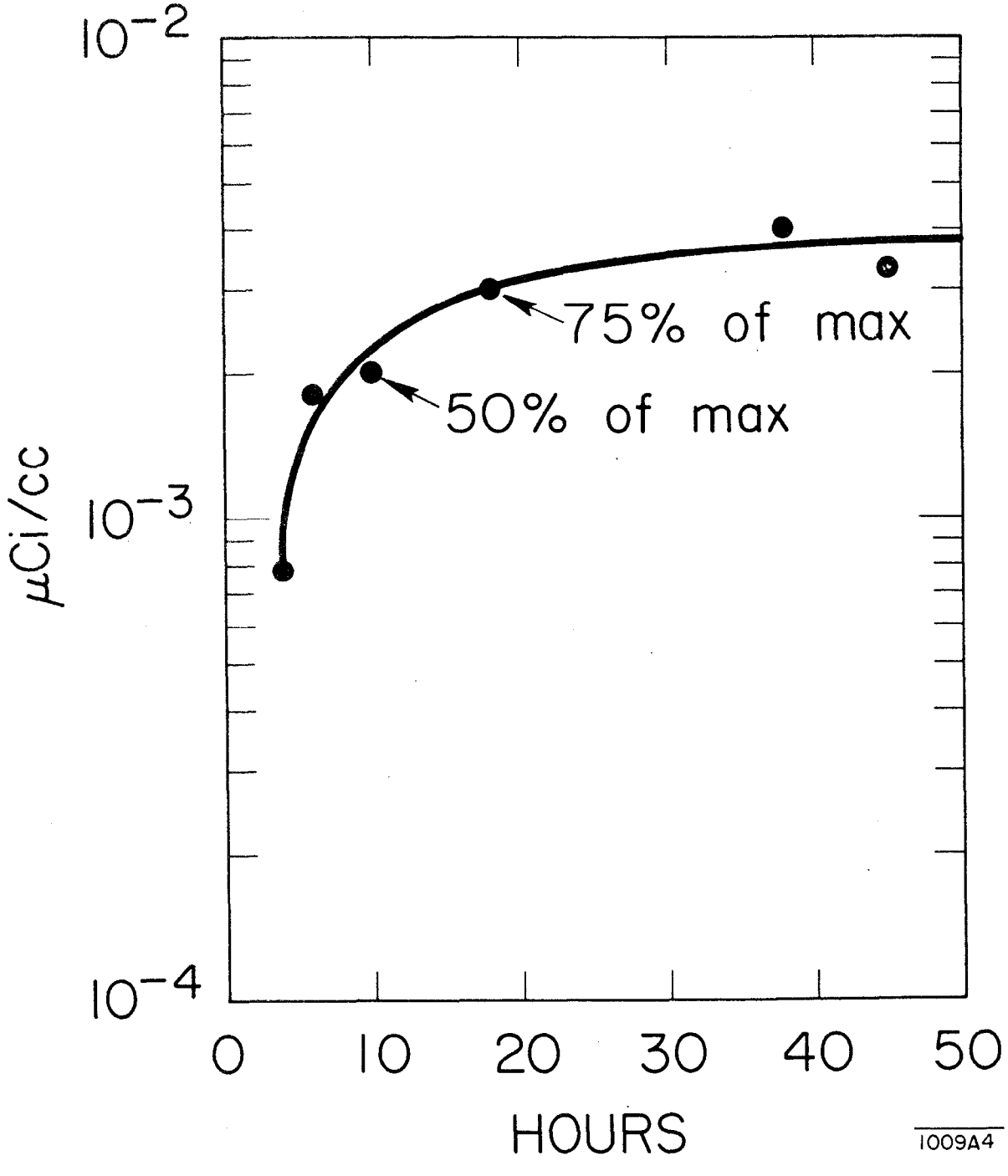
10^{-2}
10^{-3}
10^{-4}
μCi/cc
75% of max
50% of max
0
10
20
30
40
50
HOURS
1009A4

Fig. 6

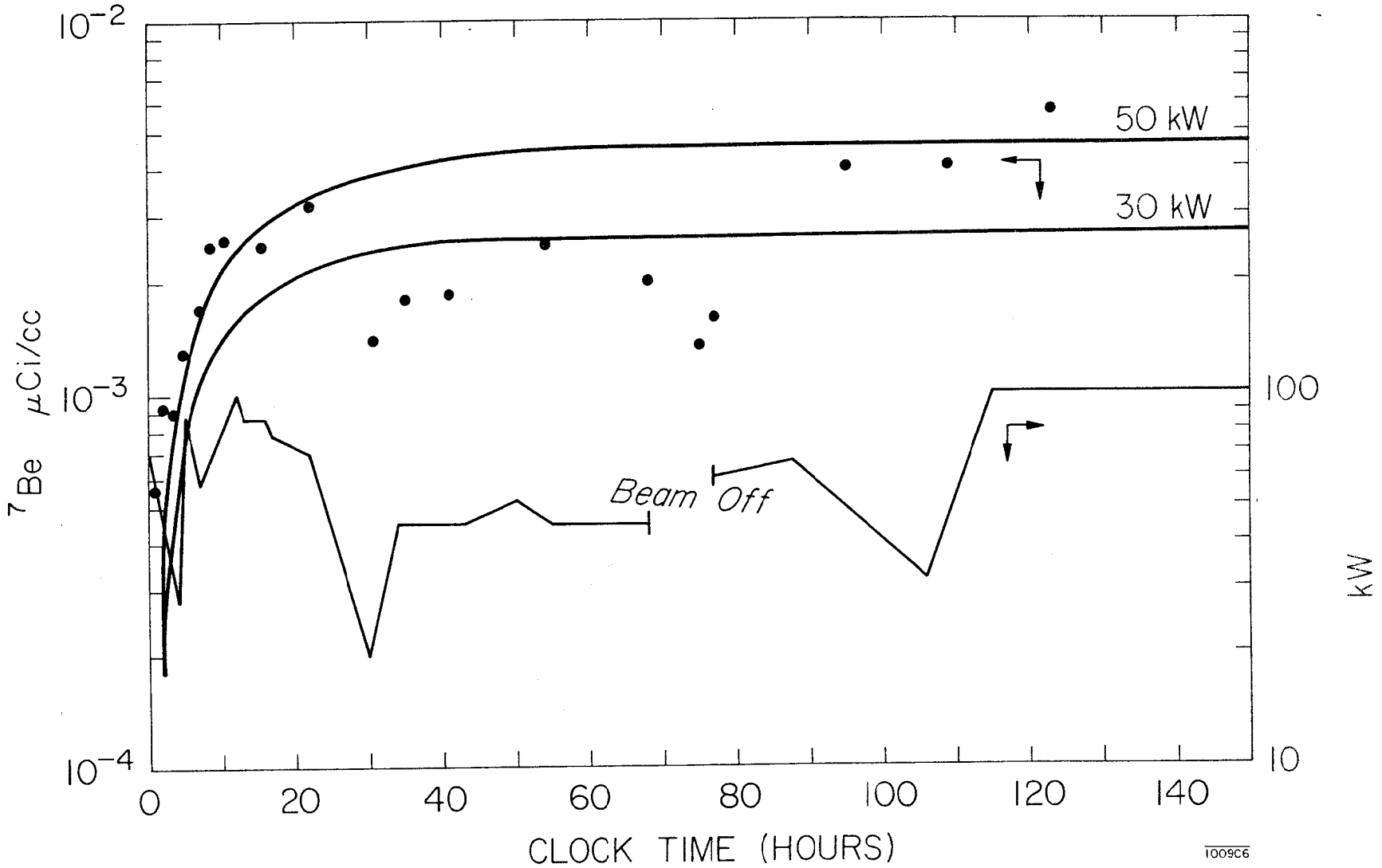
10^{-2}
10^{-3}
10^{-4}
^{7}Be μCi/cc
50 kW
30 kW
Beam Off
100
10
kW
0
20
40
60
80
100
120
140
CLOCK TIME (HOURS)
100906

Fig. 7

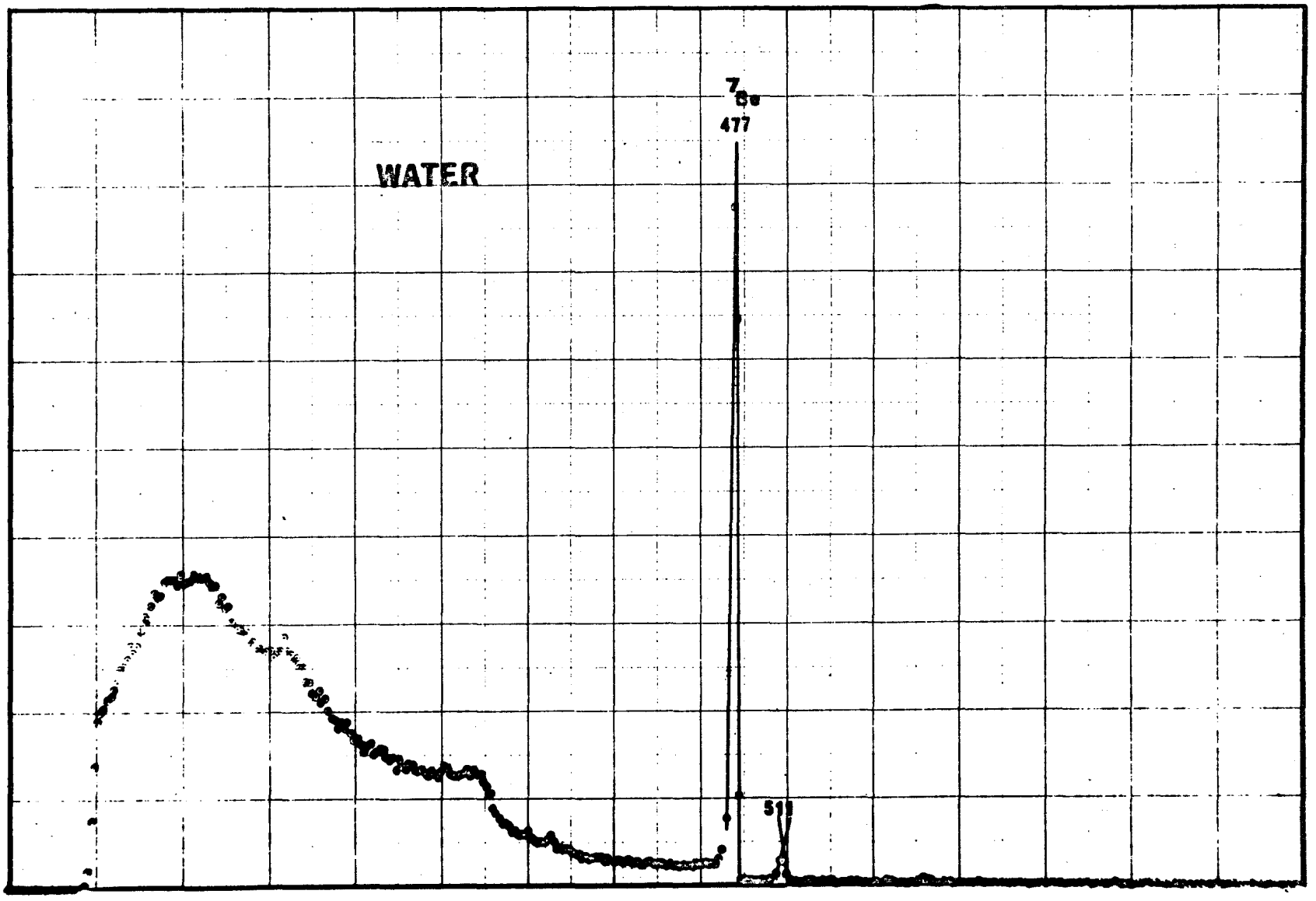

Fig. 8