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RESIDUAL RADIOACTIVITY IN THE FERMILAB ACCELERATOR ENCLOSURES

by

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Abstract

A self-propelled radiation survey vehicle is used each week to make measurements of the radiation levels in the various Fermilab accelerator enclosures resulting from residual radioactivity induced by losses from the proton beam. The vehicle is equipped with instruments which provide a strip chart record of the radiation intensity as a function of location. Other instruments integrate under this graph to yield the mean radiation intensity of a given segment of the accelerator. Plots of the mean radiation intensity as a function of time for the past fifteen months are presented here for several of the accelerator enclosures.

Introduction

The residual radioactivity present in the Fermilab beam-line enclosures is induced by high-energy protons lost from the primary beam. These protons cause spallation reactions and nuclear cascades in the steel, copper, concrete, and other materials comprising the vacuum system, magnets, supporting structures, and enclosure walls of the accelerator. Virtually all isotopes lighter than the elements present in these materials can be formed through nuclear reactions initiated by the primary protons. Thus, the radiation in the accelerator enclosures consists of β- and γ-ray emissions from many radioactive isotopes. While the resulting radiation spectrum is complex and is a function of both time and position, its combined interaction with matter is not too different from that associated with 1 MeV γ-radiation.

The Fermilab radiation survey vehicle has been described elsewhere (1). This battery-powered golf cart is equipped with a Geiger-Mueller tube, a logarithmic count-rate meter, a strip chart recorder, and the necessary power supply equipment. The strip chart is advanced by pulses which are initiated with a signal obtained from one of the wheels of the vehicle. Over the speed range (0-10 mph) of the golf cart the chart-drive speed is directly proportional to the vehicle speed. One centimeter on the chart paper corresponds to 43 meters of vehicle travel. Although an effort is made to maintain a fixed distance of 30 cm between the G-M tube and the beam-line devices during the conduct of the survey, experience has shown that this parameter is not critical.

Procedure

During normal accelerator operations, one day of each week is devoted to routine maintenance work which requires access to beam-line enclosures by work crews. Immediately prior to these accesses, radiation surveys are conducted in all of the enclosures in order to establish safe working conditions and maximum occupancy times. The enclosures in which the radiation survey vehicle is used include the 150 m diameter, 8 GeV, Booster Accelerator, the 2 km diameter, 400 GeV Main Accelerator, and the Switchyard, through which the 400-GeV protons are distributed to the various experimental areas. Figures 1, 2, and 3 are reproductions of strip charts obtained with the survey vehicle in the Booster, the Main Ring, and the Switchyard, respectively. It should be noted that due to the highly compressed distance scale on these strip charts, the extremely narrow peaks which appear as "fine structure" on the broader features are real and are reproducible.

The Booster chart shown in Figure 1 was made on October 23, 1975, 1 1/2 hours after the beam had been turned off. The important features on this graph are the injection (period 1) and extraction (period 13) regions of the accelerator. Also clearly visible in this plot are the increased levels of radioactivity present in all of the 24 short straight sections, located at the period markers. The Main Ring chart shown in Figure 2 was made on October 16, 1975, 24 hours after the beam had been turned off. The major loss points in the Main Ring are the Transfer Hall where both injection and extraction take place and the beam abort device located at D-0. A typical Switchyard chart is shown in Figure 3. This survey was conducted on November 3, 1975, 7 hours after the beam was turned off. The highest loss point in the Switchyard is the shield at the upstream end of Enclosure C. This device limits the size of the beam entering the Lambertson magnets. Other loss points in the Switchyard include the Lambertson magnets near the upstream end of Enclosures B and C and the electrostatic septa in Enclosures B and E.

In August 1974 an important modification was made to the survey vehicle. A six-digit scaler was added which registers pulses from the G-M tube. The scaler is gated on for 50 msec each time a magnet mounted on the rim of one of the vehicle's wheels passes by a magnetic switch. (This is the same mechanism which advances the paper in the strip-chart recorder.) The number of counts registered on the scaler is, to a first approximation, independent of the vehicle speed, and is proportional to the radiation intensity averaged over a given length of enclosure. The approximation is good since the vehicle moves 20 cm per counting period at its top speed. The equipment has been calibrated and the proportionality constants have been determined for all segments of the various enclosures. Corrections for detector dead time are made to the observed count rates.

The use of this scaler permits the study of long-term changes in residual radioactivity throughout the accelerator. To make these data more meaningful, corrections are made to the scaler readings for the short-term decay in activity which takes place during the first few hours after the accelerator has been turned off. Figures 4, 5, and 6 show typical short-term decays of residual radioactivity in the Booster, Main Ring, and Switchyard enclosures, respectively.

Results

Figures 7 and 8 show the radiation intensity resulting from residual radioactivity in the Booster Accelerator as a function of time. Figure 7 contains plots of the radiation intensity, measured at a distance of 30 cm from the Booster magnets, averaged over the injection segment and over the 471 m circumference of the accelerator. All radiation intensities have been corrected to indicate their value at eight hours after the beam was turned off. Figure 8 contains similar plots of data for the extraction segment of the Booster Ring and for the total Booster less injection and extraction. Figure 9 shows the radiation intensity (8 hours after beam-off) averaged over the 6.28 km circumference of the Fermilab Main Ring and over the 150 m long Transfer Hall. Figure 10 contains a similar plot of radiation intensity for the Main Ring less the Transfer Hall and the beam abort segments.

Figures 11, 12, and 13 show the mean radiation intensities in the several enclosures comprising the Switchyard. Mean intensities were not measured in the Switchyard prior to January 1975. Errors in the measurements shown in Figures 7-13 are estimated to be within ± 20%. This degree of accuracy is sufficient since the primary function of these data is to show long-term trends in residual radioactivity. Figure 14 is a graph of the total number of protons accelerated per week in the Main Ring as a function of time. To a large extent the trends in Figure 14 are also present in the residual radioactivity graphs (Figures 7-13). In particular the sharp increase in productivity since beginning 400-GeV operation in July 1975 is apparent in the residual radioactivity throughout the accelerator. The injection and extraction efficiencies in the accelerator system are high and stable in time. This stability is demonstrated by the similarity between the residual radioactivity graphs (Figures 7-13) and the accelerator output graph (Figure 14).

Conclusions

Since August 1974, when measurements of mean radiation intensity began, the long-term trend in residual radioactivity has been rather stable in most parts of the Fermilab accelerator. Over periods of weeks, excursions related to accelerator output have been noted, but most enclosures have nearly the same level of residual activity in late 1975 as they had in mid 1974.

In conclusion, it can be said that long term residual radioactivity data of the type presented here are important in predicting the conditions which will attend projected changes in accelerator configuration and operation. From the past history of residual radioactivity build-up as a function of known proton losses the determination of future radiation levels within beamline enclosures can be made, and safe working conditions and procedures in these areas can be established.

Acknowledgements

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Reference

1. R. E. Shafer and D. D. Jovanovic, IEEE Trans. Nuc. Science NS-20, 499 (1973).

Figure Captions

Figure 1: Radiation survey vehicle strip chart of the Fermilab Booster Accelerator showing a plot of radiation intensity vs. position. The numbered marks at the top of the figure indicate the position of the short straight section in each Booster period. This survey was made on October 23, 1975.

Figure 2: Radiation survey vehicle strip chart of the Fermilab Main Ring. The event marker at the top of the chart indicates the location of quadrupole magnets (~ 30 m apart) for horizontal axis calibration. This survey was made on October 16, 1975.

Figure 3: Radiation survey vehicle strip chart of the Fermilab Switchyard showing radiation intensity vs. position on November 3, 1975.

Figure 4: Short term radioactivity decay plot for the Booster accelerator showing relative radiation intensity vs. hours after beam off.

Figure 5: Short term radioactivity decay plot for the Main Ring showing relative radiation intensity vs. hours after beam off.

Figure 6: Short term radioactivity decay plot for the Switchyard showing relative radiation intensity vs. hours after beam off.

Figure 7: Mean radiation intensity vs. time for the total Booster enclosure and for the 200 MeV proton injection segment of the Booster enclosure. For Figures 7 through 13 all intensities have been corrected to their value at 8 hours after beam off, and dashed lines indicate no surveys during these weeks.

Figure 8: Mean radiation intensity vs. time for the 8 GeV proton extraction segment of the Booster enclosure and for the total Booster less injection plus extraction.

Figure 9: Radiation intensity vs. time for the Fermilab Main Ring and for the Transfer Hall.

Figure 10: Mean radiation intensity vs. time for the Main Ring less Transfer Hall and Beam Abort.

Figure 11: Mean radiation intensity vs. time for the Switchyard Enclosures B and D.

Figure 12: Mean radiation intensity vs. time for the Switchyard Enclosure C.

Figure 13: Mean radiation intensity vs. time for the Switchyard Enclosure E.

Figure 14: Main Ring beam intensity (protons/week) vs. time. "Off" indicates periods when the accelerator systems were shut down for maintenance and development work.

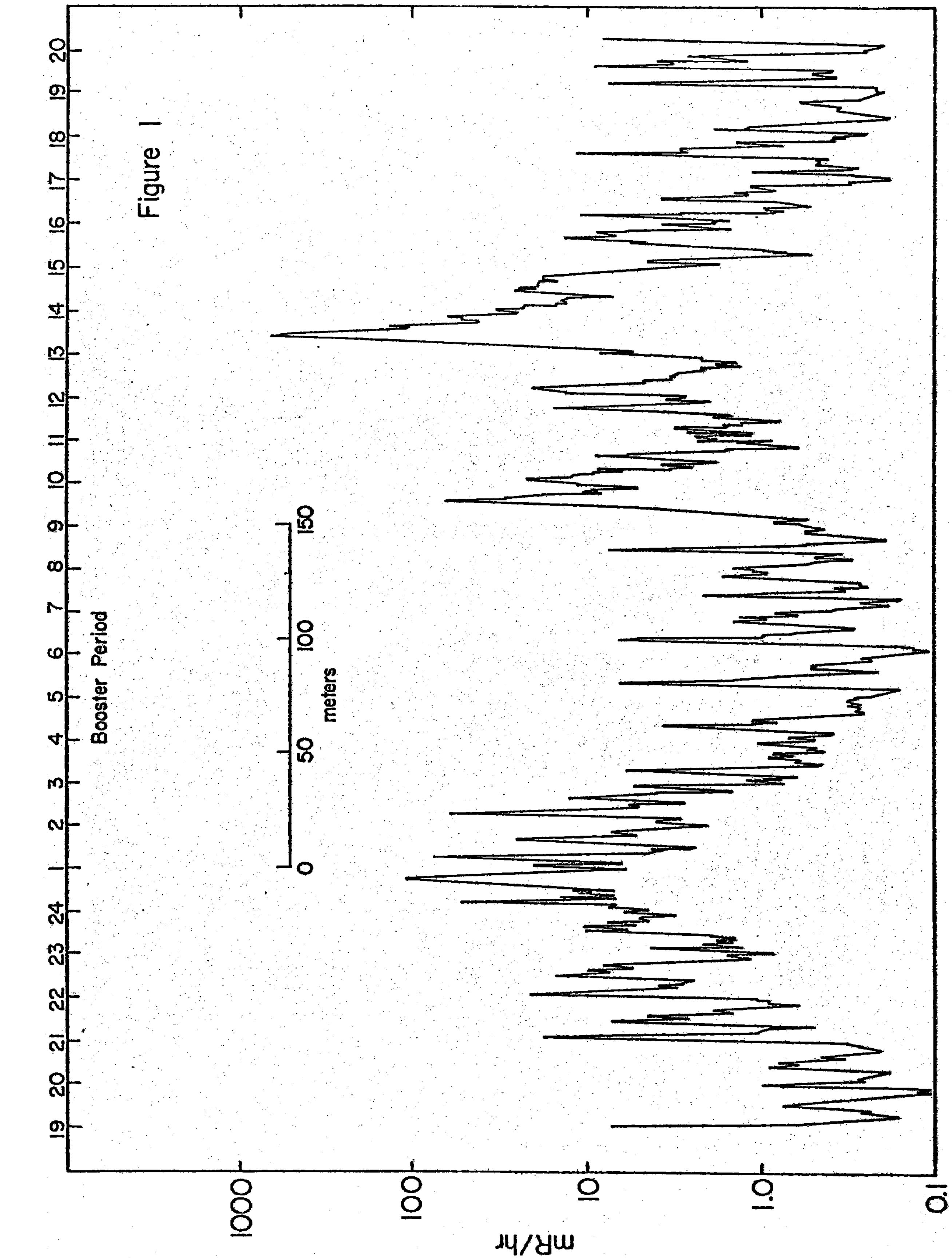
Figure 1
Booster Period
meters
mR/hr

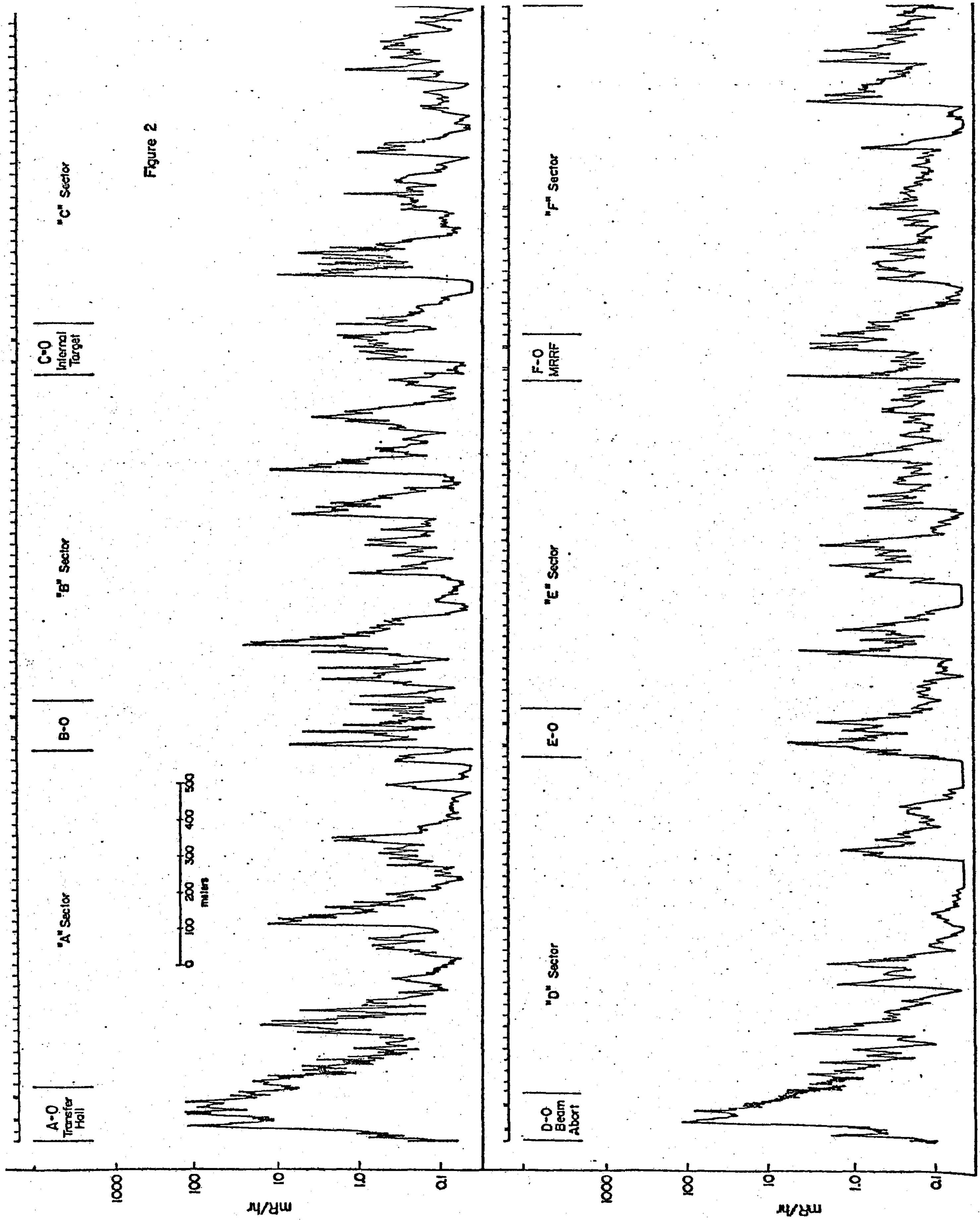
Figure 2
A-O Transfer Hall
"A" Sector
B-O
"B" Sector
C-O Internal Target
"C" Sector
D-O Beam Abort
"D" Sector
E-O
"E" Sector
F-O MRRF
"F" Sector
0 100 200 300 400 500
meters
1000
100
10
1.0
0.1
mR/hr

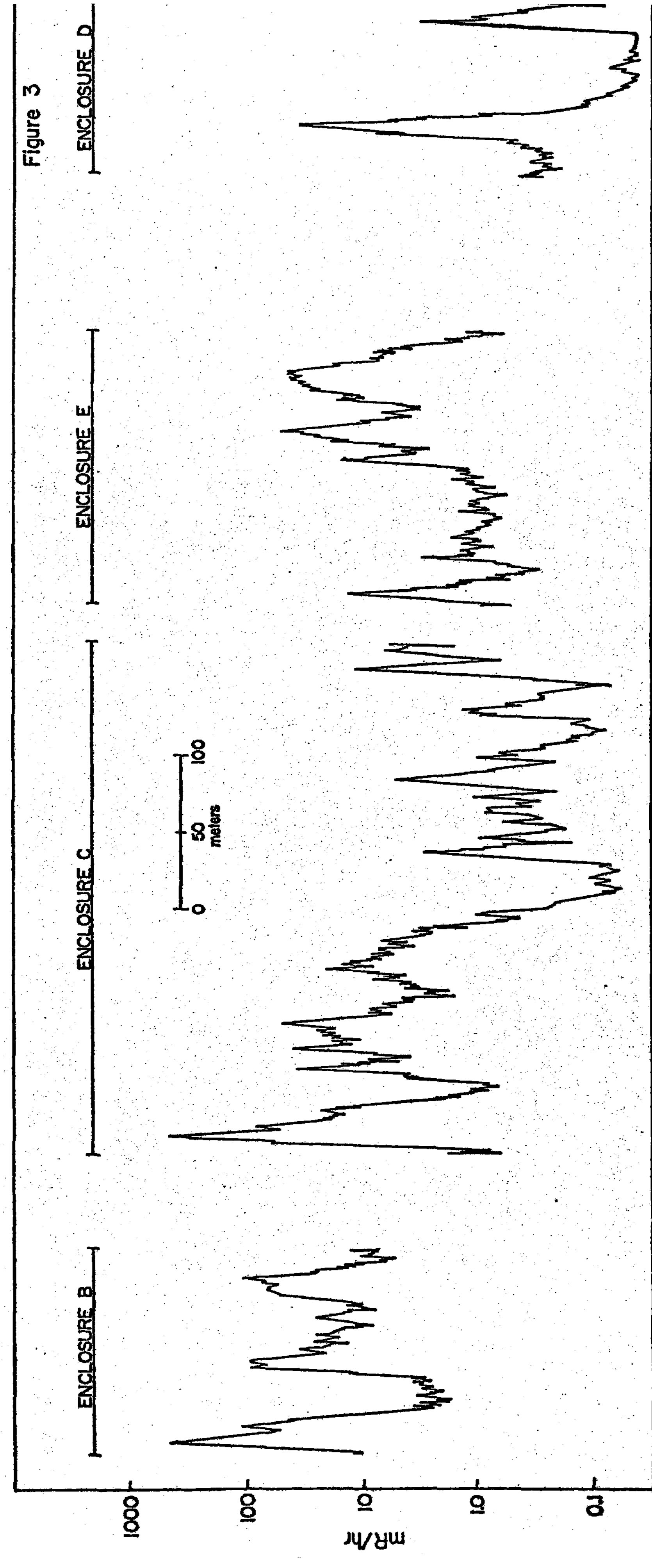
ENCLOSURE B
ENCLOSURE C
ENCLOSURE E
ENCLOSURE D
0
50
100
meters
1000
100
10
1.0
0.1
mR/hr

Figure 3

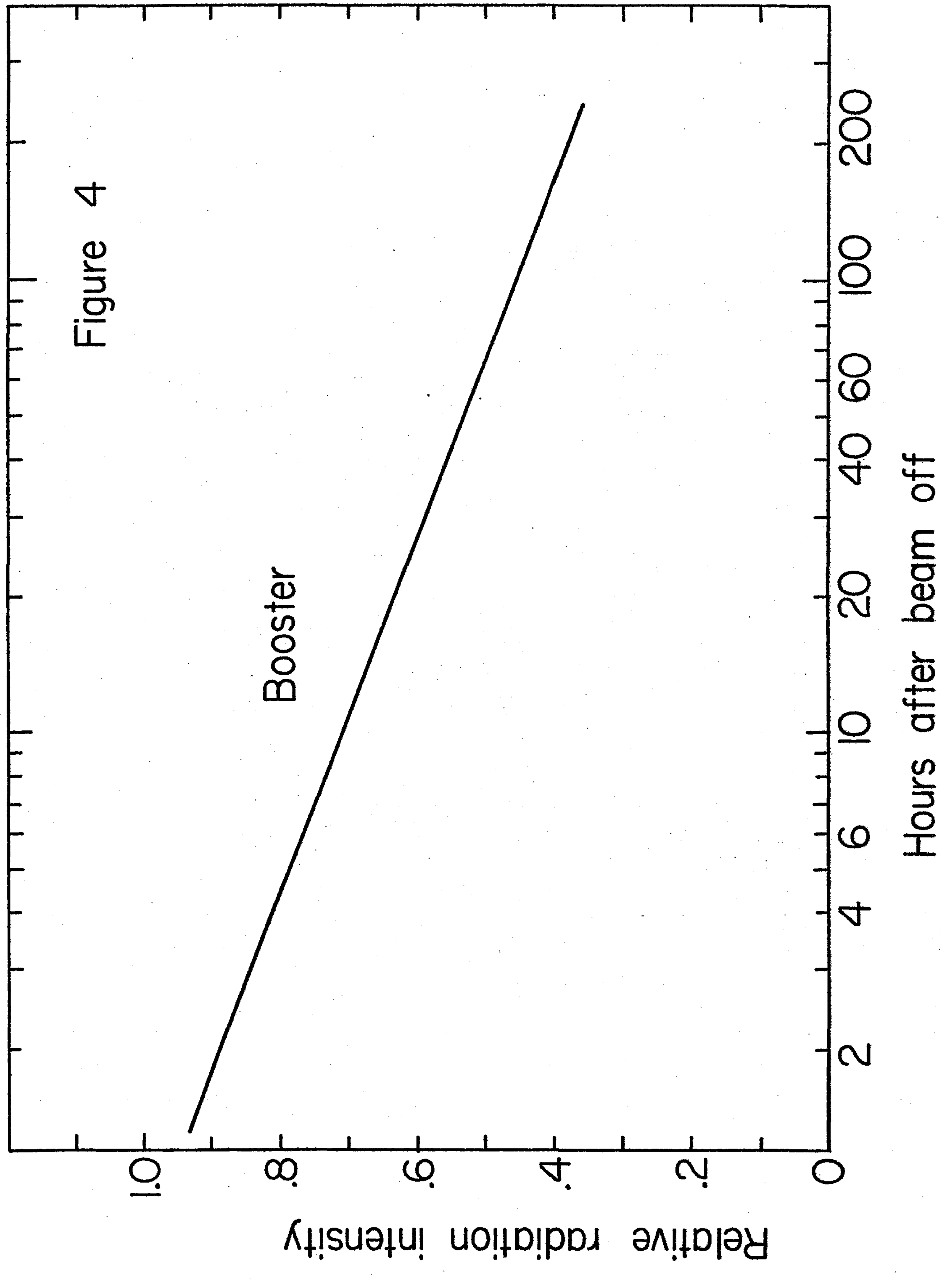
Booster
Relative radiation intensity
0
.2
.4
.6
.8
1.0
Hours after beam off
2
4
6
10
20
40
60
100
200

Figure 4

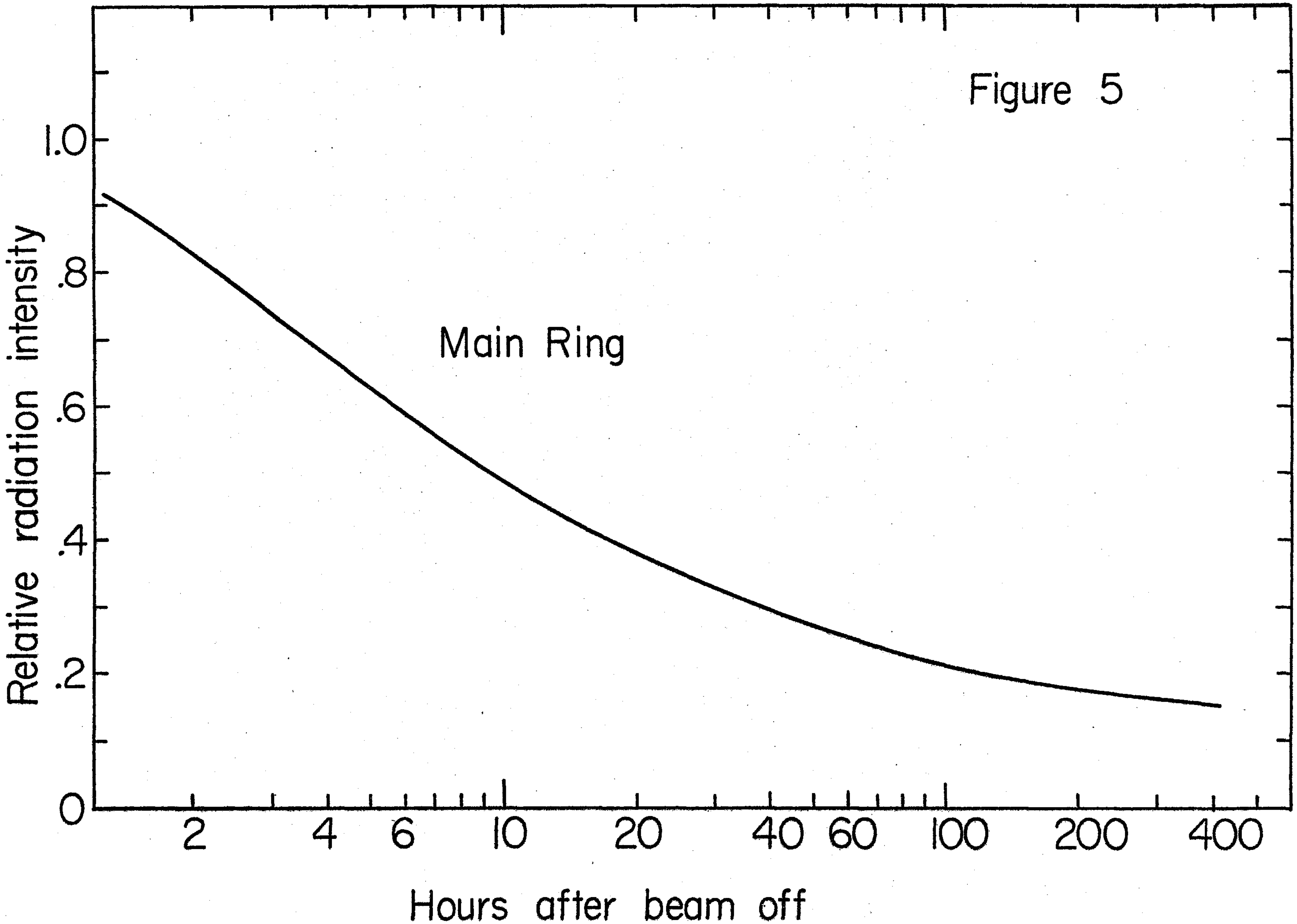
Main Ring
Relative radiation intensity
0
.2
.4
.6
.8
1.0
2
4
6
10
20
40
60
100
200
400
Hours after beam off

Figure 5

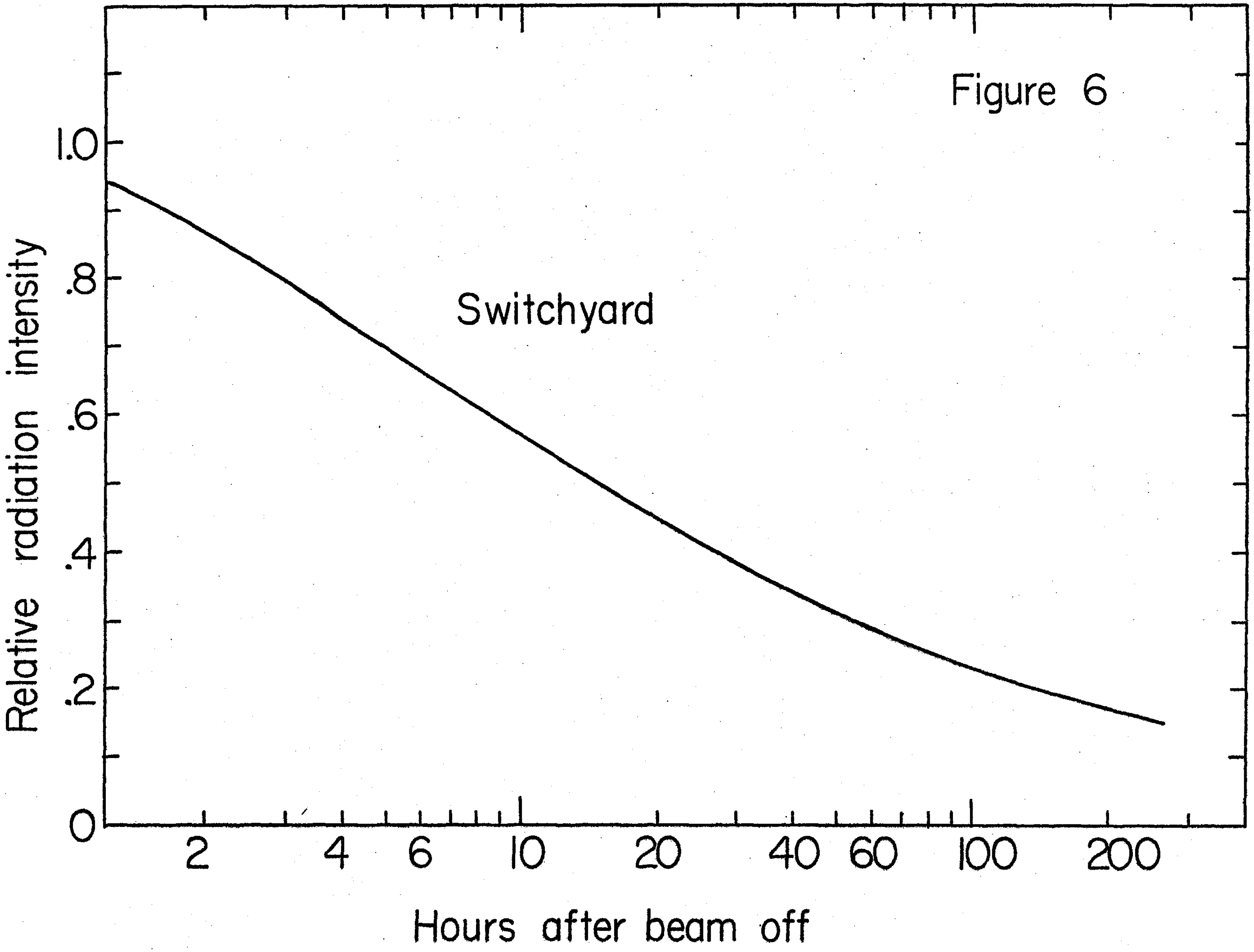
Figure 6
Switchyard
Relative radiation intensity
1.0
.8
.6
.4
.2
0
2
4
6
10
20
40
60
100
200
Hours after beam off

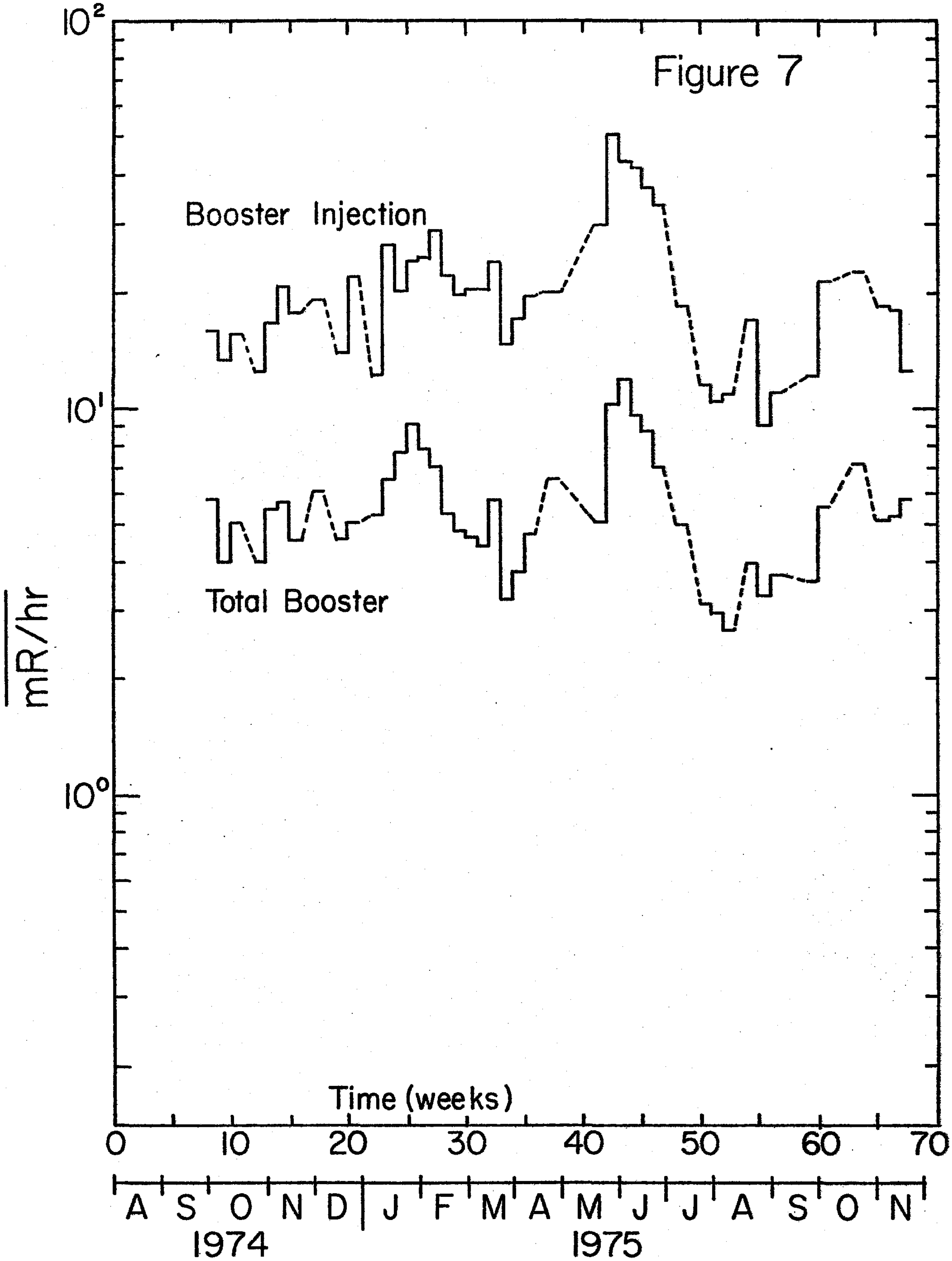

Figure 7
Booster Injection
Total Booster
mR/hr
10^2
10^1
10^0
Time (weeks)
0
10
20
30
40
50
60
70
A S O N D J F M A M J J A S O N
1974
1975

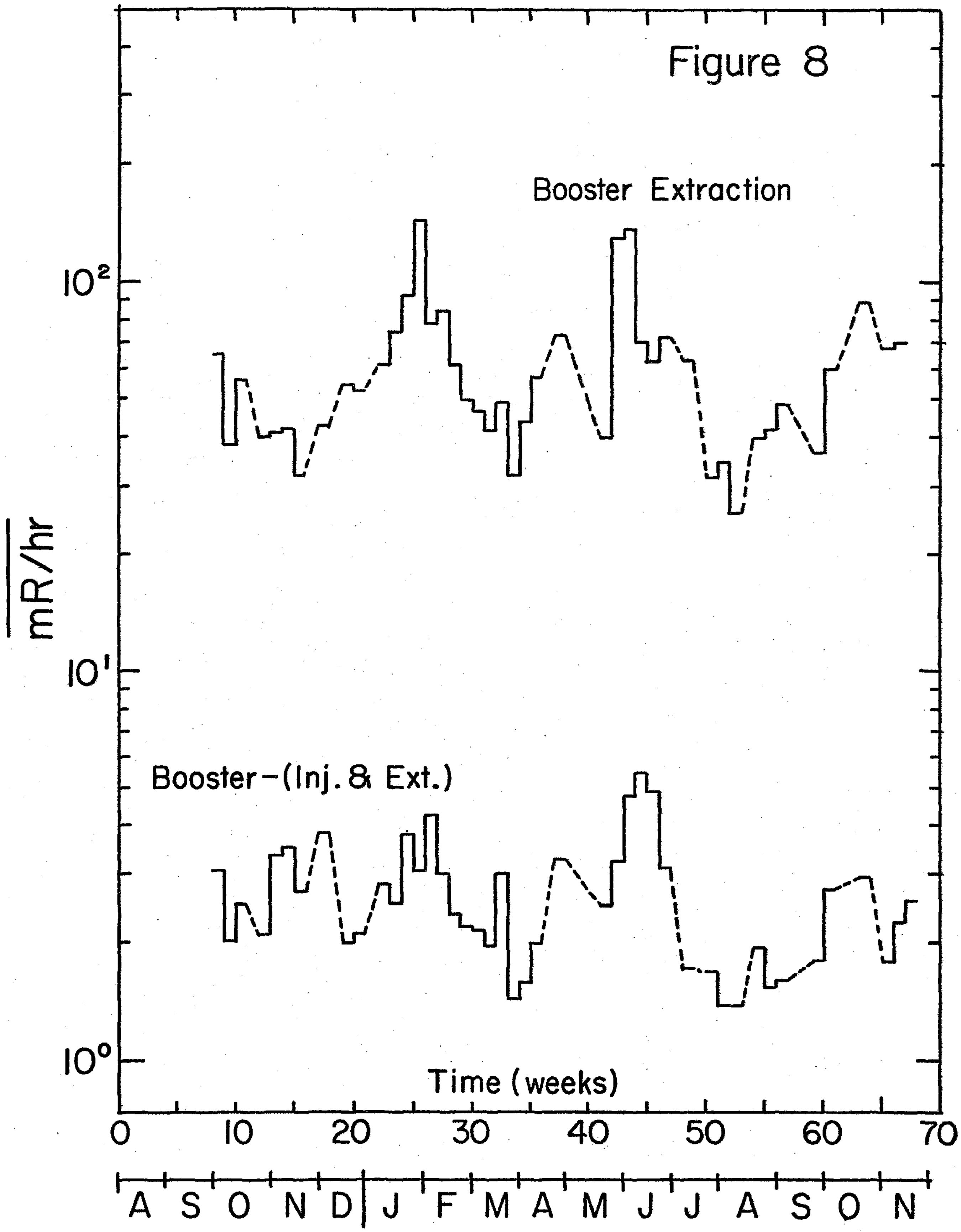
Figure 8
Booster Extraction
Booster-(Inj. & Ext.)
mR/hr
10^2
10^1
10^0
Time (weeks)
0
10
20
30
40
50
60
70
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
N

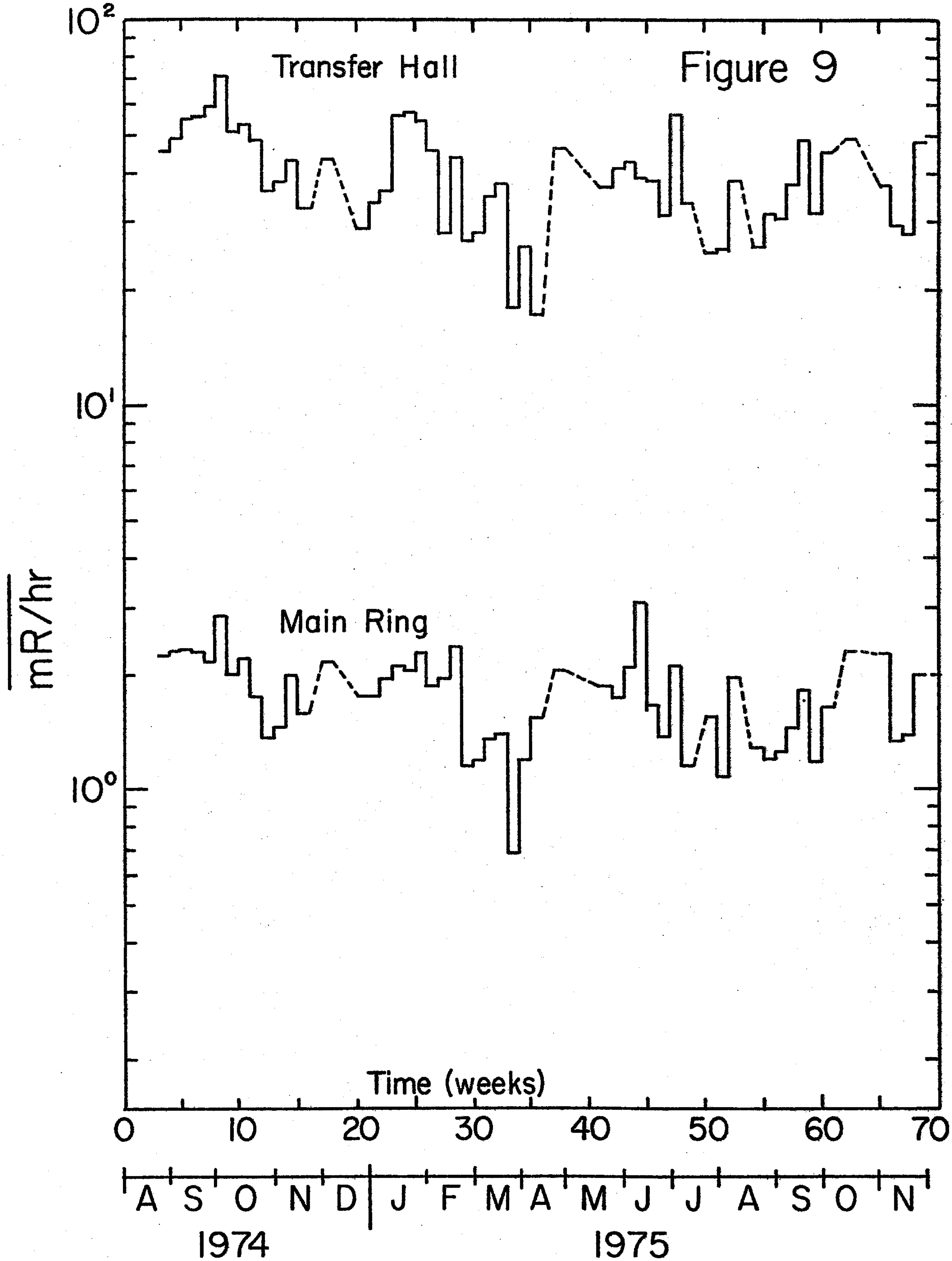
Figure 9
Transfer Hall
Main Ring
mR/hr
10²
10¹
10⁰
Time (weeks)
0
10
20
30
40
50
60
70
A S O N D J F M A M J J A S O N
1974
1975

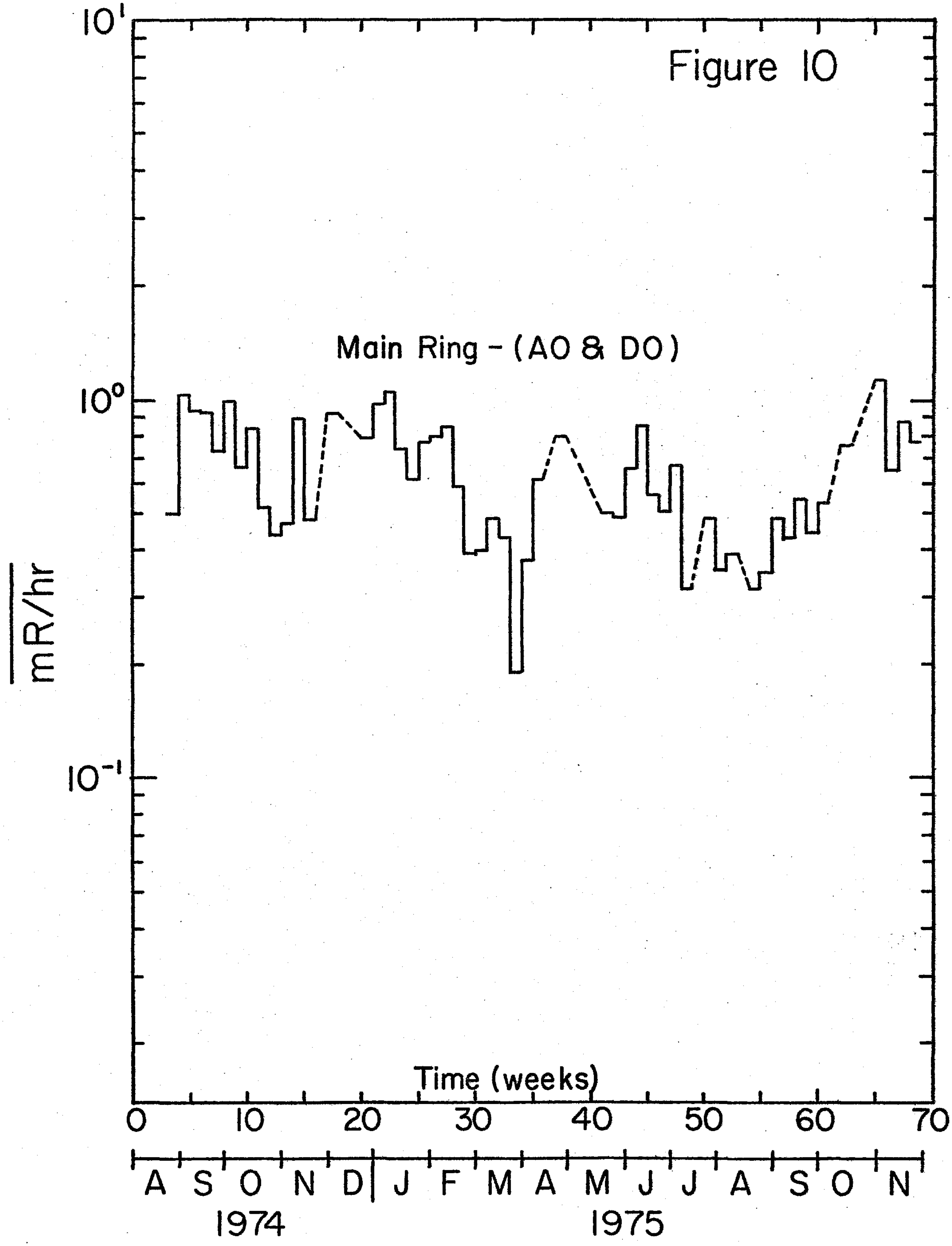
Figure 10
Main Ring - (AO & DO)
10^1
10^0
10^{-1}
mR/hr
Time (weeks)
0
10
20
30
40
50
60
70
A S O N D J F M A M J J A S O N
1974
1975

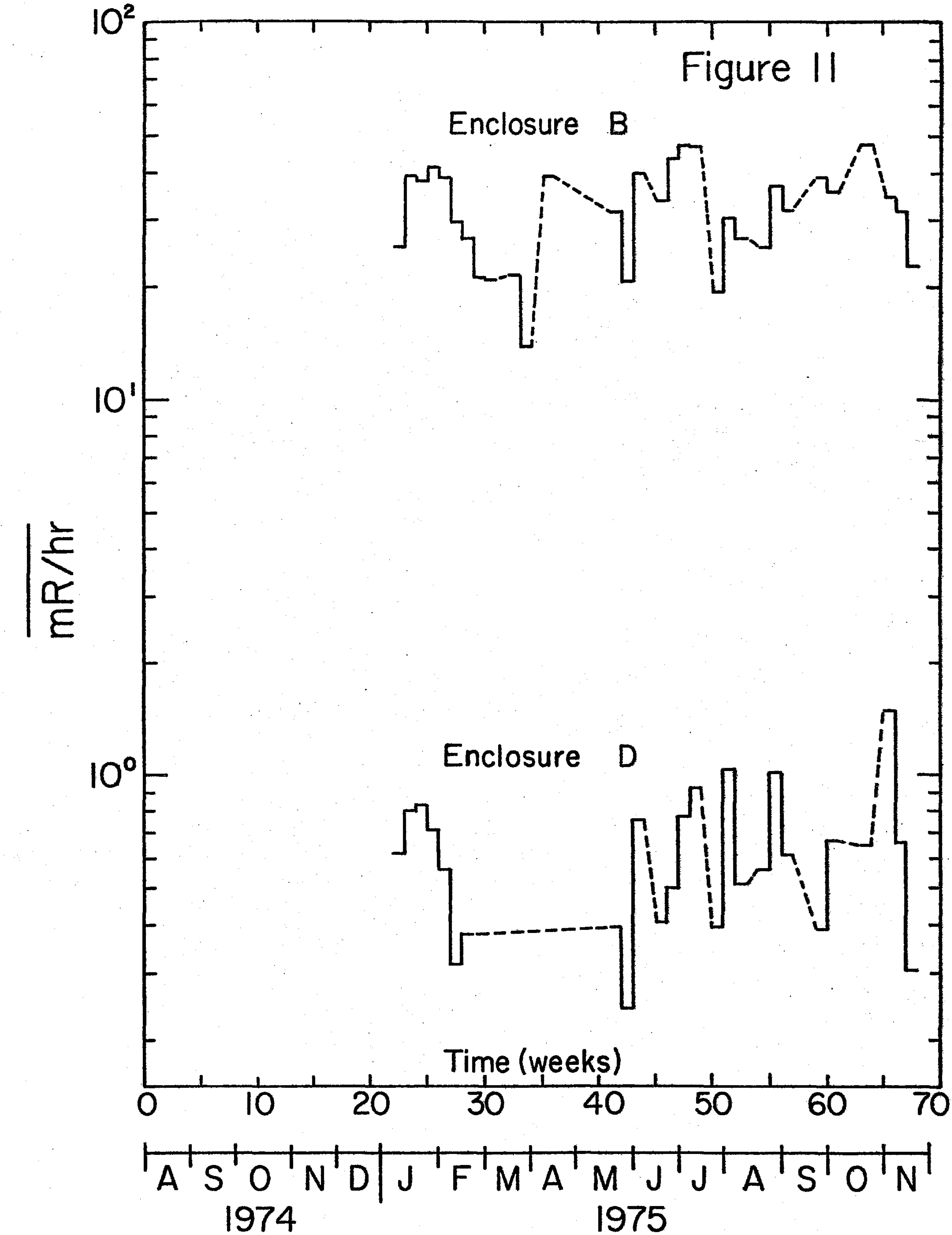
Figure II
Enclosure B
Enclosure D
mR/hr
10²
10¹
10⁰
Time (weeks)
0
10
20
30
40
50
60
70
A S O N D J F M A M J J A S O N
1974
1975

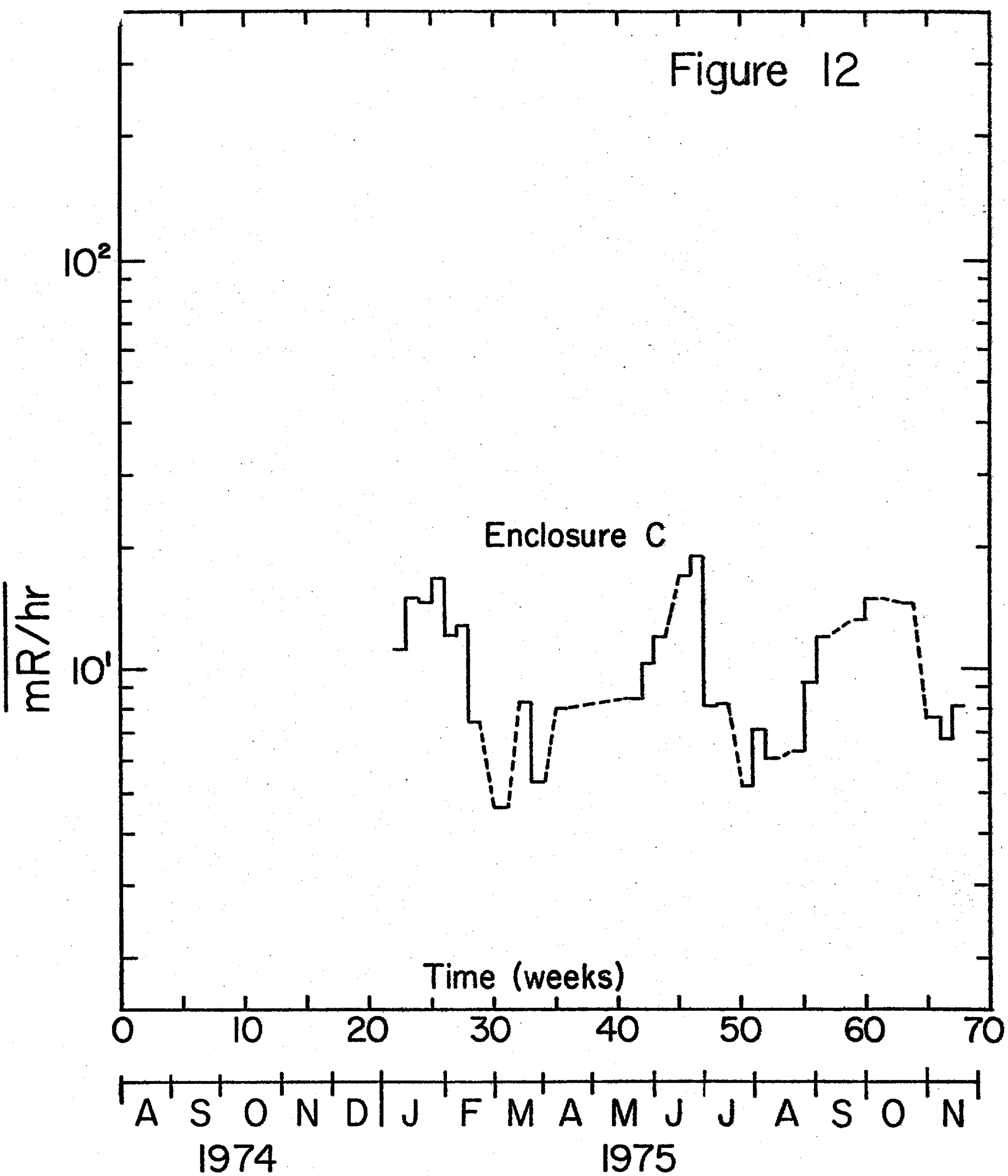
Figure 12
Enclosure C
mR/hr
10²
10¹
Time (weeks)
0
10
20
30
40
50
60
70
A S O N D J F M A M J J A S O N
1974
1975

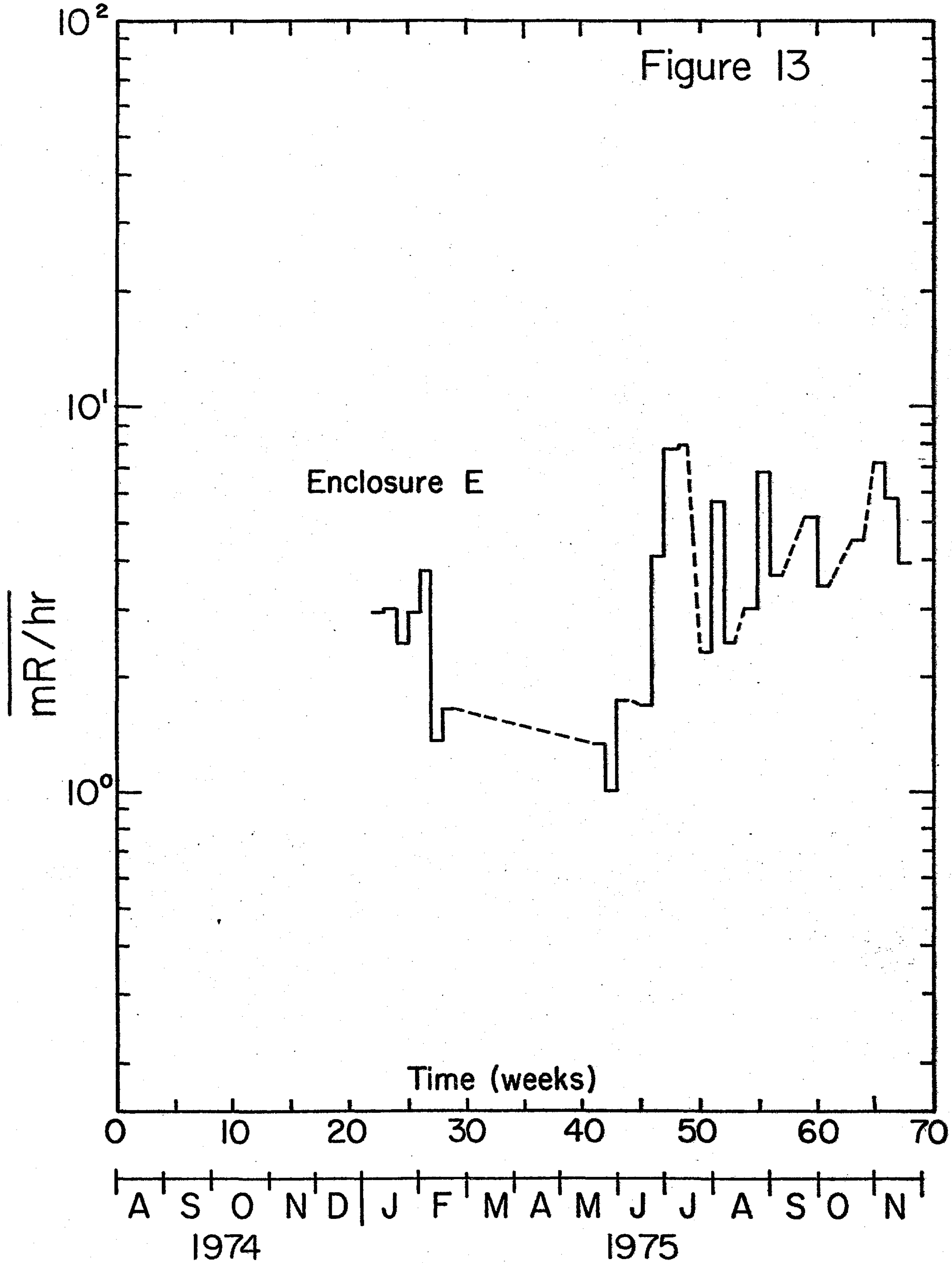
Figure 13
Enclosure E
mR/hr
10^2
10^1
10^0
Time (weeks)
0
10
20
30
40
50
60
70
A S O N D J F M A M J J A S O N
1974
1975

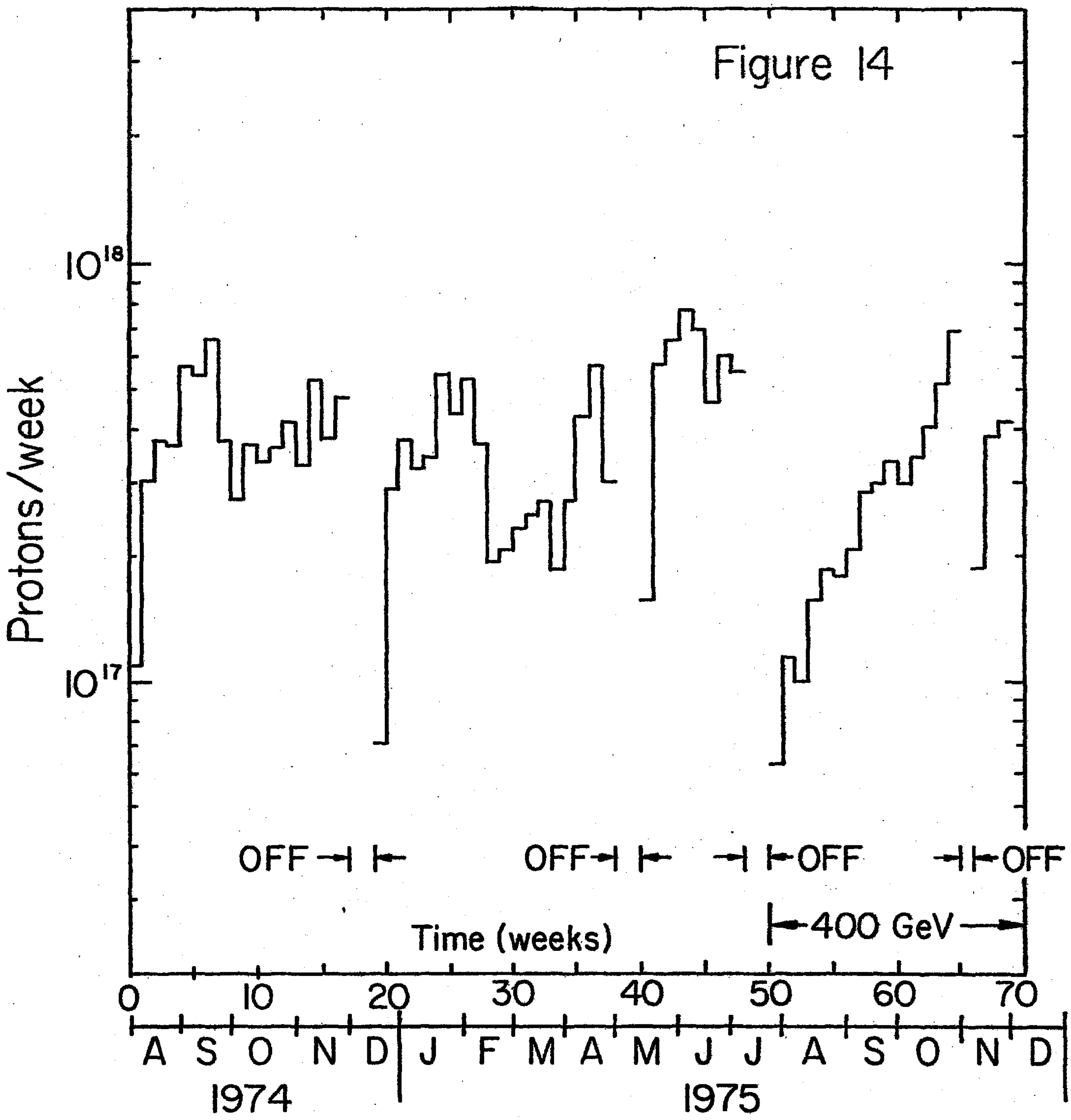
Figure 14
Protons/week
10^{18}
10^{17}
OFF
OFF
OFF
OFF
400 GeV
Time (weeks)
0
10
20
30
40
50
60
70
A S O N D J F M A M J J A S O N D
1974
1975