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Results of the Radiological Survey at the Space Radiation Effects Laboratory Newport News, Virginia

M. G. Yalcintas

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MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
DEPARTMENT OF ENERGY

Printed in the United States of America. Available from
National Technical Information Service
U.S. Department of Commerce
5285 Port Royal Road, Springfield, Virginia 22161
NTIS price codes—Printed Copy: A03; Microfiche A01

ORNL/TM-10064

HEALTH AND SAFETY RESEARCH DIVISION

Nuclear and Chemical Waste Programs
(Activity No. AH 10 05 00 0; ONLWC01)

RESULTS OF THE RADIOLOGICAL SURVEY AT THE SPACE RADIATION EFFECTS LABORATORY NEWPORT NEWS, VIRGINIA

M. G. Yalcintas

Date of Issue - August 1986

Prepared by the
OAK RIDGE NATIONAL LABORATORY
Oak Ridge, Tennessee 37831
operated by
MARTIN MARIETTA ENERGY SYSTEMS, INC.
for the
U.S. DEPARTMENT OF ENERGY
under Contract No. DE-AC05-84OR21400

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ACKNOWLEDGMENTS

The preliminary survey was performed with W. D. Cottrell, and the second survey was performed with R. D. Foley. The author wishes to acknowledge the very helpful discussions with D. E. Fields, and the typing and preparation of this report by S. E. Huckaba. The assistance received from L. Paul Page and other staff members at the Space Radiation Effects Laboratory is also acknowledged.

RESULTS OF THE RADIOLOGICAL SURVEY
AT THE SPACE RADIATION EFFECTS LABORATORY
NEWPORT NEWS, VIRGINIA*

ABSTRACT

The Space Radiation Effects Laboratory located in Newport News, Virginia, was operated by the College of William and Mary for the National Aeronautics and Space Administration (NASA). A synchrocyclotron was formerly in operation in this laboratory and a primary beam of 600 MeV protons and secondary beams of 400 MeV pions and muons were produced for the purpose of studying the effects of radiation on materials planned for use in space. The synchrocyclotron was removed in 1980. At several locations, the scattered radiation caused an induced radioactivity within the walls of the cyclotron room. A radiological survey has been performed to determine the amount of residual radioactivity on the walls. Calculations were performed to determine the thickness of the concrete walls and floor for shielding the residual radiation in the cyclotron room. Recommendations were made to minimize exposure to a potential occupant working in the building from the residual radioactivity on the walls and floor of the cyclotron room.

INTRODUCTION

The Space Radiation Effects Laboratory (SREL) located in Newport News, Virginia, was operated by the College of William and Mary for the National Aeronautics and Space Administration (NASA). A synchrocyclotron was formerly in operation in this laboratory and a primary beam of 600 MeV protons and secondary beams of 400 MeV pions and muons were produced for the purpose of studying the effects of radiation on materials, components, and systems planned for use in space. The synchrocyclotron and its accessory equipment were removed in 1980. At several locations, the scattered synchrocyclotron beam caused an induced radioactivity within the walls of the cyclotron room. The concrete shields surrounding the synchrocyclotron have been removed from the building and stored

* The survey was performed by members of the Radiological Survey Activities Group of the Health and Safety Research Division at Oak Ridge National Laboratory under DOE contract DE-AC05-84OR21400.

adjacent to the radiochemistry laboratory. The facility is no longer operational; it has been decided to decommission the synchrocyclotron. In 1980, Evaluation Research Corporation (ERC) performed a survey to determine the radiological status of the facility as a basis for selecting acceptable alternative approaches to decommissioning of the facility.[1]

In 1985, the Oak Ridge National Laboratory Radiological Survey Activities (ORNL/RASA) group was invited to perform a radiological survey to determine the amount of residual radioactivity on the walls, calculate the dose to potential occupants working in the building, and make recommendations to minimize exposures from the residual radioactivity.

PRODUCTION OF INDUCED RADIOACTIVITY

Induced activity is produced by the interactions of the scattered beam and any secondary particles produced by the primary beam interactions with materials present in the facility. The governing factors for material in the vicinity of the target generally are related to the neutron production capabilities of the accelerated beam. Among the pertinent factors are: species of particles accelerated, energy of accelerated particles, beam intensity or current, duty factor, and primary usage of accelerator.[2]

PAST DECOMMISSIONING

Around 80 accelerators of various types have already been decommissioned to date. Some of the earliest cyclotrons and betatrons were simply disassembled and the components reused for other purposes or sold as scrap metal. There are virtually no records of the very early decommissionings, although accelerator components of some early machines have been placed in exhibits at university museums and at the Smithsonian Institute exhibit entitled "Atom Smashers."[3]

Detailed information and data regarding the more recent decommissioning of accelerators is given by Opelka et al.[4] A 250-MeV synchrocyclotron at the University of Rochester was dismantled in 1971[5]. Some parts were shipped to other accelerators to be used as shielding, and other parts were buried at a waste disposal site. The highest exposure level encountered was 140 μR/h at the magnet-pole tips. The building was left intact for further use by the university.

A 6-GeV electron synchrotron at Harvard was disassembled and demolished in July 1975[4]. Major components were assigned and shipped to other laboratories. The highest induced radioactivity found at the facility was 100 μR/h at the linac converter.

The Heavy-Ion Linear Accelerator at Yale University was dismantled in 1975.[6] Most of the major components were assigned to other laboratories and shipped. Induced radioactivity was present, but it did not result in significant exposure to personnel. Following the disassembly, the building was found to be radiologically clean.

Especially in smaller accelerators, particle injectors have been transferred to other accelerator facilities, as an alternative to dismantlement.

A list of about 80 particle accelerators above 1 MV that have been decommissioned is given by Opelka et al.[4]

RADIOACTIVITY LEVELS AT ACCELERATOR DECOMMISSIONING

The types and quantities of radioactive materials that are generated by an accelerator depend on the beam energy and current. There are a limited number of components in any given accelerator that will become highly radioactive. These will be portions of the primary beam production system, transport systems, target stations, and beam stops which are directly struck by the accelerated beam as part of normal operations. For the very high energy and high intensity accelerators, those components and structures in the vicinity of points of primary beam interaction will also be highly activated by secondary particles. For example, the walls of the shield vault itself may contain significant induced radioactivity. Most of the major particle accelerators consist of iron, copper, and aluminum with minor amounts of other materials. Major exceptions to this are the use of depleted uranium and lead for certain shielding and collimation applications, and the use of aluminum for magnet windings. Activation products of iron and copper are primarily short-lived with half-lives of less than a few days.[7]

Experimental studies at a variety of accelerators have shown that in practice only a few radionuclides control the radiation field that is observed after accelerator shutdown.[9-12]. Only nuclides with half-lives between 10 minutes and 5 years are listed in reference 13. Among them Co-60, Na-22, and Mn-54 will be the controlling isotopes.

One can estimate the total quantity of radioactivity contained in a proton accelerator by using the approximation method.[8] This method is based on the fact that at equilibrium (assuming the activation products are in equilibrium), the decay rate is equal to the production rate. The production rate is related to the accelerated beam intensity and energy. As a first approximation, for accelerators of energy on the order of 600 MeV, the saturation activity is numerically equal to the beam intensity. Using the basic relationships of:

$$1\mu A = 6.025 \times 10^{12} \text{ protons/s and}$$
$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ dis/s},$$

one can calculate (assuming complete capture of the protons) an induced activity of 160 Ci/μA. This activity is distributed among the various machine components and experimental apparatus which intercept the beam. For example, if the fraction of the beam that results in the activation of the wall of the shield vault is about 1% to 2%, then 1.6 to 3.2 Ci of saturation activity from operations with a 1-μA beam protons would be expected.

Qualitatively, there is an initial rapid decay of the short-lived components in the radionuclide mix followed by a slower decay governed by the long-lived isotopes. Some generalizations can be made in regard to the shape of the decay curve. Generalized decay of accelerator-induced radioactivity can be expressed as:[8]

$$D(t) = G\, f \ln [(T+t)/t]$$

where

- $D(t)$ is the dose rate
- G a composite cross section and other nuclear reaction parameters
- f machine dependent parameter

T lifetime of accelerator

t length of decay time after shutdown

G is a function of:

1. Production cross-section of isotopes of decay constant
2. Energy of primary beam
3. Type and quantity of secondaries produced
4. Isotopic composition of the machine
5. Physical dimensions of the machine
6. Energy of gamma rays produced in radioactive decay
7. Attenuation coefficients of gamma rays produced
8. Factors involving position of beam loss in the machine
9. Geometric factors

It has been demonstrated that for an assumed 25-year old accelerator, about 30% of the radioactivity would remain two years after shutdown. From that point on, decay could be assumed to be due to the Co-60 in the material.[2]

CRITERIA FOR DECOMMISSIONING ACCELERATORS

There are no guidelines specific to the decommissioning of accelerators. The operation of accelerators is generally regulated by the state in which the accelerator is located. The Environmental Protection Agency (EPA), through the Resource Conservation and Recovery Act (RCRA) of 1976, has been given the responsibility for developing criteria and standards for the acceptable management of all hazardous waste material, including those radioactive materials from a decommissioned accelerator. A report on their work is currently under preparation. Several radiation protection guidelines must be considered in defining an acceptable level of residual activity in this decommissioning activity.

ACCEPTABLE RATIONALE FOR PERMISSIBLE RADIATION LEVEL

The International Commission on Radiation Protection (ICRP) has established an annual dose limit of 500 mrem for individual members of the general public.[14] However, it is the Commission's present view that the principal limit be 100 mrem per year for chronic exposure over a lifetime.[15] The 500 mrem per year limit is actually considered applicable to an individual member of the public exposed for a short period of time. These annual limits apply for the sum of exposures from all sources of radiation other than natural background.

It has long been recognized by radiation control professionals that it is prudent to avoid unnecessary exposure and to hold doses as low as reasonably achievable (ALARA).[16] This is determined by the state of technology and the economics of improvements in relation to the anticipated benefits from these improvements. The objective of efforts to ensure that occupational exposures are ALARA is to further reduce avoidable exposures and thereby reduce the low risks that are presumed to result from small doses. It is a common practice that ALARA philosophy is being applied for the dose rate between 100 mrem/y and background (approximately 60 mrem/y). Therefore, in this report for the SREL facility, recommendations will be made to reduce the dose rate to a level below 100 mrem/y. Since the facility is planned to be used as a research laboratory, further reduction in occupational dose should be decided by the management of the SREL taking into consideration the ALARA philosophy.

PREVIOUS RADIOLOGICAL SURVEYS AT SREL

LIST OF RADIONUCLIDES AND THEIR DECAY SINCE 1980 MEASUREMENTS

The contents of radionuclides in concrete borings were determined by R. E. Welsh, College of William and Mary, in January 1980. A radiological survey of the facility was conducted by ERC in July 1980. Estimated quantity of radionuclides in the SREL Upper Level Cyclotron Room (ULCR) as of July 1980 and October 1985 are given in Table 1, with the radionuclide half-life and energy of the gamma emmission also tabulated.

ORNL/RASA RADIOLOGICAL SURVEY

SURVEY METHOD

A comprehensive description of the radiological survey methods and instrumentation employed in the survey has been presented in another report.[17] Surveying the SREL facility included: (1) gamma exposure rates at 1 m above and at the floor surface at each grid location; (2) gamma exposure rates at surface of the walls of the ULCR and 1 m away from the wall at grid locations; (3) smear samples from selected locations in the ULCR; and (4) direct alpha and beta activity measurements on surfaces at selected locations in the ULCR. The grid system used in the ULCR is shown in Fig. 1. The pressurized ion chamber used in this survey has a diameter of 31.75 cm. Surface measurements reported in this study are actually made with the center of the tube at a distance of approximately 15 cm from the surface.

SURVEY RESULTS

Background radiation levels were determined to be 7 μR/h inside and outside of the building away from the ULCR. All measurements presented in this report are gross readings; background radiation levels have not been subtracted.

Gamma Measurements

Results of gamma radiation level measurements at grid points in the ULCR are presented in Tables 2-8. The measurements of gamma radiation for the other sections of the building do not exceed background. The middle level cyclotron room (MLCR) was inaccessible, and no measurements were taken. The results presented in this report are only from the ULCR.

Gamma exposure rates at grid points at 1 m above the floor ranged from 12 to 145 μR/h, and averaged 57 μR/h; at the floor surface they ranged from 10 μR/h to 153 μR/h and averaged 51 μR/h. Gamma exposure rates 1 m away from the walls were: north, ranged from 31 to 120 μR/h, averaged 52 μR/h; east, ranged from 13 to 145 μR/h, averaged 49 μR/h;

west, ranged from 12 to 30 μR/h, averaged 23 μR/h. Gamma exposure rates at the surface of the walls were: north, ranged from 30 to 147 μR/h, averaged 60 μR/h; east, ranged from 11 to 217 μR/h, averaged 58 μR/h; west ranged from 9 to 40 μR/h, averaged 23 μR/h. The maximum gamma exposure rate measured on floor surfaces was 153 μR/h at the south end of the ULCR at grid point E-17. The maximum gamma exposure rate measured on wall surfaces was 217 μR/h on the east wall on a circular area with a 30 cm radius approximately at grid point EB-17, 2 m above the floor. Smear sampling and direct alpha and beta readings on the walls and floor did not indicate any significant surface activity in the ULCR.

SIGNIFICANCE OF FINDINGS

The exposure rate measurements taken by ORNL/RASA were used to project radiation doses which could be received over different time intervals based on a worst case hypothetical scenario for exposure. The scenario described may not necessarily be realistic, but it provides some understanding of the type of estimates regarding the dose to potential occupants of this facility, and are based on the exposure rates reported in this study. In the SREL facility, the highest exposure rate detected on the date of ORNL measurements was 217 μR/h. Based on the 40 hour week, 50 week year, and 100% occupancy, this corresponds to 434 mrem/y (approximately 4.3 times the ICRP annual chronic lifetime exposure limit of 100 mrem). (The conversion factor from exposure to effective dose equivalent is approximately 0.7; however, for these calculations, this factor is simply taken as 1.0.) Again, this scenario is considered the "worst case" scenario, but, nevertheless, the dose rate is recommended to be reduced below 100 mrem per year. Upon achieving this limit, a further reduction may be considered if it is technically feasible and economically possible.

ALTERNATIVE DECOMMISSIONING

As previously noted, with the exception of the ULCR, there were no other areas with radioactive exposure above background. The remaining residual radioactivity poses no potential health hazard to future occupancy of this facility.

The following suggestions are only made for the ULCR as options to ensure that radiation exposures are below permissible levels:

1. Shield all locations with elevated radiation levels.
2. Create an access control area in the ULCR by surrounding it with a fence for a limited period of time.
3. Remove activated concrete in areas with elevated radiation exposure levels.

SHIELDING

In the ULCR, exposure from the residual radiation is from a direct gamma radiation field in several isolated locations on the walls and on the floor. These exposures can be reduced by placing concrete shielding in front of the areas with elevated exposure levels. Calculations were performed to determine the thickness of the concrete shielding required to reduce the level of exposure on all walls and floors in the ULCR below 100 mrem/y. A computer code, MICROSHIELD, written for the Apple II+, has been used to determine the thickness of the concrete for shielding.[18] This program is a microcomputer adaptation of mainframe code ISOSHLD II.[19] The code uses numerical integration of the point-kernel expression, including photon buildup, in the calculation of shielding for different geometries of the source and shield. MICROSHIELD contains a library of 400 radioactive isotopes, including the energy and probability per decay for commission of gamma-ray. Solution algorithms are provided for fourteen different geometries.

It was assumed that the geometry of the source within the wall of the ULCR could be represented as a truncated cone. The volume of the cone is approximately 43 m^3. It was also assumed that the four radionuclides given in Table 1 were uniformly distributed within that cone, and the thickness of the concrete slab for shielding was determined for each wall and floor. The density of the concrete in both the wall and slab shield was assumed to be 2.3 g/cm^3. Exposure rates are calculated at the surface of the shielding material.

Approximately 14 cm of concrete would reduce the exposure to 90 mrem/y in front of the "hot spot" on the east wall. The same thickness of the concrete in front of the east wall would reduce the exposure to a level of less than 90 mrem/y on the other locations. Further reduction in exposure on the east wall can be obtained by additional thicknesses. For example, 15 cm of concrete would be required to reduce the exposure rate to 79 mrem/y, and 17 cm of concrete in front of the hot spot would be required to reduce the exposure rate to approximately 60 mrem/y.

The ULCR north wall has one high exposure area at a grid point GNA about 1-1.5 m above the floor, and 11 cm of concrete would reduce that radiation to below the 100 mrem/y level. The maximum exposure rate on the west wall is approximately 79 mrem/y; therefore, no shielding would be required in front of the west wall. The floor of the ULCR has several spots exceeding the exposure level 100 mrem/y (Table 6-7). The floor requires about 12 cm of concrete to reduce the maximum exposure rate below 100 mrem/y around grid point E-17. The same thickness of concrete would reduce the exposure rate below 100 mrem/y on all parts of the floor of the ULCR. The different concrete thicknesses required to reduce the exposure level in the ULCR for different walls and the floor are summarized in Table 9.

CONTROL ACCESS AREA

The measurements made in the other part of the SREL building indicate radiation levels no higher than background. Therefore, the ULCR can be fenced and access can be controlled until the residual radioactivity has been reduced to below 100 mrem/y. The fence can be placed on grid line 21, beam tube and entrance. Assuming the relative radionuclide concentrations measured by Welsh, the exposure rate can be projected into the future.* For example, the highest reading on the east wall (217 μR/h) would be reduced by about 87% to approximately 60 mrem/y in 1999. The relative exposure factor for the next 14 years, and the corresponding exposure rates for the "hot spot" on the north wall are given in Table 10.

---

*Exposure rate R(t) at time can be expressed as:

$R(t) = Ro \, \Sigma \, \alpha_i \, e^{-\lambda_i t}$, where Ro is the exposure rate at time zero,

α_i and λ_i are empirical parameters.

REMOVAL OF ACTIVATED CONCRETE

The removal of activated concrete would pose several difficulties and may be more costly compared to the other options. The uncertainty regarding the shape and the volume of the activated concrete would make any reliable estimate almost impossible. In addition, there would be a problem of disposal of activated concrete. The holes created by the removal of the concrete would be filled with concrete. This would perhaps double the cost compared to the installation of shielding.[4] During the concrete removal process the workers may inhale the radioactive dust accidentally, and may be exposed to radiation levels higher than those measured presently.

CONCLUSION AND SUMMARY

The findings presented in this report are based on measurements taken in the ULCR by ORNL. Other parts of the SREL building were surveyed and these measurement indicated levels that are not different than background. The MLCR was not accessible; therefore, no measurements were taken in that area. Smear sampling and direct alpha and beta readings did not indicate any significant surface activity in the SREL building including the ULCR.

In the ULCR, there are several spots on the walls and on the floor where the annual dose may exceed 100 mrem (100% occupancy of 40 hours/week and 50 weeks during the year were considered). Since there is no criteria for decommissioning the accelerators, a rationale was suggested in this report based on the ICRP's annual limit for an individual member of the public and ALARA principle. Results are given to provide the information for additional exposure reduction. As a means of reducing the exposure, shielding and creation of a controlled access area in ULCR are suggested. Removal of concrete involves several uncertainties and is not recommended. By adding concrete shielding in front of the walls with higher exposure rates, the radiation exposure can be controlled, the facility could be released for occupation, and there would be no radioactive waste disposal problem. Placing 17 cm, 15 cm, and 15 cm layers of concrete in front of the east and north walls and the ULCR floor, respectively, would reduce the annual dose to about 60 mrem. The dose rate on the west wall is about 79 mrem/y on the highest point. By creating restricted access area only for the ULCR, the radiation would be controlled, the facility could be released for occupation, and cost would be much lower than that for shielding. However, the reduction of the dose rate level to about 100 and 60 mrem/y levels would require about 10 and 14 years, respectively.

In both cases periodic surveys of radiation exposure levels would be required until it is established that they will continue to meet the criteria. The surveys could be performed by placing the thermoluminescence dosimeters at several locations in the facility, and making exposure measurements on the locations identified in this report as maximum readings.

REFERENCES

1. Personal correspondence, Paul Page, administrator of the facility which provided the EAC's report to M. G. Yalcintas.

2. Mundis, R.L., et al; "Health physics considerations in accelerator decommissioning and disposal," Proc. Health Physics Midyear Symposium, Williamsburg, VA, pp. 38-48, Feb. 1979.

3. Forman, B., "Atom Smashers: Fifth Years' Preview of an exhibit on the History of High Energy Accelerators," IEEE Transactions on Nuclear Science Volume NS-24, Number 3, pp. 1896-1899, June 1977.

4. Opelka, J. H., et. al., Particle Accelerator Decommissioning, Argonne National Laboratory Report ANL/ES-82 (1979).

5. AEC contract file numbers AT (30-1)-975 and AT (30-1)-4246.

6. AEC contract file numbers AT (11-1)-3076.

7. Gollon, P.J., "Production of Radioactivity by Particle Accelerators," IEEE Transactions on Nuclear Science, Vol. NS-23, No. 4, August 1976.

8. Sullivan, A. H. and Overton, T. R., "Time Variation of the Dose Rate for Radioactivity Induced in High Energy Particle Accelerators," Health Phys. 11: 1101, 1965.

9. Wyckoff, J., "Radioactivity Produced by a Linac," IEEE Trans. Nucl. Sci., 14, 990 (1967).

10. Perry, D. R. and Shaw, K. B., "Radiation Levels in and Around Nimrod," in Proc. First Symp. on Accelerator Dosimetry and Experience, Brookhaven National Laboratory, CONF-651109 (November 1965).

11. Boom, R. W., Toth K. S. and Zucker, A., Residual Radiation of the LRL 184-Inch Cyclotron, Oak Ridge National Laboratory Report, ORNL-3158, June 1961 (Unpublished).

12. Baarli, J., "Induced Radioactivity in the CERN Accelerators," First International Conference on Shielding Around High Energy Accelerators, January 1962 (Press Universitaries de France 198 Boulevard St. Germain, Paris), p.123-128.

13. Patterson, H. W. and Thomas, R. H., Accelerator Health Physics, Academic Press, New York, 1973, p.505.

14. Annals of the ICRP, ICRP Publication 26, Recommendations of the ICRP, Pergamon Press, New York (1977).

15. Annals of the ICRP, Statement from the 1985 Paris Meeting of the ICRP, ICRP Publication 45, "Quantitative Bases for Developing a Unified Index of Harm," Pergamon Press, New York (1985).

16. Code of Federal Regulations, Part 20, U.S. Nuclear Regulatory Commission.

17. Myrick, T. E., et al., Procedures Manual for the Remedial Action Survey and Certification Activities (RASCA) Program, Oak Ridge National LAboratory, ORNL/TM-8600 (September 1982).

18. Microshield, A Program for Analyzing Radiation Shielding, GROVE Engineering, Inc., Washington Grove, MD (1980).

19. Engel, R.L., et al., ISOSHLD, A Computer Code for General Purpose Isotope Shielding Analysis, BNWL-2316, Richland, WA, U.S. Department of Energy, 1966.

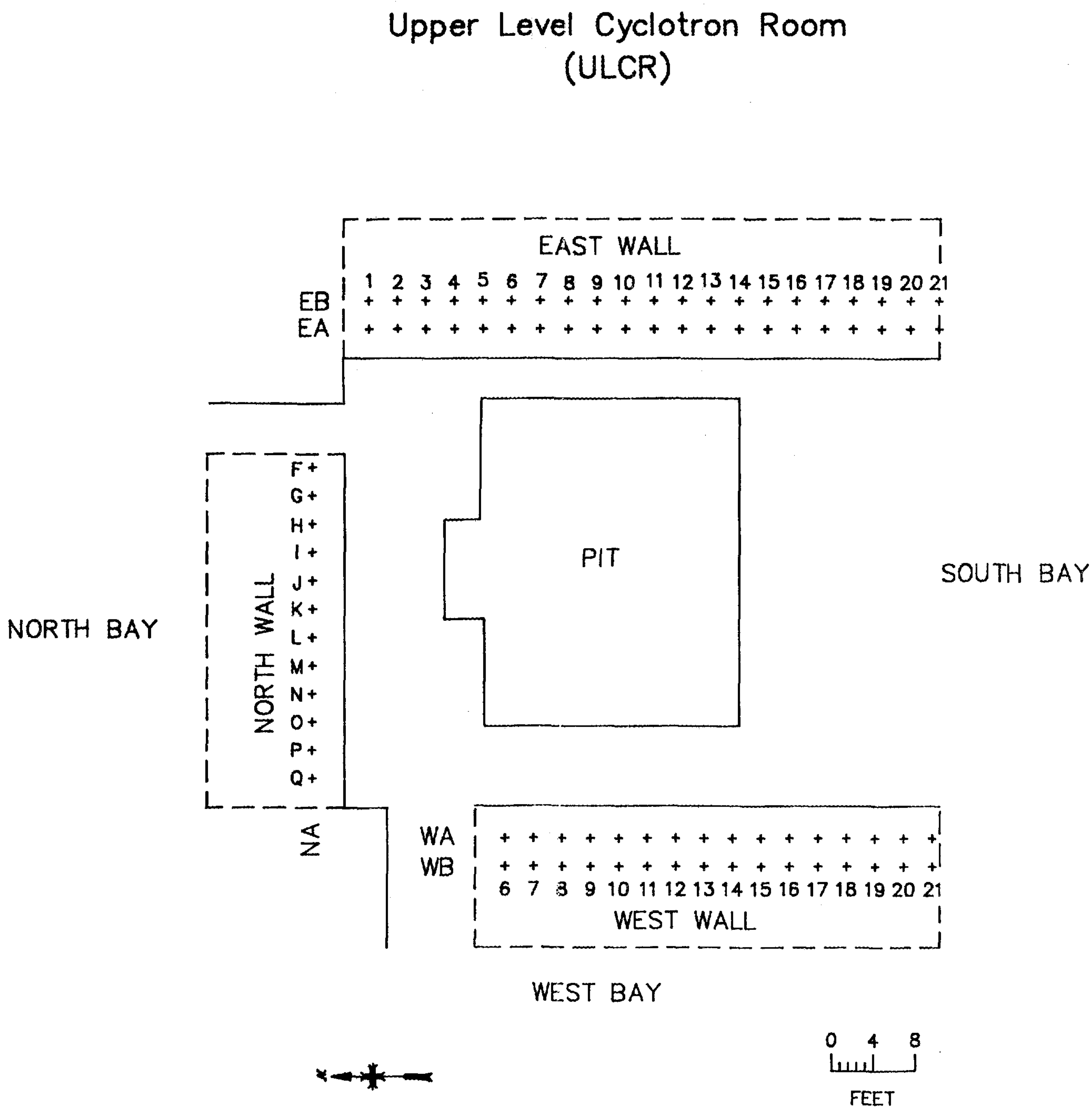

Fig. 1. Diagram showing grid points of structures in ULCR.

Table 1. Estimated quantity of radionuclides in the SREL upper level cyclotron room

Activity	Na-22	Co-60	Mn-54	Co-57
1980 (mCi)	7.2	20.0	32	0.70
1985 (mCi)	1.9	10.6	0.68	0.007
Half-life	2.6 y	5.27 y	312.7 d	270.9 d
Gamma Emission (MeV/d)	1.98	2.5	0.83	0.96

Table 2. Gamma exposure rate on the north wall of the ULCR

Grid location[a]	Gamma exposure rate[b] (μR/h)	
	1 m from the surface	At the surface
BNA	31	30
CNA	c	32
DNA	36	37
ENA	c	61
FNA	55	64
GNA	120	147
HNA	62	102
INA	c	75
JNA	48	63
KNA	c	48
LNA	41	50
MNA	c	48
NNA	40	50
ONA	c	48
PNA	37	48
QNA	c	50

[a]Grid locations shown in Fig. 1.

[b]Grid point measurements are discrete measurements at each grid point.

[c]No measurements taken at this grid point.

Table 3. Gamma exposure rate on the east wall of the ULCR

Grid location[a]	Gamma exposure rate[b] (μR/h) 1 m from the surface	At the surface
1EA	29	28
2EA	31	32
3EA	34	37
4EA	35	37
5EA	32	34
6EA	31	31
7EA	30	29
8EA	27	24
9EA	23	22
10EA	24	23
11EA	25	26
12EA	30	29
13EA	33	31
14EA	41	36
15EA	65	62
16EA	118	152
17EA	145	185
18EA	126	168
19EA	55	42
20EA	23	16
21EA	13	11
2EB	c	38
3EB	c	38
15EB	c	59
16EB	c	130
17EB	117	217

[a]See Fig. 1.

[b]Grid point measurements are discrete measurements at each grid point.

[c]No measurements taken at this grid point.

Table 4. Gamma exposure rate on the west wall of the ULCR

Grid location[a]	Gamma exposure rate[b] (μR/h)	
	1 m from the surface	At the surface
7WA	c	32
9WA	24	21
11WA	c	22
13WA	c	22
15WA	c	25
17WA	30	40
19WA	18	16
21WA	12	9

[a]See Fig. 1.

[b]Grid point measurements are discrete measurements at each grid point.

[c]No measurements taken at this grid point.

Table 5. Gamma exposure rate on the north floor of the ULCR

Grid location[a]	Gamma exposure rate[b] (μR/h)	
	1 m from the surface	At the surface
B2	31	30
B4	35	c
C3	39	32
C5	38	c
D4	42	50
D2	36	43
E3	45	61
E5	46	c
F4	47	60
F2	55	57
G3	50	61
H2	62	57
H4	47	c
I3	48	54
J2	48	47
J4	42	c
K5	39	41
K3	40	c
L2	41	41
L4	37	c
M3	38	43
M5	35	c
N2	40	43
N4	33	c
O3	34	50
O5	26	c
P4	28	31
P2	37	38
Q4	23	32
Q5	26	c
P6	29	30
O7	27	c

[a]See Fig. 1.

[b]Grid point measurements are discrete measurements at each grid point.

[c]No measurements taken at this grid point.

Table 6. Gamma exposure rate on the east floor of the ULCR

Grid location[a]	Gamma exposure rate[b] (μR/h)	
	1 m from the surface	At the surface
A0	c	28
A1	29	26
A2	31	29
A3	34	37
A4	35	34
A5	32	33
A6	31	32
A7	30	30
A8	27	26
A9	23	23
A10	24	19
A11	25	25
A12	30	25
A13	33	35
A14	41	42
A15	65	57
A16	118	97
A17	145	121
A18	126	111
A19	55	38
A20	23	19
A21	13	11

[a]See Fig. 1.

[b]Grid point measurements are discrete measurements at each grid point.

[c]No measurements taken at this point.

Table 7. Gamma exposure rate on the south floor of the ULCR

Grid location[a]	Gamma exposure rate[b] (μR/h)	
	1 m from the surface	At the surface
K17	39	51
K19	20	c
J18	33	32
J20	16	c
I21	14	c
I19	24	c
I17	53	64
H18	50	c
H20	20	c
G21	17	c
G19	34	c
G17	81	128
F18	68	98
F20	25	c
E21	17	c
E19	38	c
E17	93	153
D18	70	c
D16	c	140
D17	c	148
D20	29	c
C21	19	c
C19	46	c
C17	90	126
B18	86	c
B17	c	114
B20	31	c

[a]See Fig. 1.

[b]Grid point measurements are discrete measurements at each grid point.

[c]No measurements taken at this grid point.

Table 8. Gamma exposure rate on the west floor of the ULCR

Grid location[a]	Gamma exposure rate[b] (μR/h)	
	1 m from the surface	At the surface
P8	24	24
P10	22	18
P12	21	16
P14	24	21
P16	29	35
P18	28	29
P20	12	10
N18	26	c
N20	14	c
M21	12	c
M19	19	c
M17	35	55
L18	29	c
L17	38	56
L20	15	c
K21	13	c

[a]See Fig. 1.

[b]Grid point measurements are discrete measurements at each grid point.

[c]No measurements taken at this point.

Table 9. Gamma exposure rate as a function of concrete thickness on the ULCR walls and floor

	Concrete shield slab thickness (cm)	Gamma exposure rate	
		μR/h	mrem/y[a]
East Wall	13	52	104
	14	45	91
	15	40	79
	16	35	69
	17	30	60
North wall	10	54	107
	11	47	94
	13	36	73
	15	27	56
West wall	Existing wall	40	79
Floor	11	50	101
	13	39	78
	14	34	67
	15	29	59

[a]Forty hours per week and fifty weeks per year considered.

Table 10. Relative exposure factors and reduction of radiation level for the 217 μR/h spot during a period of 14 years

Year	Time (y)	Relative exposure factor	Gamma exposure rate	
			μR/h	mrem/y[a]
1985	0	1	217	434
1986	1	0.85	185	370
1987	2	0.73	159	318
1988	3	0.63	137	275
1989	4	0.54	119	238
1990	5	0.47	103	206
1991	6	0.41	89	178
1992	7	0.35	78	155
1993	8	0.31	68	135
1994	9	0.28	59	118
1995	10	0.24	51	102
1996	11	0.21	45	90
1997	12	0.18	39	78
1998	13	0.16	34	69
1999	14	0.13	30	60

[a]Forty hours per week and fifty weeks per year considered.

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