ALTERNATIVES TO WASTE DISPOSAL OF CYCLOTRON FACILITY AT THE SPACE RADIATION EFFECTS LABORATORY, NEWPORT NEWS, VIRGINIA

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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.

One of the alternative for decommissioning was to remove the contaminated concrete material from the wall, which would presents problem of disposing it. 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 adjacent to the radiochemistry laboratory. The facility is no longer operational; it has been decided to remove the the synchrocyclotron. In 1980, a survey was performed 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 requested to perform a radiological survey to determine the level of residual radioactivity present, and to calculate the dose to potential occupants working in the building, and make recommendations to minimize exposures from the residual radioactivity.

RADIOACTIVITY LEVELS AT ACCELERATOR DECOMMISSIONING

Over 70 accelerators have 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.

Detailed information and data are given elsewhere regarding the more recent decommissioning of accelerators (2-7). During the decommissioning of these facilities, some parts were shipped to other accelerators to be used as shielding, or for other purposes, and other parts were buried at waste disposal sites. The exposure levels encountered at different locations were as high as 3.9×10^{-2} mC/Kg/h. Some of them were found to be free of any radiation. For smaller accelerators, the most frequent practice was transfer to other accelerator facilities as an alternative to total dismantlement (4).

The types and quantities of radioactive materials that are generated by an accelerator depend on the beam energy. There are a limited number of components in any given accelerator that will become highly radioactive. These componrnts include portions of the primary beam production and transport systems, the target stations, and beam stops which are struck directly by the beam in normal operations. For the very high energy and high intensity accelerators, those components and structures in the vicinity of the primary beam also will be highly activated by secondary particles. For example, the walls of the shield vault may contain significant induced radioactivity. Most of the components of particle accelerators contain 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. 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 (8-11). Only nuclides with half-lives between ten minutes and five years are listed in Ref. 13.

Among them Co-60, Na-22, and Mn-54 are generally the major contributors to the radioactivity levels.

One can estimate the total quantity of radioactivity contained in a proton accelerator by using an approximation method (Su65). This method is based on equilibrium conditions where the decay rate of the activation products is equal to their production rate. The production rate is related to the accelerated beam intensity and energy. As a first approximation, for accelerators of energy for example of 600 MeV, the saturation activity is numerically equal to the beam intensity. Using the relationships:

$1 \mu A = 6.025 \times 10^{12}$ protons/s and

3.7×10^{10} Bq = 3.7×10^{10} dis/s,

one can calculate (assuming complete capture of the protons) a value of $592 \times 10^{10}/\mu A$. 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 5.9×10^{10} to 1.2×10^{10} Bq 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. The expression of generalized decay of accelerator-induced radioactivity is given in Su65. It has been demonstrated that for an assumed 25-year old accelerator, about 30% of the radioactivity would remain two years after shutdown (13). From that point on, decay could be assumed to be due to the Co-60 in the material.

Criteria for Decommissioning Accelerators

There are no federal 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 5 mSv for individual members of the general public (14). However, it is the Commission's present view that the principal limit be 1 mSv per year for chronic exposure over a lifetime (15). The 5 mSv-annual-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 and medical exposure. In the SREL facility, the highest exposure rate detected on the date of ORNL measurements was 5.6×10^{-5} mC/Kg/h. Based on a 40 hour week and 50 week year, this corresponds to 4.3 mSv (approximately 4 times the ICRP annual limit of 1 mSv). (The conversion factor from exposure to effective dose equivalent in the air is approximately 0.7; however, for these calculations, this factor is simply taken as 1).

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-the-art 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. Therefore, in this report for the SREL facility, recommendations will be made to reduce the dose rate to a level below 1 mSv/y. Since the facility is planned to be used as a research laboratory, further reduction of exposure to a level of background (approximately 0.6 mSv/y) in occupational dose should be decided by the management of the SREL taking into consideration the ALARA philosophy.

LIST OF RADIONUCLIDES AND THEIR DECAY SINCE 1980 MEASUREMENTS

The identification of radionuclides in concrete borings were determined in January 1980 (Pa86). 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.

TABLE I

Estimated activity (Bq) of radionuclides in the SREL upper level cyclotron room

	Na-22	Co-60	Mn-54	Co-57
1980 (estimate)	2.8×10^{8}	7.4×1^{8}	1.2×10^{9}	2.6×10^{7}
1985 (estimate)	7×10^{7}	3.9×10^{8}	2.5×10^{7}	2.6×10^{5}
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

Survey Method

A comprehensive description of the radiological survey methods and instrumentation employed in the survey has been presented elsewhere (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.

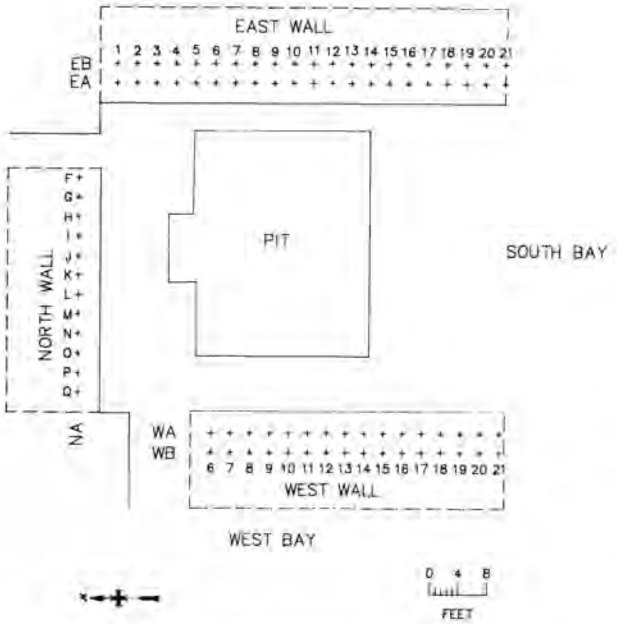

Fig. 1. Upper Level Cyclotron Room (ULCR).

Survey Results

Background radiation levels were measured at 1.8 $\times 10^{-6}$ mC/Kg/h. 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 and on the surface are shown in Table 2, for the floor and the walls of the ULCR. The maximum gamma exposure rate measured on floor surfaces was 3.9×10^{-5} mC/kg/h at the south end of the ULCR at grid point E-17. The maximum gamma exposure rate measured on wall surfaces was 5.6×10^{-5} mC/Kg/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. For calculational purposes, 100% occupancy was assumed, for a 40-hour work week during 50 weeks per year. For the worst case calculation, the annual dose to an individual would be 4.3 mSv. Again, this scenario is not considered necessarily realistic, but, nevertheless, the dose rate is recommended to be reduced below 1 mSv per year. Upon achieving this limit, a further reduction may be considered if it is technically feasible and economically possible.

TABLE II

Results of gamma exposure rate measurements on the floor and the walls of the ULCR

Location	Gamma exposure rates (mC/Kg/h)	
	Range	Average
FLOOR		
at 1 m	3.1×10^{-6}-3.7×10^{-5}	9.5×10^{-6}
at surface	2.6×10^{-6}-3.9×10^{-5}	1.3×10^{-5}
NORTH WALL		
at 1 m	7.9×10^{-6}-1.6×10^{-5}	1.1×10^{-5}
at surface	7.7×10^{-6}-3.8×10^{-5}	1.5×10^{-5}
EAST WALL		
at 1 m	3.4×10^{-6}-3.7×10^{-5}	1.2×10^{-5}
at surface	2.8×10^{-6}-5.6×10^{-5}	1.3×10^{-5}
WEST WALL		
at 1 m	3.1×10^{-6}-7.7×10^{-6}	5.9×10^{-6}
at surface	2.3×10^{-6}-1.1×10^{-5}	1.0×10^{-5}

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 is from a direct gamma radiation field associated with several isolated areas located on the walls and 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 1 mSv/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 frequency per decay of the gamma rays. 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 is required to reduce the exposure to .90 mSv/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 mSv/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 .8 mSv/y, and 17 cm of concrete in front of the hot spot would be required to reduce the exposure rate to approximately .6 mSv/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 1 mSv/y level. The maximum exposure rate on the west wall is approximately .8 mSv/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 1 mSv/y (Table 6-7). The floor requires about 12 cm of concrete to reduce the maximum exposure rate below 1 mSv/y around grid point E-17. The same thickness of concrete would reduce the exposure rate below 1 mSv/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 II.

Access Control Area

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 1 mSv/y. The fence can be placed on the entrance of the ULCR, beam tube, and on grid line 21. Assuming the relative radionuclide concentrations measured previously (1), the exposure rate can be projected into the future. For example, the highest reading on the east wall (5.6 x 10^{-5} mC/Kg/h) would be reduced by about 87% to approximately .60 mSv/y in 1999.

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 waste disposal problem 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 1 mSv (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 mSv. The dose rate on the west wall is about .79 mSv/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 1 and .60 mSv/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. Wyckoff, J., "Radioactivity Produced by a Linac," IEEE Trans. Nucl. Sci., 14, 990 (1967).

9. 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).

10. 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).

11. 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.

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

13. 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.

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.