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REUTILIZATION POTENTIAL OF ACCELERATOR COMPONENTS: A DECOMMISSIONING PERSPECTIVE*

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Abstract

There are perhaps as many as 1,200 particle accelerators in the United States, ranging in size from the very small Cockroft-Walton and electron linear accelerators to the multi-GeV research synchrotrons. At least 50 accelerators produce significant induced activation, and several hundred more are capable of producing fluxes of neutrons that could result in activation of various components of the accelerator facility. At decommissioning, some accelerators leave a legacy of low-level induced radioactivity in massive components. Although guidelines for acceptable surface contamination levels for release of materials and equipment to the general public do exist, there are presently no standards for release of materials and equipment with radioactivity distributed throughout their volumes. The decommissionings of five AEC-funded accelerators were examined: synchrocyclotrons operated by the University of Rochester and by Carnegie-Mellon University, the Cambridge Electron Accelerator, the Yale Heavy-Ion Linear Accelerator, and the Brookhaven Cosmotron. One common feature of these decommissionings was that major components usually were assigned and shipped for use or storage at other accelerator laboratories. In addition to reviewing selected past decommissionings, the authors also examined various aspects of decommissioning accelerators presently operating. The average mass with residual induced activity ranges from 1.5×10^2 kg for electrostatic devices and small cyclotrons up to 9.5×10^7 kg for a large proton synchrotron such as the Zero Gradient Synchrotron at Argonne National Laboratory. The estimated cost ($ 1978) of decommissioning ranges from $\$8.8 \times 10^4$ for an electron linac to $\$7.0 \times 10^6$ for the ZGS. Consideration of decommissioning during the design phase can decrease dismantling costs, minimize unavoidable activation areas, and maximize potential for reuse.

Introduction

Over the past several years, there has been increasing concern over the accumulation of radioactive materials at various scientific, industrial, and educational and medical facilities in the United States, and increasing pressure to ensure that any potentially serious problems are not being overlooked. The subject of nuclear facility decommissioning has recently been addressed by the U. S. Comptroller General in a June 16, 1977, report to the Congress entitled "Cleaning Up the Remains of Nuclear Facilities - a Multibillion Dollar Problem."(1) The primary thrust of the report is toward the nuclear power industry; however, other aspects of the problem, which include isotope usage and accelerator facilities, are recognized as potential problems.

The Department of Energy has initiated a comprehensive study of the quantities and types of radioactive materials in existence both at its existing facilities and at the facilities formerly utilized as part of the Manhattan Engineer District/Atomic Energy Commission (MED/AEC) program. The Division of Environmental Impact Studies at Argonne National Laboratory was requested to perform a comprehensive study of problems associated with the dismantling and disposal of all types of particle accelerators (excluding neutron generators) in the United States.

The potential for induced radioactivity is very slight at energies below 10-MeV.(2) Until recently, medical and industrial accelerators (almost exclusively electron accelerators) have been of energies less than 10-MeV; however, the use of medical linacs in the energy region above 10-MeV is now increasing at the rate of 200 to 240 units per year. A total of 2000 such units are expected to be in use in the United States eventually.(3) Heavy ion and neutron therapy both are receiving increased attention from medical researchers and may eventually add significantly to the neutron-producing accelerator population. The number of compact neutron generators used as analytical tools now exceeds 200 in the United States. Although the problems of decommissioning medical and industrial accelerators are much smaller than those associated with high-energy research machines, the medical and industrial accelerators comprise over 80% of those presently operating. As the energy of medical and industrial accelerators increases, the radiological burden on society of accelerator technology will increase and will necessitate use of proper management similar to that currently required at the larger facilities described in this paper.

History of Past Accelerator Decommissionings

Over 70 accelerators of all types have already been decommissioned. Some of the earliest cyclotrons and betatrons were simply disassembled and the components reused for other purposes or sold as scrap metal. The beam energy and intensity of the early machines were generally very low, so any induced radioactivity would have been essentially undetectable except by very sensitive survey techniques. 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: Fifty Years."(4)

Using information obtained from contract files and personal communications, the authors examined the decommissionings of five AEC-funded accelerators: the synchrocyclotrons operated by the University of Rochester and by Carnegie-Mellon University, the Cambridge Electron Accelerator at Harvard, the Yale Heavy-Ion Linear Accelerator, and the Brookhaven Cosmotron. One feature in common to all five decommissioning operations was found: components ranging from electronics to shielding to magnets were usually assigned and shipped to other laboratories for reuse or storage. In particular, magnet frames and coils, even those exhibiting induced radioactivity, were generally used again elsewhere rather than being disposed of; this was because of the high cost of new steel and copper. Other radioactive wastes generated either during the operation or the dismantling of the accelerators were shipped for disposal to a commercial burial ground. For example, the radioactive wastes from the dismantling at Rochester were shipped to the Nuclear Fuel Services burial site at West Valley, New York, for custodial care, i.e., the AEC and its successors retained title to and responsibility for the wastes. Again requiring the services of a commercial radioactive waste burial ground, the AEC turned to the Nuclear Engineering Company's burial facility at Maxey Flats, KY, for disposal of the radioactive wastes

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from the decommissioning of the Carnegie-Mellon machine.

In two of the cases considered, the Yale HILAC and the Harvard CEA, the dismantlement activities began shortly after the cessation of operation, but in the other cases examined, there was a period of at least one year between shutdown and dismantlement. In the case of the Carnegie-Mellon cyclotron, this hiatus allowed the CMU administrators to seek, without success, alternate funding from the National Cancer Institute for medical use of the accelerator. No record was found of any similar attempt by the University of Rochester or by Brookhaven. (Attempts by Princeton University to obtain alternate funding for medical uses of the 3-GeV proton synchrotron had limited success, and the facility continued to operate at a much lower level. That machine is presently mothballed.) Summaries of the five decommissionings follow.

Operation of the 130-inch, 250 MeV synchrocyclotron at the University of Rochester was terminated late in 1968, and the accelerator was dismantled during the first five months of 1971. The steel main frame of the magnet was cut into blocks and shipped to the Fermi National Accelerator Laboratory for use as shielding. The radioactive wastes were buried at West Valley, New York. The highest exposure level encountered was 140 mR/hr at the magnet pole tips. The building was left intact for further use by the university. The cost of decommissioning, approximately $104,500, was borne by the AEC.

The Cambridge Electron Accelerator, a 6-GeV electron synchrotron at Harvard, was shut down at the end of May 1973. Major components were shipped to other laboratories, but the title to some components was transferred to Harvard for the salvage value. Disassembly and demolition activities continued through July 1975. The contract termination resulted in the displacement of 83 people. The highest induced radioactivity found at the facility was 100 mR/hr at the linac converter assembly, and activities of up to 1 mR/hr were found on the tunnel walls a year after shutdown. Total recorded dose-equivalent for the decommissioning was less than 0.67 man-rem. The cost of the decommissioning to the U. S. Energy Research and Development Administration (successor to the AEC) was $735,200, including $96,500 paid to Harvard to assume responsibility for the final demolition activities.

The Nuclear Research Center owned by Carnegie-Mellon University was closed in 1969. The 130-inch, 440-MeV synchrocyclotron was dismantled in 1974 and 1975. All radioactive components were disposed of either by transfer within ERDA or burial as radioactive wastes. Other radioactive wastes that had been buried at the site were retrieved for reburial at Maxey Flats, KY. Exposure levels of up to 175 mR/hr were encountered in the cyclotron chamber in January, 1973. In preparation for sale, the site was decontaminated by removal of all radioactive components, wastes, and concrete. The cost to ERDA was approximately $504,000.

The Heavy-Ion Accelerator at Yale University was dismantled during the six-month period beginning January 1975, immediately after cessation of operations. Most of the major components were shipped to other laboratories during the disassembly. Ten technicians and three of the scientific staff were displaced by the contract termination, although some were kept on during the dismantling. Induced radioactivity was present, but did not result in significant exposure to personnel. Following the disassembly, the building was found to be radiologically clean. The $105,000 cost of decommissioning was the responsibility of the ERDA.

The Brookhaven Cosmotron, a 3-GeV proton synchrotron, was shut down on December 31, 1966. The machine was kept in standby condition for one year after shutdown. During that time the experimental area was dismantled and much of the equipment was transferred to the Alternating Gradient Synchrotron (AGS) facility at Brookhaven National Laboratory. At the end of the year, the AEC, which owned the Cosmotron, authorized its dismantlement. The reusable equipment and components were removed on a spare-time bases by Brookhaven personnel. The actual disassembly of the synchrotron ring mangets was done by contract technician labor over a three- to four-month period. The one-year waiting period resulted in a significant reduction of the induced activity levels. The magnet segments, copper windings, vacuum chambers, and vacuum pumps were placed in the radioactive material storage area, where most of them remain today. The presence of induced radioactivity in these items precluded their release to scrap dealers. A number of magnet blocks have been used as shielding at the AGS and more recently by the Fermi National Accelerator Laboratory. Because of the difficulty in removing the epoxy resin and fiber glass insulation bonded to the copper magnet windings, very few of these have been reused.

As an alternative to dismantling, accelerators, especially smaller machines such as particle injectors, have been transferred relatively intact to other accelerator facilities. For example, the AGS 50-MeV proton linac injector was moved to the Bevatron at Lawrence Berkeley Laboratory; the 2.2-GeV Cornell Electron Synchrotron was sent to Argonne National Laboratory for use as a proton booster; and the University of Chicago synchrocyclotron was shipped to Fermi National Accelerator Laboratory.

Long Range Radiological Considerations of Accelerator Design

In the usual case of accelerator design, the only radiological considerations that are carefully treated are the shielding and perhaps the target-handling machanism. There are four other areas of concern in which careful decisions can result in reduced radiation exposure to personnel during the operating life of an accelerator and lessen the magnitude of radiation problems upon decommissioning. They are (a) choice of materials, (b) physical layout of accelerator components, (c) method of assembly, and (d) care in operation.

Where choices are available, materials should be chosen to result in minimum induced activity from their use in the particular accelerator environment. For example, the use of aluminum in place of copper for magnet coils will eliminate the possibility for production of ^{60}Co in the windings. Where the option exists, components and equipment should not be placed near locations where a large fraction of the accelerated beam interacts. The intense neutron fluence at such locations will result in high levels of induced activity in nearby components and may shorten the operating life of electronic or electrical equipment. The methods of assembly and operation of such components as target positioners and septum magnets will affect radiation exposure to operating and maintenance personnel. The use of refinements such as quick disconnects and remotely operable fasteners will speed up repair and maintenance work, thereby reducing personnel exposure. Beam tuning will have an obvious effect upon the amount of spurious induced activity produced by a given accelerator. Constant striving for higher efficiency in extraction of the beam from the accelerator and transport to the target is desirable to minimize the unwanted activations.

Table 1

ESTIMATED COSTS (1978 $) FOR DISMANTLING FOUR ACCELERATORS
AT ARGONNE NATIONAL LABORATORY

Accelerator	Dismantling Period	Dismantling Activity	Packaging	Truck Transportation[a]	Disposal	Total
Zero Gradient Synchrotron[b]	2.8×10^6	2.2×10^6	4.1×10^4	1.7×10^6	2.9×10^5	7.0×10^6
60-inch Cyclotron[c]	2.1×10^5	8.5×10^5	3.6×10^4	3.3×10^5	6.2×10^4	1.5×10^6
20-MeV Tandem Van de Graaff	9.3×10^4	5.1×10^4	5.0×10^2	3.9×10^3	7.3×10^2	1.5×10^5
17-MeV Electron Linac	3.6×10^4	4.7×10^4	5.0×10^2	3.9×10^3	7.3×10^2	8.8×10^4

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[a] Transportation cost based upon distance from Chicago, Illinois, to Richland, Washington area.

[b] Activity cost includes scarfing and replacement of concrete shielding in the main ring tunnel.

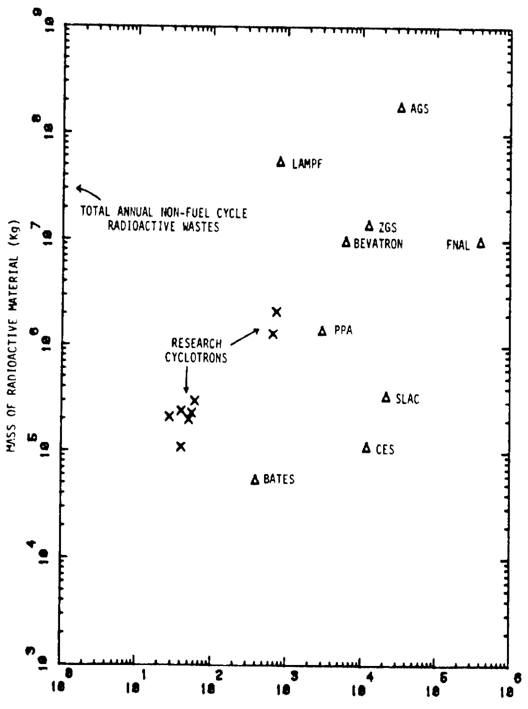
[c] Activity cost includes removal of concrete vault shielding.

High-energy accelerators (above 1-GeV) generally will require remote handling techniques or a mothballed period prior to disassembly of highly activated components. Most medium energy accelerators can be dismantled using contact methods with some localized shielding. Low-energy accelerators (below 10-MeV), such as Van de Graaffs and linear electron accelerators used in medical and industrial applications, will generally not produce radiation levels which would affect the decommissioning procedure.

Decommissioning Planning Considerations

For smaller accelerators where little or no interest has been expressed in component reutilization, it may be best to request competitive bidding on a single contract for dismantlement and removal for radioactive burial or scrap resale. The sequence for a large accelerator will include dismantlement and removal of the accelerator, demolition of concrete structures, and possibly land reclamation. The entire decommissioning process will require about 18 to 24 months, not including a possible mothballing period following shutdown. Actual dismantlement work could require six months. Part of the cost could be offset through salvage value of the nonradioactive material.

Figure 1
INDUCED ACTIVITY IN SELECTED ACCELERATORS



In Figure 1, the radioactive mass at decommissioning for selected accelerators is presented and compared with the total non-fuel cycle wastes presently generated (based on 1 x 10^6 ft^3 per year(5) assuming that the density of these wastes is equal to that of water.) The estimated costs associated with the dismantling of four representative accelerators at Argonne National Laboratory are presented in Table 1. Although hundreds of components of major accelerators are extremely massive, they present generally manageable activation levels. However, the costs exhibited in Table 1 and the masses in Figure 1 assume no recycle or reutilization at other accelerator facilities.

The massive waste, substantial cost and potential future recycle of valuable copper and iron from a decommissioned accelerator should not be ignored in the design of new accelerators. The disposal of components, such as sections of magnets, in low-level waste burial grounds merely because they contain small quantities of induced activity may represent a waste of natural resources. However, since regulations on the amount of permissible induced activity for release for unrestricted use do not exist, present practice is to send these components to other accelerator locations for reuse, to radioactive waste burial sites for disposal, or to storage areas which exist at several national laboratories. Release of this material to the general public may not be advisable at this time due to the lack of regulations which would limit the quantity of radionuclides added to the environment through this route.

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