RADIOLOGICAL PROTECTION AT PARTICLE ACCELERATORS: AN OVERVIEW

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"Igneus est ollis vigor...seminibus."
Virgil, *Aeneid* VI, 730 (ca. 50 B.C.)

ABSTRACT

Radiological protection began with particle accelerators. Many of the concerns in the health physics profession today were discovered at accelerator laboratories. Since the mid-1940s, our understanding has progressed through seven stages: observation of high radiation levels; shielding; development of dosimetric techniques; studies of induced activity and environmental impact; legislative and regulatory concerns; and disposal. The technical and scientific aspects of accelerator radiation safety are well in hand. In the U.S., there is an urgent need to move away from a "best available technology" philosophy to risk-based health protection standards. The newer accelerators will present interesting radiological protection issues, including copious muon production and high LET (neutron) environments.

INTRODUCTION

The elegant work of Cockcroft and Walton at Cambridge and Lawrence at Berkeley was reported in that *annus mirabilis* of nuclear physics, 1932; as a result, this is regarded as the year in which particle accelerators were invented. However, accelerators are 35 years or more older. Since the time of J. J. Thomson's cathode-ray tube (1894) and the discovery of Roentgen rays (1895), particle accelerators have been associated not only with major discoveries in atomic, nuclear, and fundamental particle physics but also with radiological protection.

Accelerators were first developed as research instruments, and thus, many of the concerns that now occupy health physics were first identified at accelerator laboratories. Accelerators were the first to produce the symptoms of the acute radiation syndrome; induced radioactivity; radiopharmaceuticals; transuranic elements; and by an accelerator-derived instrument, the calutron, fissile and fissionable materials. It was at an accelerator laboratory that the first studies of the radiotoxicity of the alpha-emitting transuranic elements were made. Nevertheless, accelerator radiological protection is largely perceived as something of an academic backwater aside from the mainstream; many of the subdisciplines that began at accelerators are now so large in scope that they have become separate fields of endeavor.

HISTORICAL OVERVIEW

After the Second World War, studies of the radiological environments of accelerators began in earnest, following the work started during the Manhattan Project. Our understanding of the development has been reviewed by Perry et al. (1991), who suggested that it occurred in seven stages:

1. Observation of high radiation levels.
2. Shielding studies.
3. Radiation dosimetry.

4. Studies of induced activity and radiation damage.
5. Environmental impact.
6. Legislation and regulation.
7. Disposal.

Each of these aspects will be briefly discussed.

HIGH-RADIATION LEVELS AND SHIELDING STUDIES

Many years before nuclear reactors operated, the early accelerators were powerful neutron sources. In the late 1940s and early 1950s, many accelerators of various types were constructed in several different countries. Performance often exceeded expectations, and high beam intensities led to the production of high, unwanted, ambient radiation levels. Two immediate necessities resulted: (1) to shield and (2) to quantify radiation fields.

Incentives were greatest at laboratories, like Berkeley, where new accelerators had been built aboveground and with very little shielding. At the early synchrocyclotrons buried in the ground, radiation problems were avoided, but at the cost of no improvement in understanding. The progress of shielding studies has been extensively documented in several texts to which the interested reader is referred. Suffice it to say that nowadays, accelerator shields may be defined with considerable confidence and efficiency (Patterson and Thomas, 1973; Swanson, 1979; Thomas, 1988; and Fassò, 1990).

RADIATION DOSIMETRY

Swanson and Thomas (1990) assert it is at accelerators that "the science and technology of radiation dosimetry are at their most sophisticated. In only one other class of radiation environments—those met in extraterrestrial exploration —do such novel and diverse dosimetric challenges need to be faced. Even here the dosimetrist does not encounter the range of particle intensities, variety of radiation environments, or pulsed characteristic of radiation fields."

These authors give detailed descriptions of the dosimetric systems that have proved useful in accelerator environments where measurements are made for many purposes, above and beyond the need to determine personnel exposure. Techniques that determine the physical characteristics of the radiation environment are preferred to attempts avoid the complex problem by expressing measurements in terms of a single scalar quantity, such as equivalent dose.

Philosophers might reflect on the vicissitudes of the dose-equivalent system over the past decade; the system is now so complex when applied to mixed radiation fields that is has lost its original intended virtue of simplicity.

INDUCED RADIOACTIVITY

The largest contribution to collective dose equivalent resulting from accelerator operation arises during repair, maintenance, and modification. While these doses mainly result from photons, the detailed inventory of radionuclides in accelerator environments differs from that found at nuclear reactors. High-energy hadron reactions tend to produce radionuclides that are neutron deficient and many decay by positron emission or electron capture (e.g., ^{7}Be, ^{54}Mn, ^{51}Cr).

In the decade from 1975 to 1985, there has been a general tendency for the annual collective dose equivalent at accelerators to fall by about a factor of 3. Typical collective dose equivalents at large accelerator facilities range from a few tens to a few thousand milliSievert (Perry et al., 1991).

ENVIRONMENTAL IMPACT AND DISPOSAL

Accelerator operation may expose the general public by four pathways. In order of importance they are

- Prompt radiation;
- Production of radionuclides and noxious chemicals, and release to the environment;
- Production of radionuclides in soil and groundwater near the accelerator and possible migration to water supplies;
- Radioactivity produced in materials of accelerator components that may be subsequently recycled or released to the general environment.

Measurements of the transport of neutrons to large distances (on the order of km) from the roof-less synchrotrons began at Brookhaven and Berkeley in the 1950s. These studies have been refined over the past 30 years, and this source of environmental impact is now well understood (Thomas and Stevenson, 1988; Stapleton et al., 1991; Stevenson and Thomas, 1984).

No significant population dose is expected from the latter two pathways and the second pathway is of less consequence that the first by an order of magnitude (Thomas and Rindi, 1979; Goebel, 1987).

LEGISLATION AND REGULATION

In the United States, perceptions of increasing concern for health by the general public have led legislators to reduce allowed radiation exposures to the general public using legislative and regulatory means regardless of cost. Such regulation often takes the form of control by the "best available technology"—and this often translates into merely what minimum level may be measured—rather than any assessment of risks to public health.

Such a process has resulted in a set of protection standards promulgated by the U.S. Environmental Protection Agency that is disparate and illogical. For example, under the Clean Air Act, radioactive emissions are limited to produce an annual dose equivalent of no more than 100 μSv. However, if these radionuclides were waterborne, the committed dose-equivalent limit would be 40 μSv. The annual limit for all radiation exposure from both external and internal sources is 1000 μSv. One wonders how the particular biological structure being irradiated discerns the specific origin of its own radiation exposure!

RADIOLOGICAL PROTECTION AT PARTICLE ACCELERATORS

In most respects, the operational requirements of radiological protection at particle accelerator laboratories do not substantially differ from those at other radiological facilities that have been well documented; for example, in Report 59 of the National Council on Radiological Protection and Measurements (NCRP). Nevertheless, there are aspects unique to particle accelerators that are of concern:

- Facility design,
- Personnel access control,
- Control of radioactive materials,
- Control of contamination, and
- Radioactive-waste management.

These special topics will be discussed in the new version of NCRP Report 51, which is now under revision.

THE FUTURE

Accelerators have entered into the very fabric of our life: they are applied in medicine, materials science and solid-state physics (e.g., ion-implantation);

micro-lithography; food preservation; sterilization of toxic wastes; polymerization of plastics; and radiopharmaceutical production. The applications are many and will increase in the future. Heavy ion accelerators may be used in fusion devices; accelerators will be used to incinerate radioactive waste to produce fissionable material and in plasma heating.

Research instruments now planned or under construction, such as the SSC near Dallas, are of enormous proportions—large enough to encircle a large metropolitan region—and will bring with them other, unanticipated technological spin-offs. In adopting these new technologies, it is to be hoped that society will move to develop cost-effective health standards based upon an assessment of all risks to human health and a proper placing of them in context with radiation risks. This could be a welcome change from our present obsession with the "best available technology" approach, which is not necessarily related to health risks.

These newer high-energy accelerators present two radiological issues of interest: first, the generation of muons (because of their copious production at higher energies), presenting an environmental impact; and second, the production of neutrons and other high-LET radiation. Perhaps, in the last analysis, it will be only high-LET radiations that are of concern at low doses. In the future, accelerators will provide a continuous source of high-LET radiation to which workers and nearby members of the public will be exposed. We will need to understand the radiobiological implications of such exposures and improve on our techniques of measurement to meet this important challenge.

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