PRIMARY HAZARDS OF PARTICLE ACCELERATORS

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Summary

Particle accelerator safety problems are primarily those of activation and shielding. The phenomena of activations from various nuclear particles and from photons is relatively well known. Use of low activation materials at exposed locations and of adequate shielding at all locations is basic to the art of constructing an accelerator facility that will be safe in operation and require minimum cooling time. Side effects must also be considered relative to safety. These may include fire,heat,noxious gas,electricity and possibly sound,each of which may prove hazardous to personnel and may interfere with successful experimentation. The know-how and the materials existing today make possible the design and construction of large and small particle accelerators of various types that are radiologically safe both in operation and after shutdown. Good design and construction,followed by routine safety procedures associated with such facilities,will accomplish this objective.

Each type of the more common particle accelerators inherently has different potential hazards that are characteristic of individual design, but in general, the primary hazards are common to all. Because these machines,with the exception of the electron microscope,are all well described in Volume I of the Engineering Compendium of Radiation Shielding[1], it is appropriate to proceed directly to a discussion of the hazards involved.

Radiation is the principle potential hazard of particle accelerators.This radiation hazard may be controlled by adequately shielding both the accelerator and the surrounding experimental areas. Radiation hazards are further controlled by radiation detectors,warning devices,and automatic shutdown of facility[2].

Radiation hazards originate from the machine beam and from activation of materials. Design of particle accelerators must include shielding,adequate for attenuation of all hazardous radiations at all locations.Radiation source points and regions include:targets,slits and collimators, walls of vacuum chambers at all magnents,materials in which particles or photons are absorbed,and any air path through which ionizing radiation passes. Each occupied area must be shielded effectively from all radiation source points[3].

Residual radioactivity from spallation energy nucleons can be a major hazard. Lining target areas with boron loaded carbon,marble or limestone(free of impurities)or with a pure high calcium mortar[4] are practices employed to lessen the hazard and shorten the cooling time.

Skyshine is a hazard with small accelerators where only shadow shields are used, or with large machines where an earth cover is used. The latter may be far less efficient in dry weather than when the soil has a high moisture content.

Radiation also produces many indirect hazards. These include damage to:access door interlock switch,personel safety-off switch,flashing,warning lights within the vault.fire detectors,electrical interlock switches on high voltage equipment that is a part of the installation,ozone monitors, and residual radioactivity monitors.Electrical safety devices should be shielded from direct radiation where ever this is possible.Hazards to personel will arise if accumulated radiation damage makes these safety devices inoperable through internal failure not detectable by casual inspection. These may result from either radiation induced by electrical insulation or mechanical failures,or by paralysis of sensitive electronic circuits in a radiation field[5].Relative to these hazards, it should be noted that plastics are sensitive to damage by radiation,while ceramics materials are not.

Additional hazards created by radiation effects include generated heat,noxious gas production,electricity and sound.Because each of these hazards may result from other than radiation effects, they will be discussed separately.

Fires,causing extensive monetary loss and serious delays to important research projects, have occured in accelerators for various reasons. For instance,before freon was substituted for air in Van de Graafs,and water for oil in cyclotrons, each type of machine had fires[6].

Heat is generated to some degree by all nuclear radiations. For example, assuming that Feather's rule gives the range of an electron of energy T (MeV),the approximate power dissipated per cm^3 in a slab of material thick enough to stop the electrons is given by:

$$\text{Power dissipated/cm}^3 = \frac{i\rho\Delta T}{0.54T-0.13}\ (\text{kW/cm}^3)$$

In this expression i is the beam current density in mA/cm^2, ρ the density of the material in grams/cm^3, and ΔT is the energy loss (MeV) of the electrons by ionization in the material[7].

Irradiated material may be a fire hazard as a result of several effects:high rate of internal thermal input,radiation catalysis of exothermic chemical reactions,and initiation of explosive reactions in volatile vapors through electrical, breakdown and sparking. Some of these situations can be latent,and thus are a more serious hazard. Volatile organic materials(irradiated)are a particular hazard,as their vapors may produce an explosive mixture that may be ignited by ever present sparks. These vapors also may be toxic.Thermal expansion effects of tightly sealed irradiated samples may cause explosion and fire.

An example of efforts currently being made to avoid fire hazards is the recent commercialization[8] of a shielding material,containing lead and carbon,with a hydrogen atoms content of plus 5×10^{22} cm^3.This material is inorganically bonded and is not subject to the fire hazard problems of most organic materials.

Radioactive gases and toxic gases are reaction products of irradiation of air. Ionization of air produces $^{16}O(\gamma,N)^{15}O$ and $^{14}N(\gamma,N)^{13}N$,each of which are radioactive. They have thresholds of 15.6 and 10.5 MeV,respectively,and both are positron emitters,^{15}O with a half life of 2.05 minutes, and ^{13}N with a half life of 10 minutes[9]. Positron energies are 1.68 MeV for ^{15}O and 1.2 MeV for ^{13}N. Irradiation of air produces O_3,NO,NO_2,NO_3,N_2O,N_2O_3, N_2O_4,N_2O_5,HNO_2 and HNO_3, with O_3 as the most toxic[10]. Nitrogen dioxide and ozone both have maximum permissable allowable concentrations[11]. Other gases, radioactive or toxic or both,are produced from the irradiation of various materials other than air, and consideration should always be accorded to this possibility. Ventilation of accelerator facilities and air monitoring are important hazard controls.

Electricity is always a potential hazard. Accelerators are particularly vulnerable in this respect.In addition to obvious hazards common to all electrical circuits,additional electrical hazards from nuclear radiation effects should be considered. For example, dangerous high voltage charges during operation may build up on leaded glass windows,target material or other matter, if adequate preventative measures are not taken to ground these areas.

Sound presently is not a hazard,but as accelerators become more powerful,it is possible that new conditions may be created that could produce unexpectedly a serious accoustic hazard.

Particle accelerators are of many sizes and of many design types.Each has certain hazards of different degree,but in general,except for very small machines,the hazards cited are inherent to all accelerators,and need to be controlled by safe design,good construction and ultra safe operation. Finally,one must always be aware and cautious that in removing one type of hazard,an unexpected or unrecognized secondary effect does not produce an equally dangerous hazard of another type. Fortunately,elimination of these hazards is the common objectives of all personnel responsible for any aspect of these facilities.

Four important additional references were noted after the completion of this paper.Because of the potential usefulness of these references to many readers,they are included without specific comment at the end of the references cited[12].

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