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14. ABSTRACT
PBFA-II will produce 30 MV peak output voltage. A substantial portion of the output energy will be lost as free electrons which produce hard X rays. Many X rays will have energies within the photoneutron giant resonance. A PBFA-II shot will produce about 5 x 10 E14 photoneutrons. These photoneutron reactions will induce radioactivity in and about PBFA-II. Activation of structural components in the center section will be limited by substituting aluminum for stainless steel in regions of high X ray intensity. Air will be activated above and below the center section after shots, however X ray shielding will limit initial concentrations to five times health guidelines. The short half-lives of air radioactivity will permit reentry following simple decay without ventilation. Some radioactive material will be eroded by arcing, but the resultant contamination should be small. Minuscule concentrations of radioactivity will be produced in the water surrounding the center section.

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PHOTOACTIVATION OF PBFA-II*

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Abstract

PBFA-II will produce 30 MV peak output voltage. A substantial portion of the output energy will be lost as free electrons which produce hard X rays. Many X rays will have energies within the photoneutron giant resonance. A PBFA-II shot will produce about 5 x 10 E14 photoneutrons. These photoneutron reactions will induce radioactivity in and about PBFA-II. Activation of structural components in the center section will be limited by substituting aluminum for stainless steel in regions of high X ray intensity. Air will be activated above and below the center section after shots, however X ray shielding will limit initial concentrations to five times health guidelines. The short half-lives of air radioactivity will permit reentry following simple decay without ventilation. Some radioactive material will be eroded by arcing, but the resultant contamination should be small. Minuscule concentrations of radioactivity will be produced in the water surrounding the center section.

Introduction

PBFA-II is a pulsed accelerator designed to accelerate lithium ions into deuterium-tritium filled gas targets with the hope of achieving energy breakeven in inertial confinement fusion experiments. PBFA-II will deliver 30 MV, 3 MJ, 200 TW electrical pulses to an ion diode load. The accelerator consists of two concentric cylindrical tanks and an inner vacuum insulator stack. The outer oil-filled tank contains Marx generators. The inner water-filled tank contains several tiers of coaxial transmission lines. The vacuum insulator stack contains vacuum convolutes which connect to plasma opening switches (POSs). The POSs connect to the ion diode where lithium ion beams will be created and focused onto a target at the center of the diode. Several papers given at the 5th IEEE Pulsed Power Conference will discuss many design aspects of PBFA-II, so no further details of the accelerator configuration will be presented in this paper.

Nuclear Reactions

Though PBFA-II will use electrical energy stored in its Marx generators efficiently, some energy will be lost in each section of the pulsed power chain. Beyond the POSs, 30 MV potentials will exist and a substantial portion of the initial stored energy will be lost there to 30 MeV electrons. These very energetic electrons will produce bremsstrahlung with photon energies ranging from 0 to 30 MeV. Photons with energies greater than 10 MeV can produce photoneutrons in many common materials. Photons from 10 to 30 MeV produced in the center of PBFA-II will produce photoneutrons, and about 1 to 5 E14 photoneutrons will be produced when PBFA-II fires. This neutron yield will not increase the shielding requirements for the facility nor will the neutrons themselves cause enough activation through neutron capture to cause radiation protection concerns following a shot. However, the process of creating photoneutrons (or photoprotons) leaves behind radioactive nuclei. These activated nuclei are called photoactivation and their decay will cause radiation protection problems after PBFA-II fires.

Air Activation

Photoactivation of the air above and below the vacuum insulator stack creates the most significant radiation protection problem following a PBFA-II shot. Nitrogen-13 and oxygen-16 will be produced in concentrations of importance for health protection with oxygen-16 present in concentrations lower than the applicable airborne radioactivity concentration guide and nitrogen-13 concentrations exceeding the applicable concentration guide by up to a factor of five. Both radionuclide concentrations would be three orders of magnitude higher if the air was not shielded by the thick steel radiation shields above and below the vacuum insulator stack (these shields exist to protect facility electronics from the bremsstrahlung radiation pulse). The PBFA-II facility was not originally designed to exhaust large volumes of radioactive gases because none were expected. Fortunately nitrogen-13 and oxygen-16 have short half-lives. Nitrogen-13 decays with a ten minute half-life and oxygen-16 with a two minute half-life. Reentry to the PBFA-II hi-bay and pit will simply be delayed until these radionuclides decay and disperse to acceptable concentrations.

Nitrogen-13 monitors will sample the air above and below the vacuum insulator stack after PBFA-II fires. The monitors will have remote readouts in the control/monitor room so the shot supervisor can easily determine when safe reentry is possible. The monitors will consist of a NaI crystal, photomultiplier tube detector mounted in a shielded container with the air to be monitored pumped through the shielded container. Such a device is not normally used for nitrogen-13 monitoring, but is advantageous for PBFA-II since it is insensitive to tritium gas.

Water Activation

Water surrounding the vacuum insulator stack will absorb most of the 30 MeV bremsstrahlung produced inside the stack and will sustain some photoactivation. As with air, oxygen-16 will be produced. All the oxygen-16 produced in the water will decay before reentry because oxygen-16 has a two minute half-life. Tritium will also be produced, but concentrations will not exceed a millionth of the drinking water standard for tritium in water. Photoactivation of water causes no radiation protection problems for PBFA-II.

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Structural Activation

Structures inside the vacuum insulator stack will be subjected to the most intense 30 MeV bremsstrahlung and will become photoactivated. These photoactivated structures could expose accelerator workers to ionizing radiation fields. Exposure rates of a few hundred mR/hr could be produced if stainless steel was used in the worst possible configuration and could impede accelerator operations. Should the activated components be machined, ground or welded during repairs or alterations, radioactive aerosols would be generated. To prevent workers breathing the radioactive aerosols these machining operations must take place in a specially ventilated, radioactive machine shop. Care was taken in selecting materials for components placed in the vacuum insulator to the limit potential radiation protection problems from both external exposure and from machining operations.

The vacuum convolutes are made of 6061 aluminum, an alloy very insusceptible to photoactivation. Aluminum-26m is produced in large Curie quantities in this alloy, but quickly decays with a 6.4 second half-life and causes no radiation protection problems. Small quantities of sodium-24 (15 hour half-life) will be produced from aluminum through an inefficient nuclear reaction. The 6061 alloy contains small quantities of copper and chromium which photoactivate and produce proportionally small quantities of copper-61, copper-62, copper-64 and chromium-51. The long-term buildup of photoactivatity from all radionuclides in the 6061 alloy of the vacuum convolutes will not exceed the specific activity of ordinary potassium chloride (a common, slightly radioactive salt). Photoactivation of the convolutes is not a radiation protection problem.

Photoactivation of the ion diode and mating parts of the POSs will cause minor radiation protection problems. Bremsstrahlung photon fluences are most intense in and about parts struck by the energetic electrons, such as the ion diode and portions of the POSs. The POSs and ion diode could not be entirely fabricated of 6061 aluminum because of strength limitations, electron erosion problems and other material considerations. Some stainless steel was used and is very susceptible to photoactivation mostly due to its nickel content. Massive pieces of stainless steel could photoactivate to exposure rates of a few hundred mR/hr. It would be difficult to handle large parts reading a few hundred mR/hr in the cramped confines of the vacuum insulator stack. To avoid such exposure rates, the mass of stainless steel in the ion diode was minimized. Stainless steel surfaces which will be damaged by electron erosion were designed as throwaway items so no radioactive machine shop refurbishment would be required. The POS and ion diode designs limit radiation protection problems so they will not unduly affect PBFA-II operations.

The susceptibility of copper to photoactivation was studied because copper will be used in magnet coils located near the ion diode. Copper easily photoactivates to copper-61, copper-62 and copper-64. Copper-64 is produced most abundantly and has the longest half-life (12.8 hours) of these three radionuclides. The mass and position of the coils in the diode region is such that exposure rates from the coils will not be excessive and contact handling of the coils by accelerator workers will cause only minor radiation protection problems. Should repairs or alterations be required, the coils can be allowed to decay before maching operations. The coils will not present difficult radiation protection problems from either external exposure or from machining operations.

Summary

When the lithium option was selected for PBFA-II, the accelerator was upgraded to a 30 MV machine where it was previously a non-radioactive, 5 MV machine. Control of radioactivity became a problem for early operations rather than just a potential problem for future fusion breakeven experiments. The PBFA-II designers, though unfamiliar with the engineering problems associated with radioactivity control, successfully designed the PBFA-II center section components so that radiation protection problems will have a minimal impact on accelerator operations.