FISSION FRAGMENT ION SOURCE RADIATION PROTECTION*

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Abstract

The CAlifornium Rare Ion Breeder Upgrade (CARIBU) project is an upgrade to the Argonne Tandem Linear Accelerator System (ATLAS) that provides a 37 GBq (1 Ci) ^{252}Cf source yielding neutron-rich fission fragment ions for acceleration. Fission fragments stop in a gas catcher, are extracted into an ECR ion source to increase the charge state, and then accelerated in ATLAS. The radiation fields produced by an unshielded 1 Ci ^{252}Cf source are 46 rem/hr (neutron) and 4 rem/hr (gamma) at 30 cm. A shielding system has been designed and is under construction to reduce the radiation fields to ≤ 1 mrem/hr at 30 cm from all accessible surfaces. The MCNPX code was used to model the transport of the spontaneous fission neutrons and gamma radiation, and the gamma radiation induced in the shielding materials by the neutrons. The primary neutron shielding material chosen was 5% borated polyethylene, enclosed in steel. Calculations are made for emissions of radioactive effluents, primarily noble gases, using the EPA CAP-88 computer program. The maximum credible incident scenario releases a small quantity of ^{252}Cf. Calculated dose results and mitigation methods are presented.

INTRODUCTION

The CAlifornium Rare Ion Breeder Upgrade (CARIBU) project [1, 2] is being installed at the Argonne Tandem Linear Accelerator System (ATLAS) accelerator to provide fission fragments for nuclear and astrophysics research. The CARIBU project will utilize a 37 GBq (1 Ci) ^{252}Cf spontaneous fission source to supply neutron-rich fission fragments as projectiles for nuclear and astrophysics research. The ionized fission fragments will be collected in a gas catcher, undergo further ionization (charge breeding) in an electron cyclotron resonance (ECR) ion source, and then be injected into ATLAS (see Figs. 1 and 2). In addition, fission fragments of interest can be selected, trapped, and their masses determined without acceleration.

SOURCE CASK SHIELDING

The CARIBU cask design reduces the dose rate from 0.50 Sv h^{-1} (50 rem h^{-1}) at 30 cm to 10 microSv h^{-1} (1 mrem h^{-1}) at 30 cm from the cask surface. The primary external radiation hazard from the bare source is from neutrons. Borated polyethylene (BPE) is chosen to moderate and absorb the neutrons because it has a high percentage of hydrogen (6.6 x 10^{22} atoms cm^{-3}) and boron (2.6 x 10^{21} atoms cm^{-3} or 5% by weight). A more dense material with higher atomic number is chosen to attenuate the gamma rays. The design features and accident analysis are discussed in this paper.

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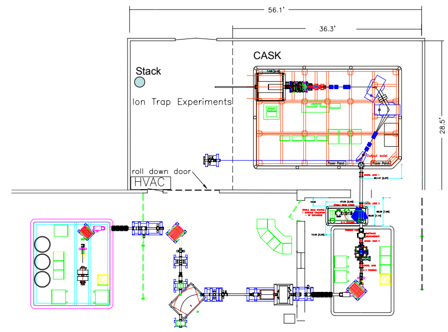

Figure 1: CARIBU ion source showing location of source cask.

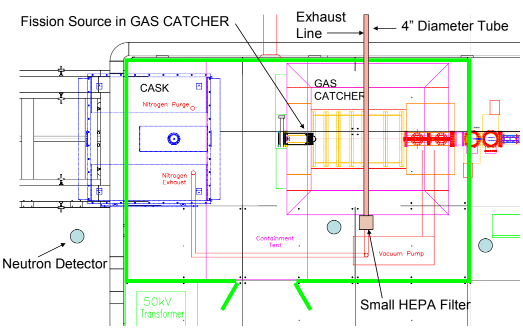

Figure 2: Cask and gas catcher. To provide additional personnel shielding, the cask will be moved into contact with gas catcher during operations.

The CARIBU cask has the following features (see Figs. 3 and 4):

1. Borated polyethylene for superior neutron attenuation.
2. Tungsten near the source for fission product gamma-ray attenuation, cask size reduction, and avoidance of radioactive mixed waste generation associated with the use of lead.
3. Remotely driven or manually operated shield door to facilitate source transfer from the CARIBU cask to the gas catcher.
4. Removable "top hat" for reduced overall height and leak-tight transport on site to ATLAS.
5. Reduced weight, ~4,500 kg (11,000 lbs), for transport. Cask designed to be moved with readily available equipment.
6. Purge gas ventilation system for controlled release of noble gases and volatiles.

7. Overlapping polyethylene fingers for eliminating neutron streaming when shielding door is closed.
8. Cart for transfer without exceeding the 30 cm (1 ft) vertical drop limit during a credible accident scenario. The cask is constructed to survive a 30 cm drop without losing integrity. Since it is only used on the site, DOT certification is not required.
9. Shielded source holder to reduce dose equivalent rate to about 1 mSv h^{-1} (100 mrem h^{-1}) if source gets stuck in the gas catcher.
10. Water extended polyester (WEP) fill for source holder to allow bakeout at 100^0 C to maintain necessary high purity in the gas catcher.
11. Accurate alignment system for positioning CARIBU cask to facilitate source transfer into the gas catcher.
12. Steel shell for enclosing polyethylene to protect source during maximum credible incident scenario (truck collision and fuel fire) and during on-site transport.
13. Seal around push rod to prevent radioactive gas leakage.
14. Covers for push rod and shielding door to prevent radioactive gas release during transport.
15. Polyethylene-filled push rod section inside cask for neutron attenuation.

CARIBU Cask Cutaway View

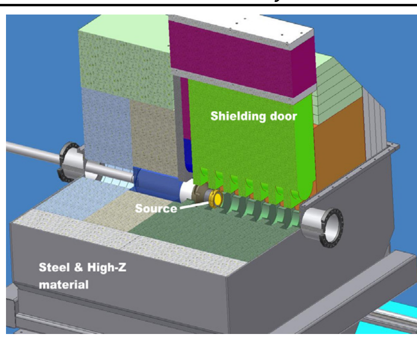

Figure 3: Source in cask with door open.

Cask Strapped on Cart at CARIBU Addition

Figure 4: Completed cask and cart.

The shielding attenuation calculations using the MCNPX code [3] developed at Los Alamos were compared with measurements using an available 4 MBq (108 microcurie) ^{252}Cf source and slabs of borated polyethylene to provide differing amounts of attenuation. The tests were repeated for WEP and Benelex (compressed wood product impregnated with hydrocarbon). The calculations and measurements were in good agreement and showed borated polyethylene has the best attenuation properties for neutrons. The thickness of the borated polyethylene used in the cask is approximately 60 cm (24 inches). See Fig. 5. The thickness of the tungsten is 5 cm (2 inches). The steel shell is 0.6 cm (0.25 inch) thick.

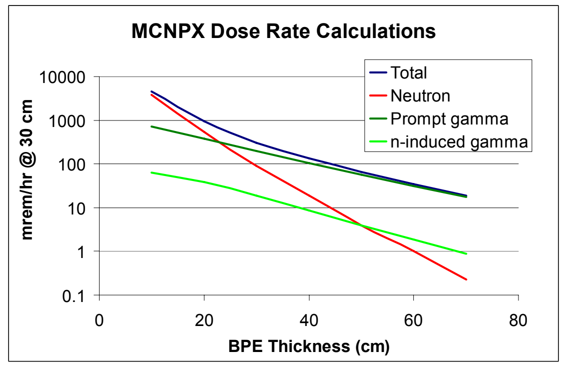

Figure 5: Dose rate vs. thickness.

GAS CATCHER SHIELDING

For operations the cask shielding door is opened and the source manually pushed into the gas catcher. See Figs. 2 and 3. The gas catcher and beam line just downstream from the gas catcher have in-place shielding of sufficient thickness to reduce the dose rate to 10 microSv h^{-1} (1 mrem h^{-1}) at 30 cm from the surface. The thickness of the neutron shielding for the gas catcher is approximately the same as for the cask. Less expensive steel is used instead of tungsten for gamma-ray attenuation since the larger shield size can be accommodated for the in-place shielding. Thinner shielding is sufficient along the beam line between the gas catcher and the first bending magnet of the isobar separator. No additional beam line shielding is anticipated after the isobar separator.

MONITORING DURING OPERATIONS

Operation and shielding properties of the CARIBU cask and gas catcher will be tested with a succession of sources: a 0.07 GBq (2 mCi) ^{252}Cf source, a 3 GBq (80 mCi) source, and finally the 37 GBq (1 Ci) production source. This provides the opportunity to gain experience utilizing weaker sources before bringing the strong source to the site. The radiation monitoring and protection systems will be tested and any problems corrected before operations with the production source. The monitoring described below utilizes interlocked neutron and gamma detectors for penetrating radiation and a flow through ion chamber for radioactive gas.

Sources

The sources are electrodeposited on stainless steel plates at Oak Ridge National Laboratory. With a half-life of 2.65 years ^{252}Cf decays by alpha emission 97% of the time and spontaneously fissions only 3% of the time.

The 2 mCi source has been received and inspected. Some loose alpha radioactivity was detected on the bare source plate near the source. An aluminum cover foil will be added to stop the ^{252}Cf recoils and minimize the release of loose radioactivity during use. For radiation protection three neutron detectors are located in the CARIBU addition (see Fig. 2). They are of the same type as used elsewhere in the ATLAS facility (^{3}He gas-filled proportional counters with polyethylene moderators) and are part of the ATLAS radiation interlock system. One is located on the high voltage platform near the HEPA and activated carbon filters which would collect any ^{252}Cf in the vacuum pump exhaust line. The primary purpose of this detector is to provide an early warning of source deterioration. The other two primarily serve as alarm system detectors of radiation penetrating the shielding.

Airborne Effluents

The airborne effluent monitoring system includes a large HEPA filter downstream of the smaller HEPA and carbon filters. The effluents are released from a stack 16 m (50 ft) above the ground after at least 100 seconds of delay in the exhaust system and a dilution of 4,200 by introduction of air into the exhaust line. This reduces the concentration to the point where it will not present a hazard if drawn back into the building. The radioactivity concentration and flow are measured before release and integrated to determine the total amount of radioactivity released.

Since the ATLAS facility is only about 100 m (approximately 300 ft) from the nearest site boundary and about 600 m (approximately 2,000 ft) from our nearest neighbor (maximally exposed member of the public), we calculated annual exposure rates for noble gas releases and accident scenarios. The exposure for the projected annual noble gases and volatiles release calculated using EPA airborne dispersion code CAP-88 and Argonne wind rose information is 1.3 microSv (0.13 mrem) at the site boundary and 0.2 microSv (0.02 mrem) at the location of the nearest neighbor. Particulates are removed by HEPA filtration. The decay of radioactive xenon following production is shown in Fig. 6. Radioactive krypton was also calculated and is lower in activity. The pathway to the stack ensures more than 100 s of delay, reducing the dose from the short-lived noble gases and volatiles. The calculated delay is 600 s, corresponding to about ten times lower xenon activity at the stack outlet. This delay and the large dilution factor will ensure that any radioactive gas exposures on site will be negligible.

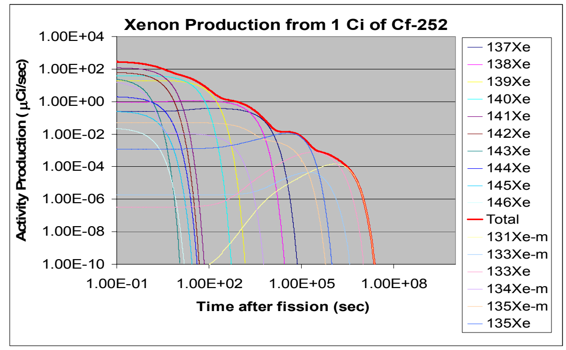

Figure 6: Radioactive xenon gas decay.

MAXIMUM CREDIBLE INCIDENT

The calculated site boundary dose for the maximum credible incident, a truck collision scenario, is approximately 5 mSv (500 mrem) from inhalation of ^{252}Cf released in the collision. The dose is based on a release fraction of 0.1% [4]. Use of this value is supported by the high melting point of californium and the fact that the cask and gas catcher are enclosed in steel to reduce the probability of release from the collision and the ensuing fire.

SUMMARY

The challenge of operating with a 37 GBq (1 Ci) ^{252}Cf electrodeposited fission fragment source is being met by careful design of the radiation shielding and protection systems. The effluents are characterized and the monitoring and alarm systems tested using two weaker sources. These sources will confirm the adequacy of the controls before the production source is introduced.

REFERENCES

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