NUREG--1396

TI91 000007

Environmental Assessment of the Thermal Neutron Activation Explosive Detection System for Concourse Use at U.S. Airports

Manuscript Completed: February 1990
Date Published: August 1990

C. G. Jones

Division of Industrial and Medical Nuclear Safety
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555

Abstract

This document is an environmental assessment of a system designed to detect the presence of explosives in checked airline baggage or cargo. The system is meant to be installed at the concourse or lobby ticketing areas of U.S. commercial airports and uses a sealed radioactive source of californium-252 to irradiate baggage items. The major impact of the use of this system arises from direct exposure of the public to scattered or leakage radiation from the source and to induced radioactivity in baggage items. Under normal operation and the most likely accident scenarios, the environmental impacts that would be created by the proposed licensing action would not be significant.

Contents

Appendices

Figures

Tables

1 INTRODUCTION

1.1 Background

The Federal Aviation Administration (FAA) became involved in developing an efficient explosive detection system in the mid-1960s. Development efforts were initially based on various technologies including vapor detection by olfactory (e.g., canines) and instrumental (chromatography) means, x ray radiography, and several nuclear methods. Although several of these technologies appeared promising, none of the early efforts yielded satisfactory results.

As a result of a rash of hijacking incidents in the early 1970s, Congress recognized the need to increase the overall security of the U.S. airspace and airport system. In the Anti-Hijacking Act of 1974, Public Law 93-366, FAA was assigned the responsibility for research and development in aviation security. In the late 1970s and 1980s, FAA sponsored several programs to develop and demonstrate a prototype explosive detection system using thermal neutron activation (TNA) analysis. The initial attempts at developing prototype systems showed that explosive detection using TNA analysis was technically feasible, but scanning times were too long for practical applications.

In September 1985, FAA awarded Science Applications International Corporation (SAIC) a contract to develop a second-generation, improved TNA explosive detection system (EDS) that could screen a larger number of bags and, in general, was more suitable for the operational screening of baggage (SAIC, 1988). Since 1985, one demonstration prototype and six other smaller production models have been, or are in the process of being, built for FAA. To test the explosive detection capabilities of these models, simulated explosives whose elemental composition and shape and, therefore, system response were similar to those of actual explosives specified by FAA were used. These simulated explosives have been validated by tests in the laboratory by comparing them with actual explosives (SAIC, 1988). Tests of the latest production model, EDS-3, showed that the system could clear all but 3 to 5 percent of the bags that did not contain explosives.

In 1988, the U.S. Nuclear Regulatory Commission (Commission or NRC) began assessing the environmental effects of installing and operating the prototype TNA system (Model EDS-2) at the ramp level of an airport. This included assessing scenarios for possible internal exposure of both workers and passengers, possible exposure of passengers or other members of the public who may consume irradiated food items packed in luggage, anticipated radiation doses, possible exposure resulting from malfunctions of the TNA system, and several types of plausible accidents. In February 1989, the NRC issued a license to FAA to use the prototype on the ramp level of international airports. SAIC developed Model EDS-2, which was originally designed as a one-of-a-kind prototype, into the current production system (Model EDS-3), which optimizes radiation levels, cost, bulk, weight, and complexity. This system, licensed for ramp use in August 1989, uses less than half the amount of californium-252 (Cf-252) and only one-quarter the radiation shielding than did the original prototype.

The findings of the NRC environmental assessments associated with these two models were summarized and published in the *Federal Register* (54 FR 33636) on August 15, 1989 (NRC, 1989). The NRC concluded that the environmental effects of normal use of the TNA system in baggage- or cargo-handling ramp areas would be insignificant.

1.2 Description of the Proposed Action

By letter dated August 22, 1989, FAA (the licensee) submitted a proposed amendment to its existing NRC License No. 29-13141-05 to operate a TNA explosive detection system for routine screening of checked baggage in the lobby or concourse areas of international airports. For concourse installations, additional shielding is added onto the sides of the EDS-3 near the source, underneath the outer panels (see Section 3.1). This new TNA system has been designated as EDS-3C and has been issued Certificate of Registration CA-590-D-118-S (California Department of Health Services, 1990). It is estimated that these systems (or their equivalent) will be installed at more than 200 major airports in the next 5 years and will be used to screen luggage on international flights (U.S. Department of Transportation, 1989). The term "concourse area" refers to the area that is used in conjunction with passenger ticketing and baggage check-in operations and is usually located in the main terminal area. The proposed action involves the following:

(1) Modification of existing concourse areas (or construction of new ones) to allow installation of an EDS-3C. If existing concourse space is insufficient, this could include additional construction of structural supports or the rebuilding of the ticketing areas for operation of the system.

(2) Installation of one Cf-252 source in an EDS-3C, containing 150 micrograms (μg) [80 millicuries (mCi)]. This includes transportation of the source within a shielded cask to the EDS-3C from outside the airport.

Since most systems will be placed in existing airport facilities, each site will differ in terms of site-specific considerations, such as distances from the ticket counters to the EDS-3C, occupancy statistics in the airport, number of

passengers, waiting time for tickets and boarding passes, and vehicular traffic. For this assessment, actual design and construction information from six international airports in this country was used to create a "model airport" for calculating radiation dose and estimating the effect of possible accident scenarios.

1.3 Previous Environmental Assessments and Supporting Documents

Several environmental documents have been prepared that are specific for the previous FAA license application for SAIC Models EDS-2 and EDS-3. FAA submitted an environmental report in support of the first prototype device in February 1988 and a revised report for public release in June 1988. In September 1988, Idaho National Engineering Laboratory (INEL) assessed for the NRC the environmental effects of the EDS-2 in the "Environmental Assessment for Explosive Detection Systems Using Thermal Neutron Activation for Airline Baggage Inspection" (INEL, 1988). On August 15, 1989, the NRC staff published a Finding of No Significant Impact in the *Federal Register* (54 FR 33636), which provided the evaluation and summary of the environmental effects of using the EDS-3 at the ramp levels of airports (NRC, 1989). Finally, SAIC submitted to the NRC an environmental report related to the proposed EDS-3C for concourse installation in October 1989 and a revised report in response to NRC questions in December 1989 (SAIC, 1989). For further technical details with respect to previous assessments, see the documents that are contained in Docket Number 030-30885 at NRC's Region I Public Document Room, 475 Allendale Road, King of Prussia, Pennsylvania 19406.

2 NEED FOR THE PROPOSED ACTION

The need for improved baggage security persists. Since 1985, more than 425 lives have been lost, several aircraft have been destroyed, and international commerce has been disrupted. The nature of the security threat today is far different from (and far more dangerous than) that in the early 1970s when screening of passengers and luggage first began. Previously, the primary threat was hijacking. Currently, it is sabotage by international terrorists seeking to influence the behavior of governments through acts of violence against commercial aviation (U.S. House of Representatives, 1989).

Although the first six TNA systems are owned and operated by FAA, the subsequent widespread use of these systems would be by the airline carriers rather than FAA. On September 5, 1989, FAA published a final rule that would require, by amendment under Section 108.25 of Title 14 of the *Code of Federal Regulations* (14 CFR), that each airline carrier use an explosive detection system that has been approved by the FAA Administrator to screen checked baggage on international flights (see U.S. Department of Transportation, 1989). So far, the only explosive detection systems that have been approved are Science Applications International Corporation (SAIC) Models EDS-3 and EDS-3C. Once this rule is enforced, an estimated 200 to 400 TNA systems will have to be licensed in both this country and abroad. FAA, in its continuing program to collect operating data in various airport environments, has requested the NRC to evaluate the TNA system in one of four possible areas on the concourse level of airports: (1) behind the check-in precounter, (2) in front of the check-in counter, (3) at a check-in area, and (4) at a curbside location near the concourse level.

Even though the EDS-3 is currently licensed for use at the ramp level of airports where baggage is sorted for loading aboard planes and has been shown to have a high sensitivity for detecting explosives in baggage, there has been some difficulty in resolving false positive ("nuisance" or "false") alarms on a small percentage of all bags inspected. These alarms are presumed to be real until they are proven to be false. Various methods are used for resolving the problem of false alarms, but the method currently used is to open and hand search the bag, which (under FAA regulations) must be done in the presence of the passenger. At John F. Kennedy (JFK) International Airport, where the EDS-3 has been in operation since September 1989, the only way to do this is by paging and locating the passenger in the terminal, having the passenger come to the TNA area, and hand inspecting the luggage in question. At JFK Airport, it has taken up to 1 hour to locate a passenger and resolve the alarm problem. At many proposed airport sites, the only practical way to screen luggage for explosives is to locate the system so that it is near the area where the baggage is checked in (at the concourse level) so that the passenger is immediately available to give his or her consent to open bags that cause an alarm. This environmental assessment addresses the expected environmental effects associated with the proposed operation of and the construction that might be necessary for SAIC Model EDS-3C at concourse locations of international airports in the United States.

3 EXPLOSIVE DETECTION SYSTEM MODEL EDS-3C

3.1 Description of the Concourse System

Model EDS-3C is shown in Figures 3.1 and 3.2. Baggage is loaded onto a conveyor, passes over one source containing 150 μg (80 mCi) of californium-252 (Cf-252), and then leaves the system at the opposite end. The Cf-252 doubly encapsulated sealed source is located inside a moderated assembly containing heavy-metal panels to shield against the direct gamma rays from the source. The principle of operation is based on the property of nuclei of elements in baggage absorbing the moderated neutrons and emitting gamma rays with energies characteristic of a particular element, such as nitrogen, which is a major constituent of all common explosives. By using many detectors and acquiring data in short time slices, the system is able to generate an image of the nitrogen distribution. The high-nitrogen density allows the system to distinguish explosives from benign high-nitrogen materials like wool or silk.

Figure 3.3 shows the EDS-3C completely assembled with the exterior panels. The mechanical structure is made of aluminum channels and beams welded together, with a welded-on outer shell of 5-mm (3/16-in.) aluminum. Aluminum was chosen because of its low interaction rate with neutrons and therefore minor production of activation gamma rays, as compared with other choices such as steel. The structure is filled with moderators of low atomic number (mainly paraffin loaded with boric acid) and is then cast into place. Sheet metal panels, not shown on the section drawings, cover the entire system for cosmetic purposes.

The TNA system consists of three major pieces of equipment: the diverter, the XENIS (x ray enhanced neutron inspection system), and the EDS-3C. The EDS-3C is the only piece that is too heavy to be placed directly on the floor without supplemental structural support. The overall area needed for the installation of the EDS-3C, the diverter, and the XENIS is approximately 41 m^2 (438 ft^2).

The TNA system consists of three modular sections with a gross weight of 12,700 kg (28,000 lb) to facilitate transportation. The end sections weigh 2,720 kg (6,000 lb) each, are supported on four legs, and impose a uniform load of 17 kilopascals (kPa) [353 pounds per square foot (psf)] on the floor area below the unit. The center section weighs 7,260 kg (16,000 lb), is supported on eight legs, and imposes a uniform load of approximately 22.4 kPa (467 psf) on the floor area below the system. These three sections are secured together at each installation site before the source is inserted. Figure 3.4 shows the dimensions of Model EDS-3C. For concourse installations, additional shielding is added on the sides of the system near the source, underneath the outer panels (Figure 3.5). This model (EDS-3C) has additional shielding consisting of plates of lead [0.64-cm (1/4-in.) thick] and polyethylene [approximately 2.5-cm (1-in.) thick]. These plates occupy hollow spaces in the outer panels, which are made of

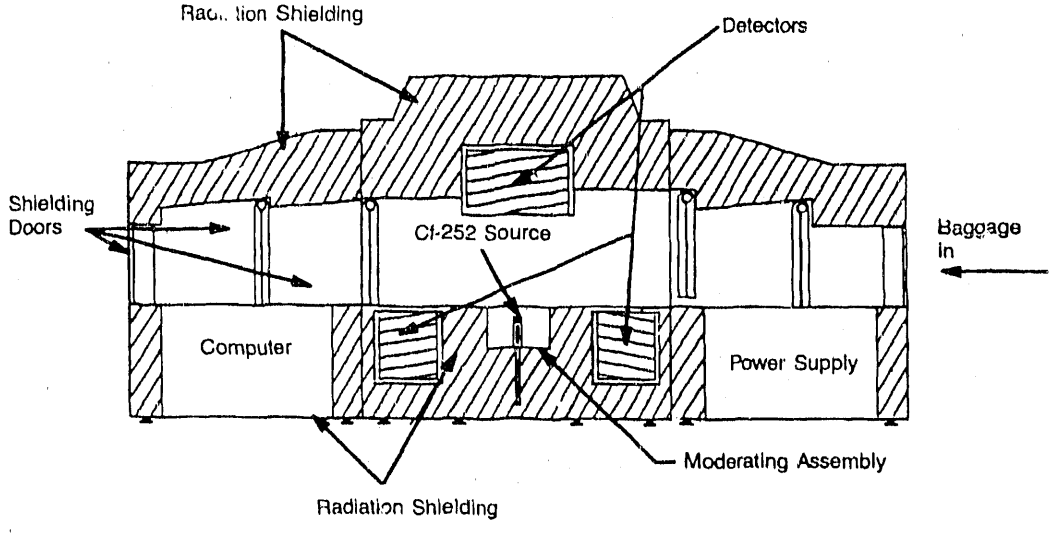


Figure 3.1 Lengthwise section of EDS-3C

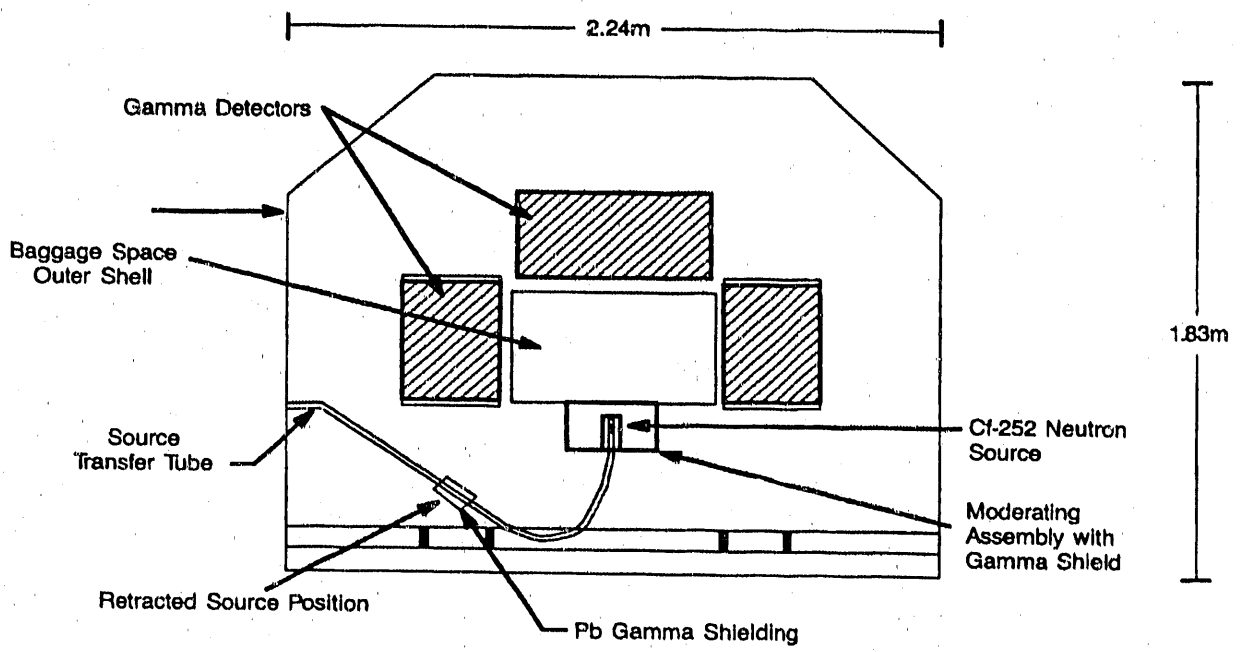


Figure 3.2 Cross-section of EDS-3C at source

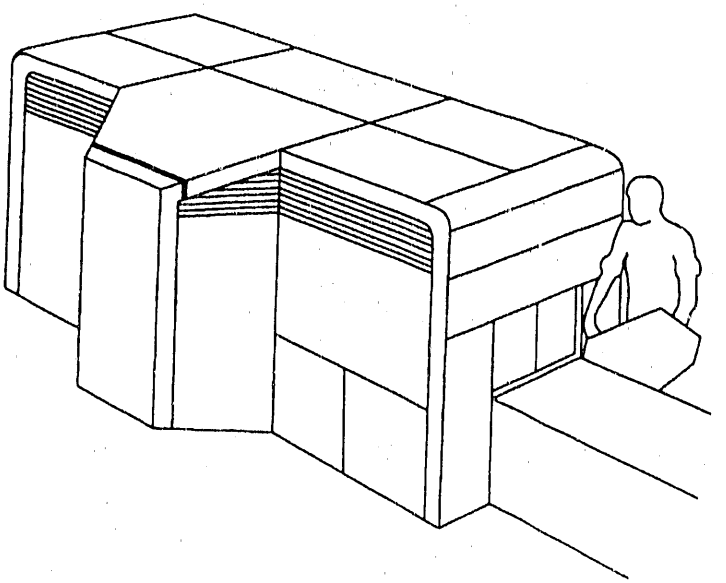


Figure 3.3 Perspective view of EDS-3C

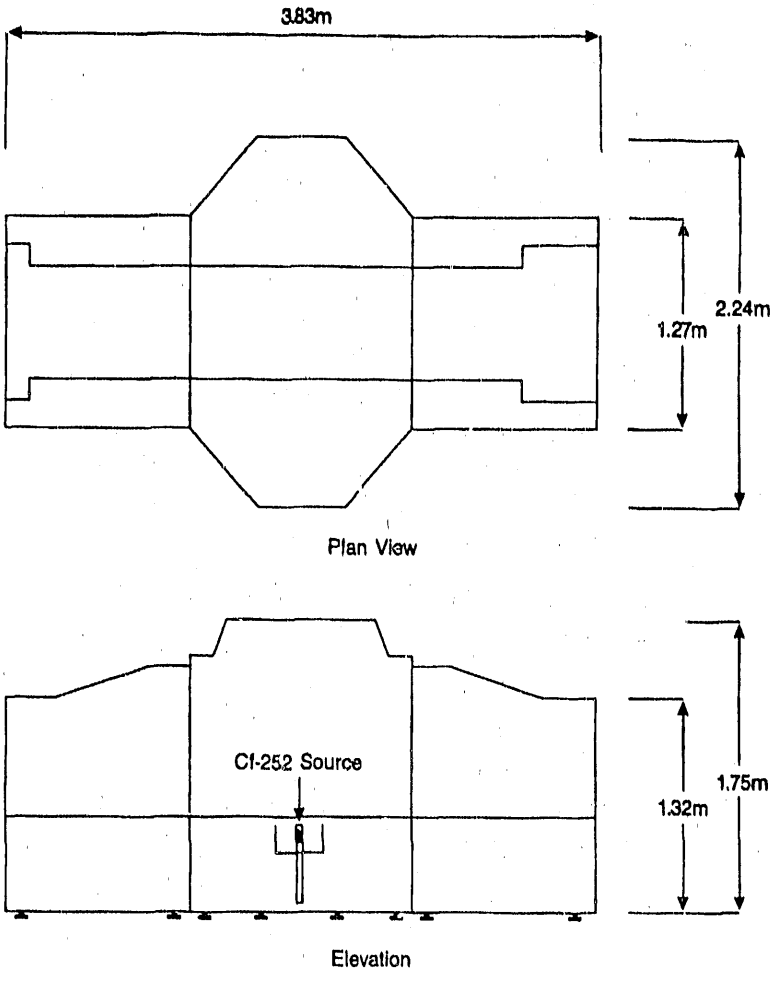


Figure 3.4 Dimensions of EDS-3C

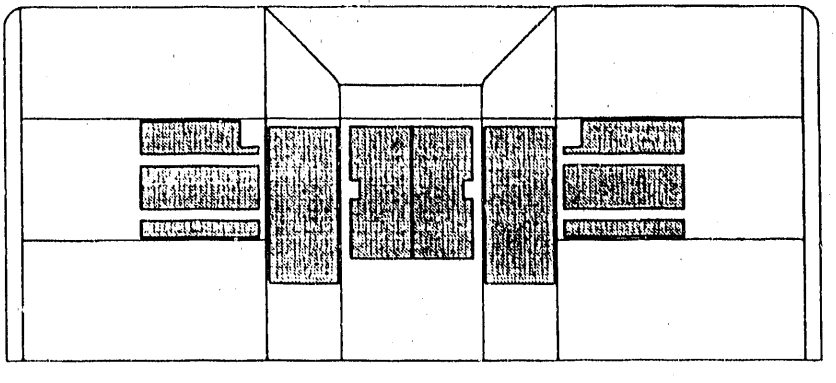


Figure 3.5 Schematic for additional shielding for EDS-3C.
Shaded areas show location of added shielding.

14-gauge steel. This shielding significantly reduces the exterior dose rate. Downward shielding has also been added in the moderating assembly. The spaces above and below the ends of the baggage cavity contain detector electronics, the system computer, electronics cooling equipment, electric distribution components, conveyor belt motors, and pulleys.

Three pivoted panels of borated polyethylene and lead at each end of the system attenuate the radiation emitted from either end of the EDS-3C (see Figure 3.1). The end panels are 10 cm (4 in.) thick and swing about vertical axes with return springs. The four inner panels hang from a horizontal pivot point with a cam-spring arrangement that allows them to be pushed up easily by the baggage. If the spring mechanism were to fail, it would fall in the closed position because of the weight of the panels. Individual position sensors for each panel are coupled to an indicator light on the main panel to show that the doors are closing when there is no baggage.

3.2 Properties of Californium-252

Californium-252 (Cf-252) decays by both alpha emission and spontaneous fission and has an effective half-life of 2.646 years. The dominant decay mechanism is alpha decay, and the alpha emission rate is about 32 times that for spontaneous fission. A 1-μg sample of Cf-252 will emit 1.97×10^7 alpha particles and undergo 6.14×10^5 spontaneous fissions per second (Knoll, 1979). The neutron energy spectrum peaks at about 1.0 megaelectronvolt (MeV), although a significant number of neutrons have energies as high as 8 or 10 MeV. Cf-252 emits 2.34×10^{12} neutrons per second per gram and 1.3×10^{13} photons per second per gram of material, exclusive of internal conversion x rays. No beta radiation has been reported from the decay process. The beta radiation associated with the equilibrium fission products during spontaneous fission is easily absorbed and does not contribute significantly to dose rates (E.I. du Pont de Nemours and Company, 1971).

The neutron fluence rate at 1 m (3.3 ft) for 1 g of Cf-252 is 1.9×10^7 neutrons/cm^2-s, the absorbed dose rate in tissue is 2.84 grays (Gy)/hr (284 rad/hr), and the dose equivalent is 24 sieverts (Sv)/hr (2400 rem/hr).

For the EDS-3C, a 150-μg doubly encapsulated, sealed neutron source (Frontier Technology Model 100 series or Amersham Model CVN.CY6) is used (California Department of Health Services, 1989). The source is mechanically attached to the end of a Teleflex cable and is held by a locking compound. The cable is approximately 5 mm (3/16 in.) in diameter, and the source adapter is 9 mm (3/8 in.) in diameter. The source can be withdrawn manually to a retracted position, which lowers radiation levels in the baggage cavity to allow routine in-cavity maintenance or to release a baggage jam.

3.3 Safety Features

The following safety features have been incorporated in the concourse version of the EDS-3 (i.e., EDS-3C):

- The outer shield doors are key locked when the EDS-3C is unattended.
- The outer shield doors are interlocked so that if the system operator removes the computer system key before locking the shielded doors, an alarm is sounded.
- In case of a baggage jam, the source can be withdrawn manually to a retracted position, allowing retrieval of luggage stuck in the cavity while the radiation fields are lower.
- The source is always confined within several layers of shielding, and a locked panel covers the Teleflex cable to which the source is mounted.
- A tamper-indicating seal is used (see Figure 3.6) to show if tampering has been attempted.
- A baggage activation monitor checks all baggage passing through the TNA system for excessive radiation levels. This monitor is equipped with both audible and visible indicators. The sensitivity is adjusted to a level that will ensure that any bag that has a surface dose rate of more than 5 μSv/hr (0.5 mrem/hr) will trigger the monitor.
- A permanent "Radioactive Material" sign with isotope identification and dated source strength is located at the locked panels that cover the source cable.
- Caution signs indicating a high-radiation area are placed at the entrance and exit of the system. A "Caution—Radioactive Materials" sign is placed on top of the system.
- Additional shielding barriers are used in any installation where the public might otherwise be exposed to the radiation field from the exit and entrance of the TNA system.
- A sign will be prominently displayed informing passengers that their luggage will be screened with a new type of detection system to detect the presence of plastic explosives. Passengers will be advised to remove needed items from their luggage before EDS-3C screening. Passengers will not have access to luggage contents once the luggage has gone through the EDS-3C and has been banded with

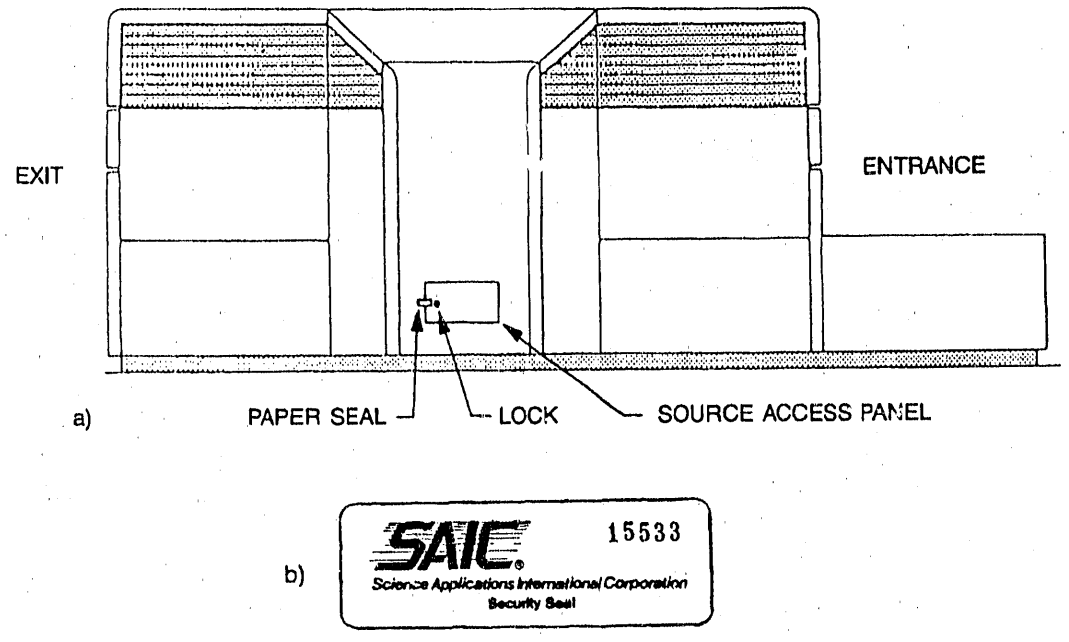


Figure 3.6 Tamper-indicating paper seal.
(a) Placement, (b) full-size sample

tamper-resistant security tape. In addition, handouts will be available for those members of the public who request more information.

In addition, several internal safety features have been added:

- A log book is used to record all routine maintenance, transfer of the source, retraction of the source, opening of computer and high-voltage access doors, personnel entering the baggage passageway (including duration), baggage jams (including reasons for jams), inspections, emergencies, and breakage of tamper-indicating seal by the operator during handling of the source or by actual or attempted tampering.
- A special shielded cask designed to reduce external radiation fields during transfer is used to move the source to or from the EDS-3C.
- Environmental monitors are used to monitor possible radiation doses in the area.
- One ion chamber gamma ray survey meter and one neutron rem meter will be kept at each site for use by the TNA operators.

4 ENVIRONMENTAL INTERFACES

4.1 System Locations

In lobby (concourse) installations, the TNA system is proposed to be installed at or near the ticket counter of an international airline, or at a terminal's curbside check-in area. For each of the scenarios, an airline baggage handler will feed the baggage into the system. As each bag leaves the system, the computer will identify each bag with a "clear" or "alarm" signal from the TNA system. In case of an alarm, the bag will be passed through the EDS-3C again. If the bag still alarms, the bag will be removed to a secure area and will be opened by the security attendant with the consent of the passenger. If the passenger does not consent, he or she will not be allowed to board the airplane.

The desirability of lobby installation stems from the FAA requirement to have the passenger present when his or her luggage is hand searched. In the ramp installation, as explained earlier, there is no convenient way to contact the passenger when a piece of luggage causes the TNA system to alarm, perhaps 30 minutes or more after initial check-in. Current methods used to locate these passengers at JFK International Airport have taken on the average approximately 1 hour.

Figure 4.1 shows the TNA system attached to an x ray inspection system labeled "XENIS" (x ray enhanced neutron inspection system). The TNA system consists of a standard commercial baggage and cargo inspection system coupled to an image processing computer. X ray image information is combined with the nitrogen distribution image information from the EDS-3C in a separate computer, which correlates the information so that a decision can be made regarding the presence or absence of a bomb (SAIC, 1989). This combination of technology has cut the false-positive rate in approximately half. XENIS also produces a combined image that can assist a trained security operator in resolving many of the remaining alarms, thus further reducing the number of passengers whose bags must be opened. The use of XENIS adds about $150,000 to the total cost of the installation, as well as requires additional space.

The following four locations for lobby installations are evaluated in this assessment:

(1) Behind the check-in counter
(2) In front of the check-in counter
(3) Pre-check-in area
(4) Curbside area

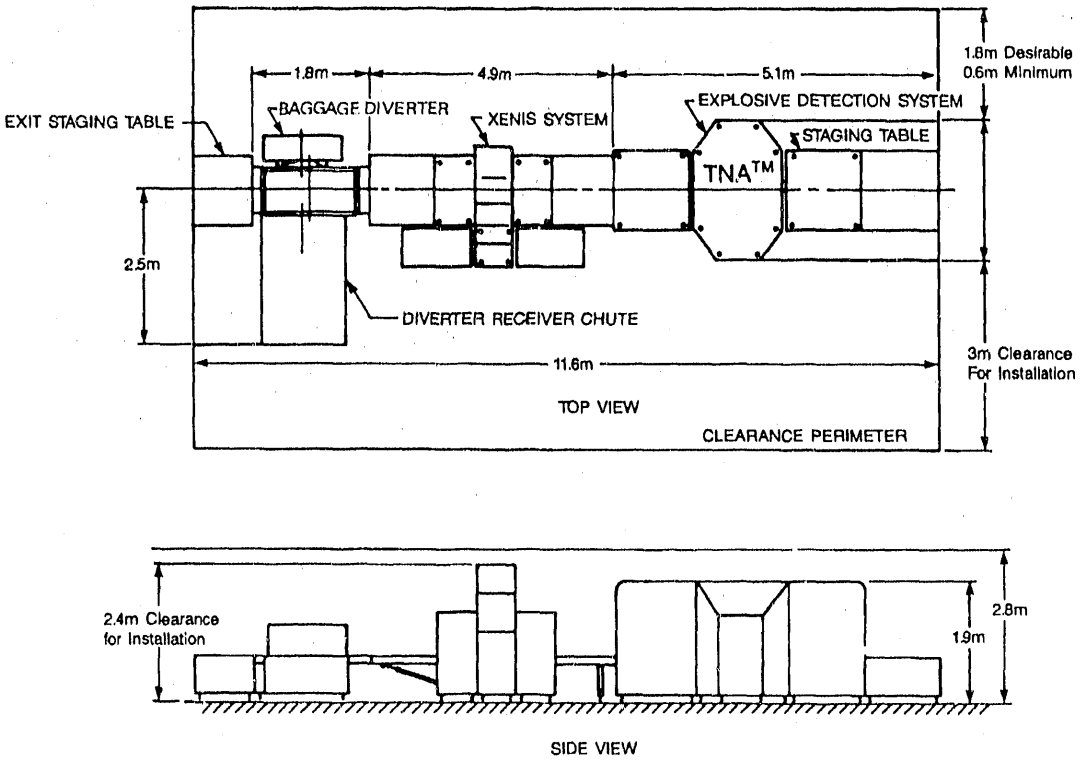


Figure 4.1 TNA explosive detection system with XENIS and diverter

4.1.1 Behind the Check-In Counter

In this scenario, the TNA system would be placed behind the counter (probably behind airline personnel) where the passengers check their baggage and get their airline tickets. Figure 4.2 shows one proposed setup for United Airlines at San Francisco International Airport. While the passenger's passport, ticket, and seat assignment were being checked, the baggage would be placed on a conveyor belt, which has two 90° turns, and enter the TNA system. If the TNA system alarmed, the passenger would be asked to step to the end of the counter where the inspection station is located to have the baggage opened. The passenger would not receive a boarding pass until the baggage had been cleared. For international check-in, which takes approximately 5 minutes per person at the counter, one TNA system could service about 20 check-in positions.

This scenario, in some respects, is similar to that for the ramp EDS–3, which has been in operation at JFK International Airport since September 1989. Passengers would still not be permitted to be next to the machine, but would, however, be able to view the EDS–3C from the ticket counter.

4.1.2 In Front of the Check-In Counter

This scenario is similar to the one described in Section 4.1.1, except that the entrance to the EDS–3C would be in the public area in front of the check-in counter (Figure 4.3), while the exit of the EDS–3C would be behind the ticket counter. Passengers would hand their luggage to a TNA airline attendant who would place it on the conveyor belt entering the TNA system. The passengers would then wait in line at the check-in counter, check to make sure that their bags had passed the TNA check, and be issued boarding passes. If a piece of luggage did not clear the TNA system, the passenger would be available to witness a hand inspection at a nearby inspection counter.

Members of the public could stand immediately next to the TNA system unless a barrier was erected, which would increase the TNA system's already considerable size. A variation of this approach would be to have the body of the TNA system behind the counter with only the entrance in front of the counter; this probably would be more difficult and expensive to integrate into an existing airport.

An advantage of this scenario over the one described in Section 4.1.1 would be that two airlines with adjacent ticket counters could both use the TNA system to screen

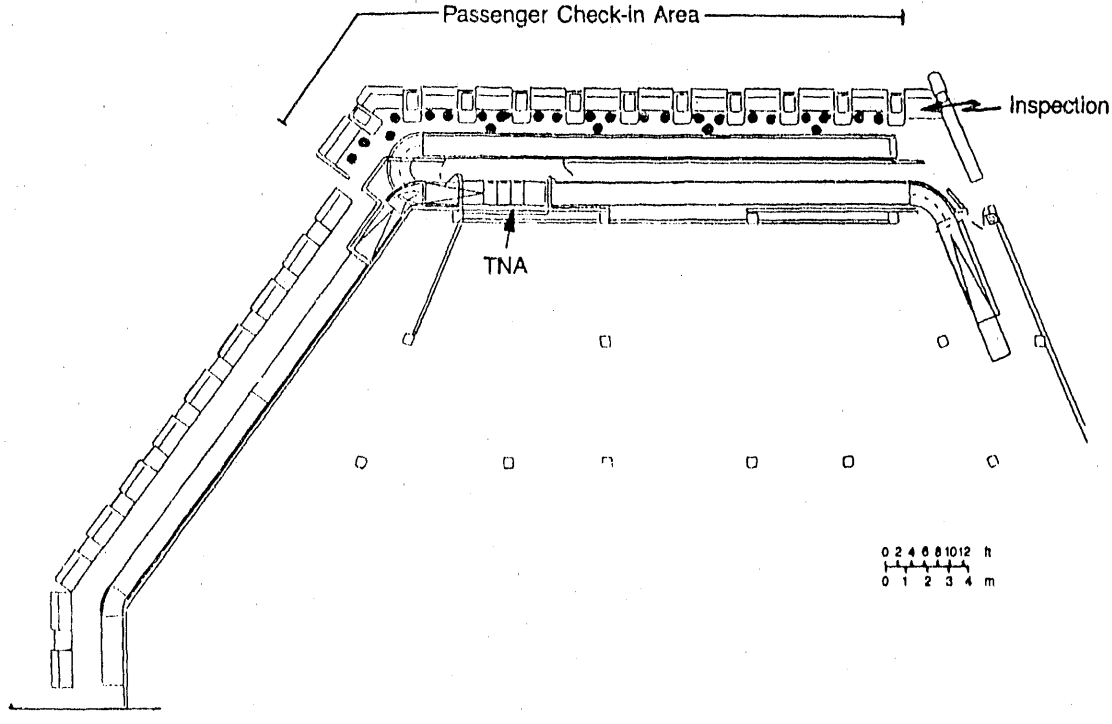


Figure 4.2 Behind the check-in counter—proposed setup for United Airlines at San Francisco International Airport (• indicates location of an agent)

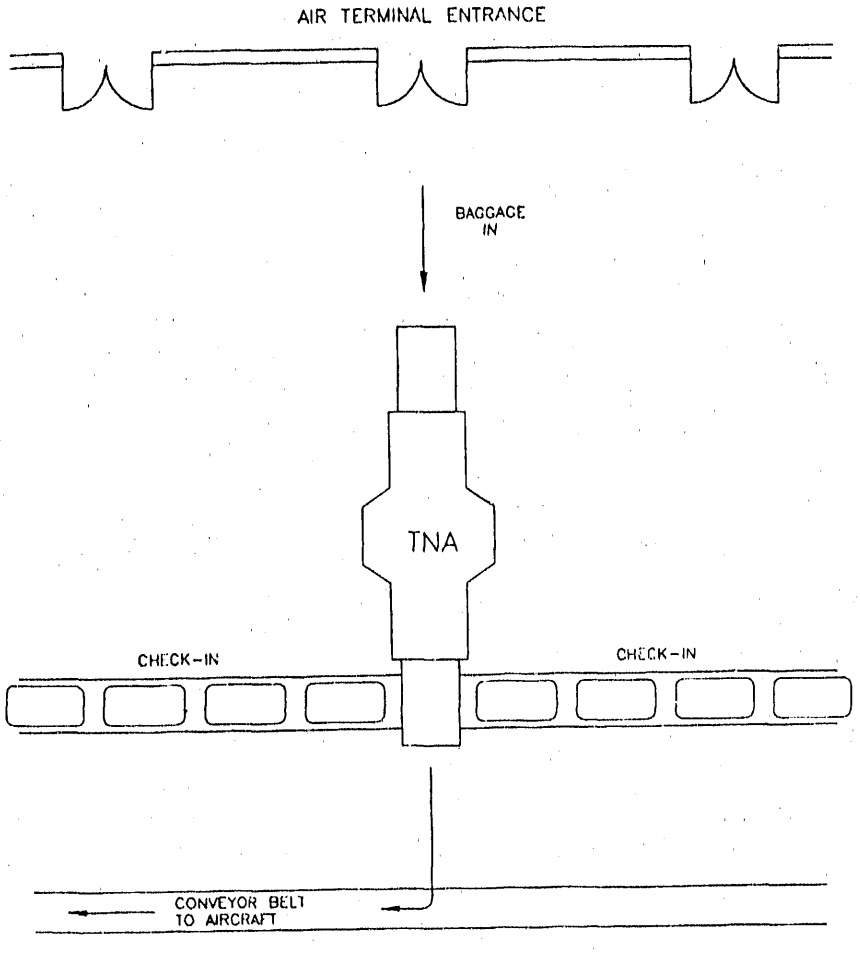


Figure 4.3 In front of check-in counter

luggage. In this case, two airlines could share the responsibility and cost of operating the TNA system. Although two airlines could also share the TNA system as illustrated in Figure 4.2, it would be much more difficult.

4.1.3 Pre-Check-In Area

In this scenario, the EDS-3C would be placed in an open area near the terminal entrance and check-in locations (Figure 4.4). When the luggage was cleared by the TNA system, the attendant at the exit would band it with tamper-resistant security tape and return it to the passenger. The passenger would then take it to the check-in counter of the appropriate airline, where it would be checked in for delivery to the aircraft.

Passengers whose bags were being inspected would come to the entrance of the TNA system, walk alongside as the bags were going through, and wait at the exit of the system. Bags resulting in an alarm would be opened at a station near the exit, perhaps at a table placed there for that purpose. In addition, other members of the general public or airline employees might come close to the TNA system as they walked about the terminal.

An advantage of this scenario is that many airlines could use this one system for screening international luggage. Passengers typically must arrive several hours before their scheduled flight is to depart, therefore allowing plenty of time to have their checked luggage screened. If passengers allowed enough time for this screening process at the beginning of their travel plans, there most probably would be no significant scheduling delays.

Several disadvantages are also foreseen in regard to this scenario. Since the passengers would have access to their luggage immediately after TNA screening, they would be exposed to the potentially radioactive contents for a time depending on the scheduled departure. If a flight was cancelled after a passenger's luggage was scanned by a

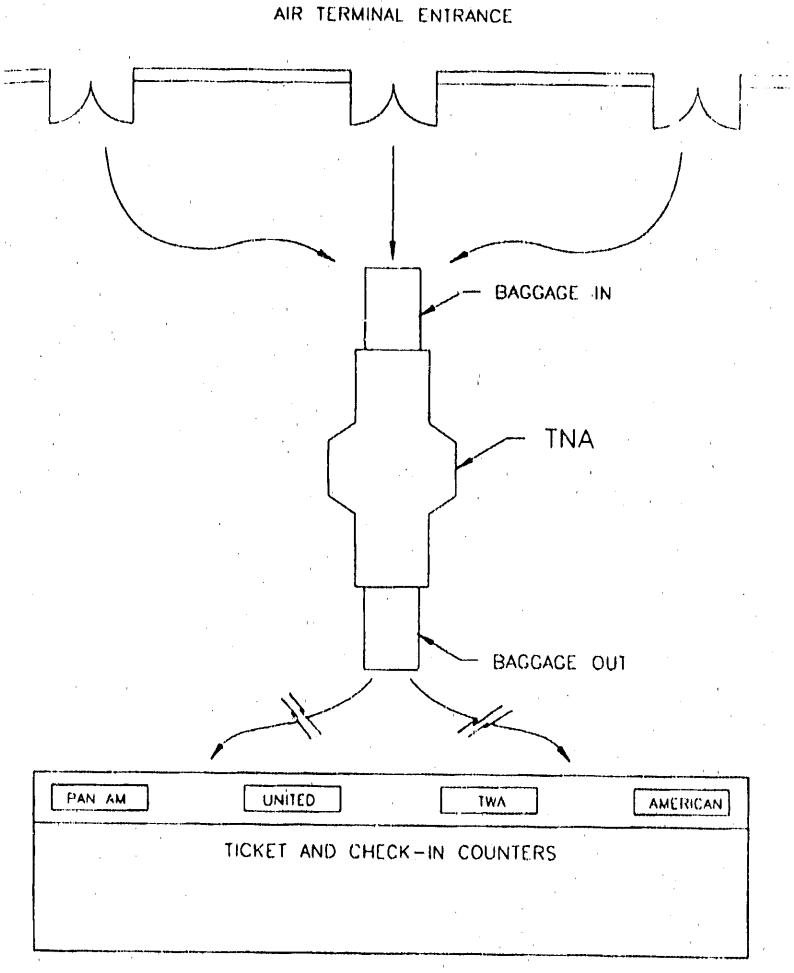


Figure 4.4 Pre-check-in area

TNA system, the passenger would have the slightly activated luggage for a longer period than during any of the other scenarios. This additional dose has been calculated and is assessed in Section 5.4.3.3.

4.1.4 Curbside Area

For this installation, the TNA system would be placed along the departure curb of an airport, similar to where curbside check-in for domestic flights is now permitted. Because the TNA system could be located in an area that would not be sheltered from the elements, it would have to be enclosed within a small building (as is currently down with the EDS-3 at JFK International Airport). In addition, this enclosure would have to be protected from vehicular traffic in the area adjacent to the system. Figure 4.5 illustrates the type of barriers and setup that would be required for this option. Vehicle barriers and Jersey walls (concrete median barriers) similar to those used in highway construction would be used in these installations (Figure 4.6). The passengers would still hand their luggage to an airline baggage handler ("sky-cap"), wait for the clear signal from the TNA computer, and then receive their claim checks after the luggage left the system. In case of an alarmed bag, the passenger would be available to witness a hand inspection, if necessary.

Passengers would come within several feet of the TNA system when they delivered their bags and, depending on the design of the installation, might walk alongside the system (as discussed in Section 4.1.3) to the exit. Alternatively, they might wait for a clear signal near the inspection station. Other members of the public might also pass near the system, but probably fewer than those in the pre-check-in scenario.

The TNA system is affected by temperature and humidity in much the same way as any other electronic equipment might be. Internal thermal design considerations have

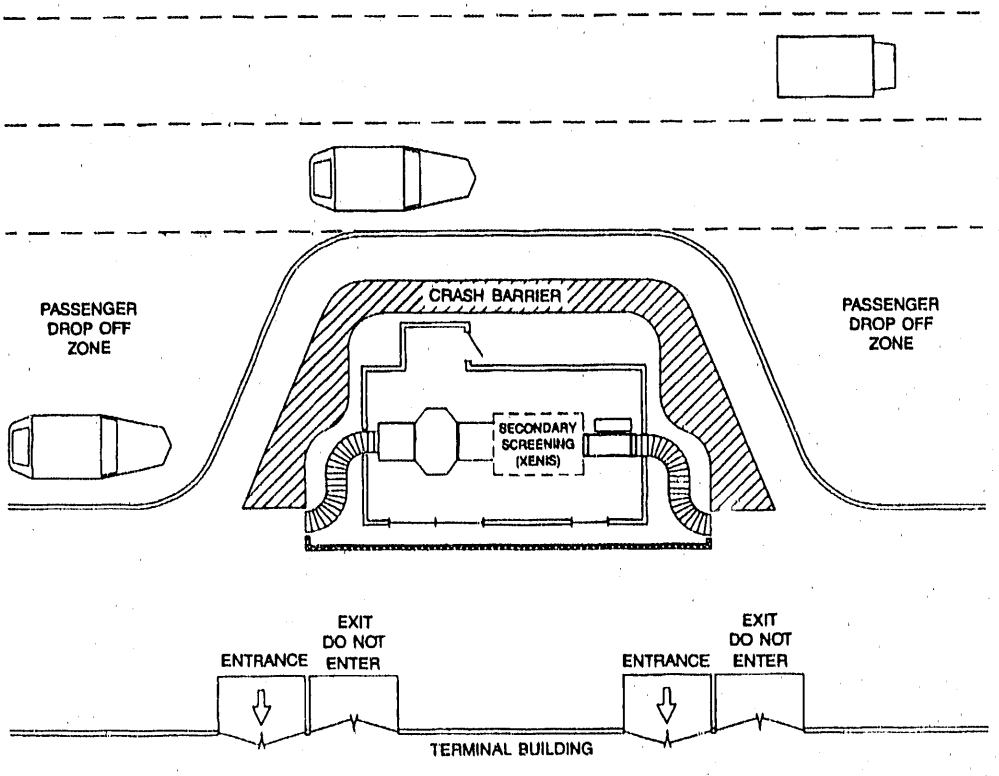


Figure 4.5 Curbside check-in

resulted in the specification of ac circuits, fans, ducting, and thermostatically controlled heaters (SAIC, 1989). Rapid changes in temperature (such as a stream of subzero air directly into the scanning chamber) could result in some damage of the detector or temporary malfunction of the computer equipment. A small building, such as the one built for the EDS-3 at JFK International Airport, would be suitable for protecting both the operating personnel and the EDS-3C from the elements. As in the case of any construction, buildings will have to be in compliance with local building codes and any other regulatory requirements.

4.2 Demography

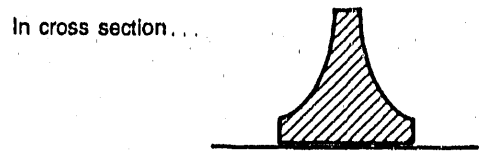
There are two types of workers who could have contact with the EDS-3C: those who would work directly with the EDS-3C (such as the operators and baggage handlers) and those whose duties would bring them infrequently near the EDS-3C (such as airline ticketing agents, supervisory personnel, and baggage cart drivers).

For purposes of this document, the public is defined as all those who are not workers as defined above. This includes all passengers and those members of the general public who may be at the airport, as well as employees who work at the airport but who do not normally frequent the main ticketing area of the airport.

The population density in the vicinity of the EDS-3C at concourse installations of airports will vary with location. However, the number of passengers whose baggage is screened by conventional x ray equipment is known. The following list shows the number of people screened annually at eight major international airports in the United States (see SAIC, 1988):

Airport	People screened
San Francisco	22.6 million
JFK	14.9 million
Los Angeles	89.7 million
Chicago-O'Hare	69.8 million
Miami	12.7 million
Detroit	31.3 million
Dallas-Ft. Worth	70.4 million
Dulles	6.6 million

Barrier system to be two phased. Phase one would consist of a deflecting shield such as is used to separate opposed lanes of traffic.



Phase two would be fluid-filled, collapsible barrels such as are used to absorb the impact of a motor vehicle. Both these systems are currently in common use on California highways.

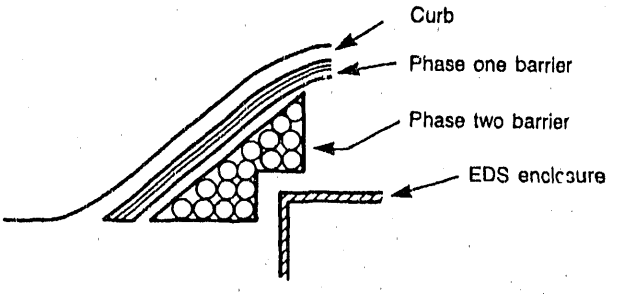


Figure 4.6 Barrier system to protect TNA operating personnel, passengers, and others from intrusion by motorized vehicles

The number of domestic and international passengers enplaning in the United States during the years 1985 through 1987 has continued to increase, as shown below (U.S. Bureau of the Census, 1989):

	Number in millions			
Passengers	**1985**	**1986**	**1987**	**Percent increase**
Domestic	357	394	416	14.2
International	25	25	31	19.4

If these trends continue at this rate, an estimated 38 million international passengers could travel in 1990.

The number of passengers traveling through each airport daily can be estimated by dividing the total number of passengers departing by the number of large airport "hubs." A large hub is one at which at least 1 percent of the total revenue passengers using all services and all operations of U.S. certified route air carriers enplane (U.S. Bureau of the Census, 1989). From 1987 statistics, we can estimate the number of passengers in an average airport to be:

$$\frac{448{,}913{,}700 \text{ departing passengers}}{28 \text{ large hubs}} = 16{,}032{,}600 \text{ passengers/yr}$$

The average number of passengers on a daily basis would be approximately 44,000 (16,032,600/365). Although only a small fraction of these passengers would be going on international travel, many of these passengers could pass near the EDS-3C. The radiological impacts of the EDS-3C located on the concourse level of airports are discussed in Section 5.4.

4.3 Source Transport

The average distance from the supplier of Cf-252 sources (located in Ohio) to various airport locations is approximately 1900 km (1200 mi). Because Cf-252 has an effective half-life of 2.646 years, periodic replacement of the source is necessary to maintain the desired neutron

fluence in the EDS-3C chamber cavity. On the basis of the estimated frequency of replacing one Cf-252 source annually, one truck shipment per EDS-3C would be expected on local and interstate highways each year. Since local roadways going to and from each airport are currently heavily traveled by cargo and industrial traffic, an additional truck shipment per year due to EDS-3C operation is not expected to be noticeable in existing traffic on local roads leading to the interstate highways. Since the estimated operational lifetime of the TNA systems is 15 years, a total of 15 shipments is anticipated for each system. Estimates of transportation accidents involving shipments of radioactive material are discussed in Section 6.

4.4 Seismology

Several of the airports that would be slated for a TNA system are located in earthquake areas. The most likely effect of an earthquake on the EDS-3C would be the shifting of the three major sections of the TNA system slightly apart, which could result in gaps in the system's shielding. To prevent this, each joint is tied together by four joining plates attached by six large bolts. A TNA system was assembled and operating at SAIC's Santa Clara, California, facility during the October 17, 1989, Loma Prieta earthquake, which measured 7.1 on the Richter scale. No effects on the TNA system were observed, and the integrity of the source was maintained.

5 ENVIRONMENTAL IMPACTS OF THE PROPOSED ACTION

5.1 Methodology

5.1.1 Regulations and Dose Criteria

The NRC promulgates regulations and establishes standards for protection against radiation arising out of activities conducted under licenses issued by the Commission. These requirements as set forth in Title 10 of the *Code of Federal Regulations* (10 CFR), Part 20, state:

> Persons engaged in [licensed] activities...should, in addition to complying with the requirements set forth in this part, make every reasonable effort to maintain radiation exposures, and releases of radioactive effluents to unrestricted areas, as low as is reasonably achievable. The term "as low as is reasonably achievable" means as low as is reasonably achievable taking into account the state of technology, and the economics of improvements in relation to benefits to the public health and safety, and other societal and socioeconomic considerations, and in relation to the utilization of atomic energy in the public interest.

Currently, 10 CFR Part 20 is being revised and will incorporate the most recent guidance from the International Commission on Radiological Protection (ICRP). This new guidance incorporates derived limits for intakes of radionuclides that have been developed using updated metabolic and dosimetric models (ICRP Publications 23, 28, and 30). Radiation doses calculated in this environmental assessment reflect the new ICRP guidance pertaining to external and internal dosimetry.

Maximum allowed values of radiation dose that may be received by workers in restricted areas (EDS-3C operators and assistants in this case) and those in unrestricted areas (other non-TNA workers, passengers, and members of the public) are provided by the NRC in the current 10 CFR Part 20:

Restricted areas	**mSv/yr (rem/yr)**
Whole body; head and trunk; active blood-forming organs; lens of eyes; or gonads	50 (5)
Hands and forearms; feet and ankles	750 (75)
Skin of whole body	300 (30)
Unrestricted areas	
Whole body (current regulations)	5 (0.5)
Whole body (proposed regulations)	1 (0.1)

The dose equivalent (H) from external exposure from sources of ionizing radiation depends on the absorbed dose (D), the effective quality factor (Q), and other modifying factors (N) that may be specified:

$$H = D \times Q \times N$$

where

H is in units of sievert (or rem)

D is in units of gray (or rad)

N is the product of any other modifying factors

The quality factor allows for the effect of higher energy deposition along particle tracks produced by various radiation types such as neutrons, alpha particles, x rays, or gamma rays. In ICRP Publication 21, a value of 2.3 is given for Q for thermal neutrons. In 1985, the ICRP, and in 1987, the National Council of Radiation Protection and Measurements (NCRP Report 91) recommended that the quality factor for neutrons be increased by a factor of 2 as an interim measure pending full review. Report 40 of the International Commission on Radiological Units (ICRU) indicates that an increase by a factor of 2.5 is justified for neutrons, but states that further review is appropriate.

Because the EDS-3C is expected to be deployed at U.S. carriers at airport locations worldwide, several international regulatory agencies that have adopted a neutron quality factor of 20 will use this environmental assessment as a reference for licensing this system at airports. Consequently, although the current NRC policy is to use a neutron quality factor of 10, in this assessment a quality factor of 20 is used for both international agreement and added conservatism.

5.1.2 Exposure Pathways

Individuals who may receive radiation exposures due to normal operations are divided into two major categories: EDS-3C workers and members of the general public. The personnel assigned to operate the EDS-3C will be specifically trained for TNA system operations. These personnel will consist of the operator and other technical assistants, such as baggage handlers and trained security specialists. Training for the TNA operators will consist of lectures and courses in radiation physics, radiation safety, biological effects of radiation, instrumentation, radiation control, and operating procedures during normal and accident conditions. Each TNA operator will have to pass a radiation safety examination covering all of these items. Other TNA workers will load and unload the bags on and off the EDS-3C. These workers will be supervised by a

TNA operator and will receive a more basic radiation safety training course that is commensurate with their limited duties. This type of training is consistent with the training specified by 10 CFR Part 19, "Notices, Instructions, and Reports to Workers; Inspections." Each individual who enters a restricted area under such circumstances that he or she receives, or is likely to receive, a dose in any calendar quarter in excess of 25 percent of the values specified in 10 CFR 20.101(a) will be required to wear personnel dosimeters. Because the only personnel that might receive a quarterly dose in excess of 25 percent will be the EDS–3C operators, they will be the only TNA employees required to wear personnel dosimetry (neutron and gamma). The TNA operator will be the only authorized user who may manipulate the source, perform the passage maintenance, and extract jammed baggage.

Non-TNA workers, passengers, and members of the public could be exposed to the low levels of radiation that might exist around the TNA system. There are three major exposure pathways to the public: exposure of persons on the concourse level near the EDS–3C, direct radiation exposure of passengers to beta or gamma fields from luggage that has been through the EDS–3C, or internal dose to passengers or other members of the public who consume a food or other irradiated item that was contained in the reclaimed luggage. Each of these exposure scenarios is evaluated in detail in Section 5.4.3.

5.2 Construction Impacts

The EDS–3C site area will be designed and modified so as to minimize construction impacts. All airport construction activities to accommodate the system will comply with Federal, State, and local regulations governing health and safety during construction, as will all operations in connection with the transportation, storage, and use of radioactive material. Work will be monitored by the airport authority at each site location, who, in most cases, also will be the governing authority issuing the initial construction permit.

A structural engineering study will be required to ensure that the weight of the EDS–3C can be accommodated safely on the concourse level of airports. Airport passenger departure and arrival areas are generally built to a much higher live-load rating than the elevated floors within the airport terminal. However, because the elevated-floor structure of airport terminals varies because of substantial differences in design, the structural requirements could change significantly from airport to airport. The exceptionally heavy loading of the EDS–3C combined with the requirement to place these systems on the concourse levels of airports creates the greatest variable in the design of an installation.

Using the information from the structural engineering study, a design team should develop conceptual documents addressing public access control, security, architectural, mechanical, and electrical requirements of the project (Peacock, 1989). Once the conceptual design package has been completed, it should be submitted to the owner, the primary user (the airline carrier), and the airport authority for initial review and approval. If the conceptual design is approved, the final design documents and contract can be drawn up. These documents should include drawings, specifications, cost estimates, and structural calculations showing the method of distributing the load and/or reinforcing the floor structure.

5.2.1 Site Requirements

Lobby or concourse TNA systems can be placed at various locations, as discussed in Section 4.1. Large, open ticketing areas on the ground level of an airport are desirable for concourse use of the EDS–3C because of the considerably reduced cost of installation. Because present airport facilities have not been planned for a system as large or as heavy as the EDS–3C, finding a suitable location in an existing airport may be difficult. Most installations will require significant floor-loading studies before a site is selected and, in some cases, may even require building a facility specifically constructed for the system (curbside scenario).

In addition to the requirements above, the surface under the system must be horizontal and level to within about 6 mm (1/4 in.) so that the system's modular components can fit together and align properly. Additional space must also be provided near the EDS–3C to store the cask and the additional radiological instrumentation that would be necessary in case of an emergency.

For installations at existing facilities, it may be necessary to build up the surface with cement grout to ensure that the cask will roll easily and align with the source-loading positions.

Transportation of the baggage from the EDS–3C to the baggage holding area for loading onto aircraft also must be provided for. This may require additional space for baggage carts near the EDS–3C or near the ticket counter. There also must be a 2-m (6.6-ft) clearance on the side of the EDS–3C where the source is inserted for access to the source cask.

If the EDS–3C is located over an occupied area, it may be necessary to add neutron and gamma ray shielding, either between the EDS–3C and the floor or to the ceiling underneath. The shielding shall be sufficient enough to bring the dose rates to less than 1 μSv/hr (0.1 mrem/hr) on the ceiling of the level below the EDS–3C. If a load distribution platform is incorporated into the design of the concourse installation, then this shielding should be incorporated into it.

5.2.2 Land Use

At the proposed Dulles International Airport site, the TNA system will be installed at the United Airlines international ticket counter. As shown in Figure 5.1, the XENIS and the EDS-3C are at right angles to one another in order to "fit" the EDS-3C into an existing ticket counter area. A nearby utility room will serve as a storage facility for the cask and the associated survey equipment needed for the EDS-3C.

Additional construction needed at the United Airlines international ticket counter will affect nearby passenger traffic patterns to some degree because of its close proximity to the security area. It is anticipated that essential rigging equipment such as air dollies or forklifts could be moved into the terminal building during a week night or on a weekend when traffic is at a minimum. If all the necessary requirements have been met and construction has been completed, the moving process should take no more than 2 to 3 days.

5.3 Nonoperational Impacts

5.3.1 Transportation

The components of the EDS-3C will be shipped individually and will be assembled at the location where the system will be used. No radiation exposure to workers or to members of the public will result from either the shipment or assembly of the system because the radiation source will not have been installed in the system. The Cf-252 source will be shipped in one shielded cask. Following assembly of the EDS-3C, the source will be transferred from the cask (see Figure 5.2) to the system. Radiation exposure to individuals could occur during transport of the Cf-252 source and during its installation or operation at the airport.

Average estimated radiation doses to the truck drivers, who might spend 24 hours at a distance of 2 m (6.6 ft) from the cask, are about 0.16 mSv (16 mrem) per driver per delivery. Transportation regulations under 10 CFR 71.50(3)(d) effectively restrict the radiation dose to 0.02 mSv/hr (2 mrem/hr) in any normally occupied parts of the vehicle. In addition, there can be no loading or unloading operations between the beginning and the end of the transportation. Assuming that there are two drivers per truck and that the used source is returned yearly to the manufacturer, yearly replacement of the source is expected to result in a collective dose to the drivers of 6×10^{-4} person-Sv (6×10^{-2} person-rem) per TNA system. If the average distance from the cask to the driver was increased to 3 m (9.8 ft), the expected collective dose would decrease to 2.8×10^{-4} person-Sv (2.8×10^{-2} person-rem). The dose to an individual member of the public during transportation of the source from the manufacturer to the site would be less than 10 μSv (1 mrem).

5.3.2 System Installation and Source Transfer

The source transport cask (see Figure 5.2) is constructed of steel, welded together, and filled with a composite neutron and gamma ray shield of water-extended polyester with lead surrounding the source position. It is a DOT-7A cask certified by the U.S. Department of Transportation that is 0.75 m (2.5 ft) in diameter and 0.84 m (2.75 ft) long.

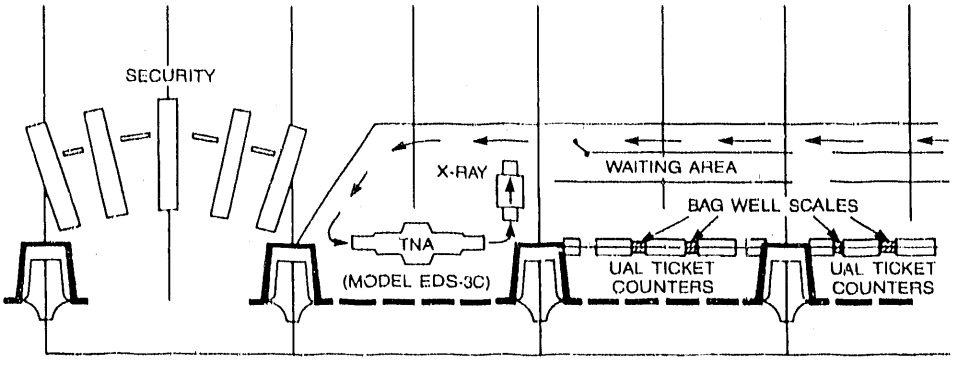


Figure 5.1 Proposed EDS-3C at Dulles International Airport

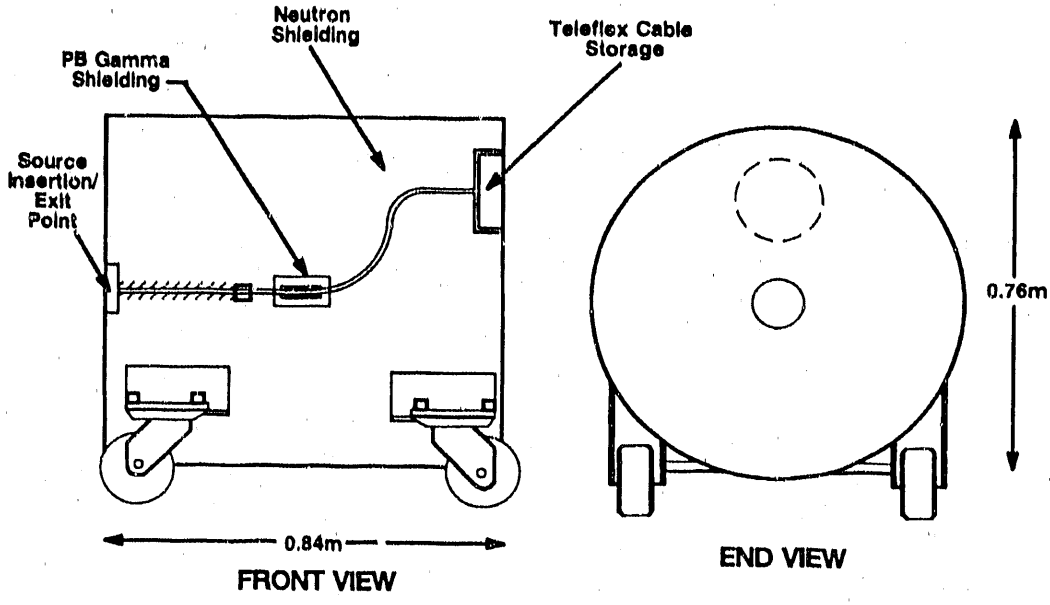


Figure 5.2 EDS-3C source transport cask

To transfer the source from the cask to the system, a special platform has been manufactured that helps guide the source into the EDS-3C (Figure 5.3). A polyethylene adapter with a conical hole fits into a recess in the end of the cask and is bolted onto the system for transfer. The cask is then rolled onto the platform and locked into position against the side of the EDS-3C, which engages the adapter with the cask recess. The source is transferred to the EDS-3C by pushing the Teleflex cable into the system until it stops. After the source is in the system and the cask and transfer adapter are removed, a flexible plastic tube is inserted over the cable and clamped into place. Its inner diameter is slightly greater than the diameter of the cable but less than the diameter of the source. At its longest length, it just reaches the "retracted source position" and thus serves as a stop to prevent the source from being retracted too far. See Appendix A for further details associated with the installation of and the radiation safety operating procedures for the EDS-3C.

The expected radiation doses outside a shipping cask loaded with a 150-μg source of Cf-252 are shown in Figure 5.4. The nearest point that a member of the public could get to the cask during source transfer would be approximately 3 m (10 ft), which would correspond to a dose rate of less than 10 μSv/hr (1 mrem/hr).

5.3.3 Radiation Exposure During Maintenance

When the EDS-3C is in the operating mode, the source will reside in a bismuth gamma ray shield and will be surrounded by a neutron moderator and absorber. If the operators must get inside the EDS-3C to perform maintenance, the source will be placed in a retracted position. In this position, the source will be surrounded by a moderator and a 25.4-mm (1-in.) lead gamma radiation shield. The radiation dose to EDS-3C operators from clearing a baggage jam is expected to be less than 0.05 mSv (5 mrem). Experience with the EDS-3 at JFK International Airport indicates that baggage jams are rare and the vast majority of these jams can be cleared without entering the cavity. In the past 6 months of operation at JFK International Airport, it has not been necessary to enter the passageway to dislodge jammed luggage.

Major maintenance work, such as repairing a broken conveyor, replacing NaI(Tl) detectors, or repairing interior-cavity materials, requires partial disassembly of the TNA system. For these types of repairs, the Cf-252 source will be removed from the system and will be placed in its shipping and storage cask. Once the source is removed from the system, radiation exposure during maintenance work will be minimal.

5.4 Operational and Radiological Impacts

5.4.1 Neutron Dose Contours

The thermal neutron flux inside the shielded TNA system was mapped using small helium-3 (He-3) detectors with a small (0.2-μg) Cf-252 source substituted for the normal 150-μg source. Flux maps were measured and then corrected for actual source strength. The detectors were calibrated against activation foils using the American

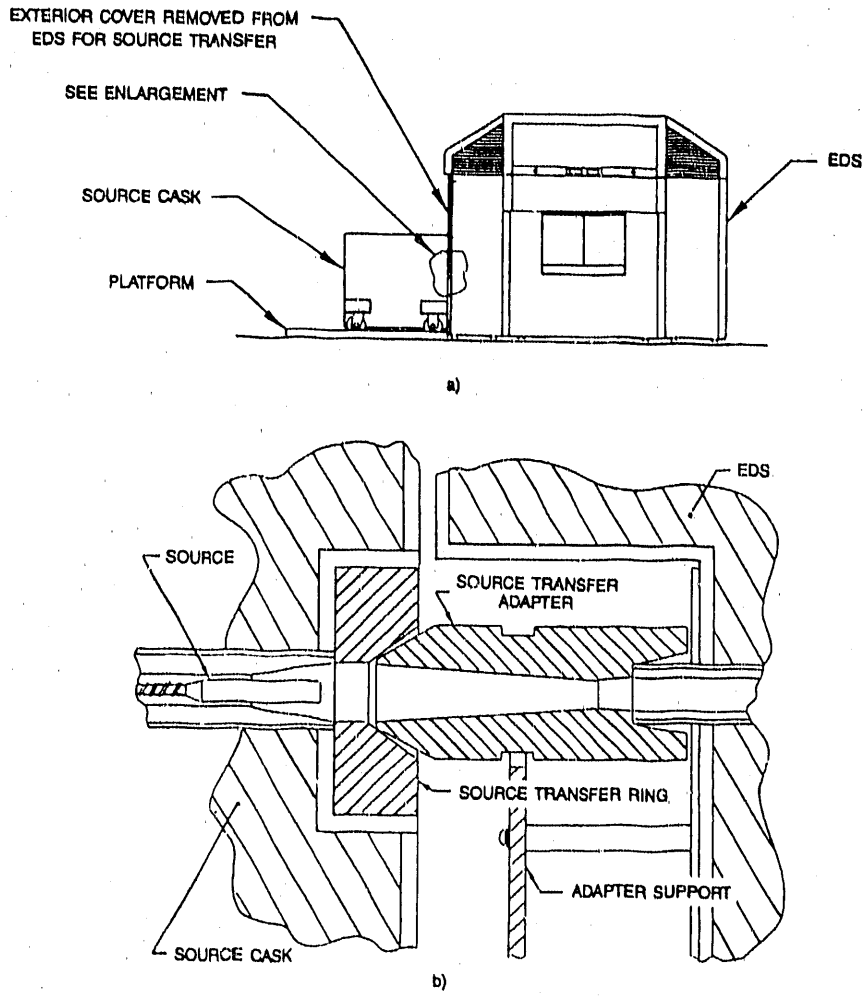
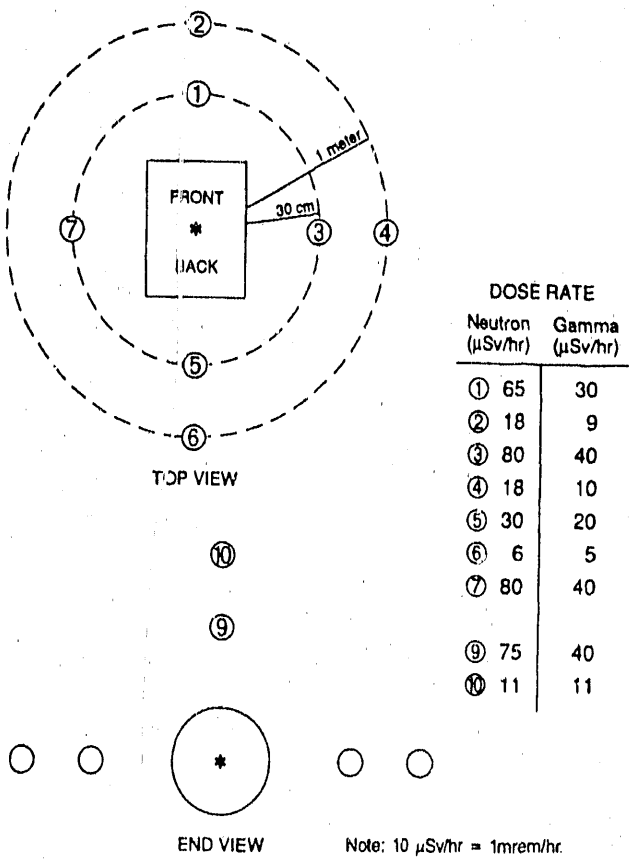


Figure 5.3 Placement of cask for source transfer. (a) Overall view, (b) detail view of source transfer ring and source transfer adapter

Society for Testing and Materials method (ASTM, 1989). The low-energy epithermal flux was measured in some of the same map locations using a cadmium foil-wrapped He-3 detector; it was nominally 3 percent of the thermal value (see SAIC, 1989). The thermal flux peak was about 8×10^4 neutrons/cm^2-s for the 150-μg source. The fluence impinging on a item as it travels through the center cavity at 15 cm (6 in.) per second was determined by integrating the mapped flux; it was calculated to be 4.5×10^5 neutrons/cm^2. The fast neutron fluence was estimated by calculating the uncollided flux and integrating along the path of the item being scanned; it was calculated to be 2.5×10^5 neutrons/cm^2.

The neutron fluence calculated with the source in the operating position provides the basis for estimating the integrated neutron flux to which the baggage would be exposed. The measured fluence values were used in estimating the activation products in baggage contents using the calculated activation rates from Erdtmann's *Neutron Activation Tables*. Tables 5.1 and 5.2 show the potential activation products, activities, and dose rates for baggage contents containing 1-kg (2.2-lb) masses of various elements. Only reactions that produced initial activities greater than 0.001 becquerel (Bq) (2.7×10^{-8} μCi) per gram of element are shown. The value of 0.001 Bq/g was chosen because that is the amount of induced radioactivity equal to one-hundredth of that contained naturally in food (see Section 5.4.4).

A cursory glance at these tables shows that the vast majority of isotopes are rare earths and elements unlikely to be found in suitcases except in trace quantities. After only a 30-second delay, the largest remaining isotopes are Sc-46m, V-52, In-116m(1), and Hf-179m, with an average dose rate of 0.18 μSv/hr (18 μrem/hr). All tables listing activity, dose rates, and total committed doses are in the



DOSE RATE

	Neutron (μSv/hr)	Gamma (μSv/hr)
①	65	30
②	18	9
③	80	40
④	18	10
⑤	30	20
⑥	6	5
⑦	80	40
⑨	75	40
⑩	11	11

Figure 5.4 EDS–3C shipping cask dose rates

International System of Units (SI) (i.e., gray, sievert, and becquerel) (ICRU Report 33). For corresponding tables using the English system of units (i.e., rad, rem, and microcurie), see Appendix B. Figure 5.5 shows the isodose contours (with loading and unloading platforms) that are based on dose rate measurements. Additional dose rate and fluence information can be found in Appendix C.

It should be noted that 1 sievert (Sv), the SI unit for dose, is equal to 100 rem (R), the English unit. In addition, the becquerel (Bq) is equal to 1 disintegration per second, and 1 microcurie (μCi) is equal to 3.7×10^4 Bq.

Activation foils provided and analyzed by the National Institute of Standards and Technology (formerly the National Bureau of Standards) were used to measure the baggage passage neutron flux in the prototype TNA system, Model EDS–2. The results (see Appendix D) were consistent with the determination of the thermal neutron fluence calculations in Tables 5.1 and 5.2.

5.4.2 Radiation Exposure of Workers

Workers such as operators, baggage handlers, and trained security screeners may be exposed to radiation from EDS–3C operations because of possible neutron activation of items in baggage or from the small radiation field in the area they occupy. Workers may be exposed to radiation via four different pathways: exposure during normal operation to leakage radiation from the Cf-252 source in the immediate area of the EDS–3C, direct radiation exposure to beta or gamma fields from luggage that has been through the EDS–3C, exposure of security screeners resulting from hand inspection of "suspect" irradiated luggage, and exposure during the transfer of the source to or from a shipping cask.

The direct radiation fields around the EDS–3C have been measured. Figure 5.6 shows that the total dose rates (neutron plus gamma) in the area occupied during baggage loading and unloading are all less than 3 μSv/hr (0.3 mrem/hr) at any distance 30 cm (1 ft) from the system. At distances greater than 1 m (3.3 ft), the total dose rates are all less than 0.9 μSv/hr (0.09 mrem/hr). As an estimate, the average dose rates from each end at 30 cm and 100 cm (1 ft and 3.3 ft) were calculated to be 0.6 and 0.45 μSv/hr (0.06 and 0.045 mrem/hr), respectively. As a result, the average dose rate for personnel would be 0.5 μSv/hr (0.05 mrem/hr).

If the EDS–3C is configured as shown in Figure 4.1, only one baggage handler would be near the TNA system

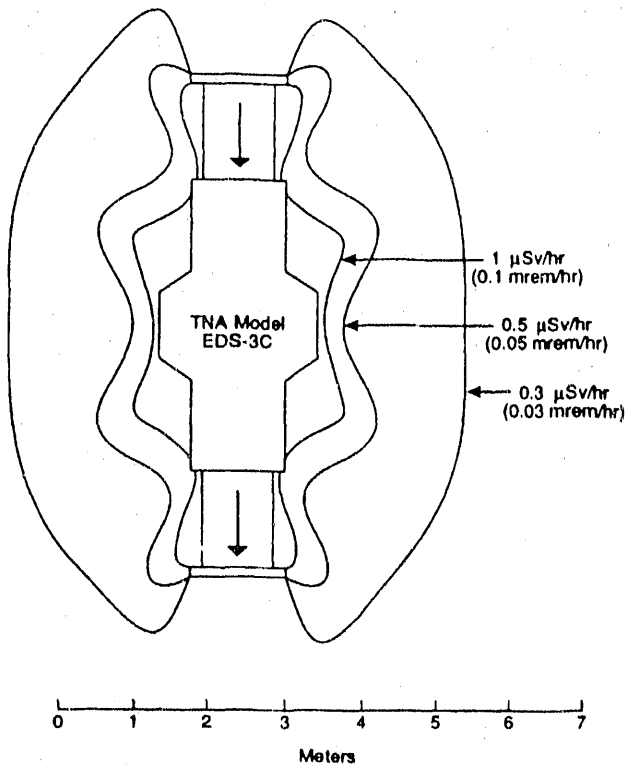


Figure 5.5 TNA system for lobby installation with isodose contours

Table 5.1 Potential activation products (for slow neutrons*) of baggage contents containing 1-kg (2.2-lb) masses of various elements

				0.5-min delay		10-min delay		60-min delay	
Product	Bq/μg	Half-life (min)	Gamma (MeV/Bq)	Activity (Bq/g)	Dose rate (μSv/hr/kg @ 30 cm)	Activity (Bq/g)	Dose rate (μSv/hr/kg @ 30 cm)	Activity (Bq/g)	Dose rate (μSv/hr/kg @ 30 cm)
H-3	8.42E-10	6.49E+06	-	3.79E-11	-	3.79E-11	-	3.79E-11	-
N-16	3.50E-03	1.19E-01	4.60E+00	8.56E-06	6.39E-08	8.05E-30	6.01E-32	0.00E+00	0.00E+00
O-19	3.51E-03	4.48E-01	1.04E+00	7.29E-05	1.23E-07	3.02E-11	5.10E-14	7.77E-45	1.31E-47
F-20	1.97E-02	1.83E-01	1.64E+00	1.33E+00	3.55E-03	3.17E-16	8.44E-19	1.86E-98	0.00E+00
Ne-23	2.43E+01	6.20E-01	1.45E-01	6.25E-01	1.47E-04	1.53E-05	3.60E-09	8.19E-30	1.92E-33
Na-24	1.80E+00	8.80E+02	4.12E+00	8.10E-02	5.41E-04	8.04E-02	5.37E-04	7.73E-02	5.16E-04
Mg-27	1.29E+00	9.46E+00	9.14E-01	5.60E-02	8.29E-05	2.79E-02	4.14E-05	7.16E-04	1.06E-06
Al-28	2.72E+02	2.24E+00	1.78E+00	1.05E+01	3.03E-02	5.55E-01	1.60E-03	1.06E-07	3.07E-10
Cl-38	5.55E+00	3.72E+01	1.49E+00	2.47E-01	5.98E-04	2.07E-01	5.01E-04	8.17E-02	1.97E-04
Ar-41	1.06E+01	1.10E+02	1.28E+00	4.75E-01	9.87E-04	4.48E-01	9.30E-04	3.27E-01	6.78E-04
Sc-46m	4.73E+04	3.12E-01	1.42E-01	7.01E+02	1.61E-01	4.81E-07	1.11E-10	2.82E-55	6.49E-59
Ti-51	3.57E+00	5.76E+00	3.50E-01	1.51E-01	8.59E-05	4.82E-02	2.74E-05	1.18E-04	6.68E-08
V-52	1.79E+03	3.75E+00	1.43E+00	7.34E+01	1.70E-01	1.27E+01	2.94E-02	1.23E-03	2.86E-06
Cr-55	3.22E+00	3.56E+00	6.57E-04	1.31E-01	1.40E-07	2.07E-02	2.20E-08	1.23E-06	1.31E-12
Mn-56	1.11E+02	1.55E+02	1.70E+00	4.98E+00	1.37E-02	4.78E+00	1.32E-02	3.82E+00	1.05E-02
Co-60m	2.33E+03	1.05E+00	1.23E-03	7.54E+01	1.50E-04	1.43E-01	2.84E-07	6.65E-16	1.33E-21
Ni-65	7.64E+00	1.51E+02	5.63E-01	3.43E-01	3.13E-04	3.28E-01	3.00E-04	2.61E-01	2.38E-04
Cu-64	4.58E+00	7.64E+02	1.95E-01	2.06E-01	6.51E-05	2.04E-01	6.46E-05	1.95E-01	6.17E-05
Cu-66	1.47E+02	5.10E+00	9.56E-02	6.18E+00	9.58E-04	1.70E+00	2.64E-04	1.90E-03	2.95E-07
Zn-69	3.69E+00	5.70E+01	4.78E-06	1.65E-01	1.28E-09	1.47E-01	1.14E-09	8.01E-02	6.21E-10
Ga-70	5.43E+01	2.11E+01	5.55E-03	2.40E+00	2.16E-05	1.76E+00	1.58E-05	3.41E-01	3.06E-06
Ga-72	2.59E+00	8.46E+02	2.03E+00	1.17E-01	3.84E-04	1.16E-01	3.81E-04	1.11E-01	3.65E-04
Ge-75m	6.38E+01	8.15E-01	5.59E-02	1.88E+00	1.70E-04	5.82E-04	5.28E-08	2.00E-22	1.81E-26
Ge-75	1.05E+00	8.28E+01	3.18E-02	4.71E-02	2.43E-06	4.35E-02	2.24E-06	2.86E-02	1.47E-06
Ge-77m	9.05E-01	8.84E-01	6.31E-02	2.75E-02	2.82E-06	1.60E-05	1.64E-09	1.52E-22	1.56E-26
As-76	3.26E+00	1.58E+03	3.37E-01	1.47E-01	8.02E-05	1.46E-01	7.98E-05	1.43E-01	7.81E-05
Sc-77m	5.69E+03	2.90E-01	9.63E-02	7.75E+01	1.21E-02	1.07E-08	1.67E-12	1.38E-60	2.15E-64
Sc-79m	2.15E+01	3.91E+00	9.57E-03	8.85E-01	1.37E-05	1.64E-01	2.55E-06	2.33E-05	3.61E-10
Sc-81	1.33E+01	1.85E+01	1.44E-02	5.87E-01	1.37E-05	4.12E-01	9.61E-06	6.32E-02	1.48E-06
Sc-83	3.45E+00	2.25E+01	1.27E+00	1.53E-01	3.15E-04	1.14E-01	2.35E-04	2.45E-02	5.04E-05
Br-80m	5.48E+00	2.65E+02	2.41E-02	2.46E-01	9.62E-06	2.40E-01	9.39E-06	2.11E-01	8.24E-06
Br-80	2.91E+02	1.77E+01	7.00E-02	1.28E+01	1.46E-03	8.85E+00	1.00E-03	1.25E+00	1.42E-04
Br-82m	2.31E+02	6.10E+00	4.22E-04	9.82E+00	6.72E-06	3.34E+00	2.28E-06	1.14E-02	7.79E-09
Kr-81m	3.77E+02	2.22E-01	1.27E-01	3.56E+00	7.34E-04	4.70E-13	9.69E-17	7.72E-81	1.59E-84
Kr-83m	1.74E+01	1.12E+02	2.26E-03	7.81E-01	2.86E-06	7.36E-01	2.70E-06	5.40E-01	1.98E-06
Rb-86m	4.20E+01	1.02E+00	5.46E-01	1.35E+00	1.19E-03	2.12E-03	1.87E-06	3.74E-18	3.31E-21
Rb-88	2.05E+00	1.78E+01	6.37E-01	9.05E-02	9.35E-05	6.25E-02	6.46E-05	8.92E-03	9.22E-06
Y-90m	4.16E+00	1.91E+02	6.30E-01	1.87E-01	1.91E-04	1.81E-01	1.84E-04	1.51E-01	1.54E-04
Nb-94m	3.80E+01	6.26E+00	1.17E-02	1.62E+00	3.07E-05	5.65E-01	1.07E-05	2.23E-03	4.23E-08
Mo-101	1.35E+00	1.46E+01	1.51E+00	5.93E-02	1.45E-04	3.78E-02	9.25E-05	3.52E-03	8.62E-06
Rh-104m	3.60E+03	4.35E+00	3.48E-02	1.50E+02	8.44E-03	3.29E+01	1.86E-03	1.14E-02	6.45E-07
Rh-104	1.54E+04	7.05E-01	1.11E-02	4.24E+02	7.63E-03	3.73E-02	6.71E-07	1.68E-23	3.03E-28
Pd-107m	8.42E+00	3.55E-01	1.52E-01	1.43E-01	3.52E-05	1.26E-09	3.11E-13	5.14E-52	1.27E-55
Pd-109m	9.12E+00	4.69E+00	1.14E-01	3.81E-01	7.05E-05	9.36E-02	1.73E-05	5.79E-05	1.07E-08
Pd-109	3.37E+00	8.08E+02	1.24E-02	1.52E-01	3.05E-06	1.50E-01	3.02E-06	1.44E-01	2.90E-06
Ag-108	5.09E+03	2.41E+00	2.94E-02	1.98E+02	9.46E-03	1.29E+01	6.16E-04	7.36E-06	3.51E-10
Ag-110	8.31E+04	4.10E-01	2.96E-02	1.61E+03	7.71E-02	1.71E-04	8.19E-09	3.38E-41	1.62E-45
In-114	9.43E+01	1.20E+00	2.21E-03	3.18E+00	1.14E-05	1.32E-02	4.72E-08	3.80E-15	1.36E-20
In-116m(2)	1.26E+06	3.63E-02	8.20E-02	4.06E+00	5.39E-04	6.96E-79	9.26E-83	0.00E+00	0.00E+00
In-116m(1)	1.29E+03	5.42E+01	2.47E+00	5.77E+01	2.31E-01	5.11E+01	2.05E-01	2.70E+01	1.08E-01

See footnotes at end of table.

Table 5.1 (continued)

Product	Bq/μg	Half-life (min)	Gamma (MeV/Bq)	0.5-min delay		10-min delay		60-min delay	
				Activity (Bq/g)	Dose rate (μSv/hr/kg @ 30 cm)	Activity (Bq/g)	Dose rate (μSv/hr/kg @ 30 cm)	Activity (Bq/g)	Dose rate (μSv/hr/kg @ 30 cm)
In-116	1.36E+04	2.37E-01	1.55E-02	1.42E+02	3.57E-03	1.22E-10	3.08E-15	3.92E-74	9.84E-79
Sn-125m	1.09E+00	9.52E+00	3.29E-01	4.73E-02	2.52E-05	2.37E-02	1.26E-05	6.22E-04	3.32E-07
Sb-122m	7.08E+00	4.21E+00	5.96E-02	2.93E-01	2.84E-05	6.14E-02	5.94E-06	1.64E-05	1.58E-09
Sb-124m	8.42E+00	1.55E+00	3.48E-01	3.03E-01	1.71E-04	4.33E-03	2.45E-06	8.48E-13	4.78E-16
Te-131	2.08E+00	2.50E+01	3.54E-01	9.23E-02	5.30E-05	7.09E-02	4.07E-05	1.77E-02	1.02E-05
I-128	2.00E+02	2.50E+01	8.75E-02	8.88E+00	1.26E-03	6.82E+00	9.68E-04	1.71E+00	2.42E-04
Xe-125m	1.70E+01	9.50E-01	1.11E-01	5.31E-01	9.56E-05	5.20E-04	9.35E-08	7.50E-20	1.35E-23
Xe-137	1.99E+00	3.84E+00	1.50E-01	8.18E-02	1.99E-05	1.47E-02	3.58E-06	1.78E-06	4.32E-10
Cs-134m	9.28E+00	1.74E-02	2.34E-02	9.38E-10	3.56E-14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ba-136m	1.31E+03	5.13E-03	1.92E+00	2.73E-28	8.51E-31	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ba-139	1.55E+00	8.33E+01	4.18E-02	6.95E-02	4.71E-06	6.42E-02	4.35E-06	4.23E-02	2.87E-06
La-140	1.92E+00	2.41E+03	2.32E+00	8.64E-02	3.25E-04	8.62E-02	3.24E-04	8.49E-02	3.19E-04
Pr-142	3.43E+00	1.15E+03	5.83E-02	1.54E-01	1.46E-05	1.53E-01	1.45E-05	1.49E-01	1.41E-05
Nd-151	3.52E+00	1.24E+01	1.69E-01	1.54E-01	4.22E-05	9.06E-02	2.48E-05	5.54E-03	1.52E-06
Sm-153	1.19E+01	2.79E+03	5.35E-02	5.35E-01	4.65E-05	5.34E-01	4.63E-05	5.28E-01	4.58E-05
Sm-155	2.81E+01	2.22E+01	8.24E-02	1.24E+00	1.66E-04	9.25E-01	1.24E-04	1.94E-01	2.60E-05
Eu-152m(2)	9.21E+00	9.60E+01	7.38E-02	4.13E-01	4.94E-05	3.86E-01	4.61E-05	2.96E-01	3.22E-05
Eu-152m(1)	1.32E+03	5.58E+02	2.41E-01	5.94E+01	2.32E-02	5.87E+01	2.29E-02	5.51E+01	2.15E-02
Gd-161	2.19E+01	3.70E+00	3.09E-01	8.97E-01	4.50E-04	1.51E-01	7.59E-05	1.30E-05	6.50E-09
Dy-165m	1.64E+05	1.26E+00	1.09E-02	5.61E+03	9.91E-02	3.02E+01	5.33E-04	3.44E-11	6.08E-16
Dy-165	8.69E+02	1.41E+02	1.28E-02	3.90E+01	8.10E-04	3.72E+01	7.73E-04	2.91E+01	6.04E-04
Ho-166	1.98E+01	1.61E+03	2.75E-02	8.91E-01	3.97E-05	8.87E-01	3.96E-05	8.68E-01	3.87E-05
Er-167m	4.79E+04	3.78E-02	9.71E-02	2.25E-01	3.55E-05	5.16E-77	8.13E-81	0.00E+00	0.00E+00
Yb-175	1.39E+00	6.03E+03	3.09E-02	6.25E-02	3.13E-06	6.25E-02	3.13E-06	6.21E-02	3.11E-06
Yb-177	1.13E+00	1.14E+02	1.22E-01	5.07E-02	1.00E-05	4.79E-02	9.47E-06	3.53E-02	6.99E-06
Lu-176m	4.78E+01	2.21E+02	1.82E-02	2.15E+00	6.34E-05	2.08E+00	6.15E-05	1.78E+00	5.26E-05
Lu-177	2.22E+00	9.66E+03	3.02E-02	9.99E-02	4.89E-06	9.98E-02	4.89E-06	9.95E-02	4.87E-06
Hf-178m	1.10E+03	7.17E-02	9.77E-01	3.94E-01	25E-04	5.23E-41	8.29E-44	0.00E+00	0.00E+00
Hf-179m	2.46E+04	3.12E-01	2.87E-01	3.65E+02	1.70E-01	2.50E-07	1.16E-10	1.47E-55	6.82E-59
W-187	3.47E+00	1.43E+03	4.31E-01	1.56E-01	1.09E-04	1.55E-01	1.09E-04	1.52E-01	1.06E-04
Re-186	3.62E+00	5.44E+03	1.80E-02	1.63E-01	4.75E-06	1.63E-01	4.75E-06	1.62E-01	4.72E-06
Re-188m	2.18E+01	1.86E+01	7.96E-02	9.63E-01	1.24E-04	6.76E-01	8.72E-05	1.05E-01	1.35E-05
Re-188	1.85E+01	1.02E+03	4.78E-02	8.32E-01	6.45E-05	8.27E-01	6.41E-05	7.99E-01	6.20E-05
Os-191m	1.19E+00	7.80E+02	6.51E-03	5.35E-02	5.65E-07	5.31E-02	5.60E-07	5.08E-02	5.36E-07
Ir-192m	3.12E+04	1.40E+00	2.47E-04	1.10E+03	4.39E-04	9.95E+00	3.98E-06	1.77E-10	7.10E-17
Ir-194	2.73E+01	1.16E+03	5.12E-02	1.23E+00	1.02E-04	1.22E+00	1.01E-04	1.29E+00	9.84E-05
Pt-199m	3.83E+00	2.40E-01	3.42E-01	4.07E-02	2.26E-05	4.97E-14	2.76E-17	9.88E-77	5.48E-80
Pt-199	3.89E+00	3.08E+01	1.07E-01	1.73E-01	3.00E-05	1.40E-01	2.43E-05	4.54E-02	7.87E-06
Au-198	1.18E+01	3.88E+03	4.03E-01	5.31E-01	3.47E-04	5.30E-01	3.46E-04	5.25E-01	3.43E-04
Hg-205	2.03E+00	5.20E+00	4.80E-03	8.55E-02	6.65E-07	2.41E-02	1.88E-07	3.08E-05	2.39E-10
Th-233	1.19E+02	2.23E+01	1.08E-02	5.27E+00	9.23E-05	3.92E+00	6.87E-05	8.30E-01	1.45E-05
U-239	1.01E+02	2.35E+01	5.21E-02	4.48E+00	3.78E-04	3.38E+00	2.86E-04	7.75E-01	6.54E-05

*Integrated thermal fluence in EDS-3C = 4.50E+05 neutrons/cm².
Note: 8.42E-10 = 8.42x10-10 etc.

Table 5.2 Potential activation products (for fast neutrons*) of baggage contents containing 1-kg (2.2-lb) masses of various elements

Target isotope	Reaction**	Product	Bq/μg	Half-life (min)	Gamma (MeV/Bq)	0.5-min delay		10-min delay		60-min delay	
						Activity (Bq/g)	Dose rate (μSv/hr/kg @ 30 cm)	Activity (Bq/g)	Dose rate (μSv/hr/kg @ 30 cm)	Activity (Bq/g)	Dose rate (μSv/hr/kg @ 30 cm)
Be-9	n,a	He-6	1.27E+03	1.34E-02	–	–	–	–	–	–	–
C-12	n,2n	C-11	1.18E-08	2.03E+01	1.02E+00	2.90E-09	4.80E-12	2.10E-09	3.47E-12	3.80E-10	6.29E-13
N-14	n,2n	N-13	1.49E-03	9.96E+00	1.02E+00	3.60E-04	5.95E-07	1.86E-04	3.07E-07	5.73E-06	9.48E-09
O-16	n,p	N-16	1.74E-03	1.19E-01	4.86E+00	2.37E-05	1.86E-07	2.22E-29	1.75E-31	0.00E+00	0.00E+00
O-18	n,a	C-15	7.98E-03	4.10E-02	3.62E+00	4.26E-07	2.50E-09	7.83E-77	4.59E-79	0.00E+00	0.00E+00
F-19	n,p	O-19	1.09E+00	4.52E-01	1.04E+00	1.27E-01	2.14E-04	5.98E-08	1.01E-10	3.05E-41	5.14E-44
F-19	n,a	N-16	2.32E+01	1.19E-01	4.86E+00	3.15E-01	2.49E-03	2.97E-25	2.34E-27	0.00E+00	0.00E+00
Ne-20	n,p	F-20	1.28E-01	1.83E-01	6.33E-01	4.82E-03	4.95E-06	1.15E-18	1.18E-21	0.00E+00	0.00E+00
Ne-22	n,a	O-19	3.92E-03	4.52E-01	1.04E+00	4.55E-04	7.68E-07	2.15E-10	3.63E-13	1.10E-43	1.85E-46
Na-23	n,p	Ne-23	7.18E-01	6.27E-01	4.39E-01	1.03E-01	7.35E-05	2.84E-06	2.02E-09	2.84E-30	2.02E-33
Na-23	n,a	F-20	1.21E+00	1.83E-01	1.63E+00	4.55E-02	1.20E-04	1.08E-17	2.86E-20	0.00E+00	0.00E+00
Mg-25	n,p	Na-25	1.67E-02	1.00E+00	3.93E-01	2.95E-03	1.88E-06	4.08E-06	2.60E-09	3.65E-21	2.33E-24
Mg-26	n,p	Na-26	6.82E-03	1.67E-02	1.81E+00	1.66E-12	4.88E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Al-27	n,p	Mg-27	1.09E-01	9.45E+00	8.93E-01	2.63E-02	3.80E-05	1.31E-02	1.90E-05	3.35E-04	4.84E-07
Si-28	n,p	Al-28	6.51E-01	2.25E+00	1.78E+00	1.40E-01	4.03E-04	7.48E-03	2.16E-05	1.53E-09	4.43E-12
Si-29	n,p	Al-29	1.00E+00	6.52E+00	2.38E+00	2.37E-01	9.15E-04	8.64E-02	3.33E-04	4.25E-04	1.64E-06
P-31	n,p	Si-31	5.14E-02	1.57E+02	8.66E-04	1.28E-02	1.80E-08	1.23E-02	1.73E-08	9.86E-03	1.38E-08
P-31	n,a	Al-28	1.90E-01	2.25E+00	1.78E+00	4.07E-02	1.18E-04	2.18E-03	6.30E-06	4.48E-10	1.29E-12
S-34	n,p	P-34	1.84E-02	2.07E-01	3.19E-01	8.63E-04	4.46E-07	1.33E-17	6.87E-21	2.67E-90	1.38E-93
Cl-37	n,a	P-34	2.69E-01	2.07E-01	3.19E-01	1.26E-02	6.52E-06	1.94E-16	1.00E-19	3.90E-89	2.02E-92
Ar-40	n,a	S-37	3.77E-03	5.06E+00	2.79E+00	8.80E-04	3.98E-06	2.40E-04	1.08E-06	2.54E-07	1.15E-09
Ca-40	n,2n	Ca-39	4.80E-03	1.45E-02	1.02E+00	5.02E-14	8.31E-17	0.00E+00	0.00E+00	0.00E+00	0.00E+00
V-51	n,p	Ti-51	2.06E-02	5.76E+00	3.58E-01	4.85E-03	2.82E-06	1.55E-03	8.98E-07	3.77E-06	2.19E-09
Cr-52	n,p	V-52	3.25E-02	3.76E+00	1.43E+00	7.41E-03	1.72E-05	1.29E-03	2.98E-06	1.28E-07	2.97E-10
Cr-53	n,p	V-53	3.60E-03	1.55E+00	1.04E+00	7.20E-04	1.21E-06	1.03E-05	1.74E-08	2.01E-15	3.40E-18
Mn-55	n,p	Cr-55	1.07E-02	3.56E+00	6.57E-04	2.43E-03	2.59E-09	3.82E-04	4.07E-10	2.26E-08	2.41E-14
Mn-55	n,a	V-52	3.70E-03	3.76E+00	1.44E+00	8.44E-04	1.97E-06	1.46E-04	3.42E-07	1.46E-08	3.40E-11
Ni-60	n,p	Co-60m	6.23E-03	1.05E+01	5.85E-02	1.51E-03	1.43E-07	8.05E-04	7.64E-08	2.97E-05	2.82E-09
Zn-64	n,p	Cu-64	2.11E-03	7.64E-02	1.89E-01	5.66E-06	1.73E-09	2.13E-43	6.53E-47	0.00E+00	0.00E+00
Zn-66	n,p	Cu-66	3.59E-03	5.10E+00	9.35E-02	8.39E-04	1.27E-07	2.31E-04	3.50E-08	2.58E-07	3.92E-11
Ga-69	n,a	Cu-66	7.86E-03	5.10E+00	9.35E-02	1.84E-03	2.78E-07	5.05E-04	7.66E-08	5.66E-07	8.58E-11
Se-77	n,n	Se-77m	1.63E+01	2.92E-01	9.70E-02	1.24E+00	1.96E-04	2.01E-10	3.16E-14	5.86E-62	9.22E-66
Br-79	n,2n	Br-78	1.03E-03	6.40E+00	1.03E+00	2.44E-04	4.07E-07	8.72E-05	1.46E-07	3.88E-07	6.49E-10
Y-89	n,n	Y-89m	3.75E+01	2.62E-01	9.01E-01	2.50E+00	3.65E-03	3.05E-11	4.46E-14	1.12E-68	1.63E-71
Ru-100	n,p	Tc-100	2.20E-03	2.67E-01	6.75E-02	1.50E-04	1.64E-08	2.94E-15	3.22E-19	1.28E-71	1.40E-75
Rh-103	n,a	Tc-100	3.97E+00	2.67E-01	6.75E-02	2.71E-01	2.97E-05	5.30E-12	5.81E-16	2.31E-68	2.53E-72
Rh-103	n,n	Rh-103m	6.43E-01	5.61E+01	1.69E-03	1.60E-01	4.38E-07	1.42E-01	3.89E-07	7.66E-02	2.10E-07
Cd-112	n,2n	Cd-111m	3.69E-02	4.87E+01	2.87E-01	9.16E-03	4.26E-06	8.00E-03	3.72E-06	3.93E-03	1.83E-06
In-115	n,n	In-115m	4.04E-02	2.70E-02	1.65E-01	2.70E-08	7.22E-12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ba-137	n,n	Ba-137m	5.00E-01	2.55E+00	5.99E-01	1.09E-01	1.06E-04	8.25E-03	8.02E-06	1.04E-08	1.01E-11
Pr-141	n,2n	Pr-140	1.25E-02	3.39E+00	5.05E-02	2.82E-03	2.31E-07	4.05E-04	3.31E-08	1.47E-08	1.21E-12

*Fast neutron fluence in EDS-3C = 2.5E+05 neutrons/cm².
**n = neutron, a = alpha, p = proton.
Note: 1.27E+03 = 1.27x10³ etc.

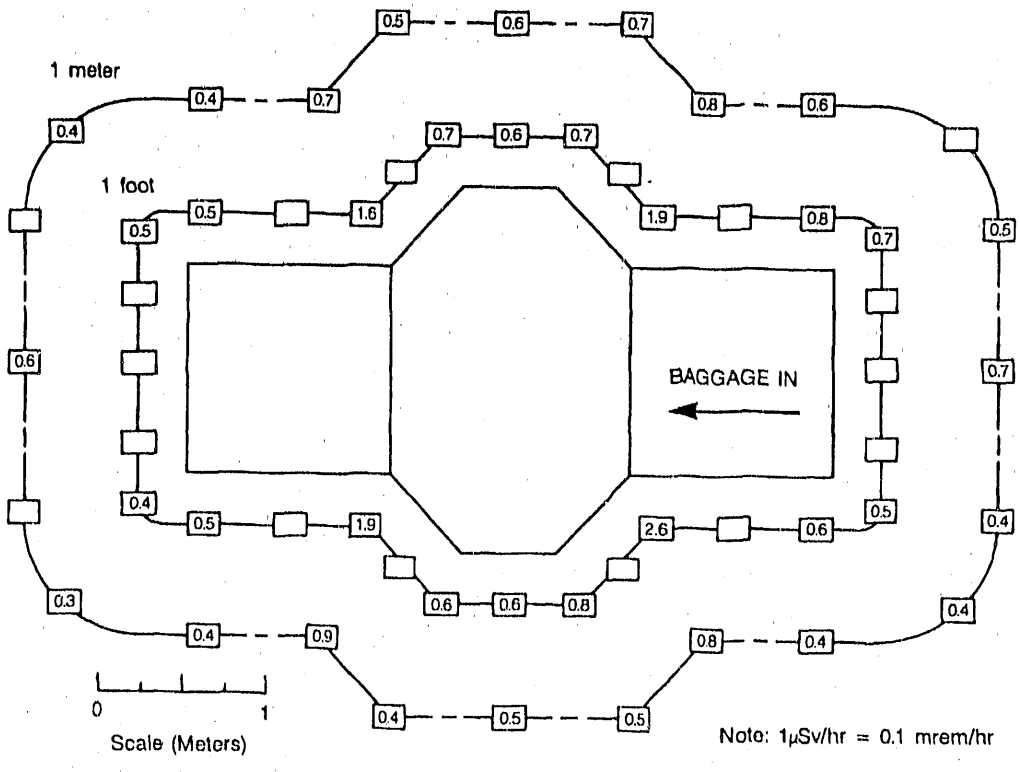


Figure 5.6 Total dose equivalent rates around EDS-3C (μSv/hr)

when loading luggage onto the conveyor belt. The other baggage handler would be at the exit of the diverter, more than 6 m (20 ft) away. In this scenario (call it Option A), only one baggage handler would be in a potential radiation field of 0.5 μSv/hr (0.05 mrem/hr). Because it is assumed that the EDS-3C will be in operation for 16 hours a day, this option requires three full-time-equivalent personnel per operating unit (three 40-hr/wk shifts). For the proposed scenario at Dulles International Airport (call it Option B), however, the EDS-3C and the XENIS are at right angles to each other. In this case, both baggage handlers could be in radiation areas of 0.5 μSv/hr (0.05 mrem/hr). This option requires six full-time-equivalent personnel per operating unit (three 40-hr/wk shifts).

The estimated annual dose to a baggage handler would be

$$0.5\ \mu Sv/hr \times 40\ hr/wk \times 50\ wk/yr = 1000\ \mu Sv = 1\ mSv/yr\ (100\ mrem/yr)$$

For Option B the estimated annual dose to baggage handlers would be $6x10^{-3}$ person-Sv ($6x10^{-1}$ person-rem) (6 baggage handlers x 1 mSv/yr); for Option A it would be $3x10^{-3}$ person-Sv ($3x10^{-1}$ person-rem) (3 baggage handlers x 1 mSv/yr) for each EDS-3C. For each of the scenarios proposed in Section 4.1, the calculated collective dose of $6x10^{-3}$ person-Sv will be used as a conservative estimate of expected radiation dose. The EDS-3C, which will be used for lobby installations, is similar to the EDS-3, which is used for ramp installations, in terms of potential radiation exposure to TNA operators. As described in SAIC's 1988 environmental report, the annual exposure to TNA operators was calculated by estimating the dose from both routine [1.2 mSv/yr (120 mrem/yr)] and source-transfer [0.8 mSv/yr (80 mrem/yr)] operations. The total exposure to an operator for each EDS-3C would be 2 mSv/yr (200 mrem/yr). For six full-time-equivalent operators, the collective dose for each system would be 0.012 person-Sv/yr (1.2 person-rem/yr).

The total dose to workers from hand searching the luggage does not depend on the choice of EDS-3C installation scenario. If the TNA system alarms, the baggage must be hand searched. This usually will take place immediately after the bag leaves the system, allowing only perhaps 15 seconds for activation products to decay. The security attendant conducting the search could get an additional dose from activation products, and because there is hand contact during the search, exposure to beta (and gamma) radiation may be possible.

Direct exposure rates from irradiated luggage are shown in Table 5.3. This is for an exposure 30 cm (1 ft) away from

Table 5.3 Major activation products of baggage contents containing 1-kg (2.2-lb) masses of various elements

				0.5-min delay		10-min delay		60-min delay	
Product	Bq/μg	Half-life (min)	Gamma (Mev/Bq)	Activity (Bq/g)	Dose rate (μSv/hr/kg @ 30 cm)	Activity (Bq/g)	Dose rate (μSv/hr/kg @ 30 cm)	Activity (Bq/g)	Dose rate (μSv/hr/kg @ 30 cm)
F-20	1.97E+02	1.83E-01	1.64E+00	1.33E+00	3.55E-03	3.17E-16	8.44E-19	1.86E-98	0.00E+00
Na-24	1.80E+00	8.80E+02	4.12E+00	8.10E-02	5.41E-04	8.04E-02	5.37E-04	7.73E-02	5.16E-04
Al-28	2.72E+02	2.24E+00	1.78E+00	1.05E+01	3.03E-02	5.55E-01	1.60E-03	1.06E-07	3.07E-10
K-42	2.39E-01	7.42E+02	2.73E+02	1.07E-02	4.76E-03	1.07E-02	4.72E-03	1.02E-02	4.50E-03
Sc-46m	4.73E+04	3.12E-01	1.42E-01	7.01E+02	1.61E-01	4.81E-07	1.11E-10	2.82E-55	6.49E-59
V-52	1.79E+03	3.75E+00	1.43E+00	7.34E+01	1.70E-01	1.27E+01	2.94E-02	1.23E-03	2.86E-06
Mn-56	1.11E+02	1.55E+02	1.70E+00	4.98E+00	1.37E-02	4.78E+00	1.32E-02	3.82E+00	1.05E-02
Sc-77m	5.69E+03	2.90E-01	9.63E-02	7.75E+01	1.21E-02	1.07E-08	1.67E-12	1.38E-60	2.15E-64
Br-80	2.91E+02	1.77E+01	7.00E-02	1.28E+01	1.46E-03	8.85E+00	1.00E-03	1.25E+00	1.42E-04
Rb-86m	4.20E+01	1.02E+00	5.46E-01	1.35E+00	1.19E-03	2.12E-03	1.87E-06	3.74E-18	3.31E-21
Rh-104m	3.60E+03	4.35E+00	3.48E-02	1.50E+02	8.44E-03	3.29E+01	1.86E-03	1.14E-02	6.45E-07
Rh-104	1.54E+04	7.05E-01	1.11E-02	4.24E+02	7.63E-03	3.73E-02	6.71E-07	1.68E-23	3.03E-28
Ag-108	5.09E+03	2.41E+00	2.94E-02	1.98E+02	9.46E-03	1.29E+01	6.16E-04	7.36E-06	3.51E-10
Ag-110	8.31E+04	4.10E-01	2.96E-02	1.61E+03	7.71E-02	1.71E-04	8.19E-09	3.38E-41	1.62E-45
In-116m(1)	1.29E+03	5.42E+01	2.47E+00	5.77E+01	2.31E-01	5.11E+01	2.05E-01	2.70E+01	1.08E-01
In-116	1.36E+04	2.37E-01	1.55E-02	1.42E+02	3.57E-03	1.22E-10	3.08E-15	3.92E-74	9.84E-79
I-128	2.00E+02	2.50E+01	8.75E-02	8.88E+00	1.26E-03	6.28E+00	9.68E-04	1.71E+00	2.42E-04
Eu-152m(1)	1.32E+03	5.58E+02	2.41E-01	5.94E+01	2.32E-02	5.87E+01	2.29E-02	5.51E+01	2.15E-02
Dy-165m	1.64E+05	1.26E+00	1.09E-02	5.61E+03	9.91E-02	3.02E+01	5.33E-04	3.44E-11	6.08E-16
Hf-179m	2.46E+04	3.12E-01	2.87E-01	3.65E+02	1.70E-01	2.50E-07	1.16E-10	1.47E-55	6.82E-59
Total					1.03E+00		2.82E-01		1.45E-01

Note: 1.97E+02 = 1.97x10² etc.

1 kg (2.2 lb) of irradiated material that has decayed 0.5, 10, and 60 minutes after leaving the EDS-3C. The elements listed (taken from Tables 5.1 and 5.2) are those whose initial activities are greater than 1 Bq/g of irradiated material 1 second after leaving the EDS-3C.

Table 5.3 shows the elements that produce the largest activation products after passing through the EDS-3C. Although aluminum is not the element with the greatest activation, studies by Westinghouse have shown that it is the most predominant one found in luggage (Westinghouse, 1986). Therefore, calculations presented in this environmental assessment for skin dose have been based on the dose from aluminum. It should be noted that because of the short range for the beta particles in tissue, a relatively small area of tissue can be considered to be an infinite plane for dose calculation purposes. This dose is due to beta particles in a thin layer of activity equal to that generated by activation in two half thicknesses, which is 4.8 Bq/cm² (1.3x10-⁴ μCi/cm²). All beta particles emitted below two half thicknesses are self-absorbed in the aluminum and therefore do not contribute to the dose.

The following assumptions were made:

- The skin of the hand is in contact with a 10-cm (4-in.) disk of aluminum for 60 seconds during the hand search.
- The entire suitcase frame is aluminum.
- Initially, approximately 10 percent (220,000) of the 2.2 million bags per year will require a hand search.

The computer code VARSKIN was used for calculating beta dose from skin contamination. Because of the limitations of VARSKIN, the smallest value that could be used to determine the beta skin dose for security screeners was 3.7x10⁴ Bq/cm² (1 μCi/cm²). Table 5.4 shows that the dose rate for a 3.7x10⁴ Bq/cm² source is 1.64x10-³ Sv/hr (0.164 rem/hr). Because the aluminum suitcase only represents a source activity of 4.8 Bq/cm² (1.3x10-⁴ μCi/cm²), the dose to both hands from a 60-second search of an aluminum suitcase is 2.1 μSv (0.021 mrem). Because the International Commission on Radiological Protection has assigned a weighting factor for skin of 0.01, the collective effective dose equivalent for this assumption is 4.5x10-⁴ person-Sv/yr (4.5x10-² person-rem/yr) for each system. This dose is shared among the three security personnel (one per shift) who conduct the searches. The passenger presenting the bag must be present during the physical

Table 5.4 Calculated beta dose to the skin from a $3.7x10^4$ Bq/cm² source

Variable	Beta dose (Sv)	
	Averaged over an area of skin at the basal layer	At points on the skin basal layer
Radius (cm)/area (cm²)		
0.5462/1.000	0.0016	–
6.14164/119.3869	0.0011	–
Horizontal distance (cm)		
0.0000	–	0.0016
3.8354	–	0.0015
4.0214	–	0.0010
4.1913	–	0.0016
4.3449	–	0.0016
4.4824	–	0.0015
4.6037	–	0.0015
4.7089	–	0.0015
4.7978	–	0.0015
4.8706	–	0.0015
4.9272	–	0.0014
4.9677	–	0.0012
4.9919	–	0.0009
5.0000	–	0.0008
5.0081	–	0.0006
5.0323	–	0.0004
5.0728	–	0.0003
5.1294	–	0.0002
5.2022	–	0.0001
5.2911	–	0.0001
5.3963	–	0.0000
5.5176	–	0.0000
5.6551	–	0.0000
5.8087	–	0.0000
5.9786	–	0.0000
6.1646	–	0.0000

Note: The doses were calculated using VARSKIN MOD 1:
Disc source with radius = 5.0000 cm
Skin thickness = 0.0070 cm
Source:
Radionuclide = Am-241
Average beta energy = 1.240 MeV
X-90 distance = 0.6470 cm
Source strength = 3.7E+04 Bq/cm²
Irradiation time = 60 s
All cell damage occurs in an area with a radius of 6.165 cm.

search, but may not participate directly in the search. The carrier shall retain control of the bag being searched, and the passenger may neither insert nor remove items from it.

The corresponding gamma ray dose was estimated by assuming that the suitcase would have the elemental composition shown in Table 5.5 (Westinghouse, 1986). The weight of aluminum was increased to 4.5 kg (9.9 lb) [from Westinghouse (1986)] to obtain a realistic gamma dose from an all-aluminum suitcase. Table 5.6 gives the activity and dose rates at 30 cm (1 ft). Clearly aluminum dominates the dose rate.

Initially, the alarmed-bag rate could be as high as 10 percent of the 2.2 million bags searched, or approximately 220,000 bags per year. Assuming that the average search takes 1 minute, a conservative estimate of the corresponding collective dose for each EDS-3C is $5.0x10^{-4}$ person-Sv/yr ($5.0x10^{-2}$ person-rem/yr) (220,000 bags/yr x 1 min/bag x 1 hr/60 min x $1.38x10^{-7}$ Sv/hr). Even if it is assumed that in the worst case, the suitcase contained 1 kg (2.2 lb) of every element listed in Table 5.3, the corresponding collective dose (at a 30-cm distance) would be about $3.8x10^{-3}$ person-Sv/yr ($3.8x10^{-1}$ person-rem/yr) for each system. These doses are shared among the three individuals as stated above. The total dose from both beta and gamma radiation to each security screener is 0.32 mSv/yr (32 mrem/yr). The collective dose to this group of individuals is $9.5x10^{-4}$ person-Sv/yr ($9.5x10^{-2}$ person-rem/yr).

5.4.3 Radiation Exposure of Passengers

Passengers and other members of the public may be exposed to radiation from EDS-3C operations because of possible neutron activation of items in their baggage or because the device produces a small radiation field in the area they occupy. As stated earlier, passengers may be exposed to radiation via three different pathways: exposure of persons on the concourse level near the EDS-3C, direct radiation exposure of passengers to beta or gamma fields from luggage that has been through the EDS-3C, or internal dose to passengers or other members of the public who consume a food or other irradiated item that was contained in the reclaimed luggage.

In Sections 5.4.3.1 through 5.4.3.4, each of the concourse scenarios proposed in this assessment is evaluated. Typically, the passengers will deliver their luggage to an attendant or baggage handler at the entrance of the EDS-3C. The attendant will place the luggage onto the conveyor belt, which will feed it into the EDS-3C. The baggage will then pass onto a roller platform or another conveyor belt from which it will be taken off by another baggage attendant. In some cases, the passengers will not have access to their luggage once it has been checked by the EDS-3C; in other scenarios, they may have to carry their luggage to a

Table 5.5 Elemental composition of the contents of an aluminum suitcase (quantities in grams)

Element	Clothing	Shoes	Toiletries	Toothpaste	Shaver	Shampoo	Paper	Suitcase	Total
Hydrogen	307.0	55.0	23.0	16.5	–	34.0	141.0	254.0	830.5
Carbon	2546.0	490.0	145.0	10.6	2.2	194.0	1006.0	1307.0	5700.8
Nitrogen	483.0	145.0	27.0	–	–	7.0	–	–	662.0
Oxygen	1054.0	218.0	32.0	107.3	–	73.0	1124.0	1163.0	3771.3
Sodium	–	–	–	0.3	–	–	–	–	0.3
Manganese	–	3.3	–	–	6.5	–	–	–	9.8
Silicon	–	0.9	–	–	1.8	–	–	–	2.7
Phosphorous	–	0.1	–	15.2	0.2	–	–	–	15.4
Sulfur	–	0.1	–	0.4	0.2	–	–	–	0.7
Iron	–	448.0	–	–	89.6	–	–	–	537.6
Calcium	–	–	–	19.6	–	–	–	–	19.6
Aluminum*	–	–	–	–	–	–	–	4540.0	4540.0

*All data are from Westinghouse (1986) report, except the weight from aluminum (this amount was increased to reflect an all-aluminum suitcase).

Table 5.6 Gamma dose rates from EDS-3C activation of the contents of an aluminum suitcase

Element	Element mass (g)	Suitcase activity (Bq)	Gamma (μSv/hr/kg @ 30 cm)	Gamma dose rate @ 30 cm (μSv/hr)
Hydrogen	830.5	–	–	–
Carbon	5700.8	5.18E-09	–	–
Nitrogen	662.0	8.88E-05	–	–
Oxygen	3771.3	4.07E-01	–	–
Sodium	0.3	2.29E-02	5.41E-04	1.62E-07
Manganese	9.8	4.81E+01	1.37E-02	1.34E-04
Silicon	2.7	1.30E-03	–	–
Phosphorous	15.4	7.40E-09	–	–
Sulfur	0.7	–	–	–
Iron	537.6	–	–	–
Calcium	19.6	–	–	–
Aluminum	4540.0	4.74E+04	3.03E-02	1.38E-01
Total				1.38E-01

Note: 5.18E-09 = 5.18×10^{-9} etc.

different ticket counter and wait in line for some time before receiving their tickets. A complete summary of collective doses for each scenario is presented in Section 5.4.5.

Additional vertical shielding barriers will be placed at either end of the EDS-3C to further lower the radiation exposure to members of the public and non-TNA personnel. These barriers will be constructed of hydrogenous material for neutron shielding and heavy metal for gamma ray absorption. They will be sufficiently thick to reduce the penetrating radiation field to less than 1 μSv/hr (0.1 mrem/hr) when the EDS-3C is running at peak capacity. For installations that could be accessible to the public, an exit housing for the conveyor belt with an opening for loading and unloading luggage will be installed.

Population distribution data on the number of international passengers enplaning at JFK International Airport were used to estimate the downward dose to passengers located under the EDS-3C. At this very busy terminal, 9,010,570 international passengers boarded an airplane in 1988 (Ryge, 1990). Statistics for 1987 (statistics for 1988 were not available at the time of this writing) show that 2.2×10^7 passengers (on domestic and international flights) flew out of New York (U.S. Bureau of the Census, 1989). Because it is not reasonable to assume that all domestic and international flight passengers would either pass by the counter where the EDS-3C was located or pass underneath the EDS-3C, it was assumed that only the international flight passengers (about 40 percent of the total passengers at JFK Airport) would be in the vicinity of the EDS-3C. If non-passenger airport visitors and other airport personnel amount to 100 percent of the passenger population density, and only a small fraction (10 percent) pass underneath the EDS-3C on their way to claim their luggage, the total number of people affected by the scenario would be 9.0×10^5.

In many cases, the baggage claim area is in the main terminal directly beneath the airline ticket counters. At San Francisco and Gatwick (London, England) International Airports, the average distance from the main level to the basement level (where the baggage reclaim areas are located) is 4.25 m (14 ft), and the concrete flooring between these two levels is approximately 20 cm (8 in.) thick. The dose rate decreases rapidly with increasing horizontal distance from the center of the TNA system because of the inverse square law (see Figure 5.6). Assuming that the dose rate in the area directly underneath the TNA system is 1 μSv/hr (0.1 mrem/hr) and that passengers only stay 15 minutes in the baggage reclaim area, the dose rate is 0.3 μSv/hr (0.03 mrem/hr). The total collective dose to this group of people passing underneath the EDS-3C is estimated to be

$$0.3\ \mu Sv/hr \times 0.25\ hr \times 9 \times 10^5\ passengers \times 10^{-6}\ Sv/\mu Sv = 6.8 \times 10^{-2}\ person\text{-}Sv/yr$$

5.4.3.1 Behind the Check-In Counter

In this scenario, the EDS-3C will be placed behind the counter where passengers check their baggage, as they currently do for international flights. Because the bags will be placed onto the conveyor belt leading to the EDS-3C, the passenger will not be close to the TNA system and will not receive any additional dose. Because the bag will not be returned to the passenger after inspection, there will be no dose from this pathway.

At the proposed site at the Dulles United Airlines international ticket counter, as many as 15 stations are available for ticket agents. Because these stations must be open for 16 hours a day, 7 days a week, this would require 50 full-time equivalent personnel (three 40-hr/wk shifts, 50 wk/yr). These ticket personnel may be 2 m (6.6 ft) from the EDS-3C, which would have a radiation area of about 0.3 μSv/hr (0.03 mrem/hr). In addition, the ticket agents will have to tag the luggage with a baggage claim check. Assuming an 8-hour shift for each ticket agent, the estimated dose to a ticket agent from nearby TNA system operations would be 0.6 mSv/yr (60 mrem/yr). The total collective dose for the ticket agents would be 0.03 person-Sv/yr (3 person-rem/yr).

If non-passenger airport visitors and other airport personnel amount to 100 percent of the passenger population density, then it can be assumed that 9.0×10^6 non-passengers could pass by the airline counter where the EDS-3C was located.

The estimated distance from the EDS-3C to nearby members of the public is about 10 m (33 ft). The potential radiation exposure from the EDS-3C at this distance is less than 1×10^{-2} μSv/hr (1 μrem/hr). Because the dose from natural background radiation is approximately 0.1 μSv/hr (10 μrem/hr), the dose to passengers walking by the EDS-3C (about 2 to 3 minutes) would be less than one-tenth the dose from natural background radiation.

Potential radiation exposure to operators [6]*	1.2×10^{-2} person-Sv
Potential radiation exposure to baggage handlers [6]*	6.0×10^{-3} person-Sv
Potential radiation exposure to ticket agents [45]*	3.0×10^{-2} person-Sv
Potential radiation exposure to security screeners [3]*	9.5×10^{-4} person-Sv
Radiation exposure to the passengers [1.1×10^6]*	0 person-Sv
Radiation exposure to nearby members of the public [9.0×10^6]*	0 person-Sv
Total for the behind-the-check-in-counter scenario	4.9×10^{-2} person-Sv

5.4.3.2 In Front of the Check-In Counter

In this scenario, the entrance of the TNA system will be placed in a public area in front of the check-in counter, and the exit will be placed behind the counter. The passenger will approach the system and wait in line until the luggage is loaded onto the conveyor belt. Members of the public could stand next to the TNA system unless a barrier was erected, which would increase the system's already considerable size. Because the luggage will not be returned to the passenger after inspection, the passenger will not be exposed to any radiation from his or her luggage. An average dose rate of 0.3 μSv/hr (0.03 mrem/hr)

*The numbers in brackets refer to the number of full-time-equivalent workers, passengers, or nearby members of the public that could be affected.

is assumed for a duration of 2 minutes (the time required to scan the bags of 10 passengers with 2 bags) while the passenger waits in line. This amounts to a 1.0×10^{-2} μSv (1 μrem) dose per passenger or 1.1×10^{-2} person-Sv (1.1 person-rem) for an estimated 1.1 million passengers per year. At Dulles Airport, approximately 430 international passengers per day fly on United Airlines (Hall, 1990). On the basis of these actual numbers, the total dose estimated at Dulles for this scenario is 1.6×10^{-3} person-Sv/yr (0.16 person-rem/yr). This dose component applies to all concourse scenarios except the one discussed in Section 5.4.3.1 (behind the check-in counter).

The estimated distance from the EDS–3C to nearby members of the public is about 4 m (13 ft). The potential radiation exposure from the EDS–3C at this distance is 7.5×10^{-2} μSv/hr (7.5 μrem/hr). Because the average dose from natural background radiation is 1×10^{-2} μSv/hr (1 μrem/hr), the dose to passengers walking by the EDS–3C would be less than that from background radiation, or about 1.2×10^{-3} μSv (1.2×10^{-1} μrem). This dose is only a small fraction of the permissible limit of 5 mSv/yr (500 mrem/yr).

If it is assumed that members of the public are near this system for about 1 minute, the estimated annual collective dose to this group is 1.1×10^{-2} person-Sv (1.1 person-rem).

Potential radiation exposure to operators [6]*	1.2×10^{-2} person-Sv
Potential radiation exposure to baggage handlers [6]*	6.0×10^{-3} person-Sv
Potential radiation exposure to ticket agents [45]*	3.0×10^{-2} person-Sv
Potential radiation exposure to security screeners [3]*	9.5×10^{-4} person-Sv
Radiation exposure to the passengers [1.1×10^6]*	1.1×10^{-2} person-Sv
Radiation exposure to nearby members of the public [9.0×10^6]*	1.1×10^{-2} person-Sv
Total for the in-front-of-check-in-counter scenario	7.1×10^{-2} person-Sv

5.4.3.3 Pre-Check-In Area

In this scenario, the EDS–3C will be placed between the terminal entrance and the ticket check-in counters (see Figure 4.4). Passengers will hand their luggage to an attendant, who will place it on the EDS–3C conveyor belt. The passengers will then walk along the length of the system as the luggage is scanned. Assuming that a passenger walks reasonably close to the system, he or she will experience an average dose rate of 1 μSv/hr (0.1 mrem/hr) for 60 seconds (26 seconds while the bag passes through the system plus some extra delay). This amounts to a dose of 1.7×10^{-2} μSv (1.7 μrem) per passenger or 0.018 person-Sv (1.8 person-rem) for an estimated 1.1 million passengers a year. Once the luggage is cleared by the EDS–3C, the attendant at the exit will band it with tamper-resistant security tape and return it to the passenger. The passenger will then carry the luggage to the check-in counter, where it will be checked in for delivery to the aircraft.

The amount of time that the passenger will carry the slightly radioactive bag will vary significantly. If for any reason the airline were to cancel a scheduled flight, the passenger would be with the luggage indefinitely. This would be the worst-case scenario for this option. The total dose rate from all the elements listed in Table 5.3 is 1 μSv/hr (0.1 mrem/hr) 30 seconds after EDS–3C screening. After a 10-minute decay, however, the dose rate decreases to 0.28 μSv/hr (0.028 mrem/hr). Assuming that 1.1 million passengers would have to carry two bags each from the EDS–3C to the international ticket counter (about 5 minutes) and wait in line 15 minutes to get to an airline ticket agent (0.28 μSv/hr could be used as the average dose rate), the estimated total collective dose annually to this group of passengers would be

$$0.28\ \mu Sv/hr \times 2.2 \times 10^6\ bags \times 0.3\ hr \times 10^{-6}\ Sv/\mu Sv = 1.8 \times 10^{-1}\ person\text{-}Sv/yr$$

The total dose to each passenger from this scenario would be 1.8×10^{-1} μSv/yr (18.5 μrem/yr). The collective dose would be 2.0×10^{-1} person-Sv/yr (20 person-rem/yr).

Because personnel at the ticket counter at many airlines will have to tag the slightly radioactive luggage with baggage claim checks and subsequently place the luggage on the conveyor belt to be transferred to the airplane, personnel also will receive a small additional dose. If 20 airlines have international ticket counters that are each staffed with 10 ticket agents, the total number of full-time-equivalent personnel needed annually would be approximately 600. If ticket agents receive the luggage 10 minutes after EDS–3C screening, the dose rate outside the luggage would be 0.28 μSv/hr (0.028 mrem/hr). Assuming it takes a ticket agent 1 minute to tag two bags from each passenger, the annual dose to each ticket agent would be 17 μSv/yr (1.7 mrem/yr):

$$\frac{2.2 \times 10^6\ bags/yr}{600\ ticket\ agents/yr} \times 0.28\ \mu Sv/hr \times 1/60\ hr = 17\ \mu Sv/yr$$

The total collective dose to the ticket personnel would be 1.0×10^{-2} person-Sv/yr (1.0 person-rem/yr).

*The numbers in brackets refer to the number of full-time-equivalent workers, passengers, or nearby members of the public that could be affected.

Passengers, their entourages, and non-TNA personnel who also may need to walk by the EDS-3C could receive some radiation dose. If non-passenger airport visitors and other airport personnel amount to 100 percent of the passenger population density, and assuming that each passenger stays 2 minutes near the EDS-3C at a distance of 3 m (10 ft) [radiation dose at this distance is 0.2 μSv/hr (0.02 mrem/hr)], the total collective dose would be

$$0.2\ \mu Sv/hr \times 2\ min \times 1\ hr/60\ min \times 10^{-6}\ Sv/\mu Sv \times 9.0\times10^{6} = 6.0\times10^{-2}\ person/Sv$$

If the time for each passenger and accompanying visitor were to increase to 5 minutes, the estimated total collective dose would be 0.15 person-Sv (15 person-rem).

Potential radiation exposure to operators [6]*	1.2×10^{-2} person-Sv
Potential radiation exposure to baggage handlers [6]*	6.0×10^{-3} person-Sv
Potential radiation exposure to ticket agents [600]*	1.0×10^{-2} person-Sv
Potential radiation exposure to security screeners [3]*	9.5×10^{-4} person-Sv
Radiation exposure to the passengers [1.1×10^{6}]*	2.0×10^{-1} person-Sv
Radiation exposure to nearby members of the public [9.0×10^{6}]*	6.0×10^{-2} person-Sv
Total for the pre-check-in-area scenario	2.9×10^{-1} person-Sv

5.4.3.4 Curbside Area

In the last scenario, the EDS-3C will be placed along the departure curb outside the main airport terminal. The passengers will hand their luggage to an attendant and wait for it to be cleared in order to receive a claim check. Depending on the specific setup, the passenger might walk alongside the system to the exit. An average dose rate of 0.3 μSv/hr (0.03 mrem/hr) is assumed for a duration of 10 minutes. Passengers will have to wait longer near the EDS-3C than in the in-front-of-the-check-in-counter scenario because they will have to wait for the baggage claim check. This amounts to a dose of 5.0×10^{-2} μSv (5 μrem) for each passenger or 5.5×10^{-2} person-Sv (5.5 person-rem) for an estimated 1.1 million passengers a year.

At many intended curbside locations, three to five sky-caps may be available for ticketing checked-in luggage. Because the sky-cap stations could be open for 16 hours a day, 7 days a week, this would require as many as 15 full-time-equivalent personnel (three 40-hr/wk shifts, 50 wk/yr). These sky-caps will have to tag the luggage with a baggage claim check. Assuming it takes a sky-cap 1 minute to tag two bags from each passenger, that each bag contains all the elements listed in Table 5.3, and that the luggage contents have decayed only 30 seconds, the estimated annual dose to each sky-cap would be 0.25 mSv/yr (25 mrem/yr):

$$\frac{2.22\times10^{6}\ bags/yr}{15\ sky-caps} \times \frac{0.1\ \mu Sv/hr}{bag} \times 1/60\ hr = 247\ \mu Sv/yr = 0.25\ mSv/yr$$

The total collective dose to this group of workers would be 3.8×10^{-3} person-Sv/yr (3.8×10^{-1} person-rem/yr).

Other members of the public might pass near the system, but much fewer than in the pre-check-in-area scenario (Section 5.4.3.3). If the assumption is made that 10 percent of the public (non-passengers) might walk near the EDS-3C on their way to the terminal, then the collective dose to this group would be 6.0×10^{-3} person-Sv (0.6 person-rem) ($0.1 \times 6.0\times10^{-2}$ person-Sv).

Potential radiation exposure to operators [6]*	1.2×10^{-2} person-Sv
Potential radiation exposure to sky-caps [15]*	3.8×10^{-3} person-Sv
Potential radiation exposure to ticket agents [600]*	0 person-Sv
Potential radiation exposure to security screeners [3]*	9.5×10^{-4} person-Sv
Radiation exposure to the passengers [1.1×10^{6}]*	5.5×10^{-2} person-Sv
Radiation exposure to nearby members of the public [9.0×10^{5}]*	6.0×10^{-3} person-Sv
Total for the curbside-area scenario	7.8×10^{-2} person-Sv

5.4.4 Effects of Irradiation on Baggage Contents

Food, medical supplies, and other consumable items are subjected daily to radiation exposures, without protective measures, above those which they would receive normally. This occurs while the items are in transit on airline flights to the desired destination. Neutron and gamma ray exposure rates have been measured for average flight paths. A 5-hour transcontinental or transatlantic flight at 12 km (7.5 mi) and at mid-latitudes would result in an absorbed dose of 15 micrograys (μGy) (1.5 mrad) or a dose equivalent of 25 μSv (2.5 mrem) to

*The numbers in brackets refer to the number of full-time-equivalent workers, passengers, or nearby members of the public that could be affected.

*The numbers in brackets refer to the number of full-time-equivalent workers, passengers, or nearby members of the public that could be affected.

the whole body (NCRP Report 94). An extreme case would be a 10-hour polar flight, for example, from California to Europe, in which case long flight times and higher cosmic-ray intensities at high latitudes would result in an absorbed dose of 50 μGy (5 mrad) or 100-μSv (10-mrem) dose equivalent. It should be noted, however, that frequent flyers and most crew members may receive annual dose equivalents of about 1 mSv (100 mrem), while some crew members may receive dose equivalents that are several times higher (see NCRP Report 94).

Passage through the TNA system would expose medicine, lotion, drugs, or other items in a suitcase to a slow neutron fluence of 4.5×10^5 neutrons/cm^2 if the item were located at the peak flux. This neutron exposure is less than that experienced from cosmic rays in Denver each year, which results in a dose equivalent rate of 0.5 mSv/yr (50 mrem/yr) (see NCRP Report 94).

5.4.4.1 Consumable Items

Passengers may also carry consumable items (including food) in their luggage. Small amounts of naturally occurring radionuclides already exist in the food that we eat. For example, potassium-40 (K-40) is a naturally occurring radioactive isotope that is contained in essentially all the food that we eat. It has an abundance (found in nature) of 0.0117 percent, a radioactive half-life of 1.25×10^9 years, and a high-energy gamma ray as well. Since K-40 has a specific activity of 838 picocuries per gram of potassium and peanuts, for example, contain 0.674 percent potassium, 1 g (0.035 oz) of peanuts contains 0.209 Bq of K-40 (National Institute of Standards and Technology, 1989). It seems reasonable to consider an amount of induced radioactivity equal to one-hundredth of that contained naturally in a single peanut to be negligible. It is for this reason that Tables 5.1 and 5.2 only include induced radioactivity greater that 0.001 Bq/g (see Section 5.4.1). Only four radioactively induced elements—rhodium (Rh), indium (In), europium (Eu), and dysprosium (Dy) (four relatively rare elements)—would exceed the amount of natural radioactivity in a 142-g (5-oz) bag of peanuts 10 minutes after they left the TNA system.

Table 5.7 shows the daily intakes of the elements that are the principal contributors to the dose that would be received and the dose estimates for each element under the assumed conditions. The mean daily intakes of various elements shown in this table were obtained from ICRP Publication 23 and apply to the "reference man" concept in radiation protection. The effective dose equivalents were calculated using dose conversion factors from ICRP Publication 30, which reflects the ICRP-based system of dose limitation and the latest metabolic models and dosimetric parameters. The table shows that salt (sodium) is the principal source of radiation exposure from consumption of food that has passed through the TNA system. About 90 percent of the committed effective dose equivalent of the 2.3×10^{-4} μSv (2.3×10^{-5} mrem) would be due to ingestion of sodium and chlorine. In principle, a passenger could open his or her luggage after a precheck-in inspection, take an item or two out of the check-in luggage to consume either at the airport or later on the airplane. Persons consuming salt pills or highly salted foods after their luggage had been screened by the EDS–3C could receive most of the radiation dose shown in Table 5.7.

Assuming 5 percent of the 1.1 million international passengers whose luggage is screened by the EDS–3C carry salt tablets or snacks (such as peanuts or salami) in their luggage and subsequently eat these items (within 30 seconds after screening), the collective dose to this group of passengers would be 1.3×10^{-5} person-Sv/yr (1.3×10^{-3} person-rem/yr). In ICRP Publication 23, a normal range of sodium (Na) intake for adults is indicated to be 2.8 to 7.8 g/day (0.1 to 0.3 oz/day). In Japanese adults, however, intakes as high as 27 g (0.95 oz) have been reported. The effective dose equivalent from a sodium intake of 27 g would be 8.6×10^{-4} μSv (8.6×10^{-5} mrem).

Both the daily intake and the dose conversion factor change with age. Table 5.8 shows both parameters for four different age groups for which dose conversion factors were available (NUREG–0172). The results show that children receive a dose from Na-24 that is about 60 percent greater than that estimated for adults. In an extreme case, a child with a 12-g/day (0.4-oz/day) sodium intake could receive a dose of 1.5×10^{-4} μSv (1.5×10^{-5} mrem) from that intake.

Because of the large amount of K-40 in the body [140 g (4.9 oz) in "reference man"], K-40 is the principal naturally occurring source of internal radiation (ICRP Publication 23). Potassium enters the body mainly through foodstuffs at the rate of about 2.5 g/day (0.09 oz/day) or 28.3 kBq/yr (NCRP Report 94). For adults, the whole-body dose conversion factor is 5.0×10^{-3} μSv/Bq (18.5 mrem/μCi); therefore, the yearly dose from foodstuffs is 0.14 mSv/yr (14.1 mrem/yr) (see ICRP Publication 30). However, because potassium is an essential element and under metabolic control, variations in dietary composition have little effect on the body content or on the radiation dose received (NUREG–0172). For example, the maximum potential dose from consumption of 10 g (0.35 oz) of potassium that was in luggage that was screened every week for 1 year by the EDS–3C would be

$$10 \text{ g/day} \times 1 \text{ day/wk} \times 52 \text{ wk/yr} \times 31 \text{ Bq/g} \times 5 \times 10^{-3} \text{ μSv/Bq} = 81 \text{ μSv/yr (8.1 mrem/yr)}$$

This is only 57 percent of the yearly dose received from foodstuffs. Thus, the conservative assumption of taking

Table 5.7 Committed effective dose equivalent from daily intakes of elements 1 hour after EDS-3C screening

Target nuclide	Mean daily intake (g)	Induced radio-nuclide	Weighted committed dose equivalent (Sv/Bq)	Becquerel/gram of element		Committed effective dose equivalent from 1 day's intake	
				0.5-min delay* (Bq/g)	10-min delay* (Bq/g)	0.5-min delay (μSv)	10-min delay (μSv)
Na-23	4.40E+00	Na-24	3.87E-10	8.10E-02	8.03E-02	1.38E-04	1.37E-04
P-31	1.40E+00	P-32	2.08E-09	1.60E-03	1.60E-03	4.65E-06	4.65E-06
Cl-37	5.20E+00	Cl-38	5.40E-11	2.48E-01	2.07E-01	6.95E-05	5.82E-05
K-41	3.30E+00	K-42	2.97E-10	1.08E-02	1.07E-02	1.06E-05	1.04E-05
Mn-55	3.70E-03	Mn-56	2.52E-10	5.00E+00	4.77E+00	4.66E-06	4.45E-06
Cu-63	3.50E-03	Cu-64	1.16E-10	2.06E-01	2.04E-01	8.37E-08	8.29E-08
As-75	1.00E-03	As-76	1.28E-09	1.47E-01	1.46E-01	1.88E-07	1.87E-07
Br-79	7.50E-03	Br-80m	6.23E-11	2.46E-01	2.40E-01	1.15E-07	1.12E-07
Br-79	7.50E-03	Br-80	1.50E-11	1.28E+01	8.84E+00	1.44E-06	9.95E-07
Total						2.29E-04	2.16E-04

*From Table 5.1.
Note: 4.40E+00 = 4.40x10⁰ etc.

Table 5.8 Age dependence of sodium intake and dose conversion factors (specific activity of 8.1x10⁻⁴ Bq/g)

Category (age)	Sodium intake, I (g/day)	Whole-body dose conversion factor, DCF* (μSv/Bq)	(mrem/μCi)	Product of I x DCF (μSv·g / Bq/day)	(mrem·g / μCi·day)
Infant (0.5 yr)	0.5	2.7E-03	10	1.4E-03	5.0
Child (5 yr)	2.0	1.6E-03	5.8	3.2E-03	11.6
Teenager (15 yr)	3.6	6.2E-04	2.3	2.2E-03	8.3
Adult (>20 yr)	4.4	4.6E-04	1.7	2.0E-03	7.5

*ICRP Publication 30.
Note: 2.7E-03 = 2.7x10⁻³ etc.
Source: NUREG-0172.

potassium (10 g) 30 seconds after it leaves the TNA system 52 times a year would not contribute significantly to the total radiation dose.

5.4.4.2 Nonconsumable Items

Neutron activation of the elements in clothing (hydrogen, carbon, nitrogen, and oxygen) does not lead to significant amounts of residual activity in suitcases, as indicated in Tables 5.1 and 5.2. Of the most highly activated isotopes after a 10-minute decay listed in Table 5.3 (vanadium, manganese, indium, and europium), only indium and to a lesser extent manganese are found in common objects. Indium, according to the *Handbook of Chemistry and Physics*, is principally used in alloys for jewelry and in dental alloys (Hodgman et al., 1960). Manganese is used primarily in copper, iron, and nickel alloys. A survey of alloys indicates that the amount of manganese is generally less than 5 percent. Typical items likely to contain these elements are jewelry, clock alarms, travel irons, electric razors, hair dryers, portable radios, and nail files.

Gold is more likely to be found in larger quantities than manganese or indium. Gold alloys used for jewelry and other objects have a gold content of 50 to 70 percent (Hodgman et al., 1960). Catalogs show that most common gold jewelry such as necklaces, earrings, and rings have a gold content ranging from about 10 g to 50 g (0.3 oz to 1.8 oz). Since the price of gold is currently about $15 a gram ($420 an ounce), one would expect that very expensive jewelry would be either worn or stored in carry-on luggage or purses by passengers. However, in an extreme case, someone could conceivably place, for example, 40 g (1.4 oz) of gold jewelry in his or her checked baggage. The

product radionuclide, gold-198, has a half-life of 2.7 days; therefore, nearly all the induced radioactivity would still be present when the owner claimed the luggage.

The total beta particle dose at a depth of 0.007 cm (2.8×10^{-3} in.) beneath the skin directly under the jewelry is estimated to be about 23 μGy (2.3 mrad) if the jewelry is worn continuously for approximately 10 days after the luggage is claimed (Sherbini, 1990). The gamma dose adds approximately 2 μSv (0.2 mrem); therefore, the total dose is 25 μSv (2.5 mrem). If the ICRP weighting factor for skin is used (0.01), the total effective dose equivalent for this assumed exposure scenario is about 0.25 μSv (0.025 mrem). If 1 percent of the passengers carry gold jewelry in their luggage and then wear it indefinitely, the effective dose equivalent is 2.8×10^{-3} person-Sv/yr (0.28 person-rem/yr). This dose is well below the public exposure limits recommended by ICRP.

Potential doses due to a malfunction of the TNA system (such as a conveyor-belt breakdown, a power failure, or a baggage jam) could be larger because of a longer neutron irradiation time. The potential effective dose equivalent from wearing gold jewelry for 10 days following EDS-3C screening could be as high as 10 μSv (1 mrem). Experience with ramp installation at JFK International Airport has shown that these irradiations are rare, usually less than one per month of operation. If this scenario occurs once each month, the resulting collective effective dose equivalent is 1.2×10^{-4} person-Sv/yr (1.2×10^{-2} person-rem/yr).

Existing Federal guidance and laboratory data both provide assurance that neutron irradiation of luggage as proposed will not cause deleterious effects. The Food and Drug Administration (FDA) has approved neutron irradiation of food using Cf-252 sources to determine its moisture content. Such irradiation is permitted for absorbed doses of up to 2 mGy (200 mrad) (21 CFR Part 179).

The effect of the system on photographic film, including both movie film and high-speed film, is undetectable under normal conditions. This was determined by testing several types of film that had been passed once and several times through the original prototype system, EDS-2 (Beckett and Schneider, 1987), which contained 340 μg of Cf-252. The film showed no effects from the radiation exposure to the EDS-2 when subjected to 50 times the standard dose. When compared with control samples, both sensiometric performance and granularity were unchanged from those of control samples. The tests and results are discussed by Beckett and Schneider (1987).

5.4.5 Summary of Collective Doses

In the previous discussions in Section 5.4, the collective dose from various pathways was derived. The collective doses to workers and security screeners do not depend on the choice of TNA system installation scenario. The total doses to passengers from the activation of consumable items and apparel are greatest for the pre-check-in scenario, because passengers (or members of the public) may have access to checked luggage immediately after it leaves the TNA system. The downward contribution to the floor below the TNA system may apply to all scenarios, and the maximum case is assumed.

The direct dose to other persons applies in varying degrees to all but the first scenario (behind the check-in counter). The scenario showing the largest collective dose is the pre-check-in-area scenario.

Tables 5.9 and 5.10 summarize the annual collective and individual doses for each of the four scenarios described in this section. The doses for all the individuals involved (operators, baggage handlers, ticket counter personnel, security screeners, passengers, and members of the public) are within the 10 CFR Part 20 limits for individuals in restricted and unrestricted areas. Table 5.10 shows that the annual dose from natural background radiation is 3 mSv/yr (300 mrem/yr), which is more than the dose from any one of the scenarios presented (NCRP Report 94).

The collective doses were calculated for several scenarios involving a single EDS-3C installed and operated in four different ways at an airport. If several of these systems were installed in an airport, the doses would be controlled by the exposure scenario (see Section 5.4.3.3) in which the passenger hands the luggage to a TNA attendant for screening, walks along the system (in the area of highest exposure rate), and retrieves the luggage at the exit of the system. Because the passenger would presumably check the luggage through a single system, it is highly probable that the passenger checking in luggage would not be in the vicinity of more than one system. Therefore, the collective and maximum doses in an airport using multiple systems in parallel probably would not exceed the results of the analysis in this section.

Table 5.9 Summary of collective doses from all scenarios

Radiation exposure	Scenario			
	Behind the counter (person-Sv)	**In front of the counter (person-Sv)**	**Pre-check-in (person-Sv)**	**Curbside (person-Sv)**
Workers				
Operators	1.2E-02	1.2E-02	1.2E-02	1.2E-02
Baggage handlers	6.0E-03	6.0E-03	6.0E-03	6.0E-03
Ticket counter personnel	3.0E-02	3.0E-02	1.0E-02	0
Security screeners	9.5E-04	9.5E-04	9.5E-04	9.5E-04
Sky-caps	0	0	0	3.8E-03
Passengers	0	1.1E-02	2.0E-01	5.5E-02
Public				
Below the TNA system	6.8E-02	6.8E-02	6.8E-02	6.8E-02
Near the TNA system	0	1.1E-02	6.0E-02	6.0E-03
From irradiation of baggage contents				
Consumable items	0	0	1.3E-05	0
Nonconsumable items (suitcase, jewelry, etc.)	2.8E-03	2.8E-03	2.8E-03	2.8E-03
Total				
Person-Sv	1.2E-01	1.4E-01	3.6E-01	1.6E-01
Person-rem	12.0	14.2	36.0	15.5

Note: 1.2E-02 = 1.2×10^{-2} etc.

Table 5.10 Summary of annual individual doses from all scenarios

Radiation exposure	Scenario				
	Behind the counter (mSv)	**In front of the counter (mSv)**	**Pre-check-in (mSv)**	**Curbside (mSv)**	**NRC limit (mSv)**
Workers					
Operators	2.0E+00	2.0E+00	2.0E+00	2.0E+00	5.0E+01
Baggage handlers	1.0E+00	1.0E+00	1.0E+00	1.0E+00	5.0E+00
Ticket counter personnel	6.0E-01	6.0E-01	1.7E-02	0	5.0E+00
Security screeners	3.2E-01	3.2E-01	3.2E-01	3.2E-01	5.0E+00
Sky-caps	0	0	0	2.5E-01	5.0E+00
Passengers	0	1.0E-05	1.8E-04	5.0E-05	5.0E+00
Public					
Below the TNA system	7.5E-05	7.5E-05	7.5E-05	7.5E-05	5.0E+00
Near the TNA system	0	1.2E-06	6.7E-06	6.7E-06	5.0E+00
From irradiation of baggage contents					
Consumable items	0	0	2.4E-07	0	–
Nonconsumable items (suitcase, clothing, etc.)	2.5E-04	2.5E-04	2.5E-04	2.5E-04	–

Notes: Natural sources of radiation:
Natural background 3.0E+00
Yearly dose from foodstuffs 1.4E-01
2.0E+00 = 2.0×10^{0} etc.

6 EFFECTS OF ACCIDENTS

For the purposes of environmental analysis, several accident scenarios were selected to conservatively bound a spectrum of accidents that could occur. Scenarios other than those discussed also would be possible, but their consequences are expected to be lower. The described scenarios are considered conservative in terms of both accident potential and radiological consequences.

In assessing potential accidents, two major factors were considered in developing a series of postulated accidents: the probability of occurrence and the subsequent severity of an accident. A complete range of postulated accidents was described in FAA's application for an amendment to its license for proposed operations. These included an accident involving the transfer of the californium-252 (Cf-252) source from the cask into the EDS-3C, an accident during transport from the manufacturer, and postulated operational accidents, such as a fire or an explosion.

The doses calculated for these accidents are effective dose equivalents resulting from the inhalation of dispersed radioactive material. Exposure pathways other than inhalation can be expected to result in minor increases in dose commitment received. Deposition of Cf-252 in soil and/or vegetables may require decontamination if the accident involves significant amounts of Cf-252.

6.1 Source-Transfer Accidents

External dose rates during transfer of a source would be slightly higher than those during normal operations because the shielding would be less as the source was moved from the transfer cask to the EDS-3C. The highest dose rate would occur at the time the source was passed from the cask into the EDS-3C. If the source were to become stuck in this position, a high radiation field would result. Figure 6.1 illustrates the isodose contours for a source in a stuck position. Additional dose rate measurements can be found in the licensee's environmental report (SAIC, 1989).

The operating procedures for the EDS-3Cs installed in concourse areas require that the source be transferred when the number of people in the airport is low and that the immediate area be cordoned off at approximately 14 m (45 ft) to limit the radiation exposures to members of the public to 0.02 mSv/hr (2 mrem/hr). TNA personnel would limit their exposure while working to dislodge the source by positioning themselves away from the interface between the cask and the EDS-3C. Their average dose rate would be about 0.2 mSv/hr (20 mrem/hr) during the 15 minutes it might take to dislodge the source. The estimated collective dose for this scenario is less than 3.0×10^{-4} person-Sv (0.03 person-rem). The estimated probability that the source might become dislodged is less than 10^{-3} per source insertion or removal (SAIC, 1989).

6.2 Transportation Accidents

The environmental impacts of radioactive shipments involving all modes of transportation in the United States under regulations in effect as of June 30, 1975, have been documented in the "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes" (NUREG-0170).

This section addresses the radiological impact of an accident resulting from the transportation of one Cf-252 source annually. Minor traffic accidents would have no effect on the integrity of the cask containing the source and would not pose a radiological hazard (Bozorgmanesh, 1981).

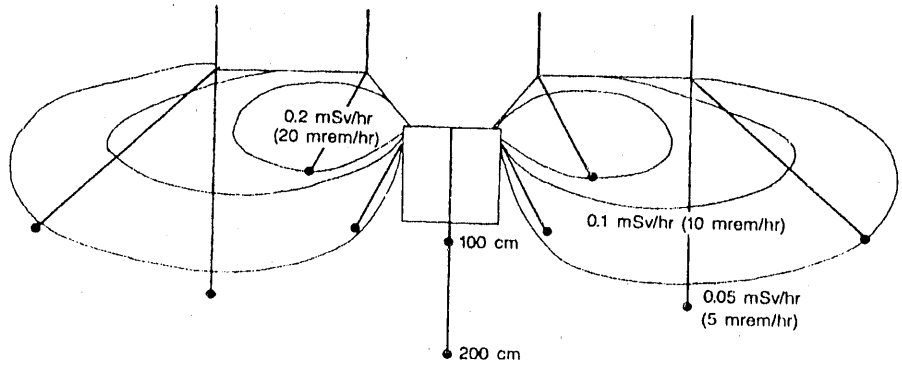


Figure 6.1 Isodose contours for source wedged at interface of cask and EDS-3C

The bulk of the cask is composed of water-extended-polyester neutron shielding, which does not melt like the borated wax compounds used previously in the prototype, Model EDS-2 (Ryge, 1989). Lead shielding around the center of the cask where the source is located reduces the gamma ray dose rate. Although the melting point of lead is about 327 °C (620 °F), a serious crash followed by a hot fire of long duration could destroy the neutron shielding and seriously compromise the gamma ray shielding. Table 6.1 shows the dose equivalent rates from neutron and gamma radiation at various distances from an unshielded 150-μg point source of Cf-252. The absorbed dose rates in tissue are based on data given for a distance of 1 m (3 ft) in ICRP Publication 21. The dose equivalent rates in Table 6.1 are based on the assumption that the mean quality factor for neutrons will increase by a factor of 2. The dose rates shown are the upper limits for a radiation field that might be present following a postulated severe accident and subsequent fire involving the truck transporting the source. The gamma ray doses rates would be much lower if the lead shield remained intact.

Table 6.1 Maximum potential dose equivalent rates from one 150-μg Cf-252 source following a severe accident and fire

Distance [m (ft)]	Dose equivalent rate (mSv/hr)		
	Neutron	Gamma	Total
1 (3.3)	7.2E+00	2.1E-01	7.4E+00
2 (6.6)	1.8E+00	5.0E-02	1.8E+00
5 (16.4)	2.8E-01	8.5E-03	2.8E-01
10 (32.8)	7.5E-02	2.1E-03	7.7E-02

Note: 7.2E+00 = 7.2x10° etc.

Table 6.1 shows that the potential for serious exposure would not exist following a postulated accident involving a fire. Cleanup of the accident would be complicated. It might require bringing in a crane to manipulate the remains of the shielded cask or bringing in another shielded cask for source storage. A large water-filled tank could serve as both a receptacle for the source and a shielding tool to provide protection against radiation emitting from the source. Careful emergency planning for such scenarios would limit the dose during recovery of the source. A person working at an average distance of 10 m (33 ft) from the source for 4 hours could receive a dose equivalent of about 0.3 mSv (30 mrem).

The second type of transportation accident is assumed to be even more severe that the scenario considered above. For this accident, it is assumed that the accident and subsequent fire lead to the complete fragmentation of the Cf-252 source and its dispersion to the atmosphere. The accidental release of radioactivity from ground level and transported in the atmosphere under stable conditions was calculated at 4 m/s (13 ft/s). NRC Regulatory Guide 1.145, "Atmospheric Dispersion Models for Potential Accident Consequence Assessments at Nuclear Power Plants," was used to calculate the average χ/Q values of 6.4×10^{-5} s/m^3 and 2.8×10^{-5} s/m^3 at 50 and 300 m (54 and 328 yd), respectively, from the accident location.

Tables 6.2 through 6.5 summarize the offsite concentrations and annual inhalation doses for 10-, 50-, and 100-percent dispersion from the Cf-252 source at 50 and 300 m, respectively, from the point of release. The resulting maximum inhalation dose for 100-percent dispersion at a distance of 50 m is 2.4×10^{-3} Sv (2.4×10^{-1} rem), which is well within the U.S. Environmental Protection Agency's (EPA, 1990) protective action guidelines (PAGs) of 0.25 Sv (25 rem) for emergency workers.

Table 6.2 Offsite concentrations [at 50 m (54 yd)] of airborne releases for various fractions of Cf-252

Total source activity (MBq/yr)	Release fraction	Emission (MBq)	χ/Q* (s/m^3)	Maximum permissible concentration (MPC) (Bq/ml)	Offsite concentration	
					(MBq/m^3)	Fraction of MPC (%)
2.96E+03	1.00E-01	2.96E+02	6.40E-05	3.70E-08	6.10E-10	1.62
2.96E+03	5.00E-01	1.48E+03	6.40E-05	3.70E-08	3.00E-09	8.12
2.96E+03	1.00E+00	2.96E+03	6.40E-05	3.70E-08	6.01E-09	16.24

*χ/Q at 50 m.
Note: 2.96E+03 = 2.96x10^3 etc.

Table 6.3 Annual inhalation dose to the nearest individual 50 m (54 yd) away from postulated Cf-252 accident

Activity* inhaled (Bq)	Dose conversion factor** (Sv/50 yr·Bq)	Committed effective dose equivalent (Sv/50 yr)
4.81E+00	5.00E-05	2.40E-04
2.40E+01	5.00E-05	1.20E-03
4.81E+01	5.00E-05	2.40E-03

*Breathing rate = 8.00E+03 m^3/yr.
**ICRP Publication 30.
Note: 4.81E+00 = 4.81x10^0 etc.

Table 6.4 Offsite concentrations [at 300 m (328 yd)] of airborne releases for various fractions of Cf-252

Total source activity (MBq/yr)	Release fraction	Emission (MBq)	χ/Q* (s/m^3)	Maximum permissible concentration (MPC) (Bq/ml)	Offsite concentration	
					(MBq/m^3)	Fraction of MPC (%)
2.96E+03	1.00E-01	2.96E+02	2.80E-05	3.70E-08	2.63E-10	0.71
2.96E+03	5.00E-01	1.48E+03	2.80E-05	3.70E-08	1.31E-09	3.55
2.96E+03	1.00E+00	2.96E+03	2.80E-05	3.70E-08	2.63E-09	7.10

*χ/Q at 300 m.
Note: 2.96E+03 = 2.96x10^3 etc.

Table 6.5 Annual inhalation dose to the nearest individual 300 m (328 yd) away from postulated Cf-252 accident

Activity* inhaled (Bq)	Dose conversion factor** (Sv/50 yr·Bq)	Committed effective dose equivalent (Sv/50 yr)
2.10E+00	5.00E-05	1.05E-04
1.05E+01	5.00E-05	5.26E-04
2.10E+01	5.00E-05	1.05E-03

*Breathing rate = 8.00E+03 m^3/yr.
**ICRP Publication 30.
Note: 2.10E+00 = 2.10x10^0 etc.

This scenario assumes that all the shielding materials are destroyed. The dose rate at 10 m, a reasonable distance for fire control and containment, is approximately 7.7x10-^{2} mSv/hr (7.7 mrem/hr). For a maximum fire-fighting time of 4 hours, the total dose to an individual would be approximately 0.31 mSv (31 mrem). Such a dose does not exceed the PAG limit of 1-rem whole-body dose (EPA, 1990). Although the dose estimates would not

necessitate offsite protective actions, all U.S. airports have implemented fire protection and emergency preparedness plans as part of their building code requirements.

The average distance from a supplier of Cf-252 sources to various airport locations was approximately 1900 km (1200 mi). The probability of a severe truck accident during shipment of a Cf-252 source to and from an airport is about 7.2×10^{-8}/yr (Sandia National Laboratory, 1978). For actual locations, the accident probability ranges from 2.9×10^{-8}/yr to 1.4×10^{-7}/yr.

The consequences of the postulated accident would depend on location. To assess the population dose resulting from the Cf-252 dispersal accident, a reference population density of 386 persons/km^2 (1000 persons/mi^2) within a 16-km (10-mi) radius of the accident location was used. It was assumed that 10 percent of the Cf-252 was released downwind and that a 60° sector was affected. The total number of people affected in this postulated scenario would be 5.2×10^4. The collective dose received by individuals within that sector out to 16 km would be about 5.5 person-Sv (550 person-rem). It should be noted, however, that dispersion and dilution of the plume due to deposition of Cf-252 on the ground will significantly reduce the radioactive airborne concentration at 16 km. For further information regarding this scenario, see the licensee's environmental report (SAIC, 1989).

6.3 Operational Accidents

The possibility exists that an accident followed by a fire at an airport could happen. If a fire followed by a large explosion were to occur, the force of the explosion could destroy the inside chamber and leave the source virtually unshielded. Table 6.1 provides an upper bound for the radiation field that could result. Unless the source was blown completely away from the EDS-3C, the field would not be radially uniform because of the presence of the shielding components. The problem of retrieving the source and placing it in a shielded container is similar to that described in Section 6.2, but the process could be aided with the use of the neutron and gamma-ray survey instruments that are always kept on site at the airport in another (but immediate) location.

To evaluate the possibility of such a bomb breaching the source encapsulation, a test was performed at the U.S. Bureau of Mines in 1988 using 4.5 kg (10 lb) of plastic explosive and a dummy (empty) source capsule simulated in an EDS-3C mockup device (U.S. Bureau of Mines, 1988). The results showed that the detonation of the charge did very little damage to the surrounding enclosure, although the mockup itself was completely destroyed. Most of the framework for the mockup was shattered, and pieces of the bismuth block and paraffin shielding were scattered around the area. The polyethylene tube containing the dummy source capsule was found essentially undamaged under the debris. Although the inner metal sleeve and polyethylene were tightly swaged onto the source capsule, the source still appeared to be in good condition, as was later verified by the source manufacturer's leak tests. For further information regarding the results of these tests, see SAIC (1988).

7 DECOMMISSIONING

The structural components of the EDS-3 and EDS-3C are not expected to contain significant amounts of radionuclides after 15 years of system operation. It is estimated that a total of 7.4×10^4 Bq (0.002 μCi) would be present, mainly as a result of the activation of bismuth in the shield. Neutron activation of the concrete platform beneath the EDS-3C is also expected to be small. After the initial testing of the prototype model (EDS-2) at both Los Angeles and San Francisco International Airports was stopped in 1988, the concrete surface under the EDS-2 was surveyed with an ion chamber survey instrument. Although the system had only been tested for 6 weeks at each airport, no activity above background was observed.

Because concrete is used as a floor barrier at most airport facilities, the amount of activation products that may be found in concrete 15 years after system operation can be calculated. Concrete is a natural choice for a shielding material; it is cheap, structurally useful, and versatile. A great deal of work has been done on conventional and special shielding concretes, and a wide variety of compositions are described in literature. Water plays a significant role in ensuring the effectiveness of concrete as a neutron shield because hydrogen is the most effective light element for slowing down neutrons from Cf-252.

For estimation purposes, it can be assumed that all the neutrons impinging on the surface below the TNA system are fission-spectrum neutrons (thermal neutrons would be strongly absorbed by the borated paraffin wax shielding). The dose rate at the bottom center outside the EDS-3C exterior shielding is approximately 0.3 mSv/hr (30 mrem/hr). For fission-spectrum neutrons, 0.3 mSv/hr corresponds to 240 neutrons/cm^2-s. Table 7.1 lists the principal constituents of concrete and the long-term activation products from this neutron flux using the data from Erdtmann (1976). Assuming the constituents of concrete are those listed in Table 7.1, the total activity (for all products) remaining after 15 years is 65 Bq (0.0017 μCi).

Although other elements such as chromium, manganese, vanadium, aluminum, sulfur, phosphorus, and titanium may also exist in elemental concrete, the elements listed in the table are the primary ones (Jaeger et al., 1970).

Table 7.1 Major constituents of concrete and long-term activation products

Constituent	Average percent composition by weight	Product	Half-life	Gamma energy (MeV)	Activity (Bq/kg)	Activity (μCi/kg)
Calcium (Ca)	22	Ar-37	34.8 d	0	4.4E+01	1.2E-03
		K-42	12.4 hr	1.52	6.7E-02	1.8E-06
Hydrogen (H)	1	H-3	12.3 yr	0	1.1E-01	3.1E-06
Oxygen (O)	51	O-15	2 min	1.02	1.8E-03	4.9E-08
Silicon (Si)	22	Mn-27	10 min	0.89	2.5E-02	6.7E-07
Carbon (C)	3	C-11	20 min	1.02	4.8E-06	1.3E-10
		Be-10	1.6E+06 yr	0	4.4E-02	1.2E-06
Iron (Fe)	0.5	Mn-54	312 d	0.83	1.3E-01	3.4E-04
Manganese (Mg)	0.5	Na-24	15 hr	4.12	7.4E+00	2.0E-04
Total					6.5E+01	1.8E-03

Note: 4.4E+01 = 4.4×10^1 etc.

8 ALTERNATIVES

8.1 Attributes for Evaluation

The primary considerations in a value-impact assessment are the attributes that are used to characterize the consequences of a proposed action. For this assessment, the staff evaluated four categories: (1) costs of each alternative, (2) health and safety impacts, (3) economic impacts, and (4) radiological impacts. The costs related to each alternative refer to the actual monetary expenditures required to implement and conduct operations under that alternative. As a baseline, the no-action alternative can be ascribed a cost of zero dollars. Although current policies and procedures for airline safety and security involve real cost expenditures, these costs are not considered in the present context because the costs for the various action alternatives are evaluated relative to the no-action alternative.

Capital costs include all monetary expenditures required to cover initial costs of system construction and installation to the point where the system is functional. Capital costs in this assessment were amortized annually over the estimated 15-year operational life of the EDS-3C assuming an interest rate of 10 percent. Operational costs include all labor, maintenance, and overhead expenditures required to operate the system. To facilitate the evaluation of relative costs on a comparable basis, annual capital and operational costs were prorated on a per-flight-passenger basis. Unit costs are expressed in terms of dollars per flight passenger.

The staff also assessed the health and safety impacts for each alternative. To determine occupational safety, it analyzed the varying degrees of baggage handling and occupational habits for each alternative. Industrial experience in regard to similar types of work environments (e.g., warehouse operations and parcel delivery) indicates the rates of lost time resulting from injury and accidental deaths of workers per unit time that can be expected for these occupations.

Potential radiological consequences constitute the major concern associated with the TNA system. Because the baggage and its contents may be activated, both workers and the public may be exposed to the radiation emitted during the decay of the induced radioactivity. In cases where hand search of alarmed bags (those that have indicated potentially positive for high nitrogen density) is required, residual radiation from the handling of the bags could also expose the public to small amounts of radiation. For purposes of value-impact assessment, the collective dose measured in person-Sv (person-rem) is the measure used to quantify the effect.

The economic impacts discussed are largely qualitative. The alternatives related to the use of the TNA system will require an additional 6 to 9 positions per operational unit; the hand-search alternative will require an equivalent increase of 33 positions. The cost in tariffs or dollar charge per flight passenger also was estimated for each alternative.

8.2 Identification and Assessment of Alternatives

In accordance with the guidance in NUREG/CR-3568, FAA evaluated a number of alternatives and selected a range of possible options for the detection of explosives in checked airline baggage. The alternatives studied did not sufficiently meet the requirements for detection of explosives as defined by FAA in "Background Technical Information for the Broad Agency Announcement" [U.S. Department of Transportation, 1989(a)]. These alternatives were the following:

- No action.
- Individual hand search of all checked luggage.
- Use of enhanced x ray screening. This might include the use of color monitoring screens with enhanced image scanners to distinguish between organic and inorganic materials.
- Use of chemical vapor detection methods. These might include use of chemical vapor detectors ("sniffers") sensitive to explosives or use of trained canines (olfactory methods).
- Use of the EDS-3 in the ramp area (as currently licensed).
- Use of the EDS-3C in the concourse area.
- Use of the EDS-3C with enhanced radiation protection features to further minimize possible human exposure to ionizing radiation in the concourse area.

Of the alternatives considered, FAA eliminated two as being ineffective and, therefore, not feasible (FAA, 1989). The alternatives considered to be ineffective (because of the FAA requirement pertaining to the percentage of false positives and the 6-second requirement for screening) were enhanced x ray screening and chemical vapor detection. The remaining alternatives are described in this section. To evaluate the relative advantages and disadvantages of these alternatives, the NRC staff performed an assessment using the methodology in NUREG/CR-3568.

To estimate the anticipated number of occupational accidents for each of the alternatives evaluated, the National

Safety Council's annual statistics for rates of occupational accidents were used (National Safety Council, 1986). These rates are expressed in terms of resulting lost workdays. For example, the following industry-related jobs are cited in the document published by the National Safety Council (1986):

Industry	Lost workday/ person-yr
Transportation and public utilities	1.05
Manufacturing	0.78
Wholesale and retail trade	0.50

To estimate the anticipated industrial accident rate, an average of the above three examples (0.75 lost workday/ person-yr) was used. For example, if one alternative required 20 employees to accomplish the job, the accident rate would be 15 lost workdays/yr (20 employees x 0.75 lost workday/person-yr).

For purposes of this assessment, the following operational assumptions were made for the EDS-3C:

- The estimated operating life of the unit is 15 years.
- The unit inspects baggage at a rate of 400 bags an hour and operates 16 hours a day.
- Approximately 6000 bags a day are inspected. Assuming each passenger has two bags, the baggage from about 1.1 million passengers will be inspected.
- Two operational personnel are required to attend the EDS-3C during operating hours. This requires six full-time-equivalent personnel per operating unit (three 40-hr/wk shifts).
- Two baggage handlers are required to load luggage onto the EDS-3C during operating hours. This requires six full-time-equivalent personnel per operating unit (three 40-hr/wk shifts).
- Estimated average annual personnel costs are as follows: the EDS operator, $60,000; each baggage handler, $45,000; and each EDS assistant or "runner," $35,000 (all estimates include overhead costs). Salary estimates are from the International Association of Machinists.

8.2.1 No Action

This alternative assumes that present policies and procedures involving inspection of checked airline baggage are continued and that present levels of security are maintained. No additional operating or capital costs are assumed.

8.2.2 Hand Search

This alternative assumes that all checked luggage is individually hand searched. It will require a significant increase in inspection staff, along with attendant labor costs. It also may require changes in airline scheduling to allow for the additional time to complete inspection procedures. Because it is assumed that capital costs for this alternative are relatively small (i.e., inspection tables), they are not considered in this assessment.

The operating costs to consider for this alternative would be (1) costs associated with the additional space needed for the inspection tables and (2) costs associated with the hiring of additional inspection personnel to hand search each piece of luggage. The average space needed for 10 inspection stations would be 186 m^2 (2000 ft^2), with a cost of approximately $269/$m^2$ ($25/$ft^2$). To inspect the same amount of baggage that an EDS-3C would be able to screen, approximately 67,000 hr/yr would be needed:

$$2 \times 10^6 \text{ bags/yr} \times 2 \text{ min/bag} \times 1 \text{ hr}/60 \text{ min} = 66{,}666 \text{ hr/yr}$$

If an employee working full time for 2000 hours a year is assumed, a total of 33 inspection personnel would be required to hand search the same number of bags as would be screened by one EDS-3C. To calculate the total labor costs, it was assumed that each inspector was paid $10 an hour, with an annual salary of $20,000 ($10/hr x 2000 hr/yr). For overhead, health insurance, general, and administrative expenses, another 100 percent was added. This amounts to $40,000 in labor costs for each inspector, resulting in a total labor cost of $1,320,000 for each inspection station (33 x $40,000/person-yr).

The total annual costs for this alternative are as follows:

Labor cost (33 x $40,000/person-yr)	$1,320,000
Space cost ($269/$m^2$ x 186 m^2)	$50,000
TOTAL ANNUAL COST	$1,370,000

Accordingly, for the hand-search option, the estimated accident rate is 25 lost workdays/yr (33 personnel x 0.75 lost workday/person-yr).

8.2.3 TNA System in Ramp Area

This alternative involves the use of the TNA system (EDS-3) in the ramp or cargo-handling area of an airport. This alternative is currently licensed and is being used at JFK International Airport in New York and Miami International Airport in Florida. It was evaluated in a previous environmental assessment (NRC, 1989).

Recent experience at JFK International Airport has shown that additional labor cost is associated with the ramp location relative to the proposed use of the EDS-3C in the lobby or concourse area. This cost is related to the logistical problem of locating and bringing

passengers whose bags have alarmed to the TNA inspection area (near the ramp area of an airport) where the bags in question are opened and inspected. This was assumed to require one assistant (during TNA system operation), 16 hours a day, 7 days a week, for a total of three assistants. The additional labor costs for these three assistants are $35,000 x 3 = $105,000. Currently, two baggage handlers and two EDS-3 trained operators must attend the unit during its operation. This requires 12 full-time-equivalent personnel for each operating unit (six 40-hr/wk shifts) at a cost of approximately $45,000 a year for each baggage handler and $60,000 a year for each operator. The average space needed for each EDS-3 is 93 m^2 (1000 ft^2), with a cost of approximately $269/$m^2$ ($25/$ft^2$). The estimated accident rate for this alternative is 11.3 lost workdays/yr (15 personnel x 0.75 lost workday/person-yr).

The capital, operational, and annual costs for this alternative are as follows:

Capital Costs	
Estimated fabrication and construction costs	$1,000,000
Installation costs	
Site modification (includes housing)	$125,000
Transportation, setup, and testing	$50,000
TOTAL CAPITAL COSTS	$1,175,000
Amortized Annual Cost ($/yr, 15 yr @ 10%)	$151,500
Operational Costs	
Space cost ($269/$m^2$ x 93 m^2)	$25,000
Labor cost	
6 operators @ $60,000/yr	$360,000
6 baggage handlers @ $45,000/yr	$270,000
3 runners @ $35,000/yr	$105,000
Source change	$25,000
Calibration, leak testing, and repair	$25,000
TOTAL OPERATIONAL COSTS	$810,000
TOTAL ANNUAL COSTS	$961,500

8.2.4 TNA System in Concourse Area

This alternative is as described in this environmental assessment. The original EDS-3 has been modified slightly for concourse installation (now designated as Model EDS-3C) to decrease the external radiation levels. Different materials were selected to reduce neutron capture gamma rays, and additional panels of borated polyethylene and lead were added to further reduce the external dose rates. Dose rate data are given in Section 3.1.

For this alternative, the cost of supplementary support and additional building materials needed for the installation of the EDS-3C at indoor and outdoor locations at the airport has been added. The indoor locations would include the following: behind the check-in counter, in front of the check-in counter, and at the pre-check-in area. The only outdoor location would be at the curbside. Because only 6 full-time operators and 6 full-time baggage handlers would be needed for the indoor scenario, the estimated accident rate for this option is 9 lost workdays/yr (12 personnel x 0.75 lost workday/person-yr).

In the curbside scenario, however, the baggage may go directly into a baggage chute rather than staying on the same level as the EDS-3C. If this were the case, only three full-time baggage handlers would be needed to load luggage onto the system; all bags leaving the system would be automatically passed to the plane. The estimated accident rate for the curbside option is 6.75 lost workdays/yr (9 personnel x 0.75 lost workday/person-yr). The decreases in estimated labor costs for the curbside scenario are reflected in Table 8.1.

To estimate the costs associated with the construction and installation of the EDS-3C at the concourse level of an airport, a structural feasibility study was performed (see Peacock, 1989). This study defined the structural concerns related to the support for the system, defined a conceptual solution for the support and placement of the system, and estimated the construction costs associated with the installation of the system. Table 8.1 shows the differences in capital and operational costs for both the curbside and indoor scenarios.

8.2.5 TNA System With Enhanced Radiation Protection

For this alternative, additional shielding, moderators, and controls are added to the basic design of the EDS-3C. These additional materials are assumed to be capable of reducing the radiation exposures by at least 50 percent. Installation cost would be increased because of the added weight and materials.

Because 6 full-time operators and 6 full-time baggage handlers would be needed for this alternative, the estimated accident rate is 9 lost workdays/yr (12 personnel x 0.75 lost workday/person-yr).

The capital, operational, and annual costs for this alternative are as follows:

Table 8.1 Construction costs for curbside and indoor EDS-3C installations

Attribute	Curbside installation	Indoor installation
Capital Costs		
Estimated fabrication costs for EDS-3C	$1,000,000	$1,000,000
Construction Costs		
Outside housing	$125,000	$0
Median barriers	$5,500	$0
Structural design fee	$7,000	$3,000
Analysis of load path through terminal	$0	$4,500
Moving equipment	$0	$5,500
Construction	$35,500	$35,500
Transportation, setup, and testing	$50,000	$50,000
TOTAL CAPITAL COSTS	$1,223,000	$1,098,500
Amortized annual capital cost ($/yr, 15 yr @ 10%)	$157,700	$141,700
Operational Costs		
Space cost ($269/m² x 93 m²)	$25,000	$25,000
Labor cost		
6 operators @ $60,000/yr	$360,000	$360,000
6 baggage handlers @ $45,000/yr	–	$270,000
3 baggage handlers @ $45,000/yr	$135,000	–
Source change	$25,000	$25,000
Calibration, leak testing, and repair	$25,000	$25,000
TOTAL OPERATIONAL COSTS	$570,000	$705,000
TOTAL ANNUAL COSTS	$727,700	$846,700

Capital Costs

Estimated fabrication and construction costs	$1,200,000
Installation costs	$200,000
TOTAL CAPITAL COSTS	$1,400,000
Amortized Annual Cost ($/yr, 15 yr @ 10%)	$180,500

Operational Costs

Same as those in Table 8.1 for indoor installation	
TOTAL OPERATIONAL COSTS	$705,000
TOTAL ANNUAL COSTS	$885,500

8.3 Summary

Table 8.2 gives the value-impact summary for the four alternatives described in the previous sections in relation to the no-action alternative. The table shows that the average cost of the TNA system, normalized to a per-flight-passenger basis, is about $0.78, and the per-flight-passenger cost for the hand-search alternative is about $1.25. The difference is attributable to the number of employees needed to hand search baggage.

The cost effectiveness of a TNA system with enhanced radiation protection features can also be determined from this study. With a marginal annual dose reduction of 0.057 person-Sv (5.7 rem) and a differential annual cost of $38,800, the cost for this system would be about $6,800/person-rem (the traditional unit of rem is used here for simplicity). This value exceeds the NRC guideline of $100/person-rem (NUREG/BR-0058); therefore, under the assumptions applied in this analysis, the enhanced radiation protection features would not be considered cost effective.

Table 8.2 Value-impact summary for airline explosive detection alternatives

Attribute	No action	Hand search	TNA system in ramp area	TNA system as proposed		TNA system with enhanced radiation protection
				Curbside	Indoor	
Costs						
Unit capital cost ($)	0	0	1,175,000	1,223,000	1,098,500	1,400,000
Amortized annual capital cost ($/yr)	0	0	151,500	157,700	141,700	180,500
Operational cost ($/yr)	0	1,370,000	810,000	570,000	705,000	705,000
Unit total cost ($/yr) (amortized annual cost plus operational cost)	0	1,370,000	961,500	727,700	846,700	885,500
Cost per flight passenger ($)	0	1.25	0.87	0.66	0.77	0.81
Health and Safety Impacts						
Aircraft safety and security	No change	Improved	Improved	Improved	Improved	Improved
Industrial accident rate (lost workdays/unit/yr)	0	25	11.3	6.7	9	9
Radiological Impacts						
Collective dose (person-Sv/unit/yr)						
Occupational	0	0	6.0E-03	1.2E-02	1.2E-02	6.0E-03
Public	0	0	1.0E-02	1.5E-01	1.4E-01	6.4E-02
Public (pre-check-in scenario)	N/A	N/A	N/A	N/A	3.4E-01	N/A
Consumable items	0	0	0	0	1.3E-05	0
Nonconsumable items	0	0	2.8E-03	2.8E-03	2.8E-03	2.8E-03
Total	0	0	1.9E-02	1.6E-01	4.9E-01	7.3E-02
Social and Economic Impacts						
Added employment	0	33	15	9	12	12
Public fear due to						
Radioactivity	None	None	Increased	Increased	Increased	Increased
Flight risks	No change	Decreased	Decreased	Decreased	Decreased	Decreased

Note: N/A = not applicable.
6.0E-03 = 6.0×10^{-3} etc.

9 SUMMARY AND CONCLUSIONS

9.1 Summary of Environmental Impacts

Requirements regarding the inspection of passengers' luggage are not new. An Executive Order of January 5, 1973, required airline companies to inspect all passengers and their hand-carried luggage for concealed guns, dangerous weapons, explosives, and incendiary devices before permitting the passengers to board commercial aircraft (NCRP Report 95). By 1985, airlines scanned the luggage for about 400 million passenger trips using x ray fluoroscopic scanning systems in the public access areas of airports. The Federal performance standard (21 CFR 102.40) for cabinet x ray systems limits x ray emissions at a point 5 cm (2 in.) from the external surface of the system to 1.3×10^{-7} coulomb/kg (0.5 mrem) in any one hour. On the basis of this exposure rate, this source would contribute about 0.003 μSv (0.3 μrem) as an annual dose equivalent to each flight passenger. Assuming 30 million passengers travel per year, the estimated annual collective effective dose equivalent is about 0.6 person-Sv (60 person-rem).

This assessment indicated that a structural engineering study will be required to ensure that the weight of the EDS–3C can be accommodated safely on the concourse level of airports. Construction, installation, and use of the EDS–3C will affect nearby passenger traffic patterns to some degree at international ticket counters. However, essential rigging equipment such as air dollies or forklifts can move the EDS–3C components into the terminal building during a week night or on a weekend when traffic in the terminal is at a minimum.

The NRC staff assessed the internal dose to passengers from irradiated foodstuffs. It determined the total effective dose equivalent from the average daily intake of the major elements contributing the largest doses (using ICRP Publication 23). If 5 percent of the passengers carried food items in their luggage and consumed it within 30 seconds of reclaiming their luggage (after it was screened by the EDS–3C), the annual collective dose to an estimated 1.1 million passengers would be 1.3×10^{-5} person-Sv (1.3×10^{-3} person-rem).

The staff calculated the collective effective dose equivalent from wearing 40 g (1.4 oz) of gold jewelry that had passed through the EDS–3C. If 1 percent of the passengers carried gold jewelry in their luggage and subsequently wore it for an extended period, the dose from this scenario would be 2.8×10^{-3} person-Sv/yr (0.28 person-rem/yr).

For the purposes of environmental analysis, the staff assessed the impact of several different accident scenarios to selectively bound a spectrum of accidents that could occur. It evaluated three potential accident scenarios (i.e., accidents that could occur during source transfer, transportation, and operation of the system) involving the partial or complete fragmentation of the Cf-252 source. The resulting maximum inhalation dose from the worst-case accident involving 100-percent dispersion of the source at a distance of 100 m (110 yd) would be 1.0×10^{-3} Sv (0.10 rem), which is well within the U.S. Environmental Protection Agency (1990) protective action guidelines of 0.25 Sv (25 rem) for emergency workers.

The staff performed a cost-benefit analysis of alternatives to the EDS–3C. The alternatives considered were the following: no action, individual hand search of checked luggage, use of the EDS–3 in the ramp area, use of the EDS–3C in the concourse area, and use of the EDS–3C with enhanced radiation protection features. The evaluation clearly demonstrated that the EDS–3C curbside alternative was the most cost-effective method of screening passenger check-in luggage.

As illustrated in this assessment, the annual dose from EDS–3C operations to members of the public could be compared with that from x ray inspection systems that have been in use since the early 1970s. Even in the worst-case scenario (pre-check-in), the maximum individual dose for passengers was 0.18 μSv/yr (18 μrem/yr), and the maximum individual dose to members of the public was 0.0067 μSv (0.67 μrem). The average doses to passengers and members of the public from all four scenarios were 0.08 μSv (0.008 mrem) and 0.04 μSv (0.004 mrem), respectively. If the additional conservatism of the neutron quality factor was not used (10 rather than 20), the above calculated doses from the EDS–3C would be half the doses shown.

On the basis of the foregoing assessment, the NRC staff concludes that the environmental effects of normal operation of the EDS–3C when located in any one of the four concourse areas of an airport are expected to be extremely small. For all scenarios, the maximum values of radiation exposure that may be received by workers in restricted areas (such as the operators) and those in unrestricted areas (other non-TNA workers, passengers, and members of the public) are well below the limits specified in 10 CFR Part 20.

9.2 Basis for Finding of No Significant Impact

On the basis of the foregoing assessment, the NRC staff concludes that the environmental impacts that would

result from the proposed licensing action would not be significant and do not warrant the preparation of an environmental impact statement. Accordingly, the staff has determined that a finding of no significant impact is appropriate.

For further technical details with respect to this action, see the application for a license dated October 31, 1986; amendments dated April 19 and August 22, 1989; the supporting environmental reports; and other related correspondence. These documents (in Docket Number 030-30885) and this final environmental assessment may be examined or copied for a fee at both the NRC's Public Document Room at 2121 L Street NW., Washington, D.C. 20555, and the NRC's Region 1 Public Document Room, 475 Allendale Road, King of Prussia, Pennsylvania 19406.

10 REFERENCES

American Society for Testing and Materials (ASTM), *Annual Book of ASTM Standards*, Sec. 12, Vol. 12.02, "Standard Method for Determining Thermal Neutron Reaction and Fluence Rates by Radioactivation Techniques," Method E262–86, Philadelphia, Pennsylvania, 1989 edition.

Beckett, L., and M. Schneider, Polaroid Corporation, letter to C. Scher, Federal Aviation Administration, October 30, 1987.

Bozorgmanesh, H., "TRANSCASK, Certification and Analysis Science Applications Inc., Cf-252 Shipping Cask Assembly," unnumbered SAIC report, Santa Clara, California, 1981.

California Department of Health Services, CA–590–D–118–S, "Registry of Radioactive Sealed Sources and Devices for SAIC Model EDS–3C," Sacramento, California, February 1990.

——, CA–590–D–122–S, "Registry of Radioactive Sealed Sources and Devices for SAIC Model EDS–3," August 1989.

Code of Federal Regulations, Title 10, "Energy," and Title 21, "Food and Drugs," U.S. Government Printing Office, Washington, D.C., revised periodically.

E.I. du Pont de Nemours and Company, Savannah River Laboratory, DP–1246, "Californium-252 Shielding Guide," Aiken, South Carolina, March 1971.

Erdtmann, G., *Neutron Activation Tables*, Verlag Chemie, Weinheim, New York, 1976.

Hall, B., United Airlines, personal telephone conversation with C. G. Jones, U.S. Nuclear Regulatory Commission, January 17, 1990 (documented in licensing file in NRC's Region I Public Document Room).

Hodgman, C. D., R. C. Weast, and A. M. Selby, eds., *Handbook of Chemistry and Physics*, Chemical Rubber Publishing Co., Cleveland, Ohio, 1960.

Idaho National Engineering Laboratory (INEL), EGG-PHY–8274, "Environmental Assessment for Explosive Detection Systems Using Thermal Neutron Activation for Airline Baggage Inspection," Idaho Falls, Idaho, September 1988.

International Commission on Radiation Units and Measurements, ICRU Report 33, "Radiation Quantities and Units," Bethesda, Maryland, April 15, 1980.

——, ICRU Report 40, "The Quality Factor in Radiation Protection," April 4, 1986.

International Commission on Radiological Protection, ICRP Publication 21, "Data for Protection Against Ionizing Radiation From External Sources," supplement to ICRP Publication 15, Pergamon Press, Oxford, England, 1971.

——, ICRP Publication 23, "Reference Man: Anatomical, Physiological, and Metabolic Characteristics," Pergamon Press, 1975.

——, ICRP Publication 28, "Statement From the 1978 Stockholm Meeting of the ICRP," Pergamon Press, 1978.

——, ICRP Publication 30, "Limits for Intakes of Radionuclides by Workers," Parts 1–3 (with supplements), Pergamon Press, 1979–1982.

——, "Statement From the 1985 Paris Meeting of the ICRP," *Health Physics*, Vol. 48, No. 6, June 1985, p. 828.

Jaeger, R. G., E. P. Blizard, and A. B. Chilton, eds., *Engineering Compendium on Radiation Shielding*, Vol. III, sponsored by the International Atomic Energy Agency, Springer-Verlag, New York, 1970.

Knoll, G. F., *Radiation Detection and Measurement*, John Wiley and Sons, New York, 1979.

National Council on Radiation Protection and Measurements, NCRP Report 91, "Recommendations on Limits for Exposure to Ionizing Radiation," Bethesda, Maryland, June 1, 1987.

——, NCRP Report 94, "Exposure of the Population in the United States and Canada From Natural Background Radiation," December 30, 1987.

——, NCRP Report 95, "Radiation Exposure of the U.S. Population From Consumer Products and Miscellaneous Sources," December 30, 1987.

National Institute of Standards and Technology, "Quantitative Assessment of Induced Radioactivity in Baggage," final report covering all phases of Interagency Agreement No. DTFA–03–87–A–00008, Gaithersburg, Maryland, March 31, 1989.

National Safety Council, *Accident Facts*, Chicago, Illinois, 1986.

Peacock, T. M., FDE LTD., Consulting Engineers, letter to P. Ryge, Scientific Applications International Corporation [Appendix L of SAIC (1989)], November 16, 1989.

Ryge, P., Science Applications International Corporation, letter to C. G. Jones, U.S. Nuclear Regulatory Commission, March 1989.

——, Science Applications International Corporation, letter to C. G. Jones, U.S. Nuclear Regulatory Commission, January 11, 1990.

Sandia National Laboratory, SAND 77-1927, "Transport of Radionuclides in Urban Environments: Working Draft Assessment," Albuquerque, New Mexico, 1978.

Science Applications International Corporation (SAIC), "Environmental Report on Explosive Detection System Using Thermal Neutron Activation for Airline Baggage Inspection," final report, Santa Clara, California, June 1988.

——, "Applicant's Environmental Report: Use of Thermal Neutron Based Explosive Detection System for Checked Baggage Inspection in Airport Lobby Areas," NRC Control Number 111217, revised report, December 1989.

Sherbini, S., U.S. Nuclear Regulatory Commission, Region I, memorandum to C. G. Jones, U.S. Nuclear Regulatory Commission, February 1990.

U.S. Bureau of the Census, *Statistical Abstracts of the United States: 1989*, 109th edition, Washington, D.C., 1989, pp. 611-612.

U.S. Bureau of Mines, "Report of Tests on the Survivability of the Neutron Source Capsule of the SAIC Nitrogen Explosive Detection System," Pittsburgh, Pennsylvania, September 1988.

U.S. Department of Transportation, Federal Aviation Administration (FAA), "Explosive Detection Systems for Checked Baggage; Final Rule (14 CFR Part 108)," *Federal Register*, Vol. 54, No. 170, September 5, 1989, pp. 36938-36949.

——, TCBAA-90-001, "Background Technical Information for the Broad Agency Announcement," Washington, D.C., November 1989(a).

U.S. Environmental Protection Agency (EPA), *Manual of Protective Action Guides and Protective Action for Nuclear Incidents*, 520/1-75-001-A, Washington, D.C., January 1990.

U.S. House of Representatives, Committee on Science, Space, and Technology, "Statement of Richard F. Lally (former Director of Aviation Security, FAA) to the Subcommittee on Transportation, Aviation and Materials," Washington, D.C., February 9, 1989.

U.S. Nuclear Regulatory Commission, "Environmental Assessment and Finding of No Significant Impact Related to Amendment of Materials License 29-13141-05; Department of Transportation, Federal Aviation Administration," *Federal Register*, Vol. 54, No. 156, August 15, 1989, pp. 33636-33639.

——, NUREG-0170, "Final Environmental Statement on the Transportation of Radioactive Material by Air and Other Modes," Vols. 1 and 2, December 1977.

——, NUREG-0172, "Age-Specific Radiation Dose Commitment Factors for a One-Year Chronic Intake," November 1977.

——, NUREG/BR-0058, "Regulatory Analysis Guidelines of the U.S. Nuclear Regulatory Commission," January 1983.

——, NUREG/CR-3568, "A Handbook for Value-Impact Assessment," Battelle Memorial Institute, Pacific Northwest Laboratory, December 1983.

Westinghouse Electric Corporation, "The Gamma and Neutron Irradiation of Pharmaceuticals," Contract No. 34-55524-WR, Pittsburgh, Pennsylvania, September 1986.

APPENDIX A
INSTALLATION AND RADIATION SAFETY OPERATING PROCEDURES FOR EDS-3C

THERMAL NEUTRON ANALYSIS (TNA™)

EXPLOSIVE DETECTION SYSTEM

RADIATION SAFETY OPERATING PROCEDURES

Revised

February 20, 1990

SCIENCE APPLICATIONS INTERNATIONAL CORPORATION
2950 Patrick Henry Drive
Santa Clara, CA 95054

CONTENTS

SECTION 1

GENERAL

1.1 STAFFING

All work on and around the system shall be done under the immediate supervision of an authorized system operator who has been trained and qualified in operation, source handling, and emergency procedures. The operator must have received training and demonstrated proficiency in radiation safety and these procedures for the explosive detection system.

1.2 PERSONNEL DOSIMETRY

TNA operators shall wear a neutron/gamma radiation badge dosimeter for all work on and around the system when the source is on site. Other personnel such as baggage handlers whose work on the TNA is limited to loading and/or unloading baggage may also be required to wear dosimeters depending on the particular installation site. Personnel must not enter the baggage passage for any reason with the source in the operating position. Film badges shall be changed on a monthly basis. The contractor for this dosimetric device will be accredited by the National Voluntary Laboratory Accreditation Program (NVLAP).

1.3 EQUIPMENT

The following equipment shall be readily available on site, in operational condition, and calibrated appropriately. Portable survey meters will be calibrated every six months with sources whose calibration is traceable to NIST.

An ion chamber survey meter capable of reading 0.1 mrem/hr.

A neutron survey meter capable of measuring levels as low as 0.1 mrem/hr.

The baggage activation exit monitor system will be mounted so that all baggage leaving the TNA is monitored. Visable and audible devices will be used as required for alarm purpose. A check source shall be available for daily operational checks.

Long-handled tools for emergency source handling and baggage retrieval.

Warning signs, yellow/magenta ropes, etc., for defining a radiation area.

Source transport cask.

Tamper-indicating seals, paper type, with SAIC logo.

1.4 DOCUMENTATION

The following documents will be on site and readily available:

Copy of the Radioactive Materials License and State X-ray machine registration.

Copies of applicable radiation safety regulations (e.g. NRC Regulations and any applicable State Regulations)

SAIC Radiation Safety Guide

Radiation Safety Operating Procedures for the TNA

Notices to employees and the public, as required

Emergency call list with numbers for:

- System Operators
- FAA (local)
- SAIC 24-hour Emergency Contact
- Airport Emergency Contact
- NRC Region Office
- State Radiation Protection Office

Copies of survey instrument calibrations, survey results, leak test results, personal dosimeter results, operator training certificates.

1.5 DAILY CHECKS

The alarm threshold for the bag activation exit monitor shall be tested daily with a check source. (See Section 4.3.) Operation of the shield doors and indicator lights shall be checked daily by observing the lights turn off and on while passing a bag through the system. Operation of the "X-ray-On" indicator lights shall also be checked daily. Completion of the above checks shall be logged daily.

1.6 ACCESS TO INTERIOR OF SHIELDING MODULES

The doors to the areas underneath the outer "skin" shall remain closed and locked; the keys will be kept in the possession of the system operator.

Access to the computer and HV power supply is limited to 1 hour per week (within any seven day period) with the source in the system.

1.7 ACCESS TO BAGGAGE PASSAGEWAY

Access, meaning personnel physically entering into the baggage passage, is prohibited unless the source is in the RETRACTED position. Briefly (on the order of one minute) reaching into the passage with tools from outside is permitted without retraction of the source.

Access is permitted only by the system operator. Gamma and neutron survey meters will be used before any person enters the baggage passage to insure that the radiation dose equivalent level is acceptable, i.e. indicating that the source is properly retracted.

The duration of stay by the operator inside the neutron interrogation region of the TNA, with the source in the retracted position, is limited to a cumulative total of one hour within any seven day period. The source will be removed from the system if the operator must be inside for longer than the one hour limit. The operator shall log his stay time in the interrogation region for dose accumulation.

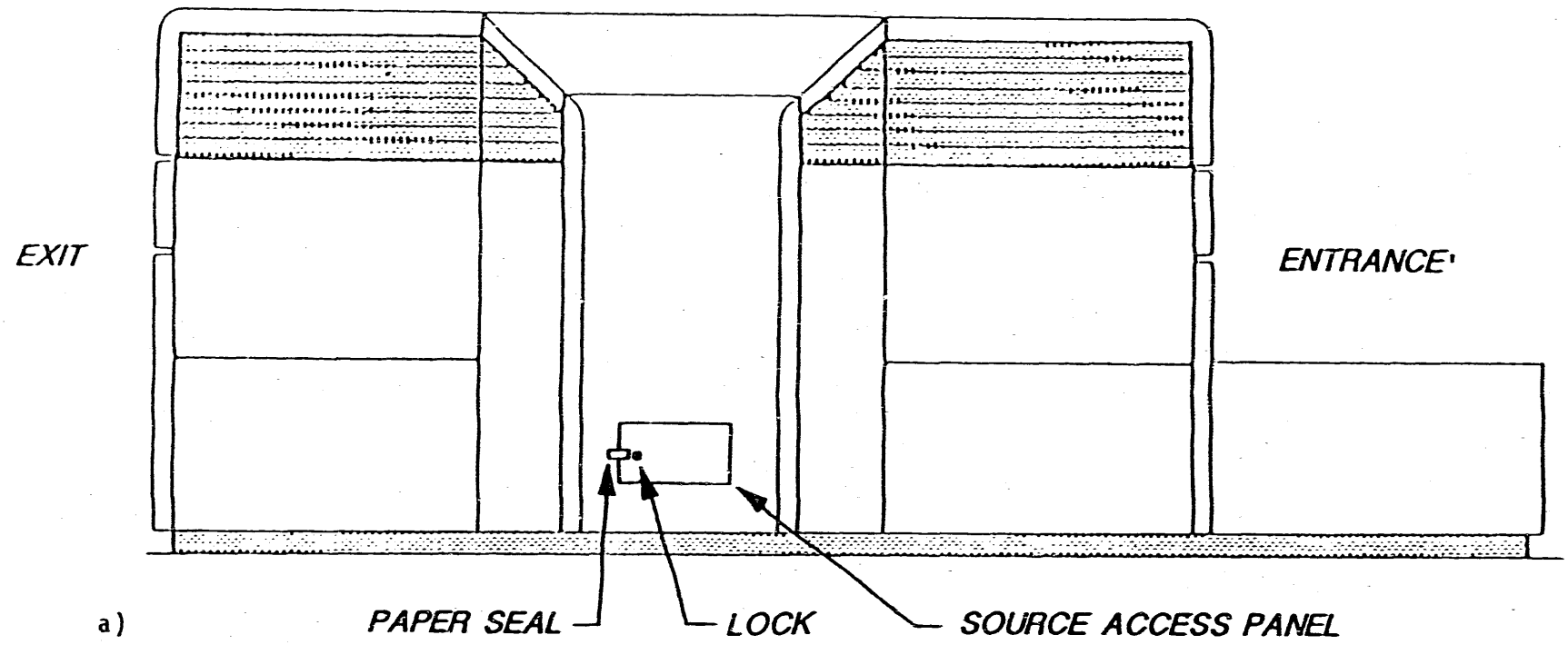
1.8 UNATTENDED SYSTEM

When the system must be left unattended, the entrance and exit doors to the baggage passageway will be closed and locked. The source shall be left in the OPERATING position to maintain the lowest external dose rates. The tamper-indicating seal must be in place. Figure 1 shows where this seal is to be located. The seal is the paper type imprinted with the SAIC logo. The date when seal was put in place shall be recorded on it.

1.9 TNA DAILY LOG

Radiation safety-related incidents shall be noted in the daily log by the system operator. Items to be noted shall include but not be limited to:

- Source transfers
- Source retractions
- Opening of the computer and high voltage supply access doors (include duration)
- Personnel entering the baggage passageway (include duration)
- Baggage jams (include reasons for jams)
- Inspections
- Emergencies
- Tamper-indicating seal breakage, by operator during source handling or by actual attempted tampering.
- Daily exit monitor calibration
- Door position indicator operation
- Proper operation of "X-ray-On" indicator light.



b)

Figure 1. Tamper-indicating Paper Seal.
a) Placement
b) Full-size Example

This log will be kept at the TNA site, available for inspection by the field maintenance staff, the radiation safety officer, and the regulatory agencies. The log shall be properly dated, and signed at completion of the work day.

1.10 SURVEYS

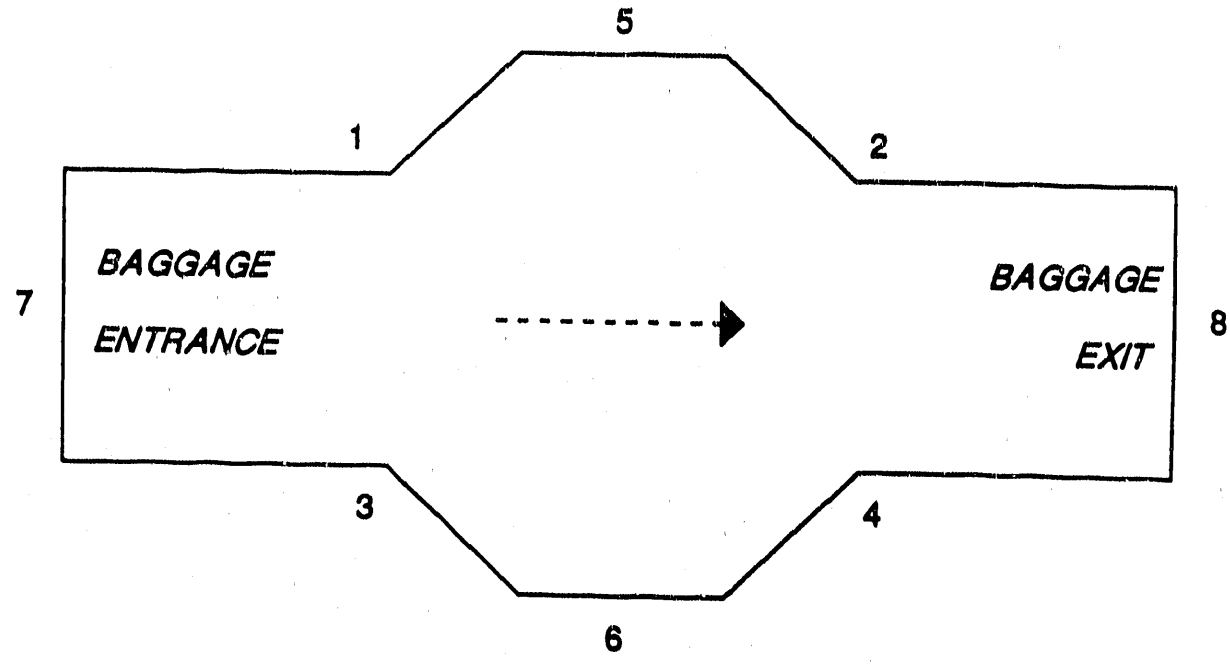
A radiation survey will be taken immediately following the initial source installation into the TNA, using both neutron and gamma ray survey meters capable of reading 0.1 mrem/hr. If a maintenance activity or unusual occurrence might have affected the TNA shielding, a new neutron and gamma ray survey must be performed before proceeding with system operation.

After routine source re-loadings or replacements, a gamma/neutron survey shall be performed; however, if no changes to the system shielding accompanied such actions, only a gamma-ray survey will need to be taken.

Dose rates shall be measured 30 cm from the surface at the locations shown in the Figure 2. The readings shall be compared with the accompanying table of expected values with the source IN or RETRACTED. If readings inconsistent with the expected values are obtained (allowing for source decay), contact SAIC for instructions. Note survey results in the log book.

1.11 TNA ALARMS

If the TNA alarms, the alarm condition must be resolved. All alarms will be treated as due to real explosives and must be resolved before the bag is permitted to be placed on the aircraft. The most direct and sure method is by inspection of the bag's contents by trained security personnel in the presence of the passenger. The suspect bag or certain suspect contents from the bag may be passed through the TNA a second time to resolve the alarm. If suspect contents have been separated out from the bag, the nonsuspect portions must also be run through the TNA to clear that portion as well. In all cases, the bag or selected contents of a bag should not pass through the TNA more than a maximum of three times. The bag should be placed in a different orientation on each successive pass through the system. If the bag fails to clear after 3 times through the TNA, survey the bag for residual activity (see Sec. 4.1) and call security for hand search if required.



DOSE RATE (mrem/hr)		
Positions	Neutron	Gamma Ray
1-4 IN	< 0.1	< 0.2
5,6 IN	< 0.1	< 0.1
7,8 IN	< 0.2	< 0.2
5 RETRACTED	< 0.4	< 0.2

Figure 2. Radiation Survey Locations and Expected Values.

SECTION 2

SOURCE HANDLING

2.1 TRANSPORT CASK

The cask is bolted to the shipping platform for shipment. The platform is also used for source transfers to assure alignment of the cask with the TNA. The cask is in flush contact with the side of the TNA so that the source is never unshielded during transfer. The front of the cask (Figure 3a) has a Source Insertion/Exit Point in the center. The Source Insertion/Exit Point has a polyethylene plug to reduce radiation beam exiting out of the source hole, to acceptable levels for shipment. This plug is covered by a removable metal plate.

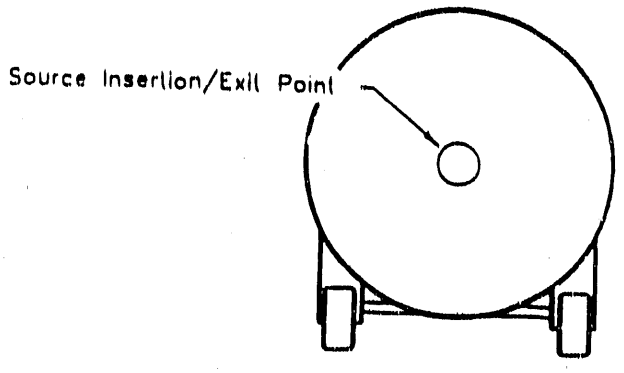
The rear of the cask (Figure 3b) has a compartment for Teleflex cable storage. This is also covered by a removable metal plate. The compartment contains a padlock, a cable lock bracket, and a removable cable pressure bracket (Figure 3c). When the cable lock bracket is fastened in place, it locks the Teleflex cable in position, holding the source in the center of the cask. The cable pressure bracket covers the cable lock bracket. The cable pressure bracket is removed by unlocking the padlock and lifting the bracket out and away from the lip on the bottom edge of the cable lock bracket. The Teleflex cable is released by partially unscrewing the two flathead screws in the cable lock bracket until it is loose enough to raise. Then the bracket is lifted up and off the Teleflex cable and the right-hand screw is tightened to hold it out of the way.

2.2 TRANSFER AND RETRACTION HARDWARE

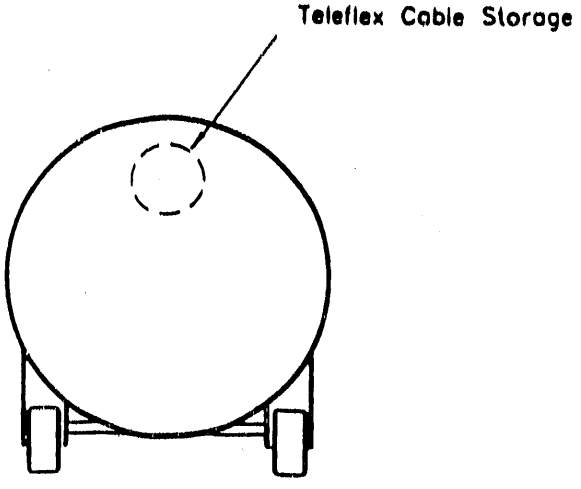
Figure 4 shows the cask in position for source transfer, and a detailed view of the source transfer ring and source transfer adapter. The ring and adapter are only used for source transfer; they are stored inside the recess in the TNA. The loose support of the adapter allows it considerable leeway in adapting to misalignment of the cask and the TNA. Both the ring and the adapter are machined from polyethylene for low friction.

Figure 5 shows the retraction stop assembly in the source cask which prevents the source from being retracted farther than the intended distance. It consists of an aluminum holder to which a polyethylene tube is attached; the inside diameter of the tube (0.25") allows the Teleflex cable to pass easily (0.21") but it is too small to let the source (0.37") go through. The tube is threaded and pinned into the holder. A swiveling bar engages the cable and clamps it in place. The bar is held in position by a padlock. When the bar is raised the cable is free to slide through. The holder is attached to the TNA by two screws which can be accessed only when the bar is raised.

a)



b)



c)

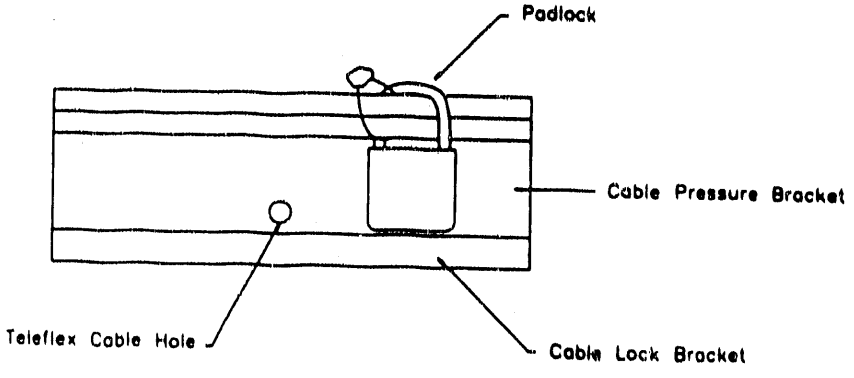
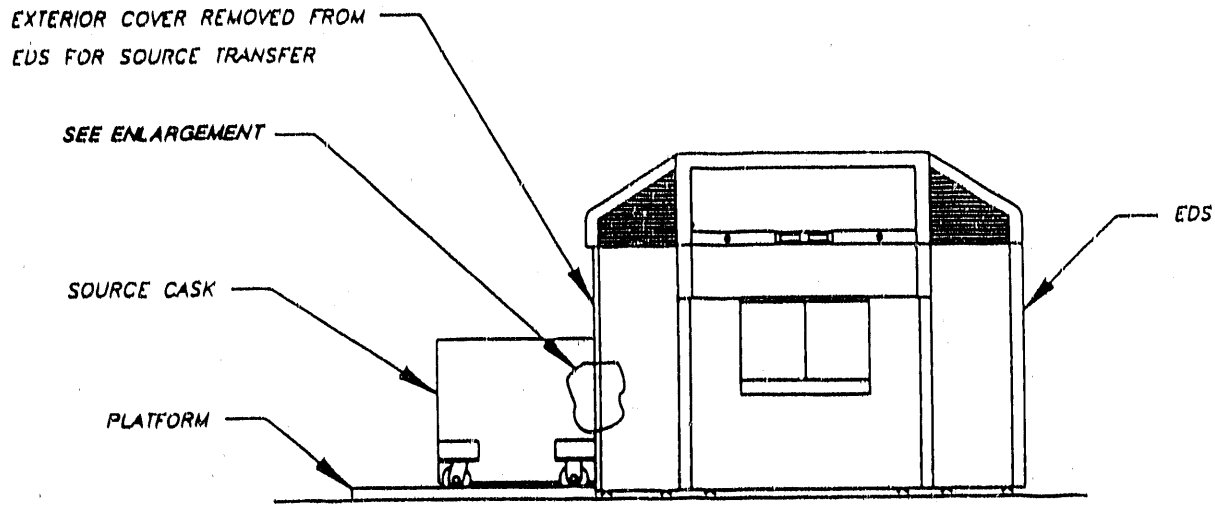
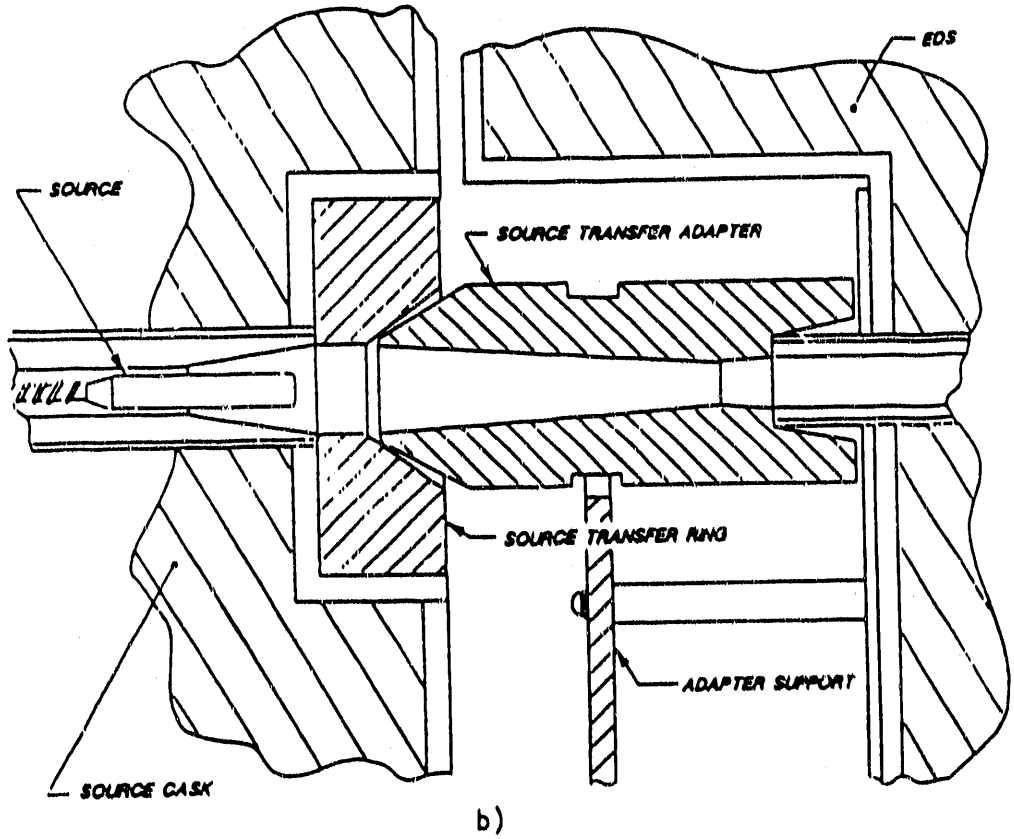


Figure 3. Transport Cask.
a) Front View
b) Rear View
c) Locking Assembly

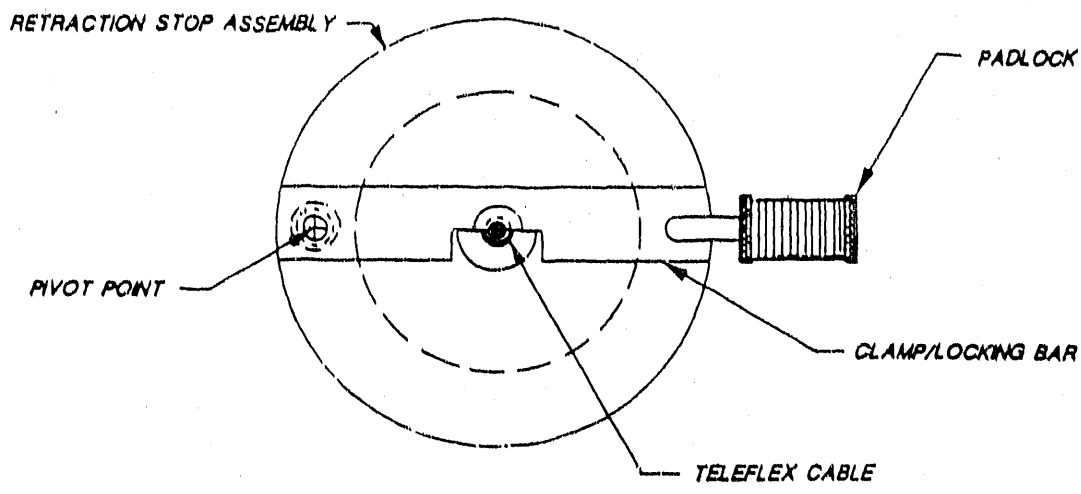


a)



b)

Figure 4. Placement of Cask for Source Transfer.
a) Overall View
b) Detail View of Source Transfer Ring and Source Transfer Adapter



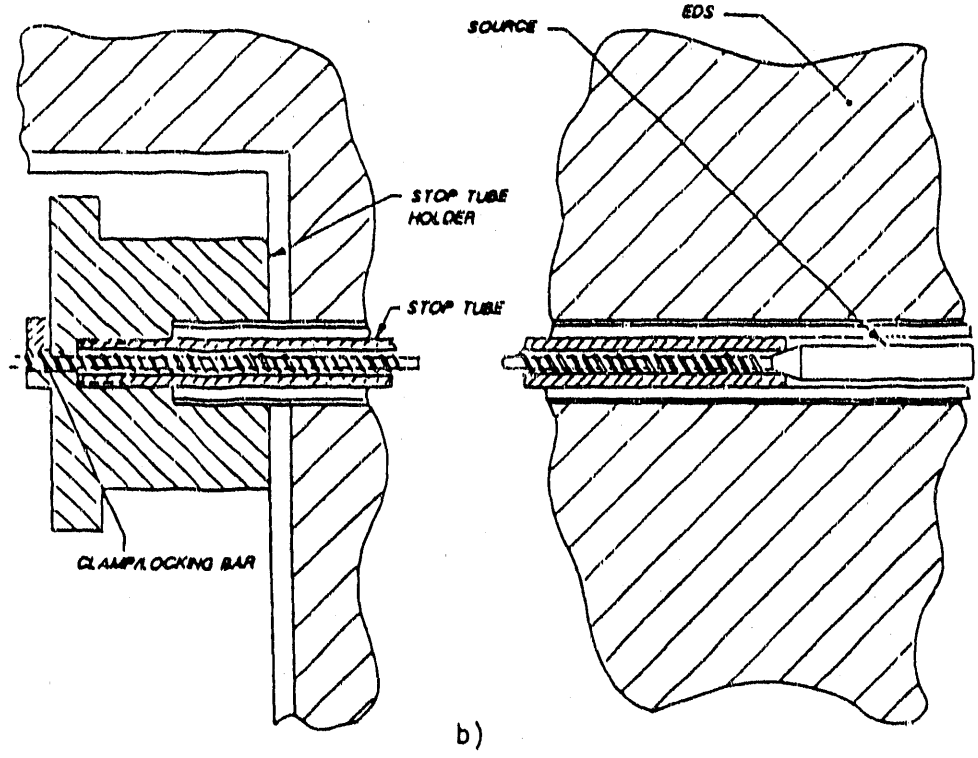


Figure 5. Retraction Stop Assembly.
a) Front View
b) Cross-section View

2.3 SPECIAL CONSIDERATIONS FOR INSTALLATIONS IN PUBLIC AREAS

These safety-critical procedures must be observed to avoid possible radiation exposure to members of the public.

Standard operations such as source installation, source exchange, or source removal for planned system maintenance shall be scheduled at a time of day when few or no nonessential personnel are present, e.g., 12 midnight. Prior to beginning any transfer operation, the "Scheduling Checklist for Source Handling" (Figure 6) shall be completed to ensure coordination of date and time with airport facility management, airport security and airline management.

To avoid possible radiation exposure to the general public or airport personnel, an area out to 45 feet in all directions from the TNA unit shall be cordoned off using yellow/magenta rope and posted with "radiation area" warning signs. At 45 feet the dose rate from a bare 150 microgram Cf-252 source is less than 2 mrem/hr. Also ensure that the airport security has cordoned off the areas above and below the unit. Only the TNA operator and other authorized personnel shall be allowed in the controlled area during source transfer operations.

When moving the source between the EDS unit and the cask, make sure the source is in its proper position by observing the cable markings (Figure 7). Use the gamma survey meter to confirm the source is the correct location.

Move the source quickly so as to minimize the time the source spends between positions, because the source path comes close to the underside of the TNA, resulting in high radiation levels in the downward direction.

It is imperative that the source not be stopped between the IN and RETRACTED positions.

2.4 LOADING

This is a safety-critical procedure which could result in a high radiation area if not carried out properly. It is possible to accidentally remove the bare source from the system, leaving it completely unshielded. The operator must review the procedure carefully before starting to make sure that it is fully understood. Also review applicable emergency procedures.

All source handling operations must be carried out by at least two people, one of whom is a qualified system operator. A survey meter must be used. Review Section 2.3 before starting.

The "Checklist for Source Loading" (Figure 8) is to be completed each time this operation is performed.

SCHEDULING CHECKLIST FOR SOURCE HANDLING

Source handling operations for TNA systems shall be done at a time of day when a minimum number of people are present (e.g. 12 midnight). In all cases, an area to 45 feet from the TNA unit shall be cordoned off to avoid possible radiation exposure to nonessential personnel. Use yellow/magenta rope and post "radiation area" caution signs. Nonessential personnel includes everyone except the TNA operators performing the source handling and other authorized personnel who may be present for maintenance or as observers. Also ensure that the airport security has cordoned off the areas above and below the TNA unit.

The necessity for a scheduled source handling procedure is anticipated for:

DATE _____ TIME _____.

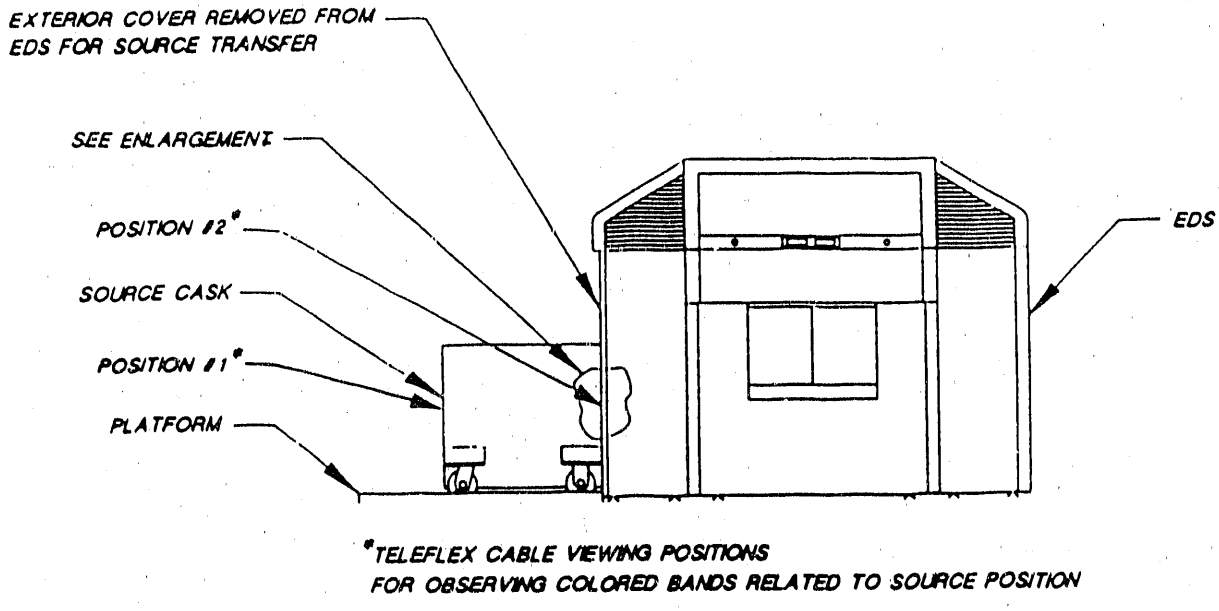
The following must be notified. Indicate the name of the person contacted along with the date and time notified.

	Name	Date	Time
Airport Facility Management	_____	_____	_____
Airport Security	_____	_____	_____
Airline Management	_____	_____	_____

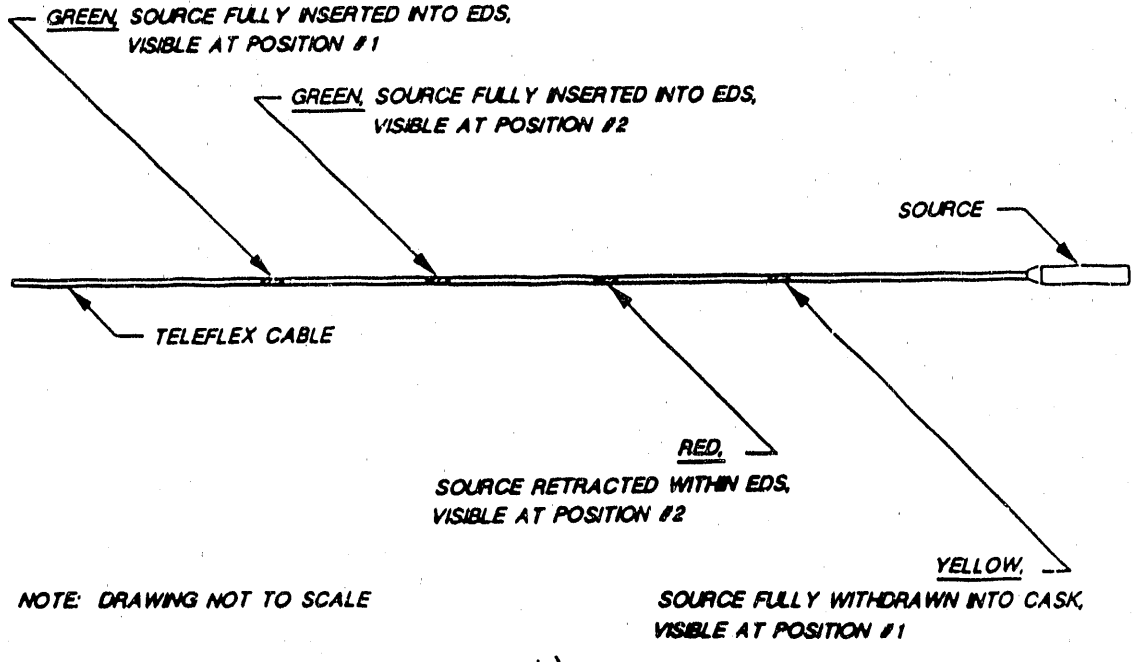
The above personnel have been notified that a source handling procedure has been schedule at the time listed above.

Operator Signatures: _____/_____

Figure 6. Scheduling Checklist for Source Handling.



a)



b)

Figure 7. Cable Markings.
a) Viewing Positions
b) Color Coding

CHECKLIST FOR SOURCE LOADING

This is a safety-critical procedure which could result in a high radiation area if not carried out properly. It is possible to accidentally remove the bare source from the system, leaving it completely unshielded. The operator must review the procedure carefully before starting to make sure that it is fully understood. Also review applicable emergency procedures.

All source handling operations must be carried out by at least two people, one of whom is a qualified system operator. A gamma survey meter must be used. Review Section 2.3 before starting.

A copy of this checklist is to be completed each time the operation is performed.

__ Familiarize yourself with the entire procedure before starting. Check off each step as it is completed on a copy of this procedure.

__ Complete "Scheduling Checklist for Source Handling".

__ Push up the TNA top cover and lift off the side panel.

__ Unfasten the cask from the platform, roll it off onto the floor.

__ Place the platform at the side of the TNA below the source access.

__ Adjust the platform leveling screws to level the platform and line up the platform holes with the tapped holes in the TNA.

__ Fasten the platform to the TNA with bolts.

__ Bolt the eye-hook bar to the system and the winch on to the cask.

__ Roll the cask up to the platform, line up the wheels with the rail.

__ Unlock and open the TNA source access door as wide as possible so it will not interfere with the cask movement.

__ Hook cable to eye-hook and crank up to about two feet from TNA.

__ Remove the cover plates from the cask Source Insertion/Exit Point and the Teleflex cable storage compartment by unscrewing the captive screws in the plate.

__ From the FRONT of the cask, remove the polyethylene plug from the Source Insertion/Exit Point by unscrewing the two screws and pulling out the plug. Avoid the radiation beam coming from the cask source hole.

Figure 8. Checklist for Source Loading

__ Mount the source transfer ring on the front of the cask with its screws, with the conical hole toward the TNA. (See Figure 4).

__ Unscrew the Retraction Stop tube assembly (tube with attached aluminum piece) retaining screws and remove the assembly from the TNA.

__ Place the source transfer adapter on the adapter support loosely held in position for transfer. (See Figure 4).

__ Crank the cask up to the TNA slowly until it is in firm contact, guiding the adapter as necessary to make sure that the adapter engages the ring properly.

__ Unlock and disengage the cable clamp at the back of the cask.

__ Insert the source into the TNA by pushing the cable into the cask until it stops. A green mark on the cable will be at the cask surface. (See Figure 7.)

__ Verify source insertion with the gamma survey meter at the TNA surface above the cask. A reading less than 0.1 mrem/hr should be obtained.

__ Release the ratchet and unwind the winch 15 turns, re-engage ratchet.

__ Slowly roll the cask away to the winch cable limit, about 18" - 2', reaching in after about 6" separation to hold the cable fixed at the TNA wall so that the source is not pulled out of the TNA.

__ Pull the cable through the front of the cask, making sure the source stays fully inserted in the TNA.

__ Remove the source transfer adapter, making sure the source stays fully inserted in the TNA, and lower the adapter support.

__ Place the Retraction Stop tube on the cable, tube first, and slide it toward the TNA, finally inserting it.

__ Screw the Retraction Stop in place.

__ Clamp the source with the clamp/locking bar and lock with padlock.

__ Coil the excess cable up neatly and tuck into the TNA source access recess.

__ Release the winch ratchet and roll the cask off the platform, detach the platform.

__ Close and lock door, replace outer panel and lower the top panel. Store the cask on its platform. Store keys securely.

__ Replace tamper-indicating paper seal.

Figure 8 (con't). Checklist for Source Loading

2.5 REMOVAL

This is a safety-critical procedure which could result in a high radiation area if not carried out properly. It is possible to accidentally remove the bare source from the system, leaving it completely unshielded. The operator must review the procedure carefully before starting to make sure that it is fully understood. Also review applicable emergency procedures.

All source handling operations must be carried out by at least two people, one of whom is a qualified system operator. A gamma survey meter must be used. Review Section 2.3 before starting.

The "Checklist for Source Removal" (Figure 9) should be completed each time this operation is performed.

2.6 STORAGE OR TRANSPORT

The following procedures shall be followed to prepare a source for storage or transport.

After placing the source in the cask, thread a tamper-indicating wire seal with the padlock through the locking holes. Close the padlock and affix a lead seal over the ends of the wire. (See Figure 3c.)

Coil up the remainder of the Teleflex cable and place it in the storage compartment. Replace the cover plate on the rear of the cask.

Unbolt the cask from the platform and roll the cask away from the TNA. Unbolt the platform from the TNA.

Insert the polyethylene plug into the front of the cask and replace the cover plate on the front of the cask. Avoid radiation beam coming from cask source hole. Thread one tamper-indicating wire seal through the holes in the two bolts on the cover plates on the front and rear of the cask.

Replace and lock the cover panel on the TNA.

For shipment, roll the cask onto the platform and bolt them together. The platform serves as a shipping pallet. Follow DOT shipping procedures for labeling and completing the forms.

If the cask will remain in a public area with the source inside for longer than 1 hour, rope off area the within 3 feet of the cask and post radiation area signs.

Place tamper-indicating paper seals on cover plates on the front and rear of the cask.

CHECKLIST FOR SOURCE REMOVAL

This is a safety-critical procedure which could result in a high radiation area if not carried out properly. It is possible to accidentally remove the bare source from the system, leaving it completely unshielded. The operator must review the procedure carefully before starting to make sure that it is fully understood. Also review applicable emergency procedures.

All source handling operations must be carried out by at least two people, one of whom is a qualified system operator. A survey meter must be used. Review Section 2.3 before starting.

A copy of this checklist is to be completed each time the operation is performed.

__ Familiarize yourself with the entire procedure before starting. Check off each step as it is completed on a copy of this procedure.

__ Complete the "Scheduling Checklist for Source Handling".

__ Push up the TNA top cover and lift off the side panel.

__ Unfasten the cask from the platform, roll it off onto the floor.

__ Place the platform at the side of the TNA below the source access.

__ Adjust the platform leveling screws to level the platform and line up the platform holes with the tapped holes in the TNA.

__ Fasten the platform to the TNA with bolts.

__ Bolt the eye-hook bar to the system and the winch on to the cask.

__ Roll the cask up to the platform, line up the wheels with the rail.

__ Unlock and open the TNA source access door as wide as possible so it will not interfere with the cask movement.

__ Hook cable to eye-hook and crank up to about two feet from TNA.

__ Remove the cover plates from the cask Source Insertion/Exit Point and the Teleflex cable storage compartment by unscrewing the captive screws in the plate.

__ From the FRONT of the cask, remove the polyethylene plug from the Source Insertion/Exit Point by unscrewing the two screws and pulling out the plug.

Figure 9. Checklist for Source Removal.

__ Mount the source transfer ring on the front of the cask with its screws, with the conical hole toward the TNA.

__ Unlock and lift the clamp/locking bar, releasing the cable.

__ Unscrew the Retraction Stop tube assembly retaining screws and remove the assembly from the TNA, being careful to leave the source fully inserted in the TNA.

__ Place the source transfer adapter over the cable, with the tapered end away from the TNA, slide it up to the TNA and position it on the adapter support loosely held in position for transfer, being careful to leave the source fully inserted in the TNA.

__ Unlock and disengage the cable clamp at the back of the cask.

__ Insert the free end of the cable into and through the cask.

__ Crank the cask up to the TNA slowly until it is in firm contact, guiding the adapter and cable as necessary to make sure that the adapter engages the ring properly and the cable does not kink.

__ Draw the source into the cask by pulling the cable from the back of the cask until it stops. A yellow mark on the cable will be at the cask back surface indicating the source is in the cask. (See Figure 7.)

__ Verify that the source is in the cask with the gamma survey meter by moving it along the surface of the cask. A maximum reading will be obtained at the middle of the cask with lower, approximately equal readings at the ends of the cask.

__ Clamp and lock the source cable at the back of the cask.

__ Coil up the excess cable and place it in the cask recess.

__ Replace the cask plug and cask covers. Avoid radiation beam coming from the cask source hole.

__ Release the ratchet and unwind the winch 15 turns, re-engage ratchet, and roll the cask away to the winch cable limit.

__ Remove the source transfer adapter, and lower the adapter support.

__ Replace the Retraction Stop tube in the TNA and fasten.

__ Release the winch ratchet and roll the cask off the platform, detach the platform.

__ Close and lock door, replace outer panel and lower the top panel. Follow procedures for storage or transport as appropriate. Store keys securely.

Figure 9 (con't). Checklist for Source Removal.

2.7 RETRACTION

Do not retract source during emergencies, except when the passageway must be entered by operator. Maximum shielding exists only when source is in the normal operating position.

The source shall be moved to the RETRACTED position if it is necessary for the operator to enter the baggage passageway for any reason. The operator must not remain in the baggage passageway for longer than 1 hour per week (total within any seven day period) even with the source retracted; note passage activities in the log with times to keep track of the time.

If the source must be retracted, keep nonessential personnel out of the work area by roping off the area to 6 feet from the side of the TNA with the source access panel. Use magenta and yellow rope and post "radiation area" caution signs. To retract the source, follow these procedures:

Unlock and remove the source cover panel from the TNA.

Pull the Teleflex cable until it is stopped by the source retraction plug. Do not remove the retraction plug.

Lock the Teleflex cable in the RETRACTED position so that it does not move back into the system.

SECTION 3

EMERGENCY PROCEDURES

These procedures shall be posted in a prominent position near the TNA for immediate reference in the event of an emergency. Figure 10 should be posted separately or as the first page.

3.1 BAGGAGE JAMS

Baggage may be stopped in the TNA due to a baggage jam; such occurrences pose no imminent danger of radiation exposure to personnel. If a jam occurs, the baggage in the TNA should be removed as soon as possible to minimize bag activation.

First, determine the cause of the stoppage. This is accomplished by opening the exit and entrance shielding doors to visually inspect the baggage passageway while remaining outside the TNA. Latch the doors in the open position. Caution: The doors must be closed again as soon as possible to minimize exposure from the passage opening. Under no circumstances should the doors be left open longer than 10 minutes, as the dose rate outside the TNA with all three doors open is approximately 20 mrem/hr.

First, use long-handled tools to clear the baggage without entering the passageway.

If it is necessary to enter the baggage passageway to unjam the system, the source must first be retracted. (See Section 2.7). Access is permitted only by the system operator. Remember to use the gamma survey meter to ensure that the source is retracted before entering passageway. If the operator's cumulative duration of stay inside the neutron interrogation region is greater than 1 hour per week (during and 7 day period) the source must first be removed from the system prior to entry by the operator.

After removing any bags that have remained in the system, use the gamma meter to survey them on the surface to ensure that the radiation level is less than 0.5 mrem/hr. If the level is higher than 0.5 mrem/hr, the bag must be put aside for at least 5 minutes until the level decays to less than 0.5 mrem/hr. See Section 4.1 for bag activation procedures.

Once the stoppage is cleared, note the time and the reason for the stoppage in the TNA Daily Log. Also note if any of the stopped baggage surveyed above the 0.5 mrem/hr level.

EMERGENCY CONTACT GUIDE

Emergency Type	Persons to be Contacted
Fire/Explosion/Disaster	1. Airport Fire Department - Immediate Emergency Assistance 2. Airport Security - Cordon off Area 3. City/State Radiation Control - Immediate Radiological Assistance 4. City/State Emergency Management 5. N.R.C. Region Office 6. SAIC/Santa Clara - Radiation Safety Officer 7. SAIC/Santa Clara - Manager of Field Operations 8. License Holder (FAA)
Radiation Safety Incidents (where there has been exposure or there is imminent danger of exposure)	1. Airport Security - Cordon off Area 2. City/State Radiation Control 3. City/State Emergency Management 4. NRC Radiation Office 5. SAIC/Santa Clara - Radiation Safety Officer 6. SAIC/Santa Clara - Manager of Field Operations 7. License Holder (FAA)
Radiation Safety Incidents (stuck source, transfer problems, etc. where there is no imminent danger of exposure)	1. Airport Security - Cordon off Area 2. SAIC/Santa Clara - Radiation Safety Officer 3. SAIC/Santa Clara - Manager of Field Operations if problem cannot be resolved 4. City/State Radiation Control 5. NRC Region Office 6. License Holder (FAA)
Operator Illness or Accident (which prevents an operator from reporting to work)	1. SAIC/Santa Clara - Manager of Field Operations 2. Operator to serve as replacement
System Failure, Imminent or Actual (due to hardware or software problems)	1. SAIC/Santa Clara - Engineer (Contact either engineer. He will contact the necessary personnel, by pager if necessary, for repair and/or shipment of parts.) 2. SAIC Radiation Safety Officer
Power Loss, Large-scale	1. Airport Facility Management 2. SAIC/Santa Clara - Manager of Field Operations 3. SAIC Radiation Safety Officer
Power Loss, to Building	1. Airport Facility Management 2. SAIC/Santa Clara - Manager of Field Operations 3. SAIC Radiation Safety Officer

Figure 10. Emergency Contact Guide

3.2 FIRE, EXPLOSION, DISASTER

Fires, explosions, or other disasters give rise to concerns for imminent danger of radiation exposure. The following procedure is supplied in checklist form for rapid and accurate handling of such emergencies.

__ Call the airport fire department.

__ Remove any injured personnel to a safe distance.

__ Give emergency first aid if necessary.

__ Call airport security.

__ Conduct area survey to determine level/extent of exposure or radioactive material release.

__ Cordon off area to a safe distance, where exposure level is less than 2 mrem/hr.

__ Call state/local radiation control for immediate radiological assistance.

__ Maintain security until assistance arrives.

__ Call NRC regional office.

__ Call SAIC radiation safety officer.

__ Call license holder.

__ Render emergency assistance as needed.

3.3 EARTHQUAKE

Earthquakes give rise to concerns for imminent danger of radiation exposure. The following procedure is supplied in checklist form for rapid and accurate handling of such emergencies.

__ Remove any injured personnel to a safe distance.

__ Give emergency first aid if necessary.

__ Visually inspect TNA for damage and areas where radiation may be released.

__ Survey area surrounding machine. If high radiation levels exist:

__ Call airport security.

__ Cordon off area to a safe distance, where exposure level is less than 2 mrem/hr.

__ Call state/local radiation control for immediate radiological assistance.

__ Maintain security until assistance arrives.

__ Call NRC regional office.

__ Call SAIC radiation safety officer.

__ Call license holder.

If no significant radiation exposure exists, clear the baggage from the system. If the power is off, follow the procedures in Section 3.6. When power is restored, or if power remained on after the earthquake, initiate system power up sequence.

3.4 SOURCE STUCK AT INTERFACE

A source stuck at the interface is a situation where there is imminent danger of radiation exposure. The following procedure for handling such a situation is given in checklist form for rapid and accurate handling of such an emergency.

__ Alert airport security personnel present. Area should already be clear.

__ Ensure area within 45 feet of TNA has been cordoned off, and that the areas above and below the system are clear.

__ Conduct a gamma survey to verify stuck source and determine extent of dose rate.

__ Attempt to dislodge source. Attempt to realign machine/cask mating by wiggling the cask from side to side, without moving the cask backwards. WARNING: Do not attempt to back out the cask. This could result in a totally unshielded source.

__ If source does not dislodge:

  __ Call state/local radiation control for immediate radiological assistance.

  __ Call NRC regional office.

  __ Call SAIC radiation safety officer.

  __ Call license holder.

  __ Maintain security until assistance arrives.

3.5 SOURCE TRANSFER INCIDENTS

Source transfer incidents include a source stuck in a cask or the TNA, a broken Teleflex cable, or a source coming off the end of the cable. These incidents pose no imminent danger of radiation exposure to personnel.

As source handling already requires airport security personnel to be present (see Section 2.3), inform them of the situation. Ensure that the area within 45 feet of the TNA has been cordoned off, and that areas above and below the TNA are clear. Attempt in all cases to push the source into a normal operating position, but do not attempt repair. Call the SAIC radiation safety officer for further instructions. Also call: 1) state/local radiation control, 2) NRC regional office, and 3) license holder.

3.6 POWER LOSS OR SYSTEM FAILURE

Power loss or system failure (e.g. conveyer belt failure) poses no imminent danger of radiation exposure. In such incidents, clear baggage from the system with long-handled tools without entering the passageway. If it is necessary to enter the passageway, retract the source first. (See Section 2.7.) Use a gamma survey meter to ensure source has been retracted before entering passageway. After removing the baggage, ensure that the shielding doors are closed and place source back into normal operating position for maximum shielding. Survey each bag to ensure residual activation is less than 0.5 mrem/hr. If the level is higher than 0.5 mrem/hr, the bag must be put aside for at least 5 minutes until the level decays to less than 0.5 mrem/hr. Call airport facility management to determine extent of power loss or call SAIC for assistance in system failures. See Section 4.1 for bag activation procedures.

3.7 DETECTION OF SOURCE LEAK

In the unlikely event that a source leak test or conveyor belt wipe test reveals a leak, it is imperative to perform the following procedures to prevent the spread of contamination and release of airborne activity.

__ Stop operation of the TNA system. Leave cask in place flush with the TNA system.

__ Ensure area within 45 feet of TNA has been cordoned off, and that the areas above and below the system are clear.

__ Conduct a gamma survey to determine extent of dose rate.

- __ Call state/local radiation control for immediate radiological assistance.
- __ Call NRC regional office.
- __ Call SAIC radiation safety officer.

__ Call license holder.

__ Maintain security until assistance arrives.

SECTION 4

BAG ACTIVATION

4.1 MONITORING

All baggage leaving the system passes the exit monitor detector. Baggage which does not trigger the alarm may be handed over to be loaded on aircraft.

Baggage which exceeds the activation threshold triggers the indicator light and audible alarms. Such bags must be checked with an ion chamber survey meter (Bicron RSO-5 or equivalent) on the surface of the bag to assure that the activity level is acceptable for loading on the aircraft. The dose rate must be less than 0.5 mrem/hr everywhere; if the bag exceeds this dose rate it must be put aside for at least 5 minutes and rechecked until the 0.5 mrem/hr level criterion is met. Five minutes is generally sufficient to ensure all residual activity of the bag and contents has decayed. Bags which continue to fail to meet the 0.5 mrem/hr criterion must remain aside since the bag itself may contain radioactive material. Notify local airport security personnel and the SAIC radiation safety officer for further instructions.

4.2 EXIT MONITOR SYSTEM

The baggage activation exit monitoring system consists of a detector assembly with lead collimator to view the baggage and an dose rate monitor type electronics package containing high voltage supply, amplification, count rate meter circuitry with adjustable threshold which triggers audible/visible alarm indicators and a signal to the TNA computer.

When a bag passes the detector, some of the activation gamma rays from the bag are detected. If the count rate exceeds the set threshold, the indicator light goes on, the audible alarm sounds and the circuit communicates the event to the TNA computer.

Bags which trigger the alarm are to be set aside to be checked using the survey meter. (See Section 4.1 above). The TNA identifies the activation alarm bags as well as explosive suspect bags. This typically operates with a mechanical diverter which physically separates these suspect bags from the baggage flow where they can be cleared individually.

4.3 CALIBRATION/CHECK PROCEDURE

This calibration procedure is used to set the exit monitor threshold where it will trigger on any bag which might have a surface dose rate above 0.5 mrem/hr.

Set threshold using a Cs-137 check source of 5 microcuries strength placed in the middle of a bag with light weight contents so that the threshold triggers when the bag passes. This bag will be one of the bags used for daily TNA operational checks. Exit monitor operation is to be verified daily as one of the regular daily system tests.

SECTION 5

Cf-252 SOURCE LEAK TEST PROCEDURE

The californium-252 sealed source must be tested for leakage of radioactive material every six months. This involves using a cotton swab to wipe the surfaces as close to the source as possible. (Wiping the source itself would result in an unacceptable exposure). Similarly, the conveyor belt is wiped as a check on accumulated activation contamination, also at six month intervals. The leak test samples are then sent to a specifically authorized agency for analysis. The address of the agency utilized in this case is:

Radiation Detection Company
ATTN: Chemistry Department
162 Wolfe Road
Sunnyvale, California 94086

The following materials are needed for the wipe tests:

- a wipe test cotton swab with plastic cover
- a wipe test filter paper with plastic bag
- an ion chamber gamma survey meter

5.1 SOURCE LEAK TEST

The source transport cask is placed in position for unloading the source. The procedures for these tasks are given in Sections 2.1, 2.5, and 2.6. The source is withdrawn into the cask, then reinserted back into the system.

The cotton swab cover is labelled with the source serial number and the current source strength is noted. The aperture of the source transport cask is wiped thoroughly with the swab, wiping as much area inside the aperture as can be reached. The cotton swab is then removed and inserted into its labelled cover.

5.2 CONVEYOR BELT WIPE TEST

The filter paper is used to wipe the surface of the TNA conveyor belt, wiping across the belt surface in at least four places.

The plastic bag is labelled, identifying the place and date, and the filter paper placed in it.

5.3 SAMPLE ANALYSIS

The cotton swab and filter paper are then held close to the survey meter to make a preliminary measurement. If the meter registers any radiation level above normal background, follow the emergency procedures in Sec. 3.7. If the radiation level of the test wipe is simply equal to the background levels, the test wipe is placed in an envelope and mailed to Radiation Detection Company.

The results of the wipe test analysis will be provided within two weeks. A record of these wipe tests and the analysis results must be maintained on file for three years following each test.

APPENDIX B
TABLES IN ENGLISH SYSTEM OF UNITS CORRESPONDING TO TABLES IN SECTIONS 5 AND 6

Table 5.1(a) Potential activation products (for slow neutrons*) of baggage contents containing 1-kg (2.2-lb) masses of various elements

Product	dps/μg**	Half-life (min)	Gamma (Mev/dis†)	0.5-min delay		10-min delay		60-min delay	
				Activity (μCi/g)	Dose rate (mrem/hr/2.2 lb @ 1 ft)	Activity (μCi/g)	Dose rate (mrem/hr/2.2 lb @ 1 ft)	Activity (μCi/g)	Dose rate (mrem/hr/2.2 lb @ 1 ft)
H-3	8.42E-10	6.49E+06	-	1.02E-15	0.00E+00	1.02E-15	0.00E+00	1.02E-15	0.00E+00
N-16	3.50E-03	1.19E-01	4.60E+00	2.31E-10	6.39E-09	2.18E-34	6.01E-33	0.00E+00	0.00E+00
O-19	3.51E-03	4.48E-01	1.04E+00	1.97E-09	1.23E-08	8.17E-16	5.10E-15	2.10E-49	1.31E-48
F-20	1.97E+02	1.83E-01	1.64E+00	3.61E-05	3.55E-04	8.58E-21	8.44E-20	0.00E+00	0.00E+00
Ne-23	2.43E+01	6.20E-01	1.45E-01	1.69E-05	1.47E-05	4.13E-10	3.60E-10	2.21E-34	1.92E-34
Na-24	1.80E+00	8.80E+02	4.12E+00	2.19E-06	5.41E-05	2.17E-06	5.37E-05	2.09E-06	5.16E-05
Mg-27	1.29E+00	9.46E+00	9.14E-01	1.51E-06	8.29E-06	7.54E-07	4.14E-06	1.94E-08	1.06E-07
Al-28	2.72E+02	2.24E+00	1.78E+00	2.83E-04	3.03E-03	1.50E-05	1.60E-04	2.87E-12	3.07E-11
Cl-38	5.55E+00	3.72E+01	1.49E+00	6.69E-06	5.98E-05	5.60E-06	5.01E-05	2.21E-06	1.97E-05
Ar-41	1.06E+01	1.10E+02	1.28E+00	1.29E-05	9.87E-05	1.21E-05	9.30E-05	8.83E-06	6.78E-05
K-42	2.39E-01	7.42E+02	2.73E+02	2.91E-07	4.76E-04	2.88E-07	4.72E-04	2.75E-07	4.50E-04
Sc-46m	4.73E+04	3.12E-01	1.42E-01	1.89E-02	1.61E-02	1.30E-11	1.11E-11	7.62E-60	6.49E-60
Ti-51	3.57E+00	5.76E+00	3.50E-01	4.09E-06	8.59E-06	1.30E-06	2.74E-06	3.18E-09	6.68E-09
V-52	1.79E+03	3.75E+00	1.43E+00	1.98E-03	1.70E-02	3.43E-04	2.94E-03	3.33E-08	2.86E-07
Cr-55	3.22E+00	3.56E+00	6.57E-04	3.55E-06	1.40E-08	5.59E-07	2.20E-09	3.31E-11	1.31E-13
Mn-56	1.11E+02	1.55E+02	1.70E+00	1.35E-04	1.37E-03	1.29E-04	1.32E-03	1.03E-04	1.05E-03
Co-60m	2.33E+03	1.05E+00	1.23E-03	2.04E-03	1.50E-05	3.85E-06	2.84E-08	1.80E-20	1.33E-22
Ni-65	7.64E+00	1.51E+02	5.63E-01	9.27E-06	3.13E-05	8.88E-06	3.00E-05	7.06E-06	2.38E-05
Cu-64	4.58E+00	7.64E+02	1.95E-01	5.57E-06	6.51E-06	5.52E-06	6.46E-06	5.28E-06	6.17E-06
Cu-66	1.47E+02	5.10E+00	9.56E-02	1.67E-04	9.58E-05	4.59E-05	2.64E-05	5.15E-08	2.95E-08
Zn-69	3.69E+00	5.70E+01	4.78E-06	4.46E-06	1.28E-10	3.97E-06	1.14E-10	2.16E-06	6.21E-11
Ga-70	5.43E+01	2.11E+01	5.55E-03	6.50E-05	2.16E-06	4.76E-05	1.58E-06	9.20E-06	3.06E-07
Ga-72	2.59E+00	8.46E+02	2.03E+00	3.15E-06	3.84E-05	3.12E-06	3.81E-05	3.00E-06	3.65E-05
Ge-75m	6.38E+01	8.15E-01	5.59E-02	5.07E-05	1.70E-05	1.57E-08	5.28E-09	5.41E-27	1.81E-27
Ge-75	1.05E+00	8.28E+01	3.18E-02	1.27E-06	2.43E-07	1.17E-06	2.24E-07	7.73E-07	1.47E-07
Ge-77m	9.05E-01	8.84E-01	6.31E-02	7.44E-07	2.82E-07	4.34E-10	1.64E-10	4.11E-27	1.56E-27
As-76	3.26E+00	1.58E+03	3.37E-01	3.96E-06	8.02E-06	3.95E-06	7.98E-06	3.86E-06	7.81E-06
Se-77m	5.69E+03	2.90E-01	9.63E-02	2.10E-03	1.21E-03	2.90E-13	1.67E-13	3.73E-65	2.15E-65
Se-79m	2.15E+01	3.91E+00	9.57E-03	2.39E-05	1.37E-06	4.44E-06	2.55E-07	6.30E-10	3.61E-11
Se-81	1.33E+01	1.85E+01	1.44E-02	1.59E-05	1.37E-06	1.11E-05	9.61E-07	1.71E-06	1.48E-07
Se-83	3.45E+00	2.25E+01	1.27E+00	4.13E-06	3.15E-05	3.08E-06	2.35E-05	6.61E-07	5.04E-06
Br-80m	5.48E+00	2.65E+02	2.41E-02	6.66E-06	9.62E-07	6.49E-06	9.39E-07	5.70E-06	8.24E-07
Br-80	2.91E+02	1.77E+01	7.00E-02	3.47E-04	1.46E-04	2.39E-04	1.00E-04	3.38E-05	1.42E-05
Br-82m	2.31E+02	6.10E+00	4.22E-04	2.65E-04	6.72E-07	9.02E-05	2.28E-07	3.08E-07	7.79E-10
Kr-81m	3.77E+02	2.22E-01	1.27E-01	9.63E-05	7.34E-05	1.27E-17	9.69E-18	2.09E-85	1.59E-85
Kr-83m	1.74E+01	1.12E+02	2.26E-03	2.11E-05	2.86E-07	1.99E-05	2.70E-07	1.46E-05	1.98E-07
Rb-86m	4.20E+01	1.02E+00	5.46E-01	3.64E-05	1.19E-04	5.72E-08	1.87E-07	1.01E-22	3.31E-22
Rb-88	2.05E+00	1.78E+01	6.37E-01	2.45E-06	9.35E-06	1.69E-06	6.46E-06	2.41E-07	9.22E-07
Y-90m	4.16E+00	1.91E+02	6.30E-01	5.05E-06	1.91E-05	4.88E-06	1.84E-05	4.07E-06	1.54E-05
Nb-94m	3.80E+01	6.26E+00	1.17E-02	4.37E-05	3.07E-06	1.53E-05	1.07E-06	6.03E-08	4.23E-09
Mo-101	1.35E+00	1.46E+01	1.51E+00	1.60E-06	1.45E-05	1.02E-06	9.25E-06	9.52E-08	8.62E-07
Rh-104m	3.60E+03	4.35E+00	3.48E-02	4.04E-03	8.44E-04	8.90E-04	1.86E-04	3.09E-07	6.45E-08
Rh-104	1.54E+04	7.05E-01	1.11E-02	1.15E-02	7.63E-04	1.01E-06	6.71E-08	4.55E-28	3.03E-29
Pd-107m	8.42E+00	3.55E-01	1.52E-01	3.86E-06	3.52E-06	3.41E-14	3.11E-14	1.39E-56	1.27E-56
Pd-109m	9.12E+00	4.69E+00	1.14E-01	1.03E-05	7.05E-06	2.53E-06	1.73E-06	1.57E-09	1.07E-09
Pd-109	3.37E+00	8.08E+02	1.24E-02	4.10E-06	3.05E-07	4.06E-06	3.02E-07	3.89E-06	2.90E-07
Ag-108	5.09E+03	2.41E+00	2.94E-02	5.36E-03	9.46E-04	3.49E-04	6.16E-05	1.99E-10	3.51E-11
Ag-110	8.31E+04	4.10E-01	2.96E-02	4.34E-02	7.71E-03	4.61E-09	8.19E-10	9.14E-46	1.62E-46
In-114	9.43E+01	1.20E+00	2.21E-03	8.59E-05	1.14E-06	3.56E-07	4.72E-09	1.03E-19	1.36E-21
In-116m(2)	1.26E+06	3.63E-02	8.20E-02	1.10E-04	5.39E-05	1.88E-83	9.26E-84	0.00E+00	0.00E+00
In-116m(1)	1.29E+03	5.42E+01	2.47E+00	1.56E-03	2.31E-02	1.38E-03	2.05E-02	7.28E-04	1.08E-02

See footnotes at end of table.

Table 5.1(a) (continued)

Product	dps/μg**	Half-life (min)	Gamma (Mev/dis†)	0.5-min delay		10-min delay		60-min delay	
				Activity (μCi/g)	Dose rate (mrem/hr/2.2 lb @ 1 ft)	Activity (μCi/g)	Dose rate (mrem/hr/2.2 lb @ 1 ft)	Activity (μCi/g)	Dose rate (mrem/hr/2.2 lb @ 1 ft)
In-116	1.36E+04	2.37E-01	1.55E-02	3.83E-03	3.57E-04	3.31E-15	3.08E-16	1.06E-78	9.84E-80
Sn-125m	1.09E+00	9.52E+00	3.29E-01	1.28E-06	2.52E-06	6.40E-07	1.26E-06	1.68E-08	3.32E-08
Sb-122m	7.08E+00	4.21E+00	5.96E-02	7.93E-06	2.84E-06	1.66E-06	5.94E-07	4.42E-10	1.58E-10
Sb-124m	8.42E+00	1.55E+00	3.48E-01	8.19E-06	1.71E-05	1.17E-07	2.45E-07	2.29E-17	4.78E-17
Te-131	2.08E+00	2.50E+01	3.54E-01	2.49E-06	5.30E-06	1.92E-06	4.07E-06	4.79E-07	1.02E-06
I-128	2.00E+02	2.50E+01	8.75E-02	2.40E-04	1.26E-04	1.84E-04	9.68E-05	4.61E-05	2.42E-05
Xe-125m	1.70E+01	9.50E-01	1.11E-01	1.44E-05	9.56E-06	1.40E-08	9.35E-09	2.03E-24	1.35E-24
Xe-137	1.99E+00	3.84E+00	1.50E-01	2.21E-06	1.99E-06	3.98E-07	3.58E-07	4.80E-11	4.32E-11
Cs-134m	9.28E+00	1.74E-02	2.34E-02	2.54E-14	3.56E-15	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ba-136m	1.31E+03	5.13E-03	1.92E+00	7.39E-33	8.51E-32	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ba-139	1.55E+00	8.33E+01	4.18E-02	1.88E-06	4.71E-07	1.73E-06	4.35E-07	1.14E-06	2.87E-07
La-140	1.92E+00	2.41E+03	2.32E+00	2.33E-06	3.25E-05	2.33E-06	3.24E-05	2.30E-06	3.19E-05
Pr-142	3.43E+00	1.15E+03	5.83E-02	4.17E-06	1.46E-06	4.15E-06	1.45E-06	4.02E-06	1.41E-06
Nd-151	3.52E+00	1.24E+01	1.69E-01	4.16E-06	4.22E-06	2.45E-06	2.48E-06	1.50E-07	1.52E-07
Sm-153	1.19E+01	2.79E+03	5.35E-02	1.45E-05	4.65E-06	1.44E-05	4.63E-06	1.43E-05	4.58E-06
Sm-155	2.81E+01	2.22E+01	8.24E-02	3.36E-05	1.66E-05	2.50E-05	1.24E-05	5.25E-06	2.60E-06
Eu-152m(2)	9.21E+00	9.60E+01	7.38E-02	1.12E-05	4.94E-06	1.04E-05	4.61E-06	7.26E-06	3.22E-06
Eu-152m(1)	1.32E+03	5.58E+02	2.41E-01	1.60E-03	2.32E-03	1.59E-03	2.29E-03	1.49E-03	2.15E-03
Gd-161	2.19E+01	3.70E+00	3.09E-01	2.43E-05	4.50E-05	4.09E-06	7.59E-06	3.51E-10	6.50E-10
Dy-165m	1.64E+05	1.26E+00	1.09E-02	1.52E-01	9.91E-03	8.15E-04	5.33E-05	9.29E-16	6.08E-17
Dy-165	8.69E+02	1.41E+02	1.28E-02	1.05E-03	8.10E-05	1.01E-03	7.73E-05	7.87E-04	6.04E-05
Ho-166	1.98E+01	1.61E+03	2.75E-02	2.41E-05	3.97E-06	2.40E-05	3.96E-06	2.35E-05	3.87E-06
Er-167m	4.79E+04	3.78E-02	9.71E-02	6.09E-06	3.55E-06	1.40E-81	8.13E-82	0.00E+00	0.00E+00
Yb-175	1.39E+00	6.03E+03	3.09E-02	1.69E-06	3.13E-07	1.69E-06	3.13E-07	1.68E-06	3.11E-07
Yb-177	1.13E+00	1.14E+02	1.22E-01	1.37E-06	1.00E-06	1.29E-06	9.47E-07	9.54E-07	6.99E-07
Lu-176m	4.78E+01	2.21E+02	1.82E-02	5.80E-05	6.34E-06	5.63E-05	6.15E-06	4.82E-05	5.26E-06
Lu-177	2.22E+00	9.66E+03	3.02E-02	2.70E-06	4.89E-07	2.70E-06	4.89E-07	2.69E-06	4.87E-07
Hf-178m	1.10E+03	7.17E-02	9.77E-01	1.07E-05	6.25E-05	1.41E-45	8.29E-45	0.00E+00	0.00E+00
Hf-179m	2.46E+04	3.12E-01	2.87E-01	9.85E-03	1.70E-02	6.75E-12	1.16E-11	3.96E-60	6.82E-60
W-187	3.47E+00	1.43E+03	4.31E-01	4.22E-06	1.09E-05	4.20E-06	1.09E-05	4.10E-06	1.06E-05
Re-186	3.62E+00	5.44E+03	1.80E-02	4.40E-06	4.75E-07	4.40E-06	4.75E-07	4.37E-06	4.72E-07
Re-188m	2.18E+01	1.86E+01	7.96E-02	2.60E-05	1.24E-05	1.83E-05	8.72E-06	2.84E-06	1.35E-06
Re-188	1.85E+01	1.02E+03	4.78E-02	2.25E-05	6.45E-06	2.23E-05	6.41E-06	2.16E-05	6.20E-06
Os-191m	1.19E+00	7.80E+02	6.51E-03	1.45E-06	5.65E-08	1.43E-06	5.60E-08	1.37E-06	5.36E-08
Ir-192m	3.12E+04	1.40E+00	2.47E-04	2.96E-02	4.39E-05	2.69E-04	3.98E-07	4.79E-15	7.10E-18
Ir-194	2.73E+01	1.16E+03	5.12E-02	3.32E-05	1.02E-05	3.30E-05	1.01E-05	3.20E-05	9.84E-06
Pt-199m	3.83E+00	2.40E-01	3.42E-01	1.10E-06	2.26E-06	1.34E-18	2.76E-18	2.67E-81	5.48E-81
Pt-199	3.89E+00	3.08E+01	1.07E-01	4.68E-06	3.00E-06	3.78E-06	2.43E-06	1.23E-06	7.87E-07
Au-198	1.18E+01	3.88E+03	4.03E-01	1.44E-05	3.47E-05	1.43E-05	3.46E-05	1.42E-05	3.43E-05
Hg-205	2.03E+00	5.20E+00	4.80E-03	2.31E-06	6.65E-08	6.51E-07	1.88E-08	8.31E-10	2.39E-11
Th-233	1.19E+02	2.23E+01	1.08E-02	1.42E-04	9.23E-06	1.06E-04	6.87E-06	2.24E-05	1.45E-06
U-239	1.01E+02	2.35E+01	5.21E-02	1.21E-04	3.78E-05	9.15E-05	2.86E-05	2.09E-05	6.54E-06

*Integrated thermal fluence in EDS-3C = 4.5E+05 neutrons/cm².
**dps = disintegration(s) per second.
†dis = disintegration.
Note: 8.42E-10 = 8.42×10^{-10} etc.

Table 5.2(a) Potential activation products (for fast neutrons*) of baggage contents containing 1-kg (2.2-lb) masses of various elements

Target isotope	Reaction**	Product	dps/μg†	Half-life (min)	Gamma (MeV/dis††)	0.5-min delay		10-min delay		60-min delay	
						Activity (μCi/g)	Dose rate (mrem/hr/2.2 lb @ 1 ft)	Activity (μCi/g)	Dose rate (mrem/hr/2.2 lb @ 1 ft)	Activity (μCi/g)	Dose rate (mrem/hr/2.2 lb @ 1 ft)
Be-9	n.a	He-6	1.27E+03	1.34E-02	–	–	–	–	–	–	–
C-12	n.2n	C-11	1.18E-08	2.03E+01	1.02E+00	7.84E-14	4.80E-13	5.67E-14	3.47E-13	1.03E-14	6.29E-14
N-14	n.2n	N-13	1.49E-03	9.96E+00	1.02E+00	9.72E-09	5.95E-08	5.02E-09	3.07E-08	1.55E-10	9.48E-10
O-16	n.p	N-16	1.74E-03	1.19E-01	4.86E+00	6.39E-10	1.86E-08	6.01E-34	1.75E-32	0.00E+00	0.00E+00
O-18	n.a	C-15	7.98E-03	4.10E-02	3.62E+00	1.15E-11	2.50E-10	2.12E-81	4.59E-80	0.00E+00	0.00E+00
F-19	n.p	O-19	1.09E+00	4.52E-01	1.04E+00	3.42E-06	2.14E-05	1.62E-12	1.01E-11	8.24E-46	5.14E-45
F-19	n.a	N-16	2.32E+01	1.19E-01	4.86E+00	8.52E-06	2.49E-04	8.02E-30	2.34E-28	0.00E+00	0.00E+00
Ne-20	n.p	F-20	1.28E-01	1.83E-01	6.33E-01	1.30E-07	4.95E-07	3.10E-23	1.18E-22	0.00E+00	0.00E+00
Ne-22	n.a	O-19	3.92E-03	4.52E-01	1.04E+00	1.23E-08	7.68E-08	5.81E-15	3.63E-14	2.96E-48	1.85E-47
Na-23	n.p	Ne-23	7.18E-01	6.27E-01	4.39E-01	2.79E-06	7.35E-06	7.69E-11	2.02E-10	7.68E-35	2.02E-34
Na-23	n.a	F-20	1.21E+00	1.83E-01	1.63E+00	1.23E-06	1.20E-05	2.93E-22	2.86E-21	0.00E+00	0.00E+00
Mg-25	n.p	Na-25	1.67E-02	1.00E+00	3.93E-01	7.98E-08	1.88E-07	1.10E-10	2.60E-10	9.87E-26	2.33E-25
Mg-26	n.p	Na-26	6.82E-03	1.67E-02	1.81E+00	4.49E-17	4.88E-16	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Al-27	n.p	Mg-27	1.09E-01	9.45E+00	8.93E-01	7.10E-07	3.80E-06	3.54E-07	1.90E-06	9.04E-09	4.84E-08
Si-28	n.p	Al-28	6.51E-01	2.25E+00	1.78E+00	3.77E-06	4.03E-05	2.02E-07	2.16E-06	4.15E-14	4.43E-13
Si-29	n.p	Al-29	1.00E+00	6.52E+00	2.38E+00	6.41E-06	9.15E-05	2.33E-06	3.33E-05	1.15E-08	1.64E-07
P-31	n.p	Si-31	5.14E-02	1.57E+02	8.66E-04	3.47E-07	1.80E-09	3.32E-07	1.73E-09	2.66E-07	1.38E-09
P-31	n.a	Al-28	1.90E-01	2.25E+00	1.78E+00	1.10E-06	1.18E-05	5.90E-08	6.30E-07	1.21E-14	1.29E-13
S-34	n.p	P-34	1.84E-02	2.07E-01	3.19E-01	2.33E-08	4.46E-08	3.59E-22	6.87E-22	7.21E-95	1.38E-94
Cl-37	n.a	P-34	2.69E-01	2.07E-01	3.19E-01	3.41E-07	6.52E-07	5.25E-21	1.00E-20	1.05E-93	2.02E-93
Ar-40	n.a	S-37	3.77E-03	5.06E+00	2.79E+00	2.38E-08	3.98E-07	6.48E-09	1.08E-07	6.88E-12	1.15E-10
Ca-40	n.2n	Ca-39	4.80E-03	1.45E-02	1.02E+00	1.36E-18	8.31E-18	0.00E+00	0.00E+00	0.00E+00	0.00E+00
V-51	n.p	Ti-51	2.06E-02	5.76E+00	3.58E-01	1.31E-07	2.82E-07	4.18E-08	8.98E-08	1.02E-10	2.19E-10
Cr-52	n.p	V-52	3.25E-02	3.76E+00	1.43E+00	2.00E-07	1.72E-06	3.48E-08	2.98E-07	3.46E-12	2.97E-11
Cr-53	n.p	V-53	3.60E-03	1.55E+00	1.04E+00	1.95E-08	1.21E-07	2.78E-10	1.74E-09	5.44E-20	3.40E-19
Mn-55	n.p	Cr-55	1.07E-02	3.56E+00	6.57E-04	6.56E-08	2.59E-10	1.03E-08	4.07E-11	6.12E-13	2.41E-15
Mn-55	n.a	V-52	3.70E-03	3.76E+00	1.44E+00	2.28E-08	1.97E-07	3.96E-09	3.42E-08	3.94E-13	3.40E-12
Ni-60	n.p	Co-60m	6.23E-03	1.05E+01	5.85E-02	4.07E-08	1.43E-08	2.18E-08	7.64E-09	8.02E-10	2.82E-10
Zn-64	n.p	Cu-64	2.11E-03	7.64E-02	1.89E-01	1.53E-10	1.73E-10	5.76E-48	6.53E-48	0.00E+00	0.00E+00
Zn-66	n.p	Cu-66	3.59E-03	5.10E+00	9.35E-02	2.27E-08	1.27E-08	6.23E-09	3.50E-09	6.98E-12	3.92E-12
Ga-69	n.a	Cu-66	7.86E-03	5.10E+00	9.35E-02	4.96E-08	2.78E-08	1.36E-08	7.66E-09	1.53E-11	8.58E-12
Se-77	n.n	Se-77m	1.63E+01	2.92E-01	9.70E-02	3.36E-05	1.96E-05	5.43E-15	3.16E-15	1.58E-66	9.22E-67
Br-79	n.2n	Br-78	1.03E-03	6.40E+00	1.03E+00	6.59E-09	4.07E-08	2.36E-09	1.46E-08	1.05E-11	6.49E-11
Y-89	n.n	Y-89m	3.75E+01	2.62E-01	9.01E-01	6.75E-05	3.65E-04	8.25E-16	4.46E-15	3.02E-73	1.63E-72
Ru-100	n.p	Tc-100	2.20E-03	2.67E-01	6.75E-02	4.06E-09	1.64E-09	7.94E-20	3.22E-20	3.46E-76	1.40E-76
Rh-103	n.a	Tc-100	3.97E+00	2.67E-01	6.75E-02	7.33E-06	2.97E-06	1.43E-16	5.81E-17	6.25E-73	2.53E-73
Rh-103	n.n	Rh-103m	6.43E-01	5.61E+01	1.69E-03	4.32E-06	4.38E-08	3.84E-06	3.89E-08	2.07E-06	2.10E-08
Cd-112	n.2n	Cd-111m	3.69E-02	4.87E+01	2.87E-01	2.48E-07	4.26E-07	2.16E-07	3.72E-07	1.06E-07	1.83E-07

See footnotes at end of table

Table 5.2(a) (continued)

Target isotope	Reaction**	Product	dps/μg†	Half-life (min)	Gamma (MeV/dis††)	0.5-min delay		10-min delay		60-min delay	
						Activity (μCi/g)	Dose rate (mrem/hr/ 2.2 lb @ 1 ft)	Activity (μCi/g)	Dose rate (mrem/hr/ 2.2 lb @ 1 ft)	Activity (μCi/g)	Dose rate (mrem/hr/ 2.2 lb @ 1 ft)
In-115	n,n	In-115m	4.04E–02	2.70E–02	1.65E–01	7.29E–13	7.22E–13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Ba-137	n,n	Ba-137m	5.00E–01	2.55E+00	5.99E–01	2.95E–06	1.06E–05	2.23E–07	8.02E–07	2.80E–13	1.01E–12
Pr-141	n,2n	Pr-140	1.25E–02	3.39E+00	5.05E–02	7.63E–08	2.31E–08	1.09E–08	3.31E–09	3.98E–13	1.21E–13

*Fast neutron fluence in EDS-3C = 2.5E+05 neutrons/cm².
**n = neutron, a = alpha, p = proton.
†dps = disintegration(s) per second.
††dis = disintegration

Note: 1.27E+03 = 1.27×10^3 etc.

Table 5.3(a) Major activation products of baggage contents containing 1-kg (2.2-lb) masses of various elements

				0.5-min delay		10-min delay		60-min delay	
Product	dps/μg*	Half-life (min)	Gamma (Mev/ dis**)	Activity (μCi/g)	Dose rate (mrem/hr/ 2.2 lb @ 1 ft)	Activity (μCi/g)	Dose rate (mrem/hr/ 2.2 lb @ 1 ft)	Activity (μCi/g)	Dose rate (mrem/hr/ 2.2 lb @ 1 ft)
F-20	1.97E+02	1.83E-01	1.64E+00	3.61E-05	3.55E-04	8.58E-21	8.44E-20	0.00E+00	0.00E+00
Na-24	1.80E+00	8.80E+02	4.12E+00	2.19E-06	5.41E-05	2.17E-06	5.37E-05	2.09E-06	5.16E-05
Al-28	2.72E+02	2.24E+00	1.78E+00	2.83E-04	3.03E-03	1.50E-05	1.60E-04	2.87E-12	3.07E-11
K-42	2.39E-01	7.42E+02	2.73E+02	2.91E-07	4.76E-04	2.88E-07	4.72E-04	2.75E-07	4.50E-04
Sc-46m	4.73E+04	3.12E-01	1.42E-01	1.89E-02	1.61E-02	1.30E-11	1.11E-11	7.62E-60	6.49E-60
V-52	1.79E+03	3.75E+00	1.43E+00	1.98E-03	1.70E-02	3.43E-04	2.94E-03	3.33E-08	2.86E-07
Mn-56	1.11E+02	1.55E+02	1.70E+00	1.35E-04	1.37E-03	1.29E-04	1.32E-03	1.03E-04	1.05E-03
Sc-77m	5.69E+03	2.90E-01	9.63E-02	2.10E-03	1.21E-03	2.90E-13	1.67E-13	3.73E-65	2.15E-65
Br-80	2.91E+02	1.77E+01	7.00E-02	3.47E-04	1.46E-04	2.39E-04	1.00E-04	3.38E-05	1.42E-05
Rb-86m	4.20E+01	1.02E+00	5.46E-01	3.64E-05	1.19E-04	5.72E-08	1.87E-07	1.01E-22	3.31E-22
Rh-104m	3.60E+03	4.35E+00	3.48E-02	4.04E-03	8.44E-04	8.90E-04	1.86E-04	3.09E-07	6.45E-08
Rh-104	1.54E+04	7.05E-01	1.11E-02	1.15E-02	7.63E-04	1.01E-06	6.71E-08	4.55E-28	3.03E-29
Ag-108	5.09E+03	2.41E+00	2.94E-02	5.36E-03	9.46E-04	3.49E-04	6.16E-05	1.99E-10	3.51E-11
Ag-110	8.31E+04	4.10E-01	2.96E-02	4.34E-02	7.71E-03	4.61E-09	8.19E-10	9.14E-46	1.62E-46
In-116m(1)	1.29E+03	5.42E+01	2.47E+00	1.56E-03	2.31E-02	1.38E-03	2.05E-02	7.28E-04	1.08E-02
In-116	1.36E+04	2.37E-01	1.55E-02	3.83E-03	3.57E-04	3.31E-15	3.08E-16	1.06E-78	9.84E-80
I-128	2.00E+02	2.50E+01	8.75E-02	2.40E-04	1.26E-04	1.84E-04	9.68E-05	4.61E-05	2.42E-05
Eu-152m(1)	1.32E+03	5.58E+02	2.41E-01	1.60E-03	2.32E-03	1.59E-03	2.29E-03	1.49E-03	2.15E-03
Dy-165m	1.64E+05	1.26E+00	1.09E-02	1.52E-01	9.91E-03	8.15E-04	5.33E-05	9.29E-16	6.08E-17
Hf-179m	2.46E+04	3.12E-01	2.87E-01	9.85E-03	1.70E-02	6.75E-12	1.16E-11	3.96E-60	6.82E-60
Total					1.03E-01		2.82E-02		1.45E-02

*dps = disintegration(s) per second.
**dis = disintegration.
Note: 1.97E+02 = 1.97×10^2 etc.

Table 5.4(a) Calculated beta dose to the skin from a 1 μCi/cm² source

Variable	Beta dose (rem)	
	Averaged over an area of skin at the basal layer	At points on the skin basal layer
Radius (in.)/area (in.²)		
0.2150/0.1550	0.164	–
2.4180/18.5050	0.105	–
Horizontal distance (in.)		
0.0000	–	0.164
1.5100	–	0.159
1.5832	–	0.103
1.6501	–	0.163
1.7106	–	0.163
1.7647	–	0.155
1.8125	–	0.154
1.8539	–	0.157
1.8889	–	0.152
1.9176	–	0.146
1.9398	–	0.136
1.9558	–	0.121
1.9653	–	0.099
1.9685	–	0.080
1.9717	–	0.063
1.9812	–	0.040
1.9972	–	0.026
2.0194	–	0.017
2.0481	–	0.010
2.0831	–	0.006
2.1245	–	0.003
2.1723	–	0.001
2.2264	–	0.000
2.2869	–	0.000
2.3538	–	0.000
2.4270	–	0.000

Note: The doses were calculated using VARSKIN MOD 1:
Disc source with radius = 1.9685 in.
Skin thickness = 0.0028 in.
Source:
Radionuclide = Al-28
Average beta energy = 1.240 MeV
X-90 distance = 0.2547 in.
Source strength = 64.5 μCi/in.²
Irradiation time = 60 s
All cell damage occurs in an area with a radius of 2.427 in.

Table 5.5(a) Elemental composition of the contents of an aluminum suitcase (quantities in ounces)

Element	Cloth-ing	Shoes	Toilet-ries	Tooth-paste	Shaver	Shampoo	Paper	Suit-case	Total
Hydrogen	10.8	1.9	0.8	0.6	–	1.2	5.0	9.0	29.3
Carbon	89.8	17.3	5.1	0.4	0.08	6.8	35.5	46.1	201.1
Nitrogen	17.0	5.1	1.0	–	–	0.2	–	–	23.4
Oxygen	37.1	7.7	1.1	3.8	–	2.6	39.7	41.0	133.0
Sodium	–	–	–	0.01	–	–	–	–	0.01
Manganese	–	0.1	–	–	0.2	–	–	–	0.3
Silicon	–	0.03	–	–	0.06	–	–	–	0.1
Phosphorous	–	0.003	–	0.5	0.007	–	–	–	0.5
Sulfur	–	0.003	–	0.01	0.007	–	–	–	0.02
Iron	–	15.8	–	–	3.2	–	–	–	19.0
Calcium	–	–	–	0.7	–	–	–	–	0.7
Aluminum*	–	–	–	–	–	–	–	160.1	160.1

*All data are from Westinghouse (1986) report, except the weight from aluminum (this amount was increased to reflect an all-aluminum suitcase).

Table 5.6(a) Gamma dose rates from EDS-3C activation of the contents of an aluminum suitcase

Element	Element mass (oz)	Suitcase activity (μCi)	Gamma (mrem/hr/ 2.2 lb @ 1 ft)	Gamma dose rate @ 1 ft (mrem/hr)
Hydrogen	29.3	–	–	–
Carbon	201.1	1.40E-13	–	–
Nitrogen	23.4	2.40E-09	–	–
Oxygen	133.0	1.10E-05	–	–
Sodium	0.01	6.20E-07	5.41E-05	1.54E-08
Manganese	0.03	1.30E-03	1.37E-03	1.17E-06
Silicon	0.1	3.50E-08	–	–
Phosphorous	0.5	2.00E-13	–	–
Sulfur	0.02	–	–	–
Iron	19.0		–	–
Calcium	0.7	–	–	–
Aluminum	160.1	1.28E+00	3.03E-03	1.38E-02
Total				1.38E-02

Note: 1.40E-13 = 1.40×10^{-13} etc.

Table 5.7(a) Committed effective dose equivalent from daily intakes of elements 1 hour after EDS-3C screening

Target nuclide	Mean daily intake (oz)	Induced radio-nuclide	Weighted committed dose equivalent (rem/Ci)	Microcuries/gram of element		Committed effective dose equivalent from 1 day's intake	
				0.5-min delay* (μCi/g)	10-min delay* (μCi/g)	0.5-min delay (mrem)	10-min delay (mrem)
Na-23	1.55E-01	Na-24	1.43E+03	6.20E-05	6.15E-05	1.38E-05	1.37E-05
P-31	4.94E-02	P-32	7.77E+03	1.22E-06	1.22E-06	4.65E-07	4.65E-07
Cl-37	1.84E-01	Cl-38	2.00E+02	1.99E-04	1.59E-04	6.95E-06	5.82E-06
K-41	1.16E-01	K-42	1.10E+03	8.24E-06	8.16E-06	1.06E-06	1.04E-06
Mn-55	1.31E-04	Mn-56	9.32E+02	3.82E-03	3.65E-03	4.66E-07	4.45E-07
Cu-63	1.24E-04	Cu-64	4.29E+02	1.58E-04	1.56E-04	8.37E-09	8.29E-09
As-75	3.53E-05	As-76	4.74E+03	1.12E-04	1.12E-04	1.88E-08	1.87E-08
Br-79	2.65E-04	Br-80m	2.31E+02	1.89E-04	1.84E-04	1.15E-08	1.12E-08
Br-79	2.65E-04	Br-80	5.55E+01	9.83E-03	6.77E-03	1.44E-07	9.95E-08
Total						2.29E-05	2.16E-05

*From Table 5.1(a).
Note: 1.55E-01 = 1.55x10^{-1} etc.

Table 5.9(a) Summary of collective doses from all scenarios

Radiation exposure	Scenario			
	Behind the counter (person-rem)	In front of the counter (person-rem)	Pre-check-in (person-rem)	Curbside (person-rem)
Workers				
Operators	1.2E+00	1.2E+00	1.2E+00	1.2E+00
Baggage handlers	6.0E-01	6.0E-01	6.0E-01	6.0E-01
Ticket counter personnel	3.0E+00	3.0E+00	1.0E+00	0
Security screeners	9.5E-02	9.5E-02	9.5E-02	9.5E-02
Sky-caps	0	0	0	3.8E-01
Passengers	0	1.1E+00	2.0E+01	5.5E+00
Public				
Below the TNA system	6.8E+00	6.8E+00	6.8E+00	6.8E+00
Near the TNA system	0	1.1E+00	6.0E+00	6.0E-01
From irradiation of baggage contents				
Consumable items	0	0	1.3E-03	0
Nonconsumable items (suitcase, clothing, etc.)	2.8E-01	2.8E-01	2.8E-01	2.8E-01
Total	1.2E+01	1.4E+01	3.6E+01	1.6E+01

Note: 1.2E+00 = 1.2x10^{0} etc.

Table 5.10(a) Summary of annual individual doses from all scenarios

Radiation exposure	Scenario				
	Behind the counter (mrem)	In front of the counter (mrem)	Pre-check-in (mrem)	Curbside (mrem)	NRC limit (mrem)
Workers					
Operators	2.0E+02	2.0E+02	2.0E+02	2.0E+02	5.0E+03
Baggage handlers	1.0E+02	1.0E+02	1.0E+02	1.0E+02	5.0E+02
Ticket counter personnel	6.0E+01	6.0E+01	1.7E+00	0	5.0E+02
Security screeners	3.2E+01	3.2E+01	3.2E+01	3.2E+01	5.0E+02
Sky-caps	0	0	0	2.5E+01	5.0E+02
Passengers	0	1.0E-03	1.8E-02	5.0E-03	5.0E+02
Public					
Below the TNA system	7.5E-03	7.5E-03	7.5E-03	7.5E-03	5.0E+02
Near the TNA system	0	1.2E-04	6.7E-04	6.7E-04	5.0E+02
From irradiation of baggage contents					
Consumable items	0	0	2.4E-05	0	–
Nonconsumable items (suitcase, clothing, etc.)	2.5E-02	2.5E-02	2.5E-02	2.5E-02	–

Notes: Natural sources of radiation:
Natural background 3.0E+02
Yearly dose from foodstuffs 1.4E+01
2.0E+02 = 2.0×10^2 etc.

Table 6.2(a) Offsite concentrations [at 50 m (54 yd)] of airborne releases for various fractions of Cf-252

Total source activity (Ci/yr)	Release fraction	Emission (Ci)	χ/Q* (s/m^3)	Maximum permissible concentration (MPC) (μCi/ml)	Offsite concentration	
					(Ci/m^3)	Fraction of MPC (%)
8.00E-02	1.00E-01	8.00E-03	6.40E-05	1.00E-12	1.62E-14	1.62
8.00E-02	5.00E-01	4.00E-02	6.40E-05	1.00E-12	8.12E-14	8.12
8.00E-02	1.00E+00	8.00E-02	6.40E-05	1.00E-12	1.62E-13	16.24

*χ/Q at 50 m.
Note: 8.00E-02 = 8.00×10^{-2} etc.

Table 6.3(a) Annual inhalation dose to the nearest individual 50 m (54 yd) away from postulated Cf-252 accident

Activity* inhaled (mCi)	Dose conversion factor** (rem/50 yr·mCi)	Committed effective dose equivalent (rem/50 yr)
1.30E-07	1.85E+05	2.40E-02
6.49E-07	1.85E+05	1.20E-01
1.30E-06	1.85E+05	2.40E-01

*Breathing rate = 8.00E+03 m^3/yr.
**ICRP Publication 30.
Note: 1.30E-07 = 1.30×10^{-7} etc.

Table 6.4(a) Offsite concentrations [at 300 m (328 yd)] of airborne releases for various fractions of Cf-252

Total source activity (Ci/yr)	Release fraction	Emission (Ci)	χ/Q* (s/m^3)	Maximum permissible concentration (MPC) (μCi/ml)	Offsite concentration (Ci/m^3)	Offsite concentration Fraction of MPC (%)
8.00E-02	1.00E-01	8.00E-03	2.80E-05	1.00E-12	7.10E-15	0.71
8.00E-02	5.00E-01	4.00E-02	2.80E-05	1.00E-12	3.55E-14	3.55
8.00E-02	1.00E+00	8.00E-02	2.80E-05	1.00E-12	7.10E-14	7.10

*χ/Q at 300 m.
Note: 8.00E-02 = 8.00×10^{-2} etc.

Table 6.5(a) Annual inhalation dose to the nearest individual 300 m (328 yd) away from postulated Cf-252 accident

Activity* inhaled (mCi)	Dose conversion factor** (rem/50 yr·mCi)	Committed effective dose equivalent (rem/50 yr)
5.68E-08	1.85E+05	1.05E-02
2.84E-07	1.85E+05	5.26E-02
5.68E-07	1.85E+05	1.05E-01

*Breathing rate = 8.00E+03 m^3/yr.
**ICRP Publication 30.
Note: 5.68E-08 = 5.68×10^{-8} etc.

APPENDIX C
DOSE RATE AND FLUENCE INFORMATION FOR EDS-3C

DOSE RATE MEASUREMENTS ON EDS-3

Dose rates for neutrons and gamma rays were measured using survey instruments for various positions and system conditions. Measurements were performed with and without the extra shielding on the sides of the system, both with the source in the operating position and in the retracted position. Additional measurements were made with the source cask placed against the system with the source positioned at the interface to simulate a source stuck in mid-transfer at the worst case position. The results of earlier measurements of radiation from the ends of the system are also given.

METHOD OF DOSE RATE MEASUREMENT

Neutron dose rates were measured using the Nuclear Research Corporation Model NP-2 Snoopy. Two instruments were used. The NP-2 uses a BF3 proportional counter inside a roughly 9"x9" cylindrical moderator/absorber to achieve a rem response. At a detector count rate of approximately two counts per second, a one mrem/hr dose rate reading is produced.

Because most of the dose rates were at the extreme low end of the meter range, the meter readings were hard to read and subject to the statistical fluctuations of individual neutrons. To alleviate this problem and achieve better precision, the readings were obtained by counting pulses from the NP-2 counter output in a counter gated by a timer. For all except the interface measurements, a counting time of 1000 seconds was used. The counter-to-dose rate calibration was obtained separately for each meter using reproducible positions at which the dose rates were high enough to provide reliable direct readings of the meter face. The statistical contribution to the counting error averaged about 10-20% at the one sigma level. The calibration error of the NP- 2 is given as 15%.

Gamma ray dose rates were obtained using a Bicron Corporation "micro rem" meter, calibrated by the manufacturer.

Figure F-1 shows the positions used for the dose rate measurements, measured at mid-cavity height. The position numbers refer to the following tables of dose rates.

Neutron dose rates given are the conventional rem readings multiplied by a factor of two in anticipation of the ICRP recommended change being put into the regulations (ICRP Publication 45; also see Section 5 of this report).

All the dose rates are normalized to the nominal maximum source strength of 150 micrograms. The data are given to three places for more accurate rounding.

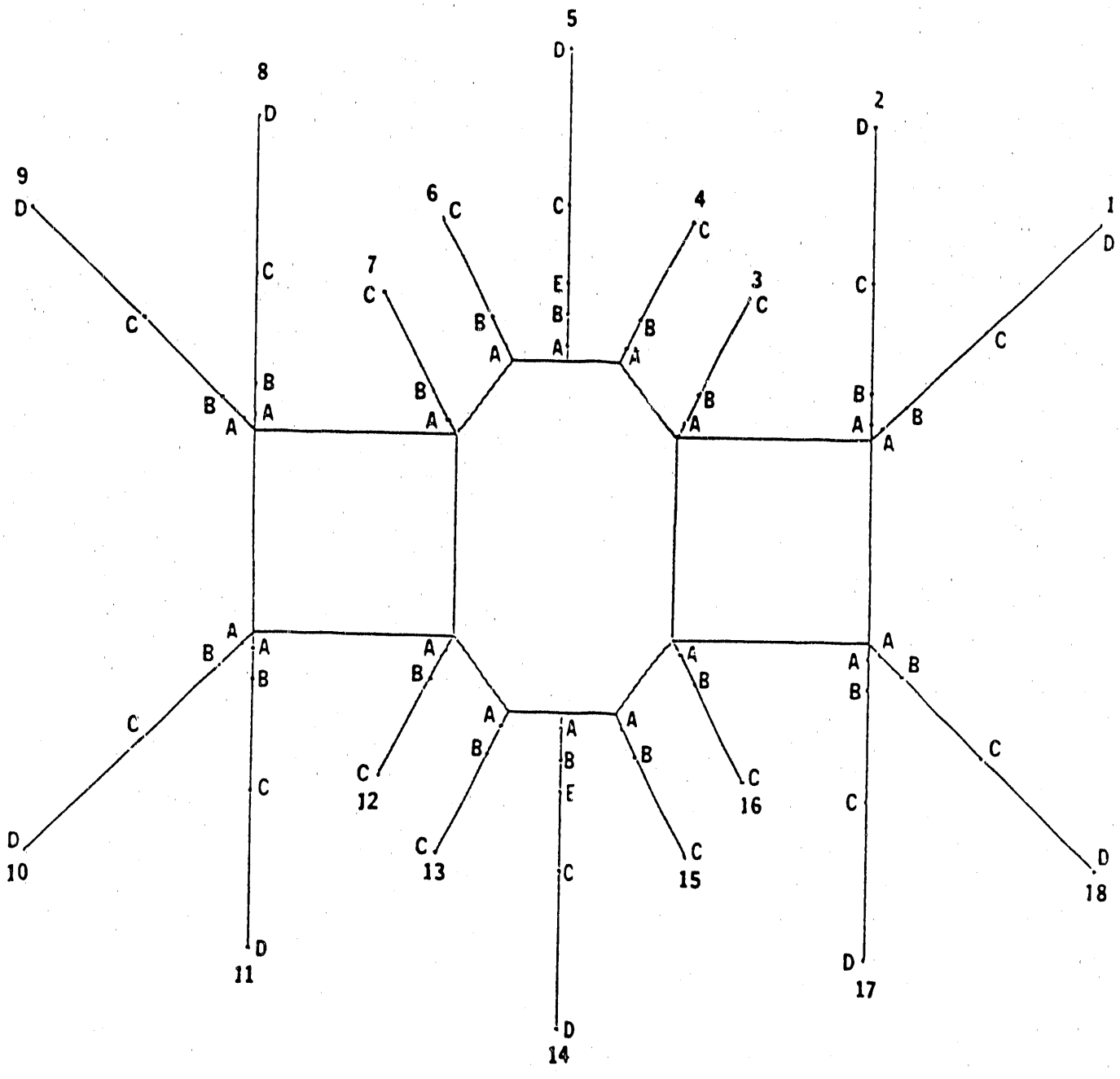


Figure F-1. Positions for dose rate measurements.

MEASUREMENT RESULTS

Tables F-1 and F-2 show results with and without extra shielding with the source in the operating position. Tables F-3 and F-4 give the results with the source in the retracted position. Figure F-2 shows approximate isodose contours for the data of Table F-1, with extra shielding, source in operating position.

For the transfer interface measurements, the cask was placed in contact with the system as for a source transfer. The source was then retracted to the interface position, using the neutron dose rate meter to find the maximum dose rate position. Measurements for this condition are given in Table F-5 and associated isodose contours given in Figure F-3.

When the EDS is in use for screening baggage, the doors will be pushed partially open by the bags to permit them to flow through. The opening is then obstructed by the bag which shields some of the neutrons and gamma rays. Individual bags vary greatly in their effectiveness as shielding, but they are on the average fairly good absorbers.

The neutron and gamma ray dose rates were measured with baggage flowing in a recycling mode. The bags were filled with clothing items, though generally not as heavily packed as bags actually seen at airports; actual heavy bags would give lower dose rates. The bag flow rate was at or above the maximum rate that the system computer can handle, 10 or more bags per minute. At this rate the doors are continuously being held partly open by the bags so that they never fully close. Lower bag flow rates result in lower dose rates.

Measurements were made on axis 100 cm from the entrance and exit ends of the EDS. The position of the body of an individual working as a baggage handler loading or unloading the EDS was also measured; this position is 75 cm (30") from the end of the EDS and 50 cm (20") off axis. These measurements were made at the mid-height of the baggage passage. For comparison, measurements were also made at these same positions without baggage flow and with the doors closed. The results of these measurements are given in Table F-6.

Table F-1. EDS-3 Dose Rates with Extra Shielding
Source in Operating Position
Neutron Q F multiplier = 2
Normalized to 150 microgram source

Position		Dose Rates <---mrem/hr---> Gamma	Neutron	Total
10 cm:				
(A)	1	0.043	0.030	0.073
	2	0.056	0.024	0.080
	3	0.173	0.166	0.339
	4	0.037	0.034	0.071
	5	0.037	0.036	0.073
	6	0.025	0.045	0.070
	7	0.142	0.105	0.247
	8	0.031	0.023	0.053
	9	0.031	0.018	0.049
	10	0.037	0.018	0.056
	11	0.037	0.014	0.051
	12	0.161	0.127	0.288
	13	0.031	0.036	0.067
	14	0.037	0.030	0.067
	15	0.037	0.034	0.071
	16	0.204	0.155	0.359
	17	0.043	0.020	0.064
	18	0.043	0.022	0.065
30 cm:				
(B)				
	1	0.037	0.033	0.070
	2	0.050	0.031	0.080
	3	0.111	0.083	0.194
	4	0.037	0.034	0.071
	5	0.025	0.037	0.062
	6	0.031	0.038	0.069
	7	0.099	0.060	0.159
	8	0.031	0.022	0.053
	9	0.025	0.025	0.049
	10	0.025	0.017	0.042
	11	0.031	0.018	0.049
	12	0.099	0.092	0.191
	13	0.031	0.032	0.063
	14	0.037	0.022	0.059
	15	0.037	0.039	0.076
	16	0.130	0.127	0.257
	17	0.043	0.016	0.060
	18	0.037	0.014	0.051

Position		Dose Rates <---mrem/hr---> Gamma	Neutron	Total
50 cm:				
(E)				
	5	0.025	0.030	0.055
	14	0.025	0.027	0.052
100 cm:				
(C)				
	1	0.025	0.023	0.048
	2	0.031	0.027	0.058
	3	0.043	0.042	0.085
	4	0.031	0.036	0.066
	5	0.025	0.033	0.058
	6	0.025	0.025	0.050
	7	0.037	0.030	0.067
	8	0.025	0.019	0.044
	9	0.019	0.024	0.042
	10	0.019	0.015	0.034
	11	0.025	0.017	0.042
	12	0.056	0.033	0.089
	13	0.025	0.020	0.045
	14	0.025	0.029	0.053
	15	0.025	0.029	0.054
	16	0.043	0.032	0.075
	17	0.031	0.012	0.043
	18	0.025	0.018	0.043
200 cm:				
(D)				
	1	0.012	0.023	0.036
	2	0.025	0.031	0.056
	5	0.019	0.025	0.043
	8	0.019	0.022	0.040
	9	0.019	0.020	0.038
	10	0.012	0.016	0.028
	11	0.019	0.016	0.034
	14	0.019	0.013	0.032
	17	0.025	0.012	0.036
	18	0.019	0.009	0.027

Table F-2. EDS-3 Dose Rates, NO Extra Shielding
Source in Operating Position
Neutron Q F multiplier = 2
Normalized to 150 microgram source

Position		Dose Rates <---mrem/hr---> Gamma	Neutron	Total
10 cm:				
(A)	1	0.045	0.035	0.079
	2	0.045	0.042	0.087
	3	0.195	0.354	0.549
	4	0.045	0.093	0.137
	5	0.033	0.074	0.108
	6	0.033	0.052	0.085
	7	0.161	0.239	0.400
	8	0.033	0.035	0.068
	9	0.033	0.032	0.066
	10	0.033	0.033	0.067
	11	0.033	0.030	0.063
	12	0.161	0.368	0.529
	13	0.036	0.137	0.173
	14	0.045	0.073	0.118
	15	0.045	0.111	0.156
	16	0.167	0.335	0.502
	17	0.056	0.047	0.103
	18	0.000	0.053	0.053
30 cm:				
(B)				
	1	0.033	0.019	0.052
	2	0.045	0.037	0.082
	3	0.139	0.184	0.324
	4	0.045	0.067	0.111
	5	0.033	0.042	0.075
	6	0.033	0.037	0.071
	7	0.111	0.116	0.228
	8	0.036	0.041	0.076
	9	0.028	0.036	0.064
	10	0.028	0.033	0.061
	11	0.390	0.059	0.449
	12	0.122	0.210	0.333
	13	0.036	0.083	0.119
	14	0.045	0.047	0.092
	15	0.045	0.072	0.116
	16	0.167	0.210	0.377
	17	0.045	0.045	0.089
	18	0.000	0.067	0.067

Position		Dose Rates <---mrem/hr---> Gamma	Neutron	Total
50 cm:				
(E)				
	5	0.028	0.037	0.065
	14	0.033	0.052	0.085
100 cm:				
(C)				
	1	0.024	0.033	0.058
	2	0.033	0.057	0.090
	3	0.053	0.061	0.114
	4	0.033	0.074	0.108
	5	0.022	0.026	0.048
	6	0.028	0.030	0.058
	7	0.045	0.068	0.113
	8	0.028	0.022	0.050
	9	0.022	0.041	0.063
	10	0.020	0.033	0.053
	11	0.031	0.031	0.062
	12	0.045	0.090	0.135
	13	0.028	0.061	0.088
	14	0.028	0.051	0.079
	15	0.033	0.062	0.095
	16	0.056	0.073	0.129
	17	0.033	0.059	0.093
	18	0.000	0.045	0.045
200 cm:				
(D)				
	1	0.017	0.017	0.034
	2	0.022	0.028	0.051
	5	0.017	0.017	0.034
	8	0.022	0.020	0.042
	9	0.013	0.041	0.054
	10	0.013	0.036	0.049
	11	0.022	0.030	0.052
	14	0.020	0.027	0.047
	17	0.022	0.038	0.061
	18	0.000	0.048	0.048

Table F-3. EDS-3 Dose Rates with Extra Shielding
Source in Retracted Position
Neutron Q F multiplier = 2
Normalized to 150 microgram source

Position		Dose Rates <---mrem/hr---> Gamma	Neutron	Total
10 cm:				
(A)	1		0.041	
	2		0.042	
	3	0.003	0.027	0.031
	4		0.028	
	5	0.004	0.036	0.040
	6		0.051	
	7		0.046	
	8		0.054	
	9		0.052	
	10	0.033	0.136	0.170
	11	0.042	0.123	0.165
	12	0.056	0.163	0.219
	13	0.056	0.257	0.313
	14	0.139	0.275	0.414
	15	0.069	0.240	0.309
	16	0.056	0.164	0.219
	17	0.042	0.193	0.235
	18	0.028	0.148	0.175
30 cm:				
(B)				
	1		0.038	
	2		0.047	
	3	0.007	0.031	0.038
	4		0.042	
	5	0.008	0.051	0.059
	6		0.052	
	7	0.009	0.045	0.053
	8		0.063	
	9	0.007	0.049	0.056
	10	0.047	0.141	0.187
	11	0.056	0.158	0.214
	12	0.100	0.166	0.266
	13	0.102	0.306	0.408
	14	0.139	0.396	0.535
	15	0.104	0.294	0.397
	16	0.102	0.208	0.311
	17	0.072	0.180	0.253
	18	0.045	0.145	0.190

Position		Dose Rates <---mrem/hr---> Gamma	Neutron	Total
50 cm:				
(E)				
	5	0.009	0.052	0.061
	14	0.130	0.396	0.527
100 cm:				
(C)				
	1		0.052	
	2		0.066	
	3		0.037	
	4		0.066	
	5		0.057	
	6		0.041	
	7	0.009	0.042	0.051
	8		0.063	
	9	0.008	0.061	0.068
	10	0.050	0.122	0.173
	11	0.072	0.193	0.266
	12	0.122	0.250	0.373
	13	0.100	0.286	0.386
	14	0.111	0.301	0.412
	15	0.100	0.282	0.382
	16	0.117	0.273	0.390
	17	0.075	0.195	0.270
	18	0.047	0.107	0.154
200 cm:				
(D)				
	1		0.051	
	2		0.057	
	5		0.042	
	8		0.042	
	9		0.053	
	10	0.011	0.087	0.098
	11	0.050	0.104	0.154
	14	0.061	0.172	0.234
	17	0.050	0.134	0.184
	18	0.036	0.068	0.104

Table F-4. EDS-3 Dose Rates, NO Extra Shielding
Source in Retracted Position
Neutron Q F multiplier = 2
Normalized to 150 microgram source

Position	Dose Rates <---mrem/hr---> Gamma	Neutron	Total
10 cm: (A)			
1			
2			
3		0.063	
4			
5			
6			
7			
8			
9			
10	0.050	0.223	0.273
11	0.060	0.247	0.307
12	0.100	0.195	0.295
13	0.090	0.319	0.409
14	0.100	0.241	0.341
15	0.085	0.333	0.418
16	0.110	0.254	0.364
17	0.060	0.280	0.340
18	0.055	0.239	0.294
30 cm: (B)			
1			
2			
3			
4			
5			
6			
7			
8			
9			
10	0.050	0.238	0.288
11	0.115	0.289	0.404
12	0.165	0.293	0.458
13	0.120	0.358	0.478
14	0.135	0.370	0.505
15	0.130	0.427	0.557
16	0.165	0.338	0.503
17	0.120	0.290	0.410
18	0.060	0.239	0.299

Position	Dose Rates <---mrem/hr--- Gamma	Neutron	Total
50 cm: (E)			
5			
14	0.150	0.453	0.603
100 cm: (C)			
1			
2			
3			
4			
5			
6			
7			
8			
9			
10	0.090	0.181	0.271
11	0.105	0.276	0.381
12	0.160	0.369	0.529
13	0.120	0.391	0.511
14	0.150	0.376	0.526
15	0.130	0.374	0.504
16	0.175	0.377	0.552
17	0.115	0.309	0.424
18	0.075	0.204	0.279
200 cm: (D)			
1			
2			
5			
8			
9			
10	0.055	0.125	0.180
11	0.070	0.156	0.226
14	0.090	0.204	0.294
17	0.085	0.175	0.260
18	0.060	0.118	0.178

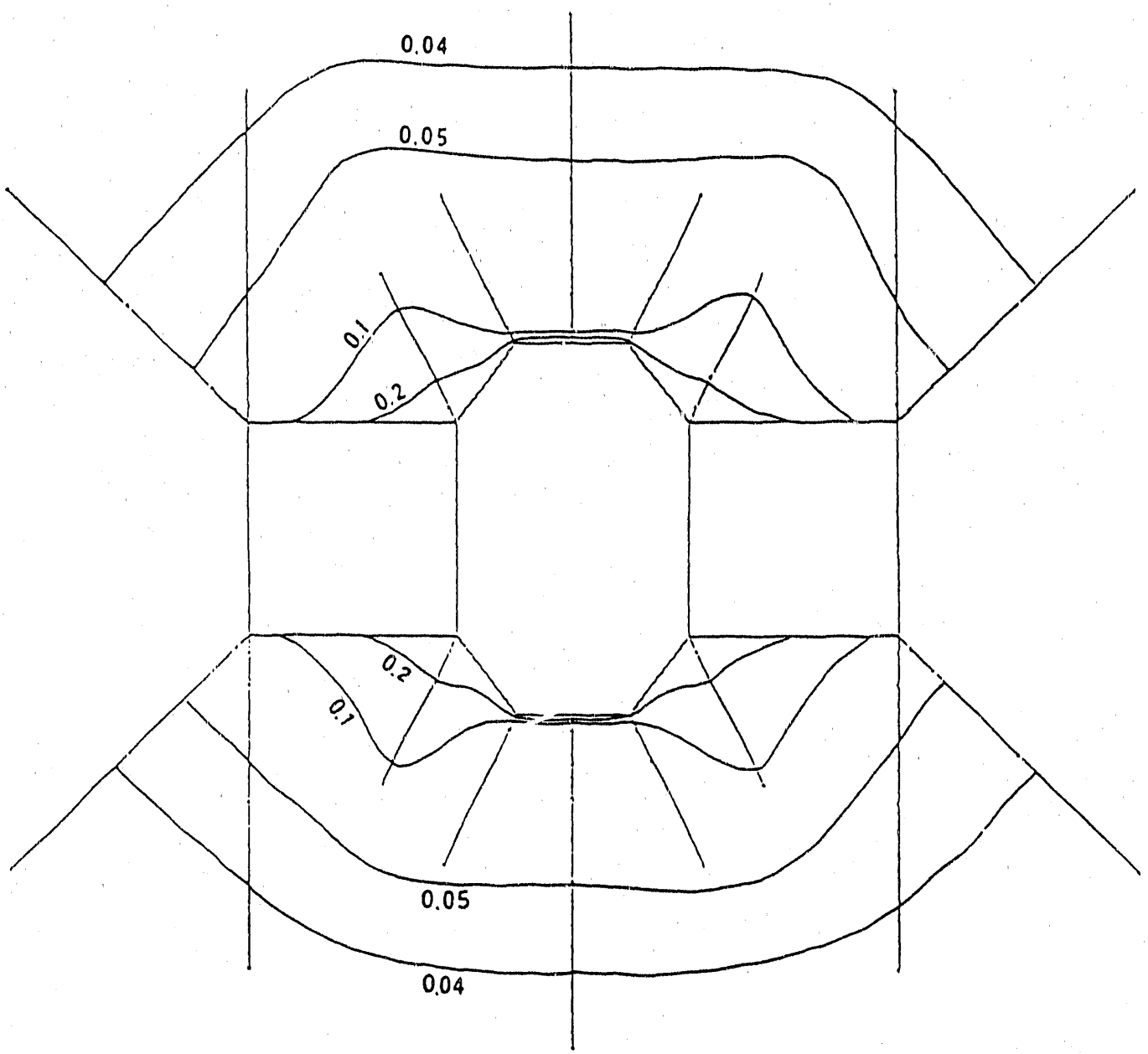


Figure F-2. Isodose contours based on dose rate measurements.

Table F-5 Dose Rate Measurements for Source "Stuck" at Interface Position During Transfer (mrem/hr)

Line #	10 cm	30 cm	100 cm	200 cm
10	9.3	8.1	11.5	5.3
11	9.3	13.1	12.6	3.7
12	14.3	26.1	20.2	
13			5.9	
14			0.5	0.8
15			6.0	
16	12.9	22.2	17.2	
17	7.8	10.9	10.1	3.1
18	7.8	11.0	8.1	4.0

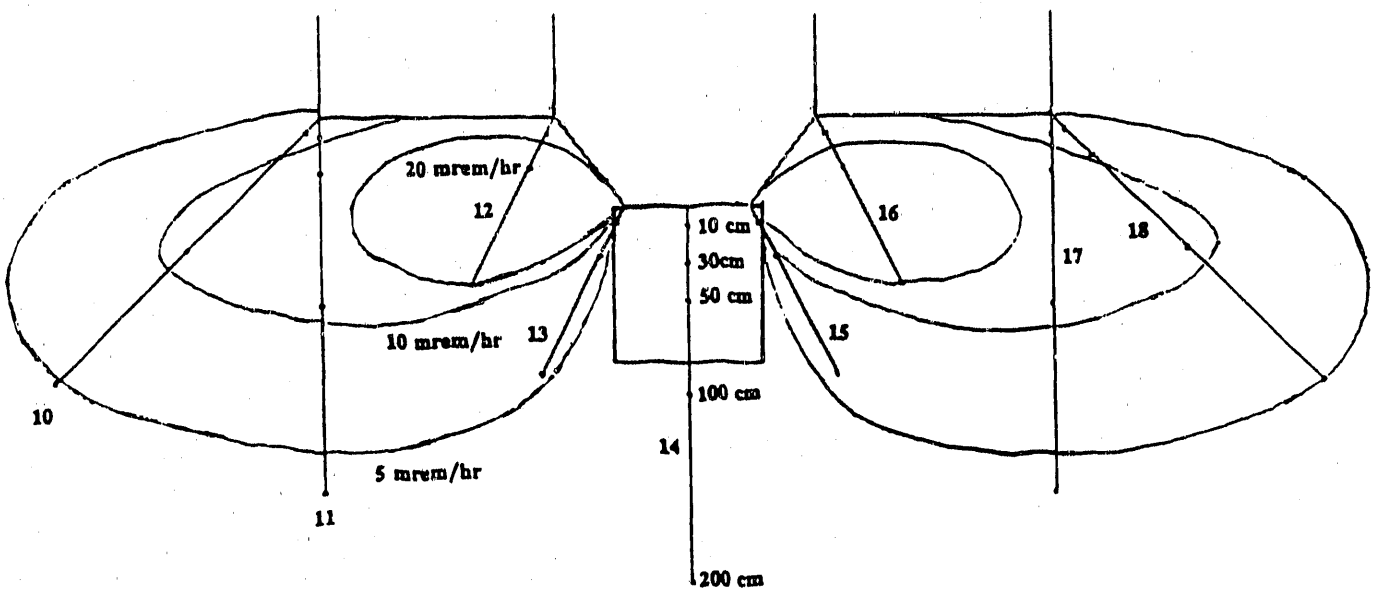


Figure F-3. Isodose contours for source "stuck" at interface of cask and EDS-3 system.

Table F-6. EDS DOSE RATES FROM ENDS

POSITION	NEUTRON DOSRAT	<<-- SCALED TO 150 ug --> N DOSRAT QF=2	GAMMA DOSRAT	TOTAL DOSRAT
100 CM, entrance	0.095	0.205	0.097	0.303
Handler, entrance	0.092	0.199	0.086	0.285
100 cm, exit	0.082	0.177	0.129	0.306
Handler, exit	0.053	0.115	0.065	0.180
no baggage flow, doors closed				
100 cm, exit	0.012	0.027	0.043	0.070
Handler, exit	0.009	0.020	0.043	0.063

APPENDIX D
NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY
REPORT ON TNA SYSTEM

QUANTITATIVE ASSESSMENT OF INDUCED RADIOACTIVITY IN BAGGAGE

Final Report
Covering All Phases of Interagency Agreement No. DTFA03-87-A-00008

March 31, 1989

Prepared for
Federal Aviation Administration

Technical Center
Atlantic City Airport, NJ 08405

Donald A. Becker
Nuclear Methods Group
Center for Analytical Chemistry
National Institute of Standards and Technology
Gaithersburg, MD 20899

QUANTITATIVE ASSESSMENT OF INDUCED RADIOACTIVITY IN BAGGAGE

INTRODUCTION

This report is the Final Report of the Interagency Agreement between the Federal Aviation Administration (FAA) (Aviation Security Branch, ACT-360; Contract No. DTFA03-87-A-00008) and the National Institute of Standards and Technology (NIST) [formerly, National Bureau of Standards (NBS)]. The title of this project is "Quantitative Assessment of Induced Radioactivity in Baggage". The Interagency Agreement became effective in April 1987. This report covers all work accomplished during the entire 2 year project.

The overall approach used by NIST involves the evaluation of induced radioactivity in each element in the periodic table, and consists of three phases. These phases are: 1) neutron activation calculations; 2) neutron fluence characterization; and 3) quantitative assessment of actual induced radioactivities.

The first phase, neutron activation calculations, involves the critical evaluation of activation calculations for the prototype neutron activation systems, and the development of a complete set of expected induced radioactivities for all elements, including thermal, epithermal, and fast neutron activations. These calculations are based on neutron fluence rates and energy spectra information provided by the FAA contractor developing the prototype systems.

The second phase consists of a systematic characterization of the neutron fluence rates in the prototype baggage transporting systems. This includes a mapping of the thermal fluence rate over the baggage travel area. Further, the neutron energy spectrum characteristics will be evaluated for the baggage irradiation area. This latter information should provide useful information on the actual epithermal and fast neutron components, if any, but may be limited due to the relatively low fluence rates expected.

The third phase of the project is the quantitative determination of actual induced radioactivity levels for a number of elements, using one or both of the FAA prototype neutron activation detection systems, as available. The data from this phase provides a verification of the calculated induced activities. The data from all three phases will then provide a comprehensive understanding of the levels of induced radioactivities to be expected from any element or combination of elements which passes through the thermal neutron activation explosive detection system (EDS). Once fully understood, the data will provide the means to systematically establish a verified maximum and expected induced radioactivity level for any material.

This project required 2 years for completion. The first 6 months of work (FY87) included all of phase one and part of phase two. The second year of work included the completion of phase two and all of phase three. In addition, the FAA requested and obtained a six month no-cost extension to this project. This Final Report contains all of the information from the entire project including all information previously reported to the FAA.

PHASE 1. NEUTRON ACTIVATION CALCULATIONS

Neutron irradiation of the various elements to form radioactive products is well understood, and the physics is relatively straightforward. The equation to calculate these values is as follows:

$$A_o = \frac{m \cdot a \cdot N_o}{A} (\phi_{th}\sigma + \phi_{epi} I) (1 - e^{-\lambda t})$$

where:

A_o = initial radioactivity, at zero decay time in units of Becquerels (disintegrations/second)

m = mass of element in grams

a = isotopic abundance of target isotope (1.00 = 100% abundance)

N_o = number of atoms/gram atomic weight (6.022×10^{23})

A = gram atomic weight of the element

ϕ_{th} = thermal neutron fluence rate (n cm^{-2} sec^{-1})

σ = thermal neutron cross section in barns (10^{-24} cm^2)

ϕ_{epi} = epithermal neutron fluence rate (n cm^{-2} sec^{-1})

I = resonance integral in barns (10^{-24} cm^2)

λ = decay constant (sec^{-1}) = $\frac{\ln 2}{\text{halflife (sec)}}$

t = irradiation time (sec)

Thus, the factor $\frac{m \cdot a \cdot N_o}{A}$ calculates the number of atoms of the element being irradiated; $(1-e^{-\lambda t})$ the saturation factor which is a characteristic of the halflife of the activation product; $\phi_{th}\sigma$ calculates the reaction rate per atom for thermal neutrons; and $\phi_{epi} I$ calculates the reaction rate per atom for epithermal neutrons. (Note: For this work the "thermal" neutron fluence and cross sections are defined as the 2200 m/s fluence and cross sections. Further, caution must be used in calculating the epithermal reaction rate per atom because the resonance integral I is highly dependent on the irradiation facility used.)

The above calculation holds for the normal case of a single activation product. In some cases there are multiple activation products, and more complicated calculations are required. While multiple activation

products will not be discussed in detail here, they have been taken into consideration where appropriate for the calculated activity values contained in this report.

Neutron Energies: Thermal, Epithermal, Fast

Nuclear reactors fueled by uranium-235 are the most common source of neutrons for irradiation. Their neutron energy spectrum consists of three components: thermal neutrons; epithermal neutrons; and fission spectrum (or fast) neutrons. A typical neutron spectrum plot is shown in Figure 1, with the three components clearly shown. The fission spectrum neutrons (or fast flux) are those obtained from the fission process, itself, with little or no moderation or thermalization. As these fast neutrons are moderated or slowed down, they contribute the second component to the spectrum, the epithermal flux. Finally, when the neutrons have been totally thermalized, they have only the normal thermal energy or Maxwellian distribution (thermal neutrons). Different irradiation environments or conditions will result in different ratios of the three components, as can be seen in Figure 2, which shows the neutron energy spectrum for the National Bureau of Standards Reactor (NBSR), pneumatic tube irradiation position RT-4. It is clear that this position is highly thermalized, with very little contribution from fast flux.

While most of the information and cross sections available in the literature have been determined for uranium-235 fission neutrons, the neutron energy spectrum for ^{252}Cf fission neutrons is virtually identically to that from ^{235}U, and thus data from uranium fission neutrons can be correctly applied to californium neutrons and vice versa. In fact, a recent publication, Compendium of Benchmark Neutron Fields for Reactor Dosimetry [1], contains substantial information gained from ^{252}Cf measurements which is used for ^{235}U reactor dosimetry. A comparison between the unmoderated fission spectrum from ^{252}Cf and the unmoderated fission spectrum from U^{235} is taken from this publication and shown as Figure 3, and demonstrates the similarity between these two fission spectra. It should also be obvious that since the neutron energy loss and thermalization processes for the two types of fission spectra are the same, the thermal and epithermal portions of the ^{252}Cf neutron energy spectrum under consideration here will be essentially identical to the ^{235}U data in the literature.

D-D Neutron Generator as a Neutron Source

The deuterium-deuterium (D-D) neutron generator is a small charged particle accelerator, which accelerates charged deuterium atoms to an energy of 150-200 kV and directs them into a deuterium target. The D-D generator is a variation of the better known deuterium-tritium (D-T) neutron generator which produces fast neutrons with an average energy of approximately 14 MeV which are used for a variety of purposes.

The D-D generator utilizes the nuclear reaction:

$$^{2}H + {}^{2}H \rightarrow {}^{3}He + {}^{1}n + 3.266\ MeV$$

with an average neutron energy output of approximately 2.5 MeV in the frontal direction [5]. However, this energy is somewhat variable depending on the neutron direction. For example, at zero degrees from frontal, a 200 kV D-D generator emits neutrons of 3.05 MeV, compared to an energy of 2.10 MeV at 150° from frontal [5]. These neutrons are moderated and thermalized in similar ways to the fission spectrum neutrons discussed above with the advantage that no high energy neutrons above ~ 3.5 MeV are produced. Thus, in the highly thermalizing environment used by the contractor in the explosive detection system (EDS), the neutron energy spectrum experienced by the baggage should not be greatly different from that expected from the ^{252}Cf system. If it is significantly different, the neutron energy measurements which are described below should document any such differences.

Neutron Energy Measurements

Measurements of neutron energies (i.e., thermal, epithermal, fast) with foil techniques are made with several conventions which, while not strictly accurate for all cases, are sufficiently accurate so that exceptions may be neglected. The first convention is that all (n, gamma) nuclear reactions which are due to neutron energies below 0.5 eV (the energy below which 1 mm of Cd absorbs virtually all neutrons; the "cadmium cutoff") are called thermal neutron reactions, and are defined using ϕ_{th} and σ. (Note: An assumption is made here that the thermalization process occurs at roughly room temperature (20 °C, 293 °K) and the neutrons thus have a velocity of approximately 2200 m/s). The second convention is that all (n, gamma) nuclear reactions which occur due to neutrons which are not absorbed by 1 mm of Cd are called epithermal neutron reactions, and are defined using ϕ_{epi} and the resonance integral cross section I. (Note: As mentioned previously, caution must be used when selecting the appropriate resonance integral to match as closely as possible the irradiation environments.) The fast neutrons are characterized by fast neutron reactions such as (n, p), (n, alpha), and (n, 2n). These fast neutron reactions have threshold energies for their production and individual measured or calculated cross sections.

These above conventions are used throughout the nuclear scientific community, and will help to understand the calculations used in Phase 1 of this project as well as the measurement techniques used in Phases 2 and 3.

Calculated Activities

Calculated radioactivities from one pass in a theoretical neutron interrogation system are shown in Table 1. These values are based on a number of assumptions including the neutron fluence rate, the neutron energy spectrum, the effective irradiation time, and on the literature values for nuclear constants. Each of these assumptions is discussed below. A second table (Table 2) lists the 35 nuclear reactions which produce the highest activity levels for one or more of the decay conditions shown. This table will also be discussed more fully below.

The general assumptions used in Table 1 are as follows:

Thermal neutron fluence rate = 1×10^6 n • cm^{-2} sec^{-1}
Epithermal neutron fluence rate = 2×10^4 n • cm^{-2} sec^{-1}
Fast neutron fluence rate = 1×10^5 n • cm^{-2} sec^{-1}
Effective irradiation time = 1 second

The thermal neutron fluence rate and effective irradiation time were chosen to provide a total neutron dose close to, but slightly higher than, the neutron dose information provided by the FAA contractor (SAIC). The best estimate of the contractor for the existing ^{252}Cf system (with two opposed 143 μg sources) was a total average fluence of ~ 5×10^5 neutrons/cm^2 per pass. Thus, the 1×10^6 thermal neutrons for a one second irradiation used in calculations for the theoretical interrogation system as shown in Table 1 should always produce a calculated activity which is somewhat higher than expected in the actual system(s).

The nuclear constants used in these calculations were generally those contained in Erdtmann's Neutron Activation Tables [2]. All activation products with halflives greater than 0.1 second were considered. Initial activities shown in Table 1 were obtained from this compilation, with modifications for the fluence rates given above. In addition, two computer programs were written in the BASIC language on a CP/M microcomputer to calculate initial activities and decayed activities from the basic nuclear constants. Using these computer programs, checks were made of the calculated activities found in Reference 2, and with a few exceptions (most of which were typographical errors in the book) the data agreed very well.

It should also be noted that these calculations assume zero neutron self-shielding effects, which is the appropriate "worst case" assumption. Elements with high neutron cross sections and/or resonance integrals (e.g., greater than ~ 10 barns) begin to see an effect called neutron self-shielding, where the interior of a thick sample "sees" fewer neutrons than the exterior of the sample, due to neutron absorption by the exterior. Thus, one gram of gold in a spherical shape would activate much less than, say, one gram of gold as a thin gold plating on the surface of many articles scattered throughout a container. This effect would reduce the expected activities of many of the activation products listed in Table 1, but is an uncontrollable variable. As a consequence, the zero neutron self-shielding assumption is used.

In Table 1, only reactions which produced initial activities greater than 0.001 Becquerel/gram of element (disintegration/sec/g) are shown. This level was chosen in order to prevent the table from becoming totally useless due to excessive size, yet contain all activities that are significant. The basis for choosing the value of 0.001 Becquerel/g, was the levels of naturally occurring radioactivity found in food. For example, ^{40}K is a naturally occurring radioactive isotope which is contained in essentially all food that we eat. It has an abundance of 0.0117%, a halflife of 1.25×10^9 years, and a high energy gamma-ray line as well. Since ^{40}K

has a specific activity of 838 picocuries/gram of potassium, and, for example, peanuts contain 0.674% potassium [3], one gram of peanuts has 5.65 pCi of ^{40}K or 0.209 Becquerels (dps). It seems reasonable to consider an amount of induced radioactivity equal to 1/100 that contained naturally in a single peanut to be negligible. [It should also be noted that the naturally occurring radionuclides ^{14}C and ^{3}H add a further 50%-100% of dose to that due to the ^{40}K disintegrations in foods.]

The data in Table 1 does not contain information on the type of emissions from the various activation products, because of the varied potential use of this information. Thus, a nuclear reaction which has a relatively high activity level but no gamma-ray emission may be significant for some considerations (e.g., ingestion of food) but not others (e.g., baggage handling). Information on the particle and gamma-ray emission abundances and energies of the various radioisotopes are readily available and can be factored in when this information is required for health physics purposes.

Table 2 contains a listing of the thirty-five activation products from Table 1 whose activity exceeded one of these criteria: >100 Becquerel/g at zero decay; >10 Becquerel/g at 1.0 minute decay; >1 Becquerel/g at 1.0 hour decay. These times were selected to illustrate: at zero decay, the maximum activity produced; at one minute decay, an activity level which may be relevant for baggage handlers; and at one hour decay, most likely the earliest time at which an airline passenger could receive their baggage after completion of a flight. It can be seen from Table 2 that in only three cases, for indium, europium and dysprosium (three relatively rare elements), would the radioactivity induced in a gram of the pure element after 1 hour decay exceed the amount of natural radioactivity in a 2 ounce bag of peanuts. It should also be noted that all of the activities shown in Table 2 were calculated by computer and the results agreed well with the data in Reference 2.

PHASE 2. EVALUATION OF NEUTRON FLUENCE RATES AND ENERGIES IN THE BAGGAGE IRRADIATION SYSTEMS

The second phase consists of a systematic characterization of the actual neutron fluence rates experienced by baggage passing through the two experimental thermal neutron explosive detection systems (EDS). There were a total of four irradiations in the EDS systems to measure the neutron fluences and energies seen by foils passing through the systems. Two irradiations used the ^{252}Cf EDS, and two irradiations used the deuterium-deuterium (D-D) neutron generator EDS system. All irradiations and the results obtained are discussed in detail below, after a brief description of the techniques used for these determinations.

Neutron Measurements Using Foil Techniques

The measurement of a neutron field using the foil activation technique is both relatively simple and fairly accurate. The various elements which may be used as indicator foils undergo nuclear reactions according to the previously described equation when passed through an EDS system or other neutron field, and they are then counted on a calibrated radioactivity detector in order to accurately determine the induced number of disintegrations per unit time.

The equation used earlier in this report for the activation calculations can be rearranged as follows:

$$\phi = \frac{C \cdot A}{m \cdot a \cdot N_o \cdot \sigma (1 - e^{-\lambda t}) \varepsilon G}$$

where:

ϕ = neutron fluence rate ($n \cdot cm^{-2} sec^{-1}$) (for the neutron energy range of interest)

C = net detector counts per second of the gamma-ray of interest corrected for decay, deadtime and pulse pileup (sec^{-1})

A = gram atomic weight of the element

m = mass of element in grams

a = isotopic abundance of target isotope (1.00 = 100% abundance)

N_o = number of atoms/gram atomic weight (6.022×10^{23})

σ = neutron cross section in barns ($10^{-24} cm^2$) (for the neutron energy range of interest)

λ = decay constant (sec^{-1}) = $\frac{\ln 2}{\text{halflife (sec)}}$

t = irradiation time (sec)

ε = detector efficiency for the gamma-ray of interest and the counting geometry used to obtain C

G = gamma-ray abundance (number of emitted γ-rays at the energy of interest per disintegration)

The above equation can be used with the 2200 m/s (thermal) neutron cross section (σ_{th}) and the activity found in a bare foil after subtraction of the activity determined in a cadmium covered foil [$C = (C_{bare} - C_{cd})$] to establish the thermal neutron fluence rate in a system. The same equation can be used with the resonance integral (I) and the activity found in a cadmium covered foil (C_{cd}) to estimate the epithermal neutron fluence rate in a system. However, it should be noted that the epithermal neutron cross sections vary considerably for different elements, and most elements have high resonance absorption peaks in their activation spectrum. Therefore, the uncertainties associated with the epithermal fluence values are correspondingly greater. For fast neutrons, the same equation is used but an entirely different nuclear reaction is used, with a neutron

energy threshold and specific reaction cross section. These calculations are used below to measure neutron fluence rates in the two EDS systems.

The use of multiple foils as was done for the irradiations described later allows an inference of both the thermal and epithermal fluences, based on the following derivation:

Since

$$(\phi\,\sigma)_{total} = (\phi_{th}\,\sigma_{th} + \phi_{epi}\,I)$$

then

$$= \phi_{th}\left[\frac{\phi_{th}\,\sigma_{th} + \phi_{epi}\,I}{\phi_{th}}\right]$$

$$= \phi_{th}\left[\sigma_{th} + \frac{\phi_{epi}}{\phi_{tn}}\,I\right]$$

Therefore, if, as in NBSR RT-4, the $\phi_{epi} = 0.02\ \phi_{th}$ is known, then for a well characterized facility like RT-4 the epithermal contribution can be estimated by $\phi\,\sigma = \phi_{th}\,[\sigma_{th} + 0.02\,I]$, and the thermal fluence can be estimated using a bare foil, by use of the $\sigma_t = \sigma_{th} + 0.02\,I$ relationship [σ_t = total (thermal + epithermal) cross section, in barns].

Thus, the epithermal fluence fraction, ϕ_{epi}/ϕ_{th}, can be roughly estimated by irradiating several elemental foils with differing resonance integral cross sections I, and solving the calculations for various epithermal fractions until the thermal fluence values agree. This was done for the first two irradiations described below, and reasonable values for the epithermal fraction were obtained. In the second two irradiations, actual cadmium covered foil irradiations were made using gold foils and the gold-cadmium ratio determined for both the D-D and ^{252}Cf systems, as well as for several of the NIST nuclear reactor irradiation positions.

Irradiation #1 - Californium - 252 System

The first foil irradiation in an EDS for this project took place on July 6, 1987, using the ^{252}Cf EDS system as set up for testing at the San Francisco airport. A package of three foils, including one each of gold, tungsten and copper, were irradiated by SAIC. The foils were positioned inside a piece of luggage and passed 10 times through the EDS. The ten passes were completed at 22:50 EDT on July 6, 1987, and that time was taken as the effective T_o. Thus all foil activities were decay corrected to that time.

Unfortunately, transfer of the irradiated foils to NIST by SAIC ran afoul of an air flight which was cancelled en route, and so we were not able to obtain the foils until ~40 hours after the end of irradiation. Two of the foils, gold and tungsten, could still be counted. The copper-64 activity, with a 12.7 hour half-life, was not able to

be used. The loss of the copper activity is particularly unfortunate because the small resonance integral for the copper provides a good measure of the thermal neutron fluence without significant activation by epithermal neutrons.

Results obtained from this first irradiation are given in Table 3. As can be seen from this table, the gold and tungsten foil data agree reasonably well, and provide an estimate of the total neutron fluence for the ^{252}Cf system of $\sim 7 \times 10^5$ n • cm^{-2} per pass (±20% relative). Evaluation of the apparent epithermal fraction provided an estimate of 6% epithermal neutrons. This I apparent epithermal fraction has a higher uncertainty than does the second irradiation, because no copper data was available to confirm the true thermal neutron fluence value. Note also that the fluence rate given above is for the date of irradiation only, July 6, 1987, due to the decay of ^{252}Cf with a 2.64 year halflife. (Note: The actual fluence values shown in Tables 2 and 3 have been recalculated using the gold-cadmium ratio data obtained from irradiations 3 and 4. This data now provides an improved evaluation of the epithermal neutron contribution, and this will be discussed more completely under the Neutron Energy Measurements section in this report.)

Irradiation #2 - D-D Neutron Generator System

The second foil irradiation took place in the prototype D-D neutron generator EDS system. The foil samples were irradiated between 15:56 and 19:39 (EDT) on September 21, 1987, by passing them through the EDS system a total of 100 times by the FAA contractor, SAIC. A total of five different foils were used, the copper, gold and tungsten used previously plus foils of nickel and titanium in an attempt to measure the fast neutron fluence.

According to P. Ryge of SAIC, the five foils were kept in the original mailing envelope, placed inside a suitcase near the top, with the remainder of the suitcase filled with "normal" travel items. This suitcase was then passed through the system 100 times over the approximately 4 hour period. The series of passes were expected to be representative of typical neutron exposure in an EDS system.

Since the irradiation process took such a long time (approximately 4 hours) an "average" end-of-irradiation time of 18:00 on September 21, 1987 was used for the calculations. In order to evaluate what effect on the results this long irradiation period might have, a calculation was also made for the hypothetical situation of a continuous irradiation of 4 hours duration. The results of this calculation for copper-64 (the worst case) show only a small effect of about 10% (for copper; less for tungsten and gold), and this data is included with all data from this second irradiation. This small effect was considered to be within the measurement uncertainty, and thus all other calculations assume the single irradiation at 18:00 hours.

The results from this second irradiation are given in Table 4. A transfer time to NIST of approximately 15 hours for the foils permitted measurement of the copper-64 radioactivity, and this provided a better estimate of both the neutron fluence/pass and the epithermal fraction. An estimate of the total neutron fluence for this D-D neutron generator system is about 3×10^5 n • cm^{-2} per pass (±20% relative). Evaluation of the epithermal fraction provides a very approximate value of 5% epithermal neutrons.

Measurement of the radioactivity in the fast neutron foils (nickel and titanium) for irradiation #2 provided no detectable radioactivity above background from fast neutron activation. This is very likely due to the very low fast neutron component in the D-D EDS system. An additional attempt to measure the fast neutron component was carried out in the third irradiation, and is described in that section.

Irradiation #3-D-D Neutron Generator System

The third EDS irradiation took place again in the prototype D-D neutron generator system which was at that time located at the Los Angeles International Airport. The foil samples were fixed to a cardboard holder in a sealed package, which was then placed unopened in a "packed" suitcase and irradiated for 100 passes through the system by SAIC. The irradiations took place between 6:00 and 8:00 pm (EST) on Monday, December 7, 1987. A total of four different foils were in the package (Au, Ni, Cu, W) plus a cadmium covered gold foil. According to P. Ryge of SAIC, the package was handled in a way to be "representative of normal exposure to the baggage transfer EDS systems."

Based on the data developed for irradiation #2 and described there, the end of irradiation time (Tzero) used was 8:00 pm EST, December 7, 1987.

The results from this third irradiation are given in Table 5. Again the transfer time for the foils package to NIST was about 15 hours, providing good counting data for the gold, copper and tungsten foils. The measured total neutron fluence per pass was approximately 2.2×10^5 n•cm^{-2}, with an uncertainty of approximately 20% (relative).

Again, there was no measurable radioactivity above background for the nickel foil, due no doubt to the very small fast neutron component in the EDS systems. A calculation of the minimum radioactivity detectable in the counting system used gave a value of $< 2 \times 10^3$ fast neutrons/pass, which is less than 1% fast neutrons.

A gold-cadmium ratio was measured in this irradiation, and these results will be discussed below under the section entitled Neutron Energy Measurements.

Irradiation #4, Californium-252 System

The fourth and final EDS irradiation of this project took place between 08:47 and 11:25 on March 29, 1988. The sample materials had been sent to P. Rygge of SAIC fixed in position inside of a large corrugated cardboard container. This container is shown schematically in Figure 4, and was the largest possible container still able to fit through the EDS system.

The system used for this fourth irradiation was the ^{252}Cf system, which was set up and working at the San Francisco airport. The box was passed unopened through the system 100 times. A transfer time of approximately 28 hours delivered it to NIST at approximately 16:00 hours, March 30, 1988.

The box contained a total of eight bare gold foils distributed as shown in Figure 4, a ninth gold foil encapsulated in cadmium (0.1 cm thick) for the cadmium ratio measurement, a copper foil, and a set of three small pure bismuth pellets. The large number of gold foils in this irradiation were used to measure the neutron fluence variation throughout the irradiation volume. Positions were selected to represent the extreme locations possible in the EDS systems.

The results from irradiation #4 are given in Tables 6 and 7. Table 6 provides the measured neutron fluence per pass for both copper and gold, and agreement between the two is very good. There is also good agreement with the gold and tungsten fluence values in Table 3, made using only ten passes in the ^{252}Cf system in the first EDS irradiation. Initially, it was puzzling that there did not seem to be an appropriate reduction in the last ^{252}Cf irradiation to account for decay of the sources, but upon calculation, the amount of decay expected is only about 17%, which could effectively be masked due to the large variation of relative fluences in the irradiation container due to position as discussed below (almost 50%).

Table 7 gives the results from the measurement of neutron fluence vs. position in the irradiation container. From this data, it is apparent that the neutron fluence is about 30% higher in the vertical center portion of the irradiation cavity (Figure 4, A-3 to A-5) compared to the vertical sides of the cavity (Figure 4, A-1 to A-2, and A-4 to A-6). The top-to-bottom fluence variation is much smaller, particularly at the edges. It should also be noted that this box was filled with several full boxes of paper towels and some additional crumpled paper towels, to add stability and weight for the handling and irradiation processes. The effective density and composition was estimated to be a little less dense than usual baggage, but not appreciably different from the contents of a suitcase primarily packed with clothing.

Neutron Energy Measurements

Neutron energy characterization was made of the EDS systems by using gold-cadmium ratio measurements for estimating the epithermal neutron fluences and with several attempts at measuring fast neutrons through

use of threshold foils. These two methods are discussed separately below. The cadmium ratio of any element is defined as the ratio of the radioactivity induced in a bare foil of the element to the radioactivity induced in a similar foil of the same element which is located in exactly the same positions, except completely encased with interlocking covers of 1 mm thick cadmium metal. Thus, for gold the cadmium ratio Au(Cd) is defined as:

$$Au(Cd) = \frac{A\phi\ (bare)}{A\phi\ (Cd)}$$

where:

$A\phi$(bare) = saturated activity at zero decay for the bare foil, and

$A\phi$(cd) = saturated activity at zero decay for the cadmium covered foil.

Gold-cadmium ratio measurements were made in irradiations 3 and 4. This information plus similar measurements for three irradiation positions in the NIST nuclear research reactor (fueled by ^{235}U) are shown in Table 8. It should be emphasized that while gold-cadmium ratio and fluence measurements are by far the most commonly used foil measurements in the nuclear field, and the high sensitivity made gold an obvious choice for this EDS study, such measurements are highly dependent upon specific foils used due to neutron self-shielding effects and the very high resonance cross sections for gold-197 (the mono-nuclidic stable isotope of gold). In this study, the gold-cadmium ratio for the ^{252}Cf EDS was very similar to the NBSR RT-3 irradiation facility, and thus the calculated fluence measurements could be compared directly to the known fluence values for this NBSR facility. What was somewhat surprising was that the neutron energy spectrum for the D-D EDS was substantially "harder" (i.e., had more energetic neutrons and a lower Au(Cd) ratio) than that from the ^{252}Cf EDS. When corrected for neutron self-shielding in the gold foils [8], the D-D system measurement indicated that 48% of the neutrons had energies above about 0.5 ev (the cadmium cut-off energy), versus 29% epicadmium neutrons for the ^{252}Cf EDS. (Note: The NBSR RT-3 irradiation facility had 26% epicadmium neutrons.)

In addition to the epithermal (i.e., epicadmium) measurements made with cadmium ratios, measurements were attempted using fast neutron threshold foils of titanium and/or nickel in irradiations number 2 and 3. All such attempts gave results in which the fast neutron product, if present, could not be detected above the background radioactivity, even with very long counts. This was not a surprise since the actual number of fast neutrons above about 2 MeV (the threshold for these fast neutron reactions) was expected to be very small. The data obtained from the best count (from a nickel foil) was used to calculate a "less than" value, which showed that there was $< 2x10^3$ fast neutrons/cm ^{2}/pass (above the 2.2 MeV threshold for this specific nuclear reaction). An actual measurement of the ^{58}Co radioactivity from the $^{58}Ni(n,p)^{58}Co$ nuclear reaction on a nickel

foil irradiated in the NBSR RT-3 facility, when normalized to the 2.2×10^5 n•cm^{-2} expected for a single pass in the D-D EDS, gave a value of 0.001 count/3 hours counting time. Even with 100 passes through the system, the expected 0.1 count/3 hours would be totally lost in the background of the lowest background counting system available. Thus, direct fast neutron measurements using threshold foils are just not possible for either EDS system unless the entire counting system is brought to the EDS system so short-lived radioactivities could be attempted, and possibly could not be measured even then due to absolute sensitivity limitations.

PHASE 3. QUANTITATIVE DETERMINATION OF INDUCED RADIOACTIVITY LEVELS

In order to verify the calculated activity values reported in Phase 1 of this study, actual measured activity levels were determined in elements exposed to the appropriate neutron fluences. This was accomplished using two different methods as described below.

Method 1 entailed the counting of induced radioactivity in pure element foils actually passed through the ^{252}Cf EDS and the D-D EDS. There are very few elements with both the sensitivity and the appropriate halflife to allow such measurements without actually moving an entire germanium detector and counting system to the airport location where the EDS was located. Three elements (copper, tungsten and gold) were used to develop this data, and the results are found in Table 9 (^{252}Cf EDS) and Table 10 (D-D EDS).

In addition, Method 2 was employed. This method utilized the NIST nuclear reactor (NBSR) RT-3 irradiation facility, shown in Table 8 to have neutron fluence characteristics very similar to the ^{252}Cf EDS except that the neutron fluence is about 1.3×10^8 times higher. A sample of well characterized material (NIST Standard Reference Material 1633, Coal Fly Ash), which has a large number of known elemental concentrations was irradiated in RT-3, counted, and the actual induced radioactivities measured were corrected to the 8×10^5 n•cm^{-2} fluence expected for one pass through the ^{252}Cf EDS. These results are found in Table 11 for 13 additional elements.

In all cases the actual measured activity levels found corresponded closely to the expected activity levels as found in Table 1 and shown again in Tables 9 through 11.

In addition to the above, one case merited special consideration. In Table 1, for the element bismuth (Z = 83), a special case is noted in a footnote. This concerns the potential problem of the bismuth-210 activation product decaying to polonium-210, which is an alpha emitter. This would most probably be ignored except that a common over-the-counter medicine contains large quantities of bismuth. Since alpha particles are easily stopped by something as thin as a sheet paper, they are usually only of concern when they may be inhaled (as radon) or ingested through food or medication.

It was therefore thought useful to consider the effect of neutron exposure in an EDS to the production of polonium-210 from bismuth. This was done in two ways: first, a detailed calculation was made following the production of bismuth-210, beta decay to polonium-210, and the alpha decay of polonium-210. Second, several pellets of pure bismuth were irradiated in Irradiation #4, with 100 passes through the ^{252}Cf EDS. This bismuth was then dissolved and the bismuth/polonium precipitated out, recovered, and counted in an alpha detection system.

The results of the above bismuth evaluations indicated that the amount of polonium-210 produced in these EDS systems is minimal. Calculation showed that 100 grams of bismuth passed through a neutron fluence of 1×10^{6} n•cm^{-2} would produce a maximum of 0.0004 decays of polonium-210 per second (d/s). Measurement of the radiochemically prepared bismuth/polonium sample (bismuth weight = 150.6 mg) which had been passed 100 times through the ^{252}Cf EDS gave no alpha counts detected for a 100 minute count, confirming the calculation of minimal production of polonium-210.

CONCLUSION

Although the initial FAA project was for the evaluation and characterization of only the ^{252}Cf EDS, soon afterwards it became apparent that for a substantial portion of the project period only the D-D system was available for irradiations. This, coupled with the expressed interest of FAA in the characteristics of both system, fostered the expansion of the project (with no additional funding) to both the ^{252}Cf and D-D systems as described below.

All three phases of this project as described in the Introduction have been completed. In Phase 1, calculations were made for the neutron irradiation of all elements under conditions similar to that found in the EDS systems, and these data are found in Tables 1 and 2. In Phase 2, the neutron fluence rates, neutron distributions, and neutron energy characteristics of both of the EDS systems were systematically evaluated and data recorded in Tables 3 through 8. In Phase 3, quantitative measurements of induced radioactivity in 16 elements were made and good agreement with the calculated activities from Table 1 found. These data are found in Tables 9 through 11.

The combined information found in this report provides a comprehensive understanding of the neutron irradiation characteristics of these two EDS systems, and provides as well the information necessary to quantitatively evaluate the induced level of radioactivity which would be produced in any specified material passing through a thermal neutron EDS system.

REFERENCES

1. J. A. Grundl and C. M. Eisenhauer, Compendium of Benchmark Neutron Fields for Reactor Dosimetry, NBSIR 85-3151, U. S. Dept. of Commerce, Washington D. C. (1986).

2. G. Erdtmann, Neutron Activation Tables, Verlag-Chemie Publishing Co., NYC (1976).

3. C. T. Young, Nuts, In Kirk-Othmer Concise Encyclopedia of Chemical Technology, Wiley-Interscience Publishing Co., NYC (1985), p. 807.

4. W. N. McElroy, et. al., HEDL Progress Report (October, 1971).

5. S. S. Nargolwalla and E. P. Przybylowicz, Activation Analysis with Neutron Generators, John Wiley & Sons, NYC (1973).

6. ASTM Annual Book of Standards, Volume 12.02, Method E262-86, "Standard Method for Determining Thermal Neutron Reaction and Fluence Rates by Radioactivation Techniques," ASTM, Philadelphia, PA (1987).

7. D.A. Becker and P.D. LaFleur, "Characterization of a Nuclear Reactor for Neutron Activation Analyses," J. Radioanal. Chem. 19, 149-157 (1974).

8. N.P. Baumann, "Resonance Integrals and Self-Shielding Factors for Detector Foils," Report No. DP-817, Savannah River Laboratory (1963).

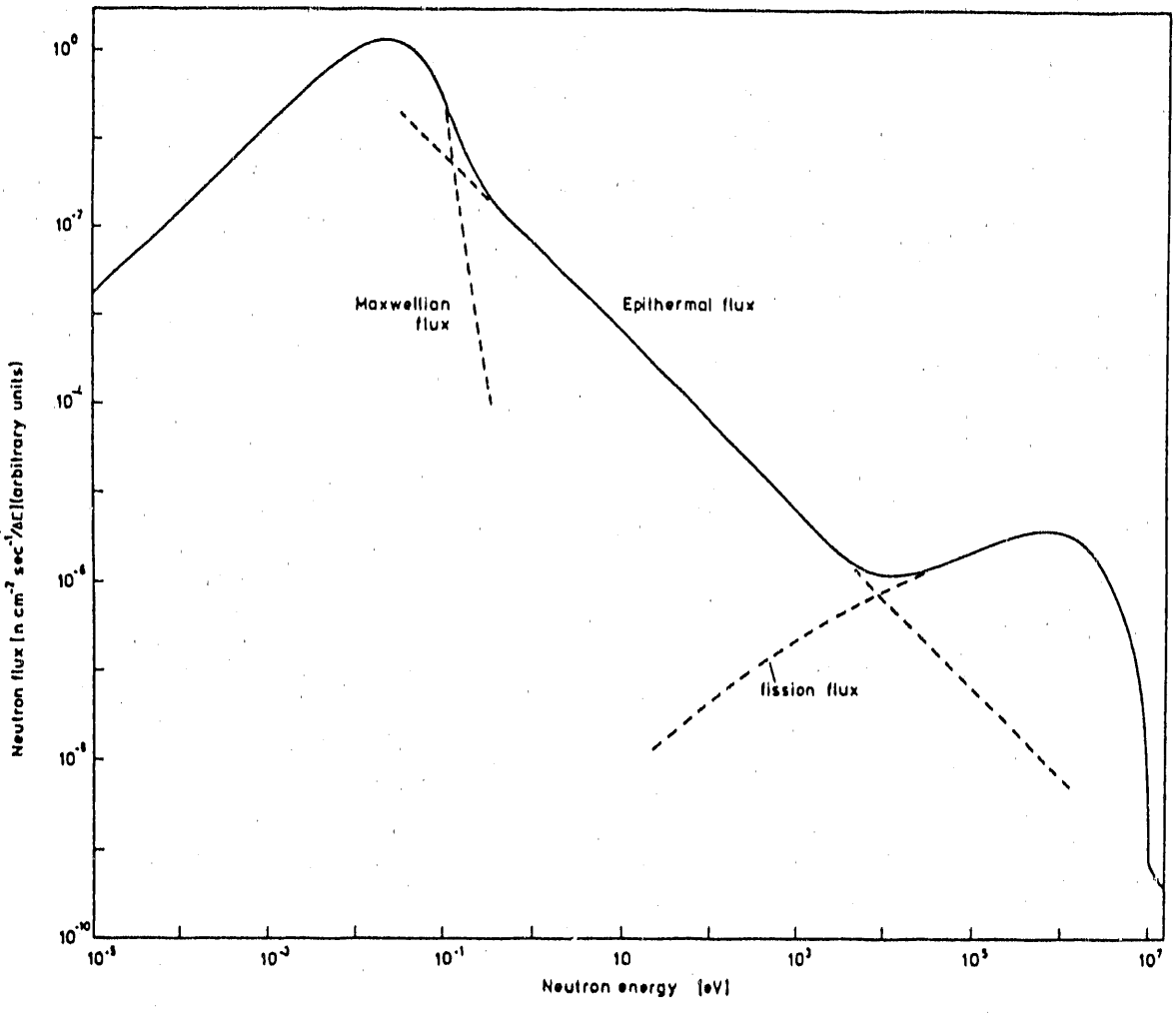


Figure 1. Typical Neutron Spectrum from a U^{235} Nuclear Reactor.

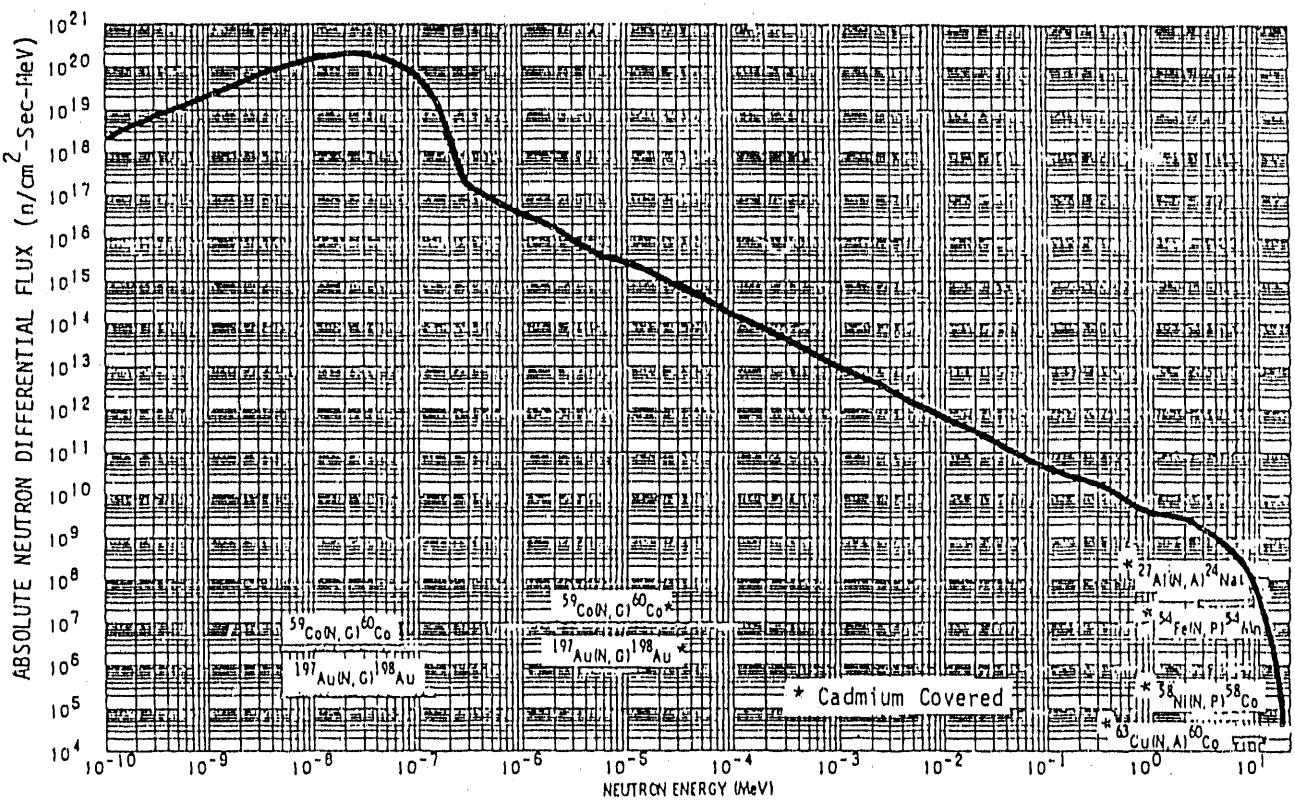


Figure 2. NIST Reactor RT-4 Position. Sand II 5th Iteration Differential Flux Solution [4].

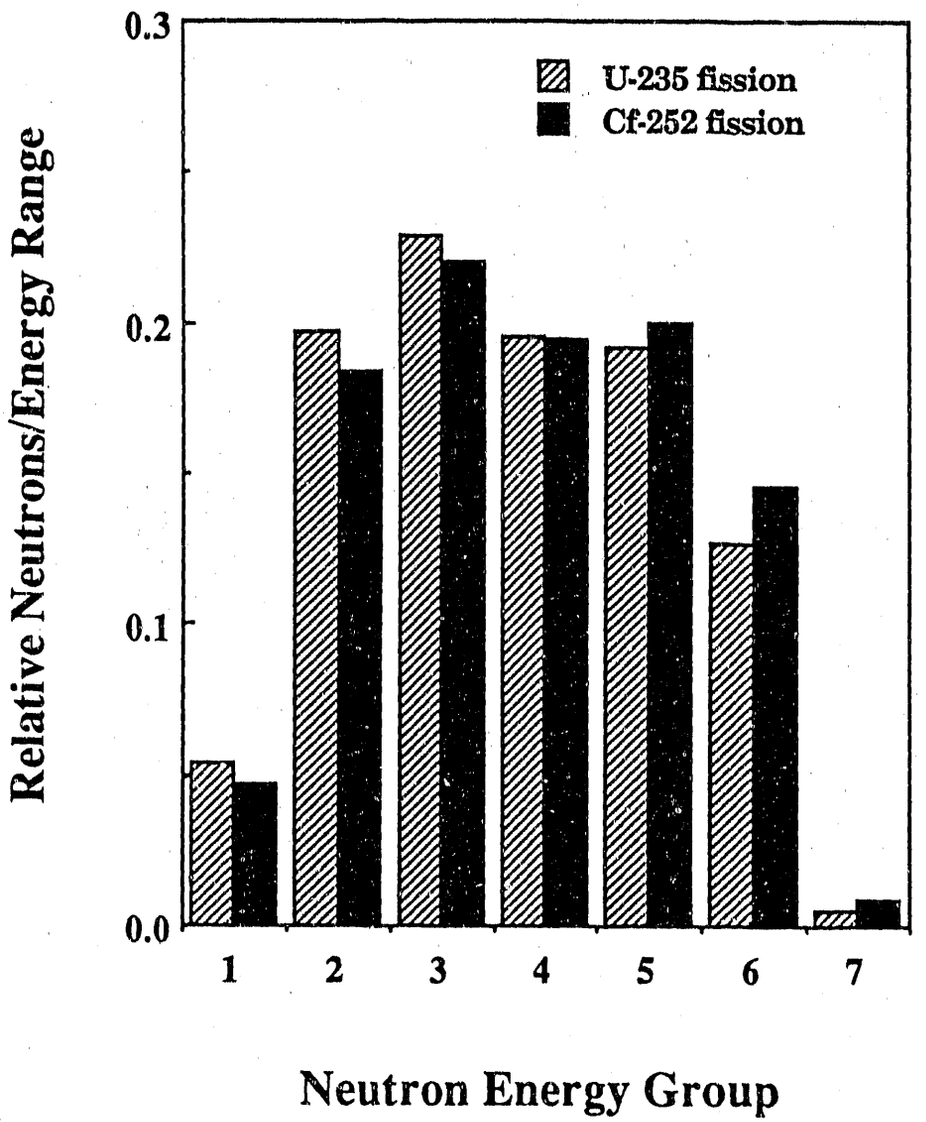


Figure 3. Course Seven Group Display of the Unmoderated Fission Neutron Spectra of Uranium-235 and Californium-252 [1]. (Note: Energy Groups are: 1) 0-0.25 MeV; 2) 0.25-0.8 MeV; 3) 0.8-1.5 MeV; 4) 1.5-2.3 MeV; 5) 2.3-3.7 MeV; 6) 3.7-8 MeV; and 7) 8-12MeV).

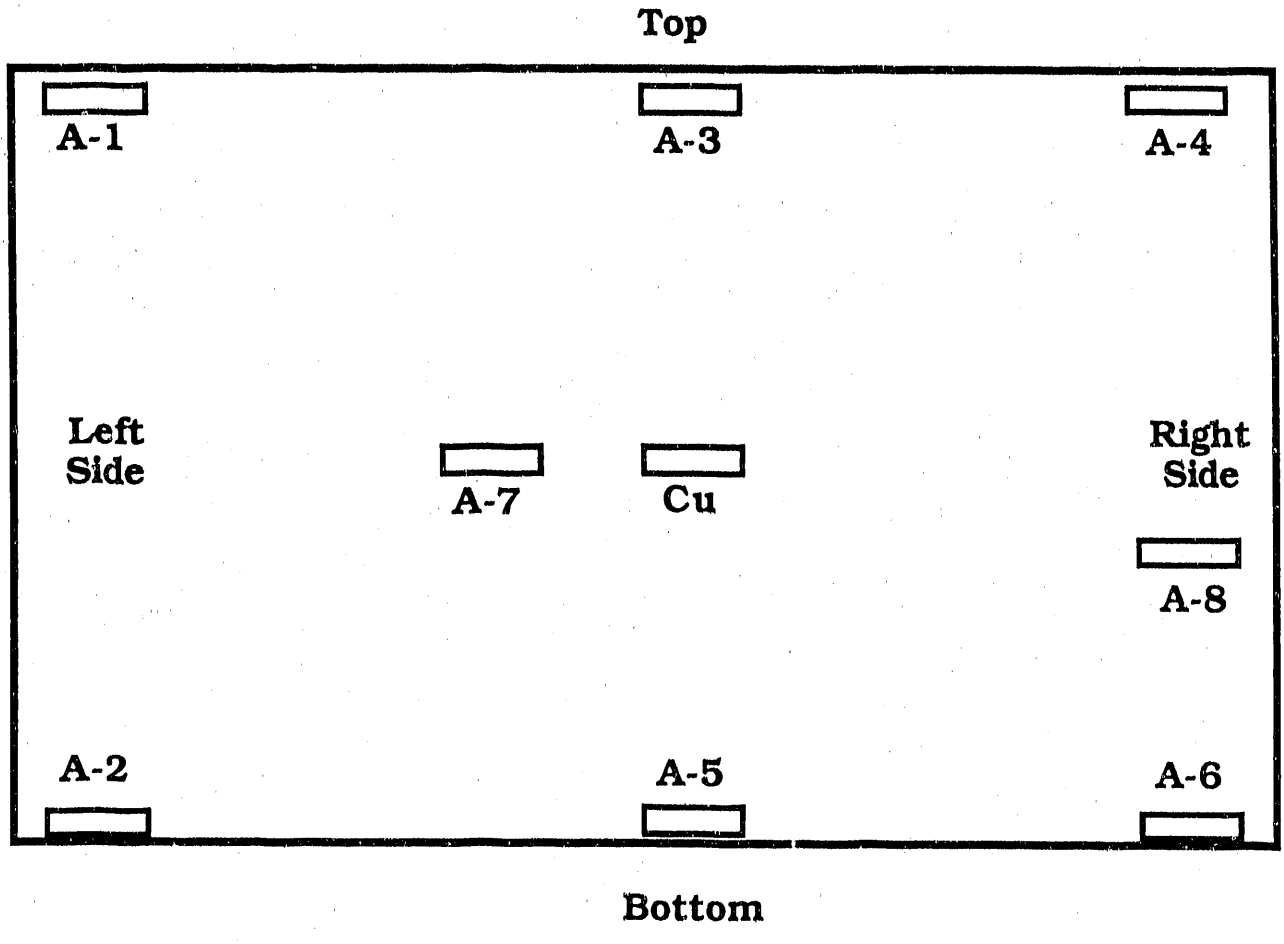


Figure 4. Front View of Container for Irradiation No. 4, Fluence Mapping [Dimensions: 0.406 m (16 in) high; 0.660 m (26 in) wide; approximately 0.762 m (30 in) long]. (See Table 7 for fluence values).

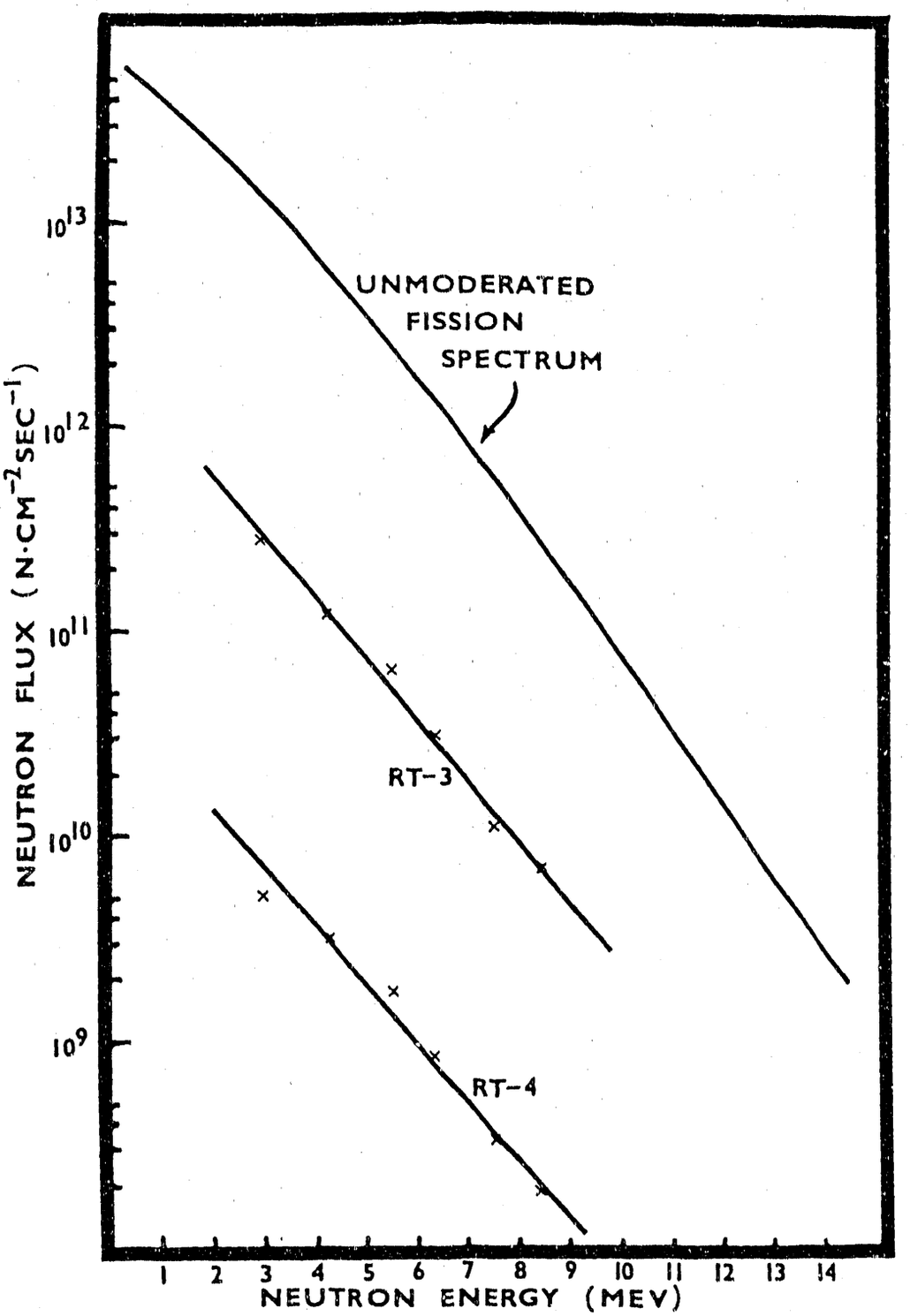


Figure 5. Integral Neutron Fluence Rate for the RT-3 and RT-4 Irradiation Positions in the NIST Nuclear Reactor [Note: Unmoderated Fission Spectrum is that of Uranium-235 (Refernce 7)].

Table 1. Calculated Activities from One Pass in a Neutron Interrogation System

Target		Reaction	Activation Product	Product Halflife	Activity (decays/sec/gram of element)		
Z	Isotope				Initial	1 min decay	1 hour decay
1	Hydrogen		none[a]		*	*	*
2	Helium		none		*	*	*
3	Lithium-6	n,α	Hydrogen-3	12.35 y	0.011	0.011	0.011
4	Beryllium-9	n,α	Helium-6	0.802 s	1280	*	*
5	Boron		none		*	*	*
6	Carbon		none		*	*	*
7	Nitrogen-15	n,γ	Nitrogen-16	7.13 s	0.0004	*	*
7	Nitrogen-14	n,2n	Nitrogen-13	9.96 m	0.0001	*	*
8	Oxygen-18	n,γ	Oxygen-19	27.1 s	0.0004	*	*
8	Oxygen-18	n,α	Carbon-15	2.46 s	0.001	*	*
9	Fluorine-19	n,γ	Fluorine-20	11.0 s	19.7	0.449	*
9	Fluorine-19	n,p	Oxygen-19	27.1 s	0.11	0.024	*
9	Fluorine-19	n,α	Nitrogen-16	7.13 s	2.32	0.007	*
10	Neon-22	n,γ	Neon-23	37.6 s	2.43	0.804	*
10	Neon-20	n,p	Fluorine-20	11.0 s	0.013	*	*
11	Sodium-23	n,γ	Sodium-24	15.02 h	0.180	0.180	0.172
11	Sodium-23	n,p	Neon-23	37.6 s	0.072	0.024	*
11	Sodium-23	n,α	Fluorine-20	11.0 s	0.121	0.003	*
12	Magnesium-26	n,γ	Magnesium-27	9.45 m	0.129	0.120	0.002
12	Magnesium-25	n,p	Sodium-25	60 s	0.002	0.001	*
12	Magnesium-26	n,p	Sodium-26	1.0 s	0.001	*	*

[a]None greater than 0.001 decays/sec/gram of element (<0.001 Becquerel/g)
*Less than 0.001 decays/sec/gram of element (<0.001 Becquerel/g)

Table 1. Calculated Activities from One Pass in a Neutron Interrogation System (Cont.)

Target		Reaction	Activation Product	Product Halflife	Activity (decays/sec/gram of element)		
Z	Isotope				Initial	1 min decay	1 hour decay
13	Aluminum-27	n,γ	Aluminum-28	2.25 m	27.2	20.0	*
13	Aluminum-27	n,p	Magnesium-27	9.45 m	0.011	0.010	*
14	Silicon-30	n,γ	Silicon-31	2.62 h	0.006	0.006	0.005
14	Silicon-28	n,p	Aluminum-28	2.25 m	0.065	0.048	*
14	Silicon-29	n,p	Aluminum-29	6.52 m	0.100	0.090	*
15	Phosphorus-31	n,γ	Phosphorus-32	14.28 d	0.002	0.002	0.002
15	Phosphorus-31	n,p	Silicon-31	2.62 h	0.005	0.005	0.004
15	Phosphorus-31	n,α	Aluminum-28	2.25 m	0.019	0.014	*
16	Sulfur-36	n,γ	Sulfur-37	5.06 m	0.001	0.001	*
16	Sulfur-34	n,p	Phosphorus-34	12.4 s	0.002	*	*
16	Sulfur-36	n,α	Silicon-33	6.3 s	0.001	*	*
17	Chlorine-37	n,γ	Chlorine-38	37.2 m	0.555	0.545	0.181
17	Chlorine-37	n,γ	Chlorine-38m	0.8 s	12.0	*	*
17	Chlorine-37	n,α	Phosphorus-34	12.4 s	0.027	0.001	*
17	Chlorine-35	n,p	Sulfur-35	87.2 d	0.001	0.001	0.001
18	Argon-40	n,γ	Argon-41	1.83 h	1.06	1.05	0.726
19	Potassium-41	n,γ	Potassium-42	12.36 h	0.024	0.024	0.023
20	Calcium-48	n,γ	Calcium-49	8.72 m	0.042	0.039	*
21	Scandium-45	n,γ	Scandium-46	83.8 d	0.022	0.022	0.002
21	Scandium-45	n,γ	Scandium-46m	18.7 s	4825	522.	*
22	Titanium-50	n,γ	Titanium-51	5.76 m	0.357	0.317	*

*Less than 0.001 decays/sec/gram of element (<0.001 Becquerel/g)

Table 1. Calculated Activities from One Pass in a Neutron Interrogation System (Cont.)

Target		Reaction	Activation Product	Product Halflife	Activity (decays/sec/gram of element)		
Z	Isotope				Initial	1 min decay	1 hour decay
23	Vanadium-51	n,γ	Vanadium-52	3.755 m	179.	149.	0.003
23	Vanadium-51	n,p	Titanium-51	5.76 m	0.002	0.002	*
24	Chromium-50	n,γ	Chromium-51	27.71 d	0.002	0.002	0.002
24	Chromium-54	n,γ	Chromium-55	3.56 m	0.322	0.265	*
24	Chromium-52	n,p	Vanadium-52	2.755 m	0.003	0.002	*
25	Manganese-55	n,γ	Manganese-56	2.582 h	11.1	11.1	8.49
25	Manganese-55	n,p	Chromium-55	3.56 m	0.001	0.001	*
26	Iron		none[a]		*	*	*
27	Cobalt-59	n,γ	Cobalt-60	5.272 y	0.002	0.002	0.002
27	Cobalt-59	n,γ	Cobalt-60m	10.48 m	233.	218.	4.40
28	Nickel-64	n,γ	Nickel-65	2.520 h	0.013	0.013	0.010
28	Nickel-58	n,p	Cobalt-58m	8.94 h	0.001	0.001	0.001
28	Nickel-60	n,p	Cobalt-60m	10.48 m	0.001	0.001	*
29	Copper-63	n,γ	Copper-64	12.74 h	0.458	0.458	0.434
29	Copper-65	n,γ	Copper-66	5.10 m	14.7	12.8	0.004
30	Zinc-68	n,γ	Zinc-69	57 m	0.369	0.365	0.178
30	Zinc-68	n,γ	Zinc-69m	13.9 h	0.002	0.002	0.002
30	Zinc-70	n,γ	Zinc-71	2.4 m	0.028	0.021	*
31	Gallium-69	n,γ	Gallium-70	21.1 m	5.43	5.25	0.756
31	Gallium-71	n,γ	Gallium-72	14.10 h	0.259	0.259	0.247
31	Gallium-69	n,α	Copper-66	5.10 m	0.001	0.001	*

[a]None greater than 0.001 decays/sec/gram of element (<0.001 Becquerel/g)
*Less than 0.001 decays/sec/gram of element (<0.001 Becquerel/g)

Table 1. Calculated Activities from One Pass in a Neutron Interrogation System (Cont.)

Target		Reaction	Activation Product	Product Halflife	Activity (decays/sec/gram of element)		
Z	Isotope				Initial	1 min decay	1 hour decay
32	Germanium-70	n,γ	Germanium-71	11.2 d	0.004	0.004	0.004
32	Germanium-74	n,γ	Germanium-75	82.8 m	0.105	0.104	0.064
32	Germanium-74	n,γ	Germanium-75m	48.9 s	6.38	2.73	*
32	Germanium-76	n,γ	Germanium-77	11.30 h	0.001	0.001	0.001
32	Germanium-76	n,γ	Germanium-77m	54.3 s	0.871	0.405	*
33	Arsenic-75	n,γ	Arsenic-76	26.3 h	0.326	0.326	0.318
34	Selenium-76	n,γ	Selenium-77m	17.5 s	568.	52.8	*
34	Selenium-78	n,γ	Selenium-79m	3.89 m	2.15	1.80	*
34	Selenium-80	n,γ	Selenium-81	18.5 m	1.33	1.28	0.140
34	Selenium-80	n,γ	Selenium-81m	57.3 m	0.069	0.068	0.033
34	Selenium-82	n,γ	Selenium-83	22.5 m	0.345	0.335	0.054
34	Selenium-82	n,γ	Selenium-83m	70.0 s	0.040	0.022	*
34	Selenium-77	n,n'	Selenium-77m	17.5 s	1.63	0.151	*
35	Bromine-79	n,γ	Bromine-80	17.4 m	29.1	28.0	2.67
35	Bromine-79	n,γ	Bromine-80m	4.42 h	0.548	0.547	0.468
35	Bromine-81	n,γ	Bromine-82	35.4 h	0.007	0.007	0.007
35	Bromine-81	n,γ	Bromine-82m	6.1 m	23.1	20.6	0.025

*Less than 0.001 decays/sec/gram of element (<0.001 Becquerel/g)

Table 1. Calculated Activities from One Pass in a Neutron Interrogation System (Cont.)

Target		Reaction	Activation Product	Product Halflife	Activity (decays/sec/gram of element)		
Z	Isotope				Initial	1 min decay	1 hour decay
36	Krypton-78	n,γ	Krypton-79	34.9 h	0.001	0.001	0.001
36	Krypton-78	n,γ	Krypton-79m	50 s	0.074	0.032	*
36	Krypton-80	n,γ	Krypton-81m	13.3 s	37.7	1.65	*
36	Krypton-82	n,γ	Krypton-83m	1.86 h	1.74	1.73	1.20
36	Krypton-84	n,γ	Krypton-85m	4.48 h	0.023	0.023	0.020
36	Krypton-86	n,γ	Krypton-87	76 m	0.012	0.012	0.007
37	Rubidium-85	n,γ	Rubidium-86	18.65 d	0.001	0.001	0.001
37	Rubidium-85	n,γ	Rubidium-86m	1.018 m	4.20	2.13	*
37	Rubidium-87	n,γ	Rubidium-88	17.7 m	0.205	0.197	0.020
38	Strontium-84	n,γ	Strontium-85m	67.7 m	0.004	0.004	0.002
38	Strontium-86	n,γ	Strontium-87m	2.81 h	0.044	0.044	0.034
39	Yttrium-89	n,γ	Yttrium-90	64.0 h	0.026	0.026	0.026
39	Yttrium-89	n,γ	Yttrium-90m	3.19 h	0.416	0.414	0.335
39	Yttrium-89	n,n'	Yttrium-89m	15.7 s	3.75	0.265	*
40	Zirconium		none		*	*	*
41	Niobium-93	n,γ	Niobium-94m	6.26 m	3.80	3.40	0.005
42	Molybdenum-92	n,γ	Molybdenum-93m	6.85 h	<0.002	<0.002	<0.001
42	Molybdenum-98	n,γ	Molybdenum-99	66.02 h	0.001	0.001	0.001
42	Molybdenum-100	n,γ	Molybdenum-101	14.6 m	0.135	0.129	0.008
43	Technetium		unstable/not found naturally				
44	Ruthenium-102	n,γ	Ruthenium-103	39.6 d	0.001	0.001	0.001
44	Ruthenium-104	n,γ	Ruthenium-105	4.44 h	0.029	0.029	0.025

*Less than 0.001 decays/sec/gram of element (<0.001 Becquerel/g)

Table 1. Calculated Activities from One Pass in a Neutron Interrogation System (Cont.)

Target		Reaction	Activation Product	Product Halflife	Activity (decays/sec/gram of element)		
Z	Isotope				Initial	1 min decay	1 hour decay
45	Rhodium-103	n,γ	Rhodium-104	42 s	1543.	573.	*
45	Rhodium-103	n,γ	Rhodium-104m	4.35 m	360.	307.	0.025
45	Rhodium-103	n,α	Technetium-100	16 s	0.397	0.030	*
45	Rhodium-103	n,n'	Rhodium-103m	56 m	0.064	0.063	0.030
46	Palladium-106	n,γ	Palladium-107m	21.3 s	0.842	0.119	*
46	Palladium-108	n,γ	Palladium-109	13.46 h	0.337	0.337	0.320
46	Palladium-108	n,γ	Palladium-109m	4.69 m	0.912	0.787	*
46	Palladium-110	n,γ	Palladium-111	22 m	0.088	0.085	0.013
46	Palladium-110	n,γ	Palladium-111m	5.5 h	0.001	0.001	0.001
47	Silver-107	n,γ	Silver-108	2.41 m	509.	382.	*
47	Silver-109	n,γ	Silver-110	24.6 s	8310.	1532.	*
48	Cadmium-106	n,γ	Cadmium-107	6.5 h	0.002	0.002	0.002
48	Cadmium-110	n,γ	Cadmium-111m	48.7 m	0.022	0.022	0.009
48	Cadmium-114	n,γ	Cadmium-115	53.5 h	0.002	0.002	0.002
48	Cadmium-116	n,γ	Cadmium-117	2.6 h	0.002	0.002	0.001
48	Cadmium-116	n,γ	Cadmium-117m	3.4 h	0.001	0.001	0.001
48	Cadmium-112	n,2n	Cadmium-111m	48.7 m	0.004	0.004	0.002
49	Indium-113	n,γ	Indium-114	71.9 s	9.43	5.29	*
49	Indium-113	n,γ	Indium-114m	49.51 d	0.001	0.001	0.001
49	Indium-115	n,γ	Indium-116	14.2 s	1360.	72.7	*
49	Indium-115	n,γ	Indium-116m	54.2 m	129.	127.	59.9
49	Indium-115	n,γ	Indium-116m'	2.16 s	127000	0.001	*
49	Indium-115	n,n'	Indium-115m	4.50 h	0.004	0.004	0.003

*Less than 0.001 decays/sec/gram of element (<0.001 Becquerel/g)

Table 1. Calculated Activities from One Pass in a Neutron Interrogation System (Cont.)

Target		Reaction	Activation Product	Product Halflife	Activity (decays/sec/gram of element)		
Z	Isotope				Initial	1 min decay	1 hour decay
50	Tin-112	n,γ	Tin-113m	20 m	0.018	0.017	0.002
50	Tin-120	n,γ	Tin-121	26.8 h	0.002	0.002	0.002
50	Tin-122	n,γ	Tin-123m	40.1 m	0.012	0.012	0.004
50	Tin-124	n,γ	Tin-125m	9.2 m	0.109	0.101	0.001
51	Antimony-121	n,γ	Antimony-122	2.72 d	0.073	0.073	0.072
51	Antimony-121	n,γ	Antimony-122m	4.2 m	0.708	0.600	*
51	Antimony-123	n,γ	Antimony-124	60.3 d	0.003	0.003	0.003
51	Antimony-123	n,γ	Antimony-124m	93 s	0.842	0.538	*
51	Antimony-123	n,γ	Antimony-124m'	20.3 m	0.013	0.013	0.002
52	Tellurium-126	n,γ	Tellurium-127	9.4 h	0.019	0.019	0.018
52	Tellurium-128	n,γ	Tellurium-129	70 m	0.057	0.056	0.031
52	Tellurium-130	n,γ	Tellurium-131	25.0 m	0.208	0.202	0.039
53	Iodine-127	n,γ	Iodine-128	25.00 m	20.0	19.5	3.79
54	Xenon-124	n,γ	Xenon-125	17.0 h	0.008	0.008	0.008
54	Xenon-124	n,γ	Xenon-125m	57 s	1.7	0.820	*
54	Xenon-126	n,γ	Xenon-127m	72 s	0.014	0.008	*
54	Xenon-130	n,γ	Xenon-131m	11.99 d	0.053	0.053	0.053
54	Xenon-132	n,γ	Xenon-133	5.29 d	0.001	0.001	0.001
54	Xenon-134	n,γ	Xenon-135	9.17 h	0.003	0.003	0.003
54	Xenon-134	n,γ	Xenon-135m	15.3 m	0.001	0.001	*
54	Xenon-136	n,γ	Xenon-137	3.84 m	0.200	0.167	*

*Less than 0.001 decays/sec/gram of element (<0.001 Becquerel/g)

Table 1. Calculated Activities from One Pass in a Neutron Interrogation System (Cont.)

Target		Reaction	Activation Product	Product Halflife	Activity (decays/sec/gram of element)		
Z	Isotope				Initial	1 min decay	1 hour decay
55	Cesium-133	n,γ	Cesium-134	2.06 y	0.002	0.002	0.002
55	Cesium-133	n,γ	Cesium-134m	2.9 h	0.928	0.924	0.731
56	Barium-130	n,γ	Barium-131m	14.6 m	0.009	0.009	0.001
56	Barium-135	n,γ	Barium-136m	0.31 s	131.	*	*
56	Barium-136	n,γ	Barium-137m	2.55 m	0.039	0.030	*
56	Barium-138	n,γ	Barium-139	83.3 m	0.155	0.154	0.094
56	Barium-137	n,n'	Barium-137m	2.55 m	0.500	0.085	*
57	Lanthanum-139	n,γ	Lanthanum-140	40.23 h	0.190	0.190	0.187
58	Cerium-136	n,γ	Cerium-137	9.0 h	0.014	0.014	0.013
58	Cerium-138	n,γ	Cerium-139m	56 s	0.054	0.026	*
58	Cerium-140	n,γ	Cerium-141	32.51 d	0.005	0.005	0.005
58	Cerium-142	n,γ	Cerium-143	33.0 h	0.027	0.027	0.026
59	Praseodymium-141	n,γ	Praseodymium-142	19.16 h	0.343	0.343	0.331
59	Praseodymium-141	n,γ	Praseodymium-142m	14.6 m	13.3	12.7	0.770
59	Praseodymium-141	n,2n	Praseodymium-140	3.39 m	0.012	0.010	*
60	Neodymium-146	n,γ	Neodymium-147	10.99 d	0.007	0.007	0.007
60	Neodymium-148	n,γ	Neodymium-149	1.73 h	0.073	0.073	0.049
60	Neodymium-150	n,γ	Neodymium-151	12.4 m	0.352	0.333	0.034
61	Promethium		unstable/not found naturally				
62	Samarium-152	n,γ	Samarium-153	46.5 h	1.19	1.19	1.17
62	Samarium-154	n,γ	Samarium-155	22.2 m	2.81	2.72	0.432

*Less than 0.001 decays/sec/gram of element (<0.001 Becquerel/g)

Table 1. Calculated Activities from One Pass in a Neutron Interrogation System (Cont.)

Target		Reaction	Activation Product	Product Halflife	Activity (decays/sec/gram of element)		
Z	Isotope				Initial	1 min decay	1 hour decay
63	Europium-151	n,γ	Europium-152	13.4 y	0.020	0.020	0.020
63	Europium-151	n,γ	Europium-152m	9.3 h	132.	132.	123.
63	Europium-151	n,γ	Europium-152m'	96 m	0.921	0.914	0.597
63	Europium-153	n,γ	Europium-154	8.5 y	0.002	0.002	0.002
64	Gadolinium-158	n,γ	Gadolinium-159	18.6 h	0.040	0.040	0.039
64	Gadolinium-160	n,γ	Gadolinium-161	3.7 m	2.19	1.82	*
65	Terbium-159	n,γ	Terbium-160	72.3 d	0.014	0.014	0.014
66	Dysprosium-156	n,γ	Dysprosium-157	8.1 h	0.003	0.003	0.003
66	Dysprosium-164	n,γ	Dysprosium-165	2.35 h	86.2	85.8	64.2
66	Dysprosium-164	n,γ	Dysprosium-165m	1.256 m	16400	9420	6.81
67	Holmium-165	n,γ	Holmium-166	26.8 h	1.98	1.98	1.93
68	Erbium-162	n,γ	Erbium-163	75 m	0.022	0.022	0.013
68	Erbium-164	n,γ	Erbium-165	10.36 h	0.016	0.016	0.015
68	Erbium-166	n,γ	Erbium-167m	2.27 s	4790.	*	*
68	Erbium-168	n,γ	Erbium-169	9.3 d	0.002	0.002	0.002
68	Erbium-170	n,γ	Erbium-171	7.5 h	0.085	0.085	0.077
69	Thulium-169	n,γ	Thulium-170	130 d	0.030	0.030	0.030
70	Ytterbium-168	n,γ	Ytterbium-169	32.02 d	0.005	0.005	0.005
70	Ytterbium-174	n,γ	Ytterbium-175	4.19 d	0.139	0.139	0.138
70	Ytterbium-176	n,γ	Ytterbium-177	1.9 h	0.113	0.112	0.078
71	Lutecium-175	n,γ	Lutecium-176m	3.69 h	4.78	4.77	3.96
71	Lutecium-176	n,γ	Lutecium-177	6.71 d	0.222	0.222	0.221

*Less than 0.001 decays/sec/gram of element (<0.001 Becquerel/g)

Table 1. Calculated Activities from One Pass in a Neutron Interrogation System (Cont.)

Target		Reaction	Activation Product	Product Halflife	Activity (decays/sec/gram of element)		
Z	Isotope				Initial	1 min decay	1 hour decay
72	Hafnium-177	n,γ	Hafnium-178m	4.3 s	110.	0.007	*
72	Hafnium-178	n,γ	Hafnium-179m	18.7 s	2460	2.66	*
72	Hafnium-179	n,γ	Hafnium-180m	5.5 h	0.007	0.007	0.006
72	Hafnium-180	n,γ	Hafnium-181	42.4 d	0.003	0.003	0.003
73	Tantalum-181	n,γ	Tantalum-182	115 d	0.008	0.008	0.008
73	Tantalum-181	n,γ	Tantalum-182m	15.9 m	0.038	0.036	0.003
74	Tungsten-184	n,γ	Tungsten-185m	1.64 m	0.014	0.009	*
74	Tungsten-186	n,γ	Tungsten-187	23.9 h	0.347	0.347	0.337
75	Rhenium-185	n,γ	Rhenium-186	90.6 h	0.362	0.362	0.359
75	Rhenium-187	n,γ	Rhenium-188	16.7 h	1.85	1.85	1.77
75	Rhenium-187	n,γ	Rhenium-188m	18.6 m	2.18	2.10	0.233
76	Osmium-190	n,γ	Osimium-191	15.3 d	0.002	0.002	0.002
76	Osmium-190	n,γ	Osmium-191m	13.0 h	0.119	0.119	0.113
76	Osmium-192	n,γ	Osimium-193	30.2 h	0.017	0.017	0.017
77	Iridium-191	n,γ	Iridium-192	74.3 d	0.090	0.090	0.090
77	Iridium-191	n,γ	Iridium-192m	1.4 m	3120	1900	*
77	Iridium-193	n,γ	Iridium-194	19.38 h	2.73	2.73	2.63
78	Platinum-196	n,γ	Platinum-197	18.3 h	0.006	0.006	0.006
78	Platinum-196	n,γ	Platinum-197m	81 m	0.007	0.007	0.004
78	Platinum-198	n,γ	Platinum-199	30.8 m	0.389	0.380	0.101
78	Platinum-198	n,γ	Platinum-199m	14.1 s	0.383	0.020	*
79	Gold-197	n,γ	Gold-198	2.695 d	1.18	1.18	1.17

*Less than 0.001 decays/sec/gram of element (<0.001 Becquerel/g)

Table 1. Calculated Activities from One Pass in a Neutron Interrogation System (Cont.)

Target		Reaction	Activation Product	Product Halflife	Activity (decays/sec/gram of element)		
Z	Isotope				Initial	1 min decay	1 hour decay
80	Mercury-196	n,γ	Mercury-197	64.1 d	0.042	0.042	0.042
80	Mercury-196	n,γ	Mercury-197m	23.8 h	0.004	0.004	0.004
80	Mercury-198	n,γ	Mercury-199m	42.6 m	0.004	0.004	0.002
80	Mercury-202	n,γ	Mercury-203	46.60 d	0.001	0.001	0.001
80	Mercury-204	n,γ	Mercury-205	5.2 m	0.203	0.178	*
81	Thallium-205	n,γ	Thallium-206	4.2 m	0.651	0.552	*
82	Lead		none[a]		*	*	*
83	Bismuth		none[b]		*	*	*
84	Polonium		unstable/not found naturally				
85	Astatine		unstable/not found naturally				
86	Radon		unstable/not found naturally				
87	Francium		unstable/not found naturally				
88	Radium		unstable/not found naturally				
89	Actinium		unstable/not found naturally				
90	Thorium-232	n,γ	Thorium-233	22.2 m	11.9	11.5	1.83
91	Protactinium		unstable/not found naturally				
92	Uranium-238	n,γ	Uranium-239	23.5 m	10.1	9.81	1.72

[a]None greater than 0.001 decays/sec/gram of element (<0.001 Becquerel/g)
*Less than 0.001 decays/sec/gram of element (<0.001 Becquerel/g)

[b]The special case of ^{209}Bi (n,γ) $^{210}Bi \xrightarrow{\beta^-} {}^{210}Po$ is discussed in the text under Phase 3.

Table 2. Listing of Calculated Activities from Table 1 Having the Highest Activities as Defined in the Text[a]

Target		Activation Product	Product Halflife	Activity (decays/sec/gram of element)		
Z	Isotope			Initial	1 min decay	1 hour decay
4	Beryllium-9	Helium-6	0.802 s	1280	*	*
13	Aluminum-27	Aluminum-28	2.25 m	27.2	20.0	*
21	Scandium-45	Scandium-46m	18.7 s	4825	522	*
23	Vanadium-51	Vanadium-52	3.76 m	179	149	0.003
25	Manganese-55	Manganese-56	2.58 h	11.1	11.1	8.49
27	Cobalt-59	Cobalt-60m	10.48 m	233	218	4.40
29	Copper-65	Copper-66	5.10 m	14.7	12.8	0.004
34	Selenium-76	Selenium-77m	17.5 s	568	52.8	*
35	Bromine-79	Bromine-80	17.4 m	29.1	28.0	2.67
35	Bromine-81	Bromine-82m	6.1 m	23.1	20.6	0.025
45	Rhodium-103	Rhodium-104	42 s	1543	573	*
45	Rhodium-103	Rhodium-104m	4.35 m	360	307	0.025
47	Silver-107	Silver-108	2.41 m	509	382	*
47	Silver-109	Silver-110	24.6 s	8310	1532	*
49	Indium-115	Indium-116	14.2 s	1360	72.7	*
49	Indium-115	Indium-116m	54.2 m	129	127	59.9
49	Indium-115	Indium-116m'	2.16 s	127000	0.001	*
53	Iodine-127	Iodine-128	25.0 m	20.0	19.5	3.79
56	Barium-135	Barium-136m	0.31 s	131	*	*
59	Praseodymium-141	Praseodymium-142m	14.6 m	13.3	12.7	0.770

[a]For Initial Activity, >100 dps/g; for 1 minute decay, >10 dps/g; for 1 hour decay, >1 dps/g.
*Less than 0.001 decays/sec/gram of element (<0.001 Becquerel/g)

Table 2. Listing of Calculated Activities from Table 1 Having the Highest Activities as Defined in the Text[a] (Cont.)

Target		Activation Product	Product Halflife	Activity (decays/sec/gram of element)		
Z	Isotope			Initial	1 min decay	1 hour decay
62	Samarium-152	Samarium-153	46.5 h	1.19	1.19	1.17
63	Europium-151	Europium-152m	9.3 h	132	132	123
66	Dysprosium-164	Dysprosium-165	2.35 h	86.2	85.8	64.2
66	Dysprosium-164	Dysprosium-165m	1.26 m	16400	9420	6.81
67	Holmium-165	Holmium-166	26.8 h	1.98	1.98	1.93
68	Erbium-166	Erbium-167m	2.27 s	4790	*	*
71	Lutecium-175	Lutecium-176m	3.69 h	4.78	4.77	3.96
72	Hafnium-177	Hafnium-178m	4.3 s	110	0.007	*
72	Hafnium-178	Hafnium-179m	18.7 s	2460	2.66	*
75	Rhenium-187	Rhenium-188	16.7 h	1.85	1.85	1.77
77	Iridium-191	Iridium-192m	1.4 m	3120	1900	*
77	Iridium-193	Iridium-194	19.38 h	2.73	2.73	2.63
79	Gold-197	Gold-198	2.695 d	1.18	1.18	1.17
90	Thorium-232	Thorium-233	22.2 m	11.9	11.5	1.83
92	Uranium-238	Uranium-239	23.5 m	10.1	9.81	1.72

[a]For Initial Activity, >100 dps/g; for 1 minute decay, >10 dps/g; for 1 hour decay, >1 dps/g.
*Less than 0.001 decays/sec/gram of element (<0.001 Becquerel/g)

Table 3. Neutron Fluence Results from Irradiation

No. 1 (^{252}Cf)

Element	Activation Product	Foil Weight (g)	Gamma Ray Energy (kev)	Neutron Fluence per pass (n/cm^2)[a]
Gold	^{198}Au	0.7502	411	7.5×10^5
Tungsten	^{187}W	2.9598	479	7.6×10^5

[a]Actual fluence values recalculated from first report using redetermined absolute efficiency values and using the procedure from ASTM Standard Method E262 for gold. This procedure could only be used after the gold-cadmium ratios had been measured. See text under Irradiation #4.

Table 4. Neutron Fluence Results from Irradiation

No. 2 (D-D Generator)

Element	Activation Product	Foil Weight (g)	Gamma Ray Energy (kev)	Neutron Fluence per pass (n/cm^2)[a]
Copper	^{64}Cu	9.294	511	3.0×10^5
	^{64}Cu	9.294	511	2.9×10^{5b}
Gold	^{198}Au	0.7653	411	2.7×10^5
Tungsten	^{187}W	3.332	1497	3.4×10^5

[a]Actual fluence values recalculated from first report using redetermined absolute efficiency values and using the procedure from ASTM Standard Method E262 for gold. This procedure could only be used after the gold-cadmium ratios had been measured. See text under Irradiation #4.

[b]This value calculated for a continuous 4 hour irradiation at lower fluence instead of a single higher fluence irradiation (See text).

Table 5. Neutron Fluence Results from Irradiation

No. 3 (D-D Generator)

Element	Activation Product	Foil Weight (g)	Gamma Ray Energy (kev)	Neutron Fluence per pass (n/cm^2)[a]
Gold	^{198}Au	0.7503	411	1.9×10^5
Copper	^{64}Cu	11.14	511	2.7×10^5
Tungsten	^{187}W	3.331	479	2.0×10^5

Table 6. Neutron Fluence Results from Irradiation

No. 4 (^{252}Cf)

Element	Activation Product	Foil Weight (g)	Gamma Ray Energy (kev)	Neutron Fluence per pass (n/cm^2)[a]
Gold	^{198}Au	0.3148	411	7.9×10^5
Copper	^{64}Cu	7.417	511	7.7×10^5

Table 7. Neutron Fluence vs. Position in ^{252}Cf EDS Using Gold Foils

Foil I.D.	Position in Container[a]	Relative Fluence	Measure Fluence per passs (n/cm^2)
A-1	Top/Left	0.87	6.9×10^5
A-2	Bottom/Left	0.86	6.8×10^5
A-3	Top/Middle	1.13	8.9×10^5
A-7	Middle/Middle	1.00	7.9×10^5
A-5	Bottom/Middle[b]	1.31	10.3×10^5
A-4	Top/Right	0.89	7.0×10^5
A-8	Lower Middle/Right	0.85	6.7×10^5
A-6	Bottom/Right	0.85	6.7×10^5
		Average	7.6×10^5 (±17%)[c]
		Range	6.7×10^5 to 10.3×10^5

[a]See Figure 4 for diagram of positions in container.

[b]This folld had moved somewhat by the time it was received back at NIST. Exact position during irradiation sequence is thus unknown, but fluence value is consistent with the position given here and shown in Figure 4.

[c]Uncertainty value shown is the 1σ standard deviation of all eight foils.

Table 8. Results from Cadmium Ratio Measurements

Irradiation Facility	Gold-Cadmium Ratios (This Study)	Previously Measured Cadmium Ratios (Ref. 7)[a]		
		Gold	Copper	Cobalt
D-D EDS (Irrad. #3)	5.0	----	----	----
^{252}Cf EDS (Irrad. #4)	8.3	----	----	----
NBSR RT-3	9.2	10.3	65	42
NBSR RT-1	18.3	----	----	----
NBSR RT-4	82.7	87	540	390

[a]See text about using caution in comparing different foil element cadmium ratios and even measurements for the same element such as gold when small differences in thickness can produce significant differences in neutron self-shielding factors.

Table 9. Comparison of Calculated and Measured Radioactivities from One Pass in the ^{252}Cf EDS [Irradiations No. 1 (Tungsten) and No. 4 (Gold and Copper)]

Target		Activation Product	Product Halflife	Calculated[a] Initial Activity (d/g/s)	Measured Activity	
Z	Isotope				Initial Activity (d/s/g)	Gamma Ray
29	Copper-63	Copper-64	12.74 h	0.458	0.374	511 keV
74	Tungsten-186	Tungsten-187	23.9 h	0.347	0.217	479 keV
79	Gold-197	Gold-198	2.695 d	1.18	1.08	411 keV

[a]Calculated Initial Activity is that found in Table 1 of this report, calculated for the conditions described (thermal fluence = 1 x 10^6 n·cm^2 per pass). [Note from Table 6 that the ^{252}Cf EDS puts out about 0.8 of this fluence/pass.]

Table 10. Comparison of Calculated and Measured Radioactivities One Pass in the D-D EDS [Irradiation No. 3]

Target		Activation Product	Product Halflife	Calculated[a] Initial Activity (d/g/s)	Measured Activity	
Z	Isotope				Initial Activity (d/s/g)	Gamma Ray
29	Copper-63	Copper-64	12.74 h	0.458	0.127	511 keV
74	Tungsten-186	Tungsten-187	23.9 h	0.347	0.077	479 keV
79	Gold-197	Gold-198	2.695 d	1.18	0.342	411 keV

[a]Calculated Initial Activity is that found in Table 1 of this report, calculated for the conditions described (thermal fluence = 1 x 10^6 n·cm^2 per pass). [Note from Table 5 that the D-D EDS actually puts out only about ¼ of this fluence/pass.]

Table 11. Comparison of Calculated and Measured Radioactivities from One Pass in a Simulated EDS

Target		Activation Product	Product Halflife	Calculated[a] Initial Activity (d/g/s)	Measured Activity[b]	
Z	Isotope				Initial Activity (d/s/g)	Gamma Ray
24	Chromium-50	Chromium-51	27.71 d	0.002	0.003	320 keV
26	Iron-58	Iron-59	44.50 d	<0.001[c]	0.0001	1099 keV
27	Cobalt-59	Cobalt-60	5.272 y	0.002	0.002	1332 keV
30	Zinc-64	Zinc-65	243.9 d	<0.001	0.0001	1115 keV
37	Rubidium-85	Rubidium-86	18.65 d	0.001	0.001	1076 keV
38	Strontium-84	Strontium-85	64.84 d	<0.001	0.00004	514 keV
51	Antimony-123	Antimony-124	60.3 d	0.003	0.002	1691 keV
55	Cesium-133	Cesium-134	2.06 y	0.002	0.002	796 keV
56	Barium-130	Barium-131	11.8 d	<0.001	0.00004	496 keV
63	Europium-151	Europium-152	13.4 y	0.020	0.018	964 keV
63	Europium-151	Europium-152	13.4 y	0.020	0.017	1408 keV
65	Terbium-159	Terbium-160	72.3 d	0.014	0.011	879 keV
72	Hafnium-180	Hafnium-181	42.39 d	0.003	0.003	482 keV
73	Tantalum-181	Tantalum-182	114.5 d	0.008	0.007	1221 keV

[a] Calculated Initial Activity is that found in Table 1 of this report calculated for the conditions described (thermal fluence = 1 x 10^6 n·cm^2 per pass).

[b] In this Table, the measured activity was obtained using the NBSR RT-3 irradiation facility at NIST, which was shown to be very similar to the ^{252}Cf EDS facility (see text). The counting data this obtained was corrected to the experimentally determined ^{252}Cf EDS fluence of 8 x 10^5 n·cm per pass.

[c] Isotopes having calculated initial activities of less than 0.001 decays/gram/second were not included in Table 1, as specified in the text.

NRC FORM 335 (2-89) NRCM 1102, 3201, 3202

U.S. NUCLEAR REGULATORY COMMISSION

BIBLIOGRAPHIC DATA SHEET

(See Instructions on the reverse)

1. REPORT NUMBER (Assigned by NRC, Add Vol., Supp., Rev., and Addendum Numbers, If any.)

NUREG-1396

2. TITLE AND SUBTITLE

Environmental Assessment of the Thermal Neutron Activation Explosive Detection System for Concourse Use at U.S. Airports

3. DATE REPORT PUBLISHED

MONTH	YEAR
August	1990

4. FIN OR GRANT NUMBER

5. AUTHOR(S)

C. G. Jones

6. TYPE OF REPORT

Technical

7. PERIOD COVERED (Inclusive Dates)

1989–February 1990

8. PERFORMING ORGANIZATION – NAME AND ADDRESS (If NRC, provide Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address; if contractor, provide name and mailing address.)

Division of Industrial and Medical Nuclear Safety
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555

9. SPONSORING ORGANIZATION – NAME AND ADDRESS (If NRC, type "Same as above"; if contractor, provide NRC Division, Office or Region, U.S. Nuclear Regulatory Commission, and mailing address.)

Same as above.

10. SUPPLEMENTARY NOTES

11. ABSTRACT (200 words or less)

This document is an environmental assessment of a system designed to detect the presence of explosives in checked airline baggage or cargo. The system is meant to be installed at the concourse or lobby ticketing areas of U.S. commercial airports and uses a sealed radioactive source of californium-252 to irradiate baggage items. The major impact of the use of this system arises from direct exposure of the public to scattered or leakage radiation from the source and to induced radioactivity in baggage items. Under normal operation and the most likely accident scenarios, the environmental impacts that would be created by the proposed licensing action would not be significant.

12. KEY WORDS/DESCRIPTORS (List words or phrases that will assist researchers in locating the report.)

Explosive Detectors
Thermal Neutron Activation
TNA
EDS
Airline Baggage Inspection Systems
SAIC Model EDS-3C
Californium-252
Federal Aviation Administration (FAA)
Concourse Explosive Detectors

13. AVAILABILITY STATEMENT

Unlimited

14. SECURITY CLASSIFICATION

(This Page) Unclassified

(This Report) Unclassified

15. NUMBER OF PAGES

16. PRICE

END

DATE FILMED

10/18/90