NUREG-1405

Inadvertent Shipment of a Radiographic Source from Korea to Amersham Corporation, Burlington, Massachusetts

U.S. Nuclear Regulatory Commission

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ABSTRACT

Amersham Corporation, Burlington, Massachusetts, a licensee of the U.S. Nuclear Regulatory Commission (NRC), authorized to manufacture and distribute iridium-192 and cobalt-60 source assemblies for use in radiography equipment, received a shipment of 14 source changers on March 8, 1990, that were being returned from their product distributor, NDI Corporation in Seoul, Korea. One source changer contained a small sealed source in an unshielded location. Amersham employees retrieved the source, secured it in a hot cell, and notified NRC's Region I. Subsequently, NRC dispatched an Incident Investigation Team to perform a comprehensive review of this incident and determine the potential for exposure to those who handled the source changer and to members of the general public. This report describes the incident and the methodology used in the investigation and presents the Team's findings and conclusions.

THE TEAM MEMBERS

Members of the NRC Incident Investigation Team for the Korean Source Incident on March 8, 1990, are as follows:

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ABBREVIATIONS

AI	Automated Industries
BNL	Brookhaven National Laboratory
CAL	Confirmatory Action Letter
CFR	Code of Federal Regulations
CFS	container freight station
DOT	U.S. Department of Transportation
DU	depleted uranium
ECG	East Coast Group
EST	Eastern Standard Time
HMR	Hazardous Materials Regulations
HMTA	Hazardous Materials Transportation Act
HP	health physicist
IAEA	International Atomic Energy Agency
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IMDG	International Maritime Dangerous Goods
IMO	International Maritime Organization
INC	Industrial Nuclear Company
ISI	International Specialists Incorporated
KINS	Korean Institute of Nuclear Safety
KIT	Korean Industrial Testing Company
LSA	low specific activity
MOST	Ministry of Science and Technology (Korea)
MOU	Memorandum of Understanding
NOS	not otherwise specified
NRC	U.S. Nuclear Regulatory Commission
NVOCC	non-vessel operating common carrier
ORAU	Oak Ridge Associated Universities
PPQ	plant protection quarantine
PST	Pacific Standard Time
RSO	Radiation Safety Officer
S/N	serial number
UN	United Nations
USCG	United States Coast Guard
USDA	U.S. Department of Agriculture
WCG	West Coast Group

GLOSSARY

Activity means a measure of the strength of a radioactive source, measured in units of curies.

Attenuation means reduction of radiation intensity as it passes through any material, for example, lead shielding.

Background radiation means radiation emitted from naturally occurring radioactive materials in the earth or from cosmic rays.

Byproduct material means radioactive material obtained as a byproduct from nuclear reactors.

Cytogenic evaluation means to study blood cells to determine chromosomal aberrations induced by radiation exposure.

Common carrier means a "for-hire" carrier who serves the general public and does not own the material being transported. The carrier is required to obtain operating authority from the Interstate Commerce Commission or equivalent State Utilities Commission and to publish freight rates. Common carriers are exempt from the licensing requirements of the NRC and Agreement States.

Depleted uranium means uranium having a smaller percentage of uranium-235 than found in naturally occurring uranium.

Dose means the amount of radiation absorbed by an object, expressed in roentgen, rem, or rads. Rem is used in this report.

Excepted package means a radioactive material package, which, although still regulated in transportation, is excepted from most requirements, such as marking, labeling, specified packaging, and shipping documentation.

Half-value layer means the thickness of a material that will reduce the amount of radiation passing through the material to one-half of its original intensity.

Hot cell means a shielded box or enclosure for storing and processing radioactive materials that must be remotely handled.

In-bond means storage or shipment in a locked condition with controlled access for United States Customs Service import duty payment considerations.

J-Tube means a shielded tube for housing a source inside of a source changer.

Package means packaging plus radioactive material contents as presented for transport.

Packaging means the assembly of one or more components, less the radioactive contents, which are intended to meet the packaging requirements of the regulations.

Pigtail or source pigtail assembly means the part of a radiography source assembly that includes the source cable and connector but not the source itself.

Placard means a sign that is placed on a vehicle to indicate the hazard classification of the material being transported. The sign bears a symbol, word, and color that are peculiar to the hazard class of material.

Radiography source capsule or source means the small sealed metal capsule containing the radioactive materials that omit the gamma rays used in radiography.

Special Form means radioactive in a form that limits leakage or dispersal of the material, for example, a sealed source.

Source changer means a shielded container with two holes for sources, one containing a new source and one to hold the old source being replaced.

Time and motion study means an evaluation of the proximity and duration that an individual was near a source of radiation for the purpose of estimating radiation exposure.

Wipe test means an evaluation of removable contamination on a surface or object, wherein an absorbent material such as paper or cloth is rubbed across a surface and subsequently analyzed for radioactivity in a counting instrument.

Worst-case scenario means a situation for which it is assumed that no designed or incidental shielding absorbed radiation from the source emitting it.

1 INTRODUCTION

On March 8, 1990, Amersham Corporation (Amersham), Burlington, Massachusetts, a licensee of the U.S. Nuclear Regulatory Commission (NRC), authorized to manufacture and distribute iridium-192 and cobalt-60 source assemblies for use in radiography equipment, received a shipment of 14 source changers that were being returned from their product distributor, NDI Corporation in Seoul, Korea. The source changers, shielded devices used to transport sealed source assemblies, were reported to be empty according to their shipping documentation and the expectation of Amersham, the NRC licensee.

When the devices arrived at Amersham, the wooden crate in which the source changers were shipped had been broken apart, leaving the source changers scattered over the floor of the trailer of the truck in which they had been delivered. One of the units, Serial Number SU-610, exhibited radiation as high as 10 rem per hour at approximately 18 inches from its surface and 150 rem at contact.

After further examination, using proper radiological controls, Amersham's employees discovered that the source changer contained a small sealed source capsule in the unshielded portion of the housing. Using source retrieval techniques and equipment, Amersham employees were able to safely remove the capsule and secure it in a hot cell for evaluation and analysis after which Amersham's Radiation Safety Officer advised NRC's Region I office of the incident.

NRC discovered that the shipment of source changers originated in Seoul, Korea; was transported across that country to Pusan, Korea; was then transported to Los Angeles by ship; and subsequently carried across the United States by a domestic motor carrier. The NRC determined that the potential existed for significant radiation exposure to a variety of individuals, depending on their proximity to the source and their duration of exposure. Consequently, NRC dispatched an Incident Investigation Team (Team) (App. A) to perform a comprehensive review of this event and determine the potential for exposure to those who handled the source changer and to members of the general public who came in close proximity to it.

Section 2 of this report contains a narrative description of the incident and a detailed sequence of events reconstructed from the Team's analysis of personnel interviews, drivers' logs, experimental results obtained by the Amersham Corporation at the Team's request, written correspondence with the involved companies in Hong Kong and Korea and with Korean government officials, simulated situations, and quarantined equipment, including the radiographic source itself. Section 3 describes the methods used by the Team to collect and evaluate information about the event and to identify individuals who might have been in close proximity to the source.

Section 4 chronicles the efforts made to identify the isotopic composition and activity (curie level) of the source or to identify the manufacturer of the source so that information needed for dose estimates could be obtained from those in the best position to provide this information. Sections 5 and 6 present the results of the analysis of potential exposures of individuals and the techniques used to estimate the extent of those exposures.

Section 7 discusses the adequacy of the source changer as a shipping package, and Section 8 analyzes the regulatory requirements over the return of radiographic sources to the United States from a foreign country, as well as their transport within the United States.

Section 9 briefly discusses related events and information, and Section 10 presents the report's findings and conclusions. Iridium-192 and the properties related to its use in radiographic sources are described in Appendix B.

2 INCIDENT NARRATIVE AND CHRONOLOGY

This section describes the sequence of events that pertains to the accidental shipment of an approximate 3-curie, iridium-192 sealed source from Seoul, Korea, to Burlington, Massachusetts, between January 20 and March 8, 1990. Events preceding the actual shipment are also described to more fully explain the occurrence and better characterize casual factors.

The Incident Investigation Team (Team) obtained its knowledge of events in South Korea from responses to inquiries from the following organizations:

Amersham Corporation, Burlington, Massachusetts;

International Atomic Energy Agency, Vienna, Austria;

Fidelity Transport, Incorporated, Norwalk, California;

NDI Corporation, Seoul, Republic of Korea, through Amersham Corporation, Hong Kong and Burlington, Massachusetts;

Ministry of Science and Technology and the Korean Institute of Nuclear Safety, Seoul, Republic of Korea; and

U.S. Department of State, Washington, D.C.

The Team obtained information about the effect of this incident in the United States from direct investigation, independent measurements, and interviews with the persons involved. Additionally, the following organizations provided information and assistance:

U.S. Customs Service (Port of Los Angeles and Long Beach, California, and the Boston Logan Airport, Massachusetts, and Nogales, Arizona);

U.S. Coast Guard (Marine Safety Office, Los Angeles and Long Beach, California);

U.S. Department of Transportation, (Office of Hazardous Materials Transportation and the Office of Enforcement, Washington, D.C.); and

Amersham Corporation, Burlington, Massachusetts.

For a detailed, day-by-day chronology of this incident, beginning with the date of the original shipment of the source by its manufacturer, see Appendix C, Event Chronology Table.

2.1 Incident Events in the Republic of Korea

On April 18, 1989, the Industrial Nuclear Company (INC), San Leandro, California, shipped an iridium-192 radiography source (certified as 56 curies on April 13,

1989) to their distributor, Boo Kyung Sa, Ltd., Seoul, Korea (Fig. 2.1). The source was shipped in a Model Ir-50 source changer, certified by the U.S. Nuclear Regulatory Commission (NRC) as a Type B package for shipments of iridium-192 in special form, not to exceed 120 curies. On April 24, 1989, Boo Kyung Sa, Ltd., provided the source to Korea Industrial Testing Company (KIT), Seoul, Korea, for use in an industrial radiography camera (Refs. 1, 2, and 3).

According to the Radiation Safety Officer (RSO) at INC, some Korean companies often remove "depleted" sources from radiography cameras and store them in source changers until radioactivity in the sources has decayed sufficiently to allow their disposal. The RSO said that INC has never had a source returned from any of its customers in the Republic of Korea.

Amersham Corporation's (Amersham) Korean distributor, NDI Corporation, also supplies radiographic sources to the KIT. Amersham Corporation supplied a Model 500-SU source changer (Fig. 2.2) containing a 64-curie Model G-3 iridium-192 radiography source through NDI to KIT on October 31, 1989 (Ref. 4). The RSO at Amersham indicated that their company ships approximately 20 sources a month to NDI Corporation.

The information that Amersham gave to the Team indicates that KIT later used the Model 500-SU source changer as a storage container for depleted sources after the new Model G-3 source was removed for installation in an exposure device. One of the depleted sources included INC source No. 1062. A KIT employee failed to remove the source when the source changer was returned to NDI Corporation for shipment to Amersham Corporation in Burlington, Massachusetts.

The Korean Institute of Nuclear Safety (KINS) and Ministry of Science and Technology (MOST) reviewed the activities that occurred in Korea related to this incident and determined that events occurred in the Republic of Korea in the following sequence (Refs. 6 and 7). Corroborative details were provided by the Daeil Shipping Company of Seoul, Korea, a Non-Vessel Operating Common Carrier (NVOCC), through its agent in the United States, Fidelity Transport, Incorporated, also an NVOCC (see Ref. 4).

On or about January 18, 1990, KIT gave one source changer (a Model 500-SU, Serial Number (S/N) SU-610) to a representative from NDI Corporation to be returned to Amersham Corporation. Neither NDI nor KIT surveyed the changer for radioactivity because they believed it to be empty.

The NDI representative transported the source changer back to NDI Corporation in the trunk of his car. It was then stored with other source changers in a storage area at NDI's facility, known as the RI storage area, until January 20, 1990. Surveys of the RI storage area conducted by NDI on that date indicated radiation levels of between 0.03 and 0.5 millirem per hour. Natural background radiation levels are usually between 0.02 and 0.05 millirem per hour. Surveys on various surfaces of the source changers indicated radiation readings of between 0.9 millirem and 1.2 millirem per hour. Usual radiation levels measured on the depleted uranium (DU) in source changers is between 0.2 millirem and 3.0 millirem per hour (Refs. 8 and 9). DU is used as shielding material for source changers because of its high density.

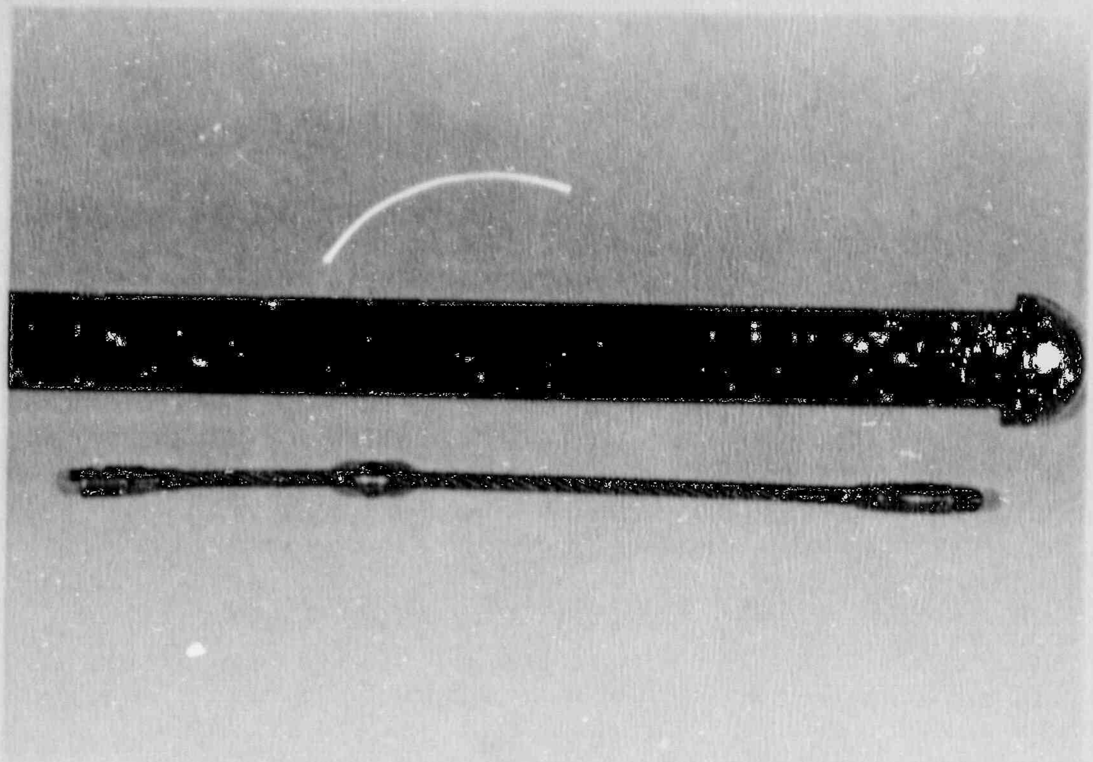

Figure 2.1 Industrial Nuclear Corporation Radiographic Source on Pigtail

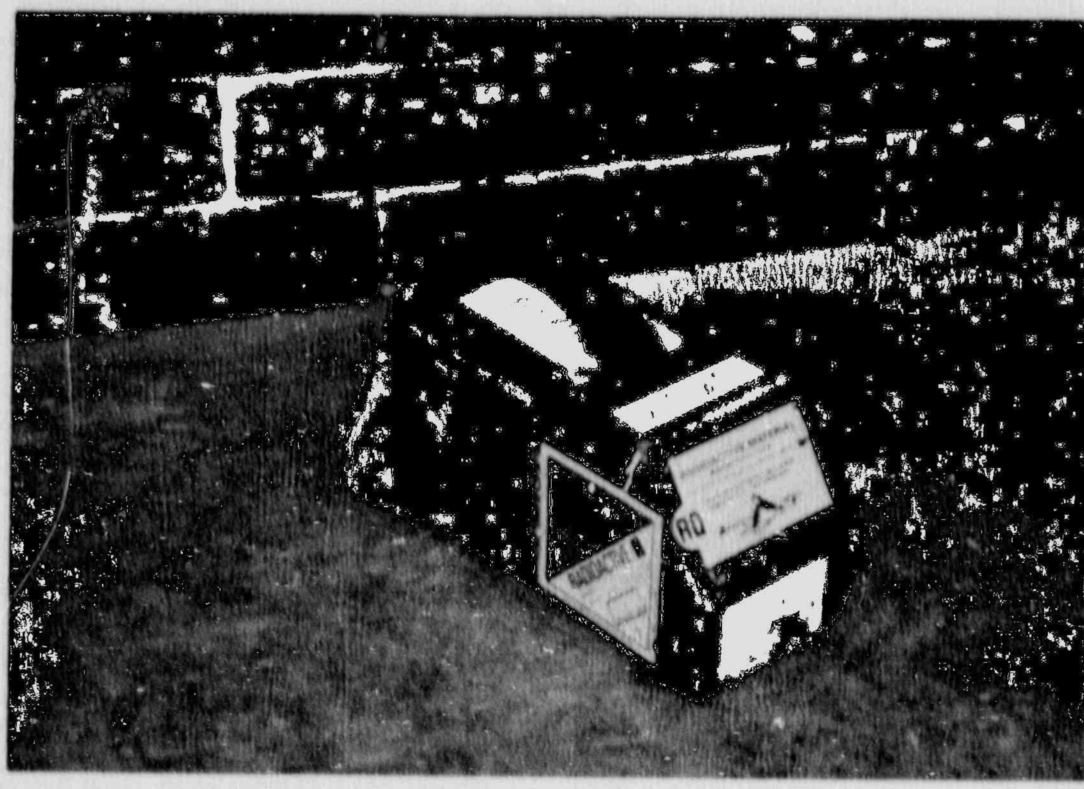

Figure 2.2 Model 500-SU Source Changer

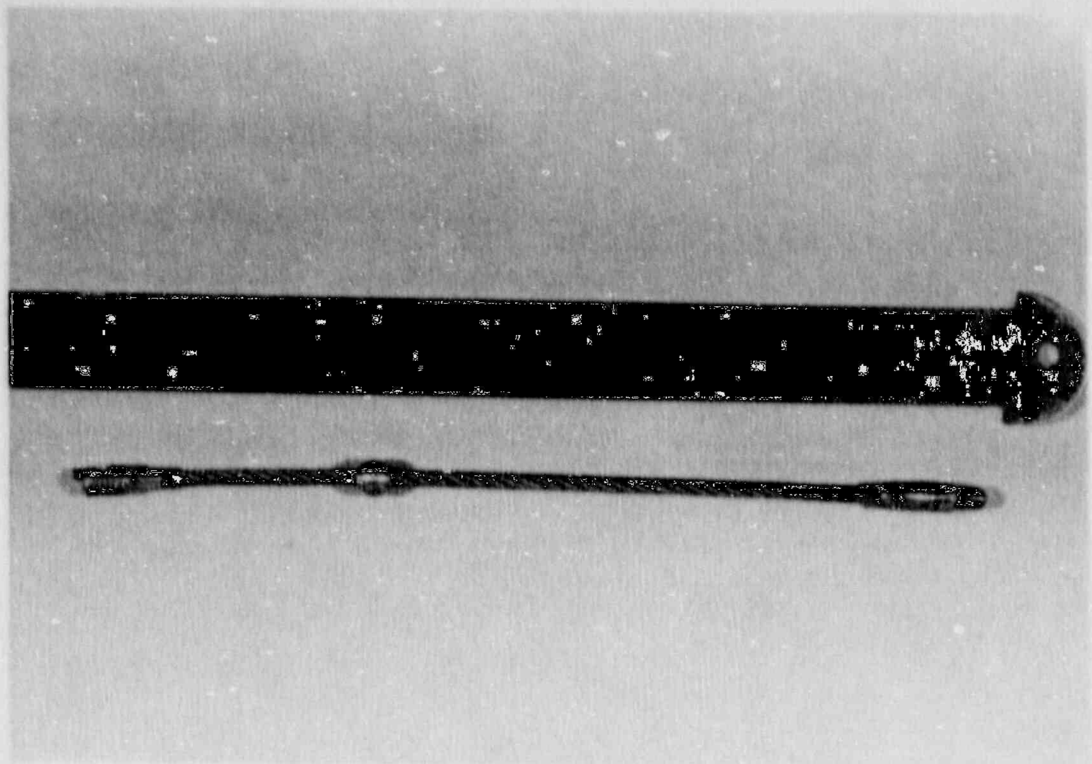

Figure 2.1 Industrial Nuclear Corporation Radiographic Source on Pigtail

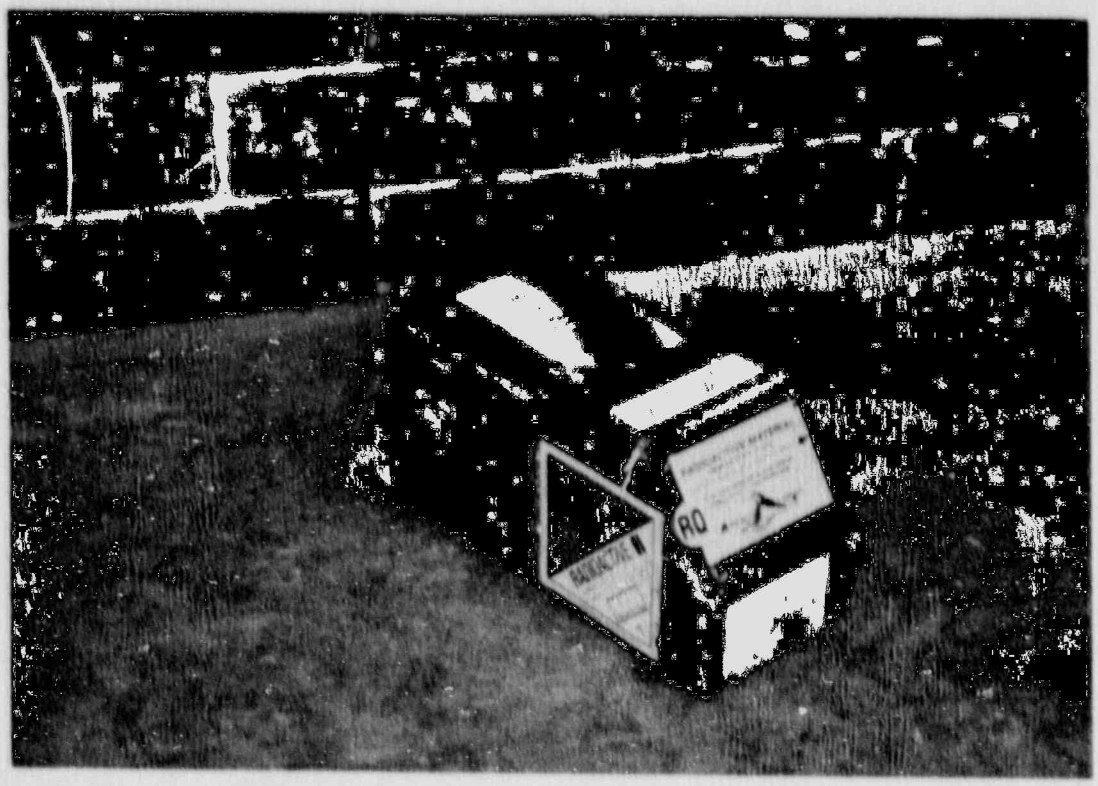

Figure 2.2 Model 500-SU Source Changer

On January 20, 1990, the source changer taken from KIT, and 13 other changers, were trucked by Daeil Shipping Company to the U-Jin Packing Company in Seoul, where the U-Jin Packing Company made a wooden crate to hold the source changers. On January 21, 1990, the crate with 14 source changers enclosed, was trucked to Pusan, Korea, and delivered to the Dongbu Express Company's Container Freight Station on January 22, 1990 (Ref. 10).

On January 28, 1990, Dongbu Express Company placed the crate in a transoceanic shipping container and loaded it aboard the S.S. HANJIN MOKPO, a South Korean ocean container cargo ship. On January 29, 1990, this ship departed Pusan for Los Angeles, California (Refs. 10 and 11). The ship arrived off the Los Angeles-Long Beach harbor on February 9, 1990. It did not arrive in port until February 11, 1990, because of a labor action that involved marine pilots and the unavailability of a berth for docking at Hanjin's Los Angeles terminal (Ref. 11).

The crew of the vessel consisted of 26 officers and seamen. The ship was carrying 14,233 tons of general containerized cargo. The crate containing the source changers was located in container No. HJCU704673-1, which was stored in ship's Bay No. 30, 8 feet above deck level, starboard side, directly in front of the ship's superstructure (Figs. 2.3 and 2.4) (Refs. 12 and 13).

In a meeting with NRC management and Team personnel on March 21, 1990, representatives from KINS and MOST stated that they traced the route of the source changer in Korea and evaluated those individuals that may have been exposed to radiation at the Korea Cancer Center Hospital, Seoul, Korea. No personnel exposures were identified. Consequently, the Korean authorities speculated that the source was probably located within the DU shield when the representative from the NDI Corporation obtained the source changer from KIT on January 18, 1990, and that the source probably remained shielded until it arrived at Pusan (see Ref. 7).

In response to inquiries from the U.S. Department of State, KINS and MOST representatives theorized that because the wooden crate containing the 14 source changers was damaged when it arrived in Los Angeles, the damage may have been sustained when the crate was being loaded into the ocean container in Pusan. Under this supposition, the Korean authorities speculated that impact substantial enough to damage the crate may have been sufficient to knock the source out of its shielded position (Ref. 14).

As of March 21, 1990, the Korean authorities indicated that their investigation was still in progress and that they would evaluate the potential for radiation exposure of the S.S. HANJIN MOKPO's 26-person crew.

In response to U.S. State Department communications (cables dated March 12, 21, 26, and 28, 1990) through the U.S. Embassy-Seoul, the government of the Republic of Korea indicated that they are preparing a report about their investigation of this matter (Refs. 15, 16, 17, and 18).

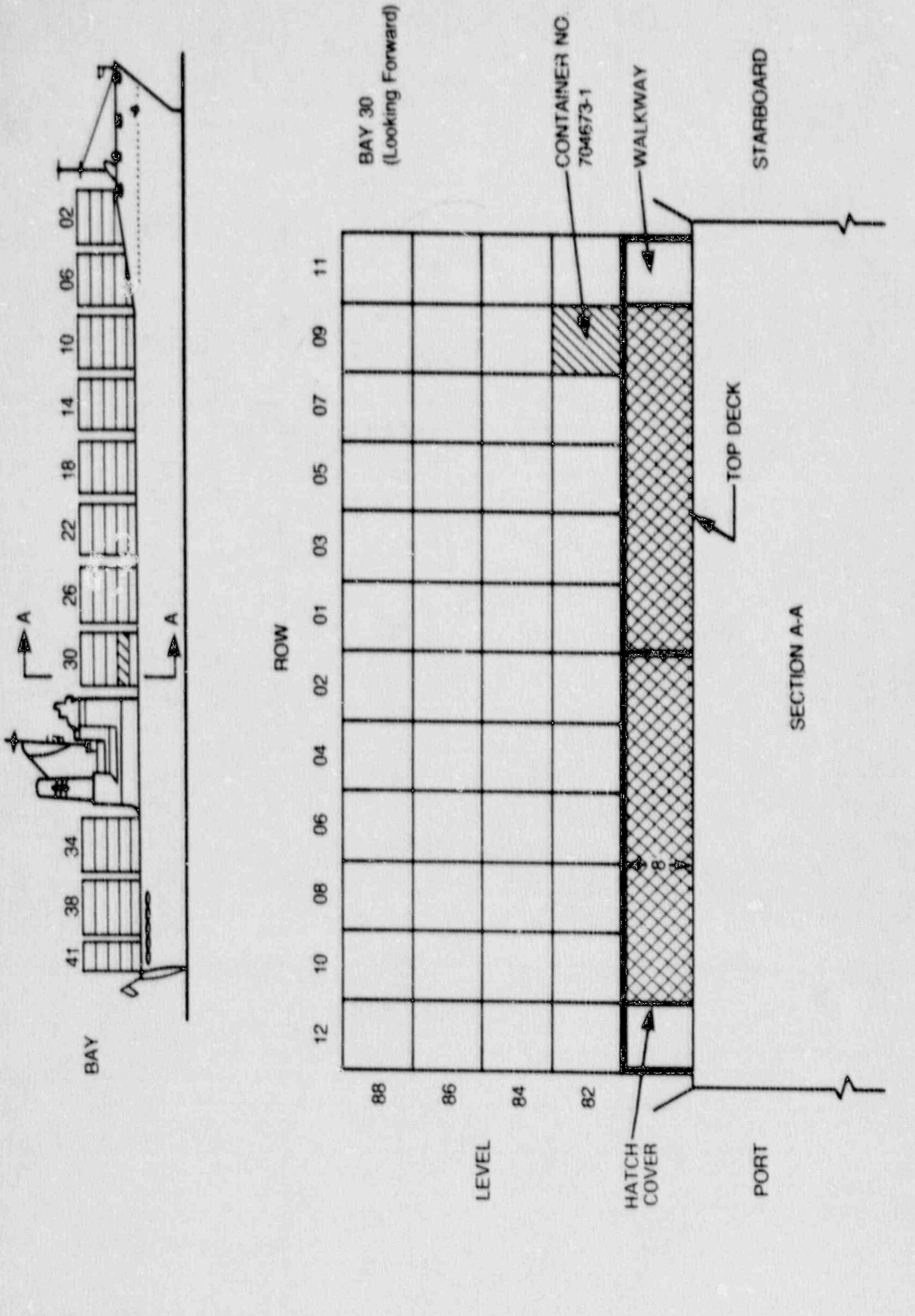

Figure 2.3 SS. HANJIN MOKPO General Storage Plan

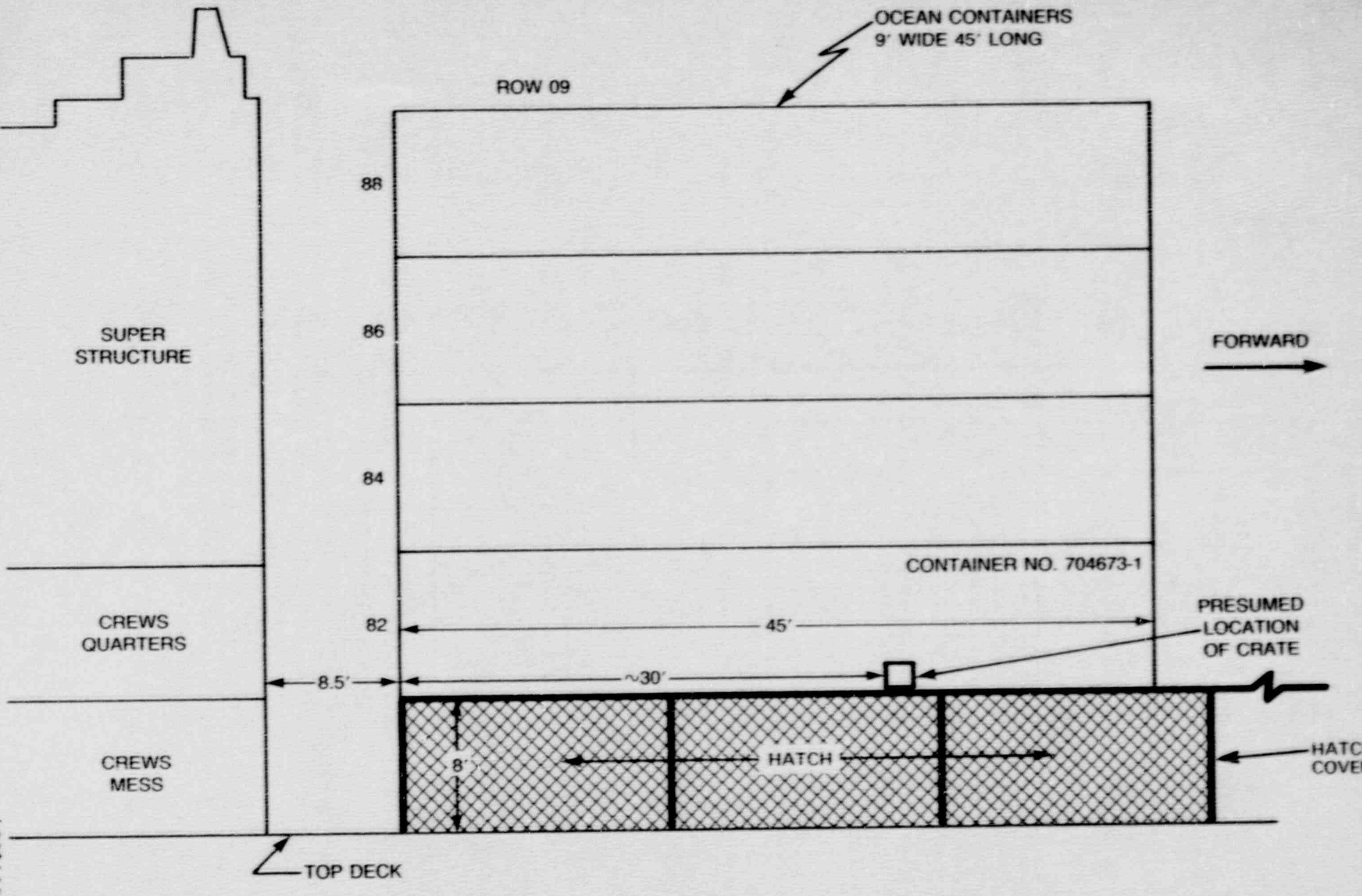

Figure 2.4 SS. HANJIN MOKPO Bay 30, Row 9

2.2 Incident Events in the United States

At 6:05 a.m.* on February 11, 1990, the S.S. HANJIN MOKPO docked in Hanjin's Berth 127 at the Port of Los Angeles (Fig. 2.5) (see Refs. 11 and 13). At 6 p.m. PST, workers began to unload the ocean containers from the ship. The ocean container carrying the damaged crate with the 14 source changers was unloaded at approximately 2 a.m. PST, February 13, 1990, and placed on a container trailer-chassis (Fig. 2.6) (Ref. 19).

The Hanjin Shipping Company's bill of lading indicated that the container housed several items of cargo, including an item identified as "1 BOX RADIOISOTOPES." The Commercial Invoice and the Packing List (Ref. 20) identified the shipper as NDI Corporation and the consignee as Amersham Corporation in Burlington, Massachusetts. A rider attached to the bill of lading (see Ref. 19) described the freight as, "1 Box, 371 KGS, .23 CBM, Said to contain: 14 ea of transportation empty container of radioisotopes--Model SU 500, S/N 547, 666, 527, 610, 618, 530, 556, 517, 522, 518, 689, 660, 699, 559." These devices, described as empty containers, were later identified as Amersham/Automation Industries Model 500-SU source changers. Such devices are approved by NRC Certificate of Compliance 9006 for the shipment of sealed-source iridium-192 in quantities not to exceed 120 curies.

The container and trailer chassis unit were placed in Storage Position J-053 at Hanjin's Los Angeles-Long Beach port terminal facility, roughly in the middle of the large storage area, and away from personnel traffic and buildings (Fig. 2.7). The container remained stored at that location until 9 a.m. PST, February 14, 1990, when it was picked up by Nova Transportation Services Company and transported to Nova's Container Freight Station (CFS), 355 West Carob Street, Compton, California, approximately 20 miles from the terminal facility.

Between 10 a.m. and 12 noon PST, February 14, 1990, the container was opened and the cargo removed. After removal, the crate containing the source changers was stored in Nova's CFS warehouse at Storage Space No. 28, a location approximately 30 feet from the warehouse's trailer loading area (Figs. 2.8 and 2.9). Nova's cargo receipt documentation stated that the crate was damaged when it was removed from the ocean container (Ref. 21).

U.S. Customs Service Officials did not inspect the crate upon its entry into the United States. According to the form "U.S. Customs Transportation Entry and Manifest of Goods Subject to Customs Inspection," the crate was considered to be an "in-bond" shipment to Boston, that is, to be transported by a bonded carrier and restricted from delivery to the final consignee until cleared by U.S. Customs Service in Boston, Massachusetts (Ref. 22).

At approximately 6 p.m. PST, February 16, 1990, the crate and other freight to be delivered to eastcoast destinations were loaded and sealed aboard an enclosed 48-foot trailer, in the reverse order of its planned delivery to facilitate unloading. The crate containing the source changers was the first item loaded into the trailer because its destination, Boston, was the final discharge point. The crate was positioned in the front-right corner of the trailer (Fig. 2.10).

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* All times given in this section are local times unless otherwise specified.

Figure 2.5 An HANJIN Ship at Berth with Containers

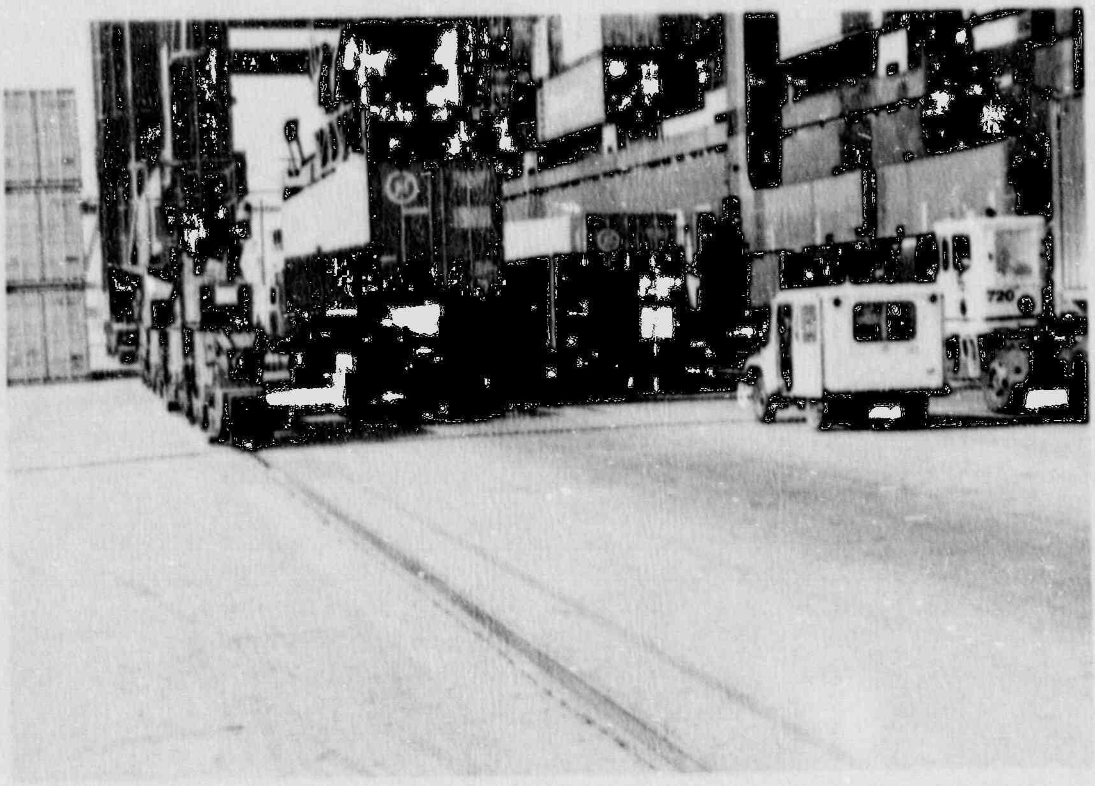


Figure 2.6 Container Trailer-Chassis in HANJIN Dock, Los Angeles-Long Beach

Figure 2.5 An HANJIN Ship at Berth with Containers

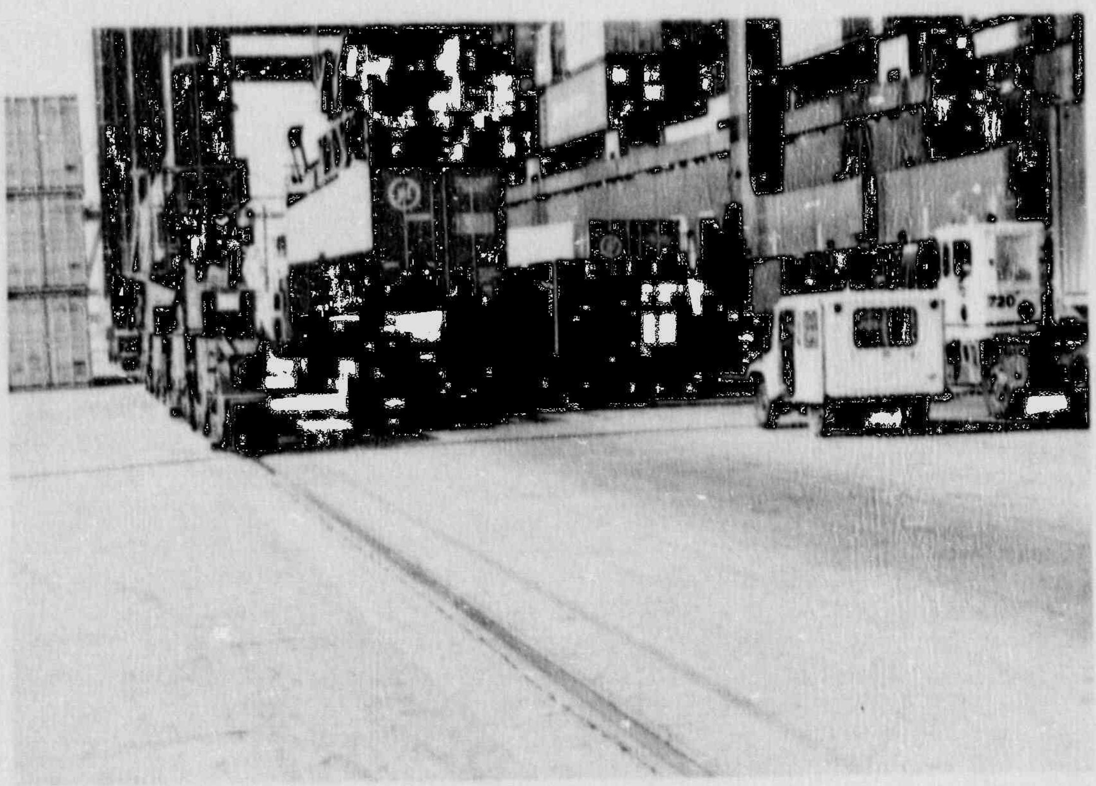


Figure 2.6 Container Trailer-Chassis in HANJIN Dock, Los Angeles-Long Beach

Figure 2.7 Container Storage Area J-53, Los Angeles-Long Beach

Figure 2.8 View From Location No. 28 in Nova Warehouse Toward Shipping Clerk Desk

Figure 2.9 Nova Storage Location No. 28

Figure 2.7 Container Storage Area J-53, Los Angeles-Long Beach

Figure 2.8 View From Location No. 28 in Nova Warehouse Toward Shipping Clerk Desk

Figure 2.9 Nova Storage Location No. 28

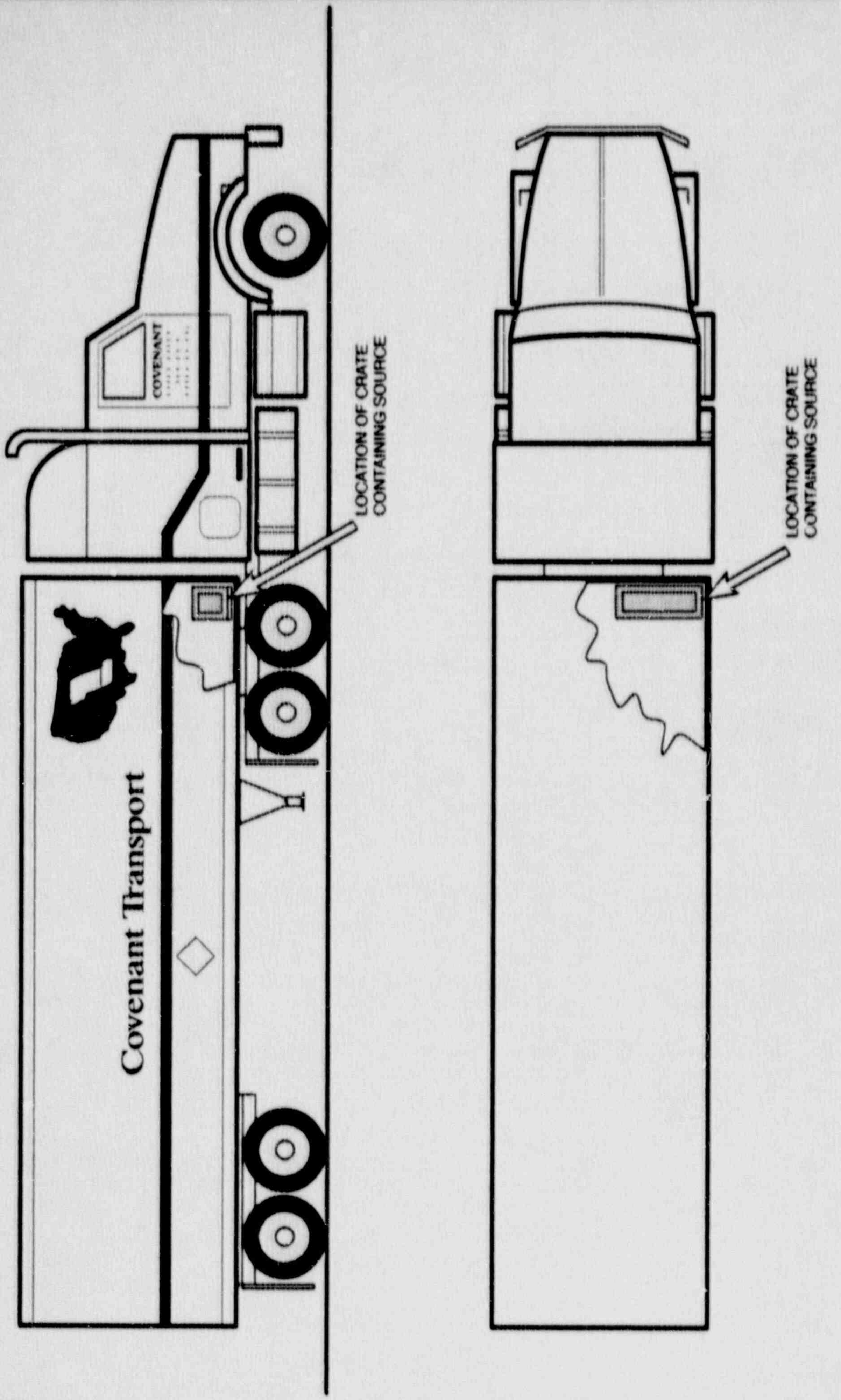


Fig. 2.10 Covenant Truck Showing Location of Source Crate in the Trailer.

Transport documentation (Ref. 23) indicated that the trailer contained four separate freight consignments to be discharged, respectively, at --

1. Nu Tranz Freight Systems, Inc., 119 McLaughlin Road, Coraopolis, Pennsylvania;

2. Port East Transfer, Inc., 1801 South Clinton Street, Baltimore, Maryland;

3. Evans Delivery Service, 3755 East Thompson Street, Philadelphia, Pennsylvania; and,

4. Patriot Trucking, Incorporated, 161 Prescott Street, Boston, Massachusetts.

At approximately 8 p.m. PST, February 16, 1990, a tractor (1989 Kenworth T-800) with two drivers from Covenant Transport, Incorporated (Covenant), Chattanooga, Tennessee, a senior driver and a driver trainee, picked up the trailer for the eastbound trip (Fig. 2.11).

The truck route across the country is shown in Fig. 2.12 (Ref. 24). The Team created the following trip chronology from interviews with the senior driver and the driver trainee and from a review of the senior driver's trip log as provided to the Team (Refs. 25, 26, and 27):

February 16, 1990

At 11:30 p.m.,* the two Covenant drivers left the Nova CFS in Compton, California, and began the eastbound trip. They made two separate stops to weigh the truck before they headed east on Interstate 10 to Interstate 15. However, snow blocked their passage on Interstate 15 and, therefore, they returned to San Bernardino and remained overnight at a motel. The drivers reported that the truck was parked in the motel parking lot away from the motel and automobile and pedestrian traffic.

February 17, 1990

At 6:30 p.m., the drivers resumed the eastbound trip.

February 18, 1990

At 4 a.m., the drivers stopped for approximately 10 minutes at the Holbrook Truck Plaza, Holbrook, Arizona. At 11:30 a.m., they stopped for approximately 30 minutes for refueling in Amarillo, Texas. At 4 p.m., the drivers arrived at Oklahoma City, Oklahoma, for refueling and dinner. They left Oklahoma City about 6 p.m. and drove continuously until 9 a.m., February 19, 1990.

February 19, 1990

At 9 a.m., the drivers arrived in Terre Haute, Indiana, and took a short break. They continued traveling until 1:30 p.m. when they stopped for fuel at Hebron, Ohio, at Exit 126 on Interstate 70.

*All times cited are Eastern Standard Time (EST), the convention used by the senior driver to maintain the trip log.

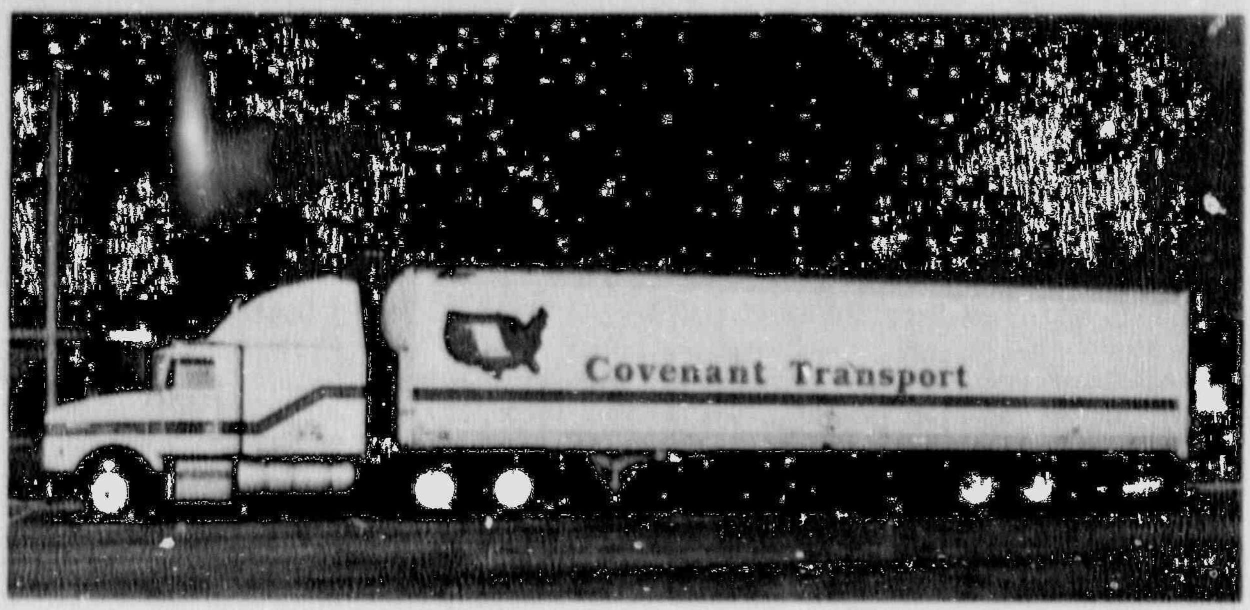


Figure 2.11 Side View of Covenant Truck

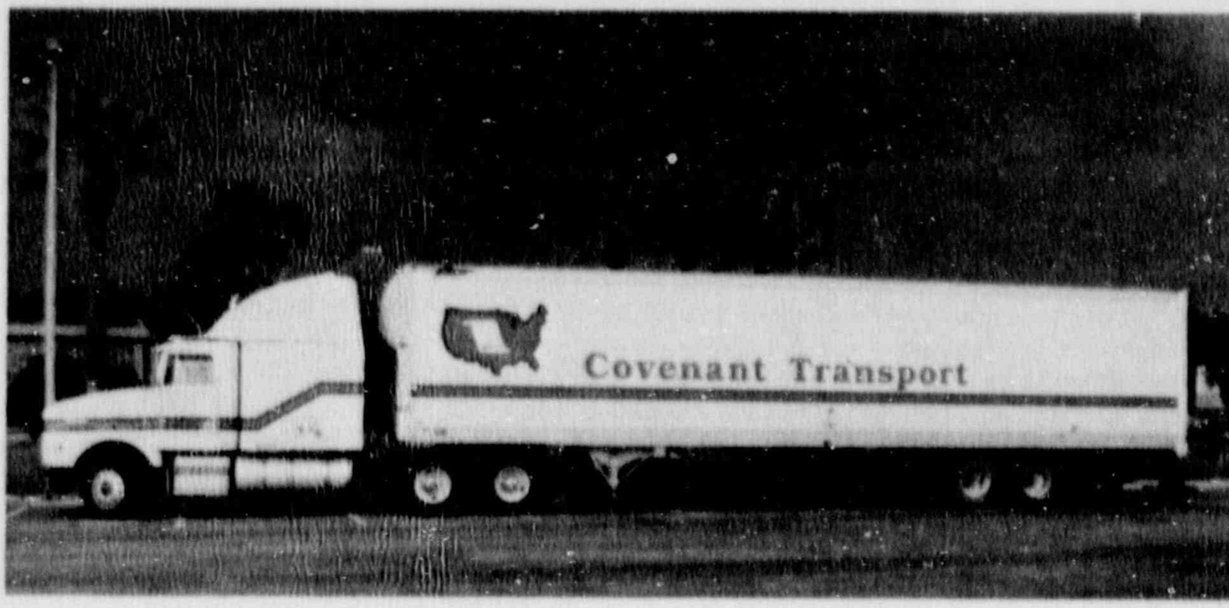
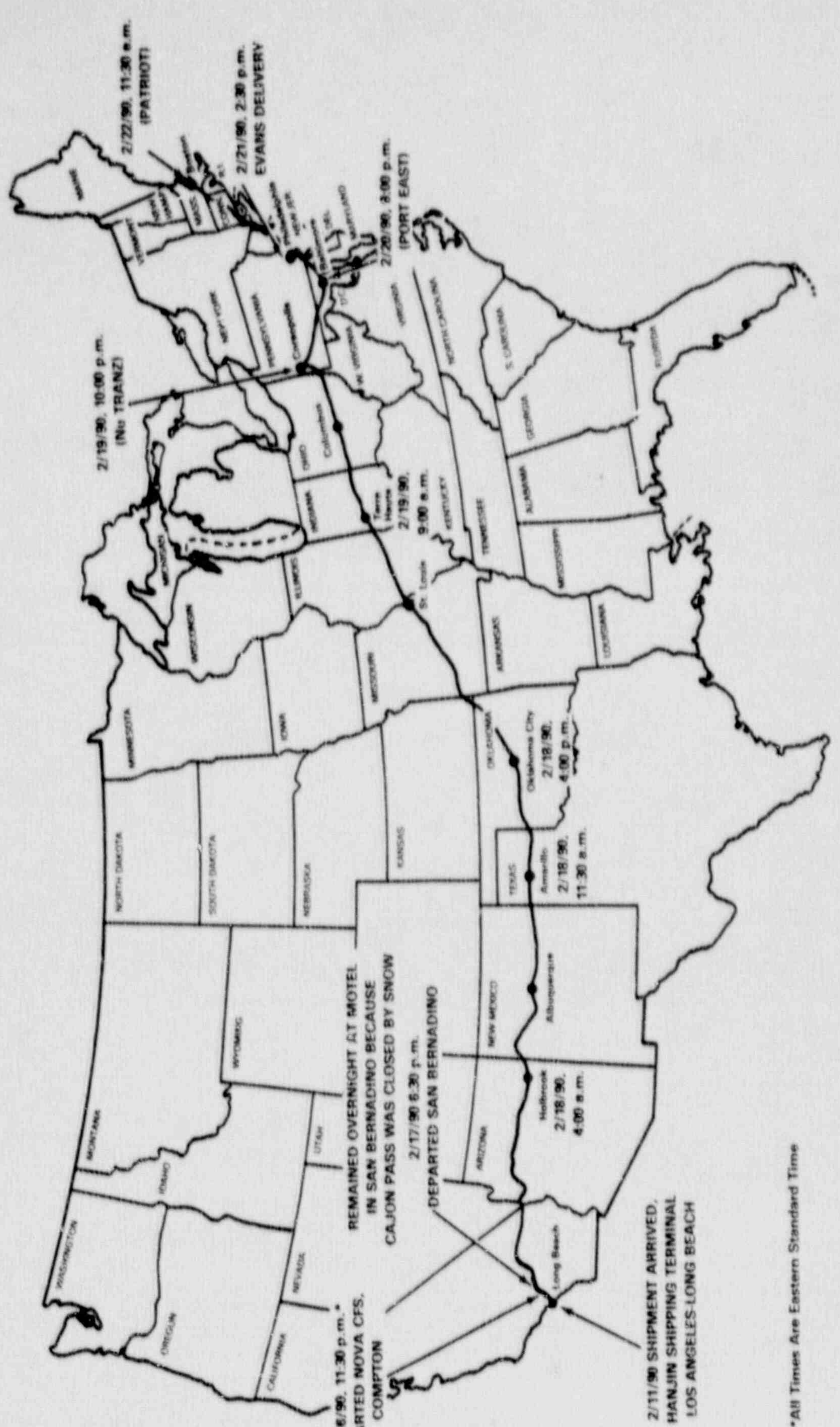


Figure 2.11 Side View of Covenant Truck



*All Times Are Eastern Standard Time

Figure 2.12 Route of Covenant Truck No. 311, February 16-22, 1990

At 4 p.m., they resumed travel, and they arrived at Nu Tranz Freight Systems, Inc. (Nu Tranz), Coraopolis, Pennsylvania, at 10 p.m. The truck was parked at the Nu Tranz terminal, and both drivers slept on board overnight.

February 20, 1990

Nu Tranz employees unloaded the first consignment between 9 a.m. and 11 a.m. At 11 a.m., the drivers left Nu Tranz and drove south on Interstate 79 to eastbound Interstate 376 and from there to eastbound Interstate 76/70 to Maryland. At approximately 4 p.m., they stopped at a restaurant for about 30 minutes somewhere between Hagerstown and Frederick, Maryland, on Interstate 70.

At 5:30 p.m., the drivers stopped at truck weighing scales at the New Market Scale House for vehicle inspection and a weight check by the Maryland State Police. At 8 p.m., they arrived at the Port East Transfer Warehouse, Inc. (Port East), Baltimore, Maryland. They parked the truck at the Port East terminal and slept onboard overnight.

February 21, 1990

Between 8 a.m. and 11 a.m., Port East employees unloaded the second shipment. At 11 a.m., the Covenant drivers left Baltimore northbound on Interstate 95, arriving at Evans Delivery Service, Philadelphia, Pennsylvania, at 2:30 p.m. to unload the third shipment. Both Covenant drivers and one Evans Delivery Service employee unloaded the shipment.

At 4:30 p.m., the drivers left the Evans Delivery Service for Boston, Massachusetts. At 7:30 p.m., they took a 30-minute break at a truck service plaza in the vicinity of Exit 37, Interstate 95 (northbound) in Connecticut and resumed travel at 8 p.m.

At about 10 p.m., the drivers were stopped at a scale house in Connecticut and were cited by the Connecticut State Police for failing to have a proper State highway permit. The second driver, a trainee, was cited for failing to properly maintain his driver's trip log. At 11 p.m., the drivers stopped at a truck service plaza at Exit 13, Interstate 90 eastbound, and parked between two other trucks having sleeper berths. Both drivers slept onboard overnight.

February 22, 1990

At 9:30 a.m., the drivers resumed travel on Interstate 90, arriving at the Patriot Trucking Company's (Patriot) facility at Logan Airport in Boston, Massachusetts, at 11:30 a.m. to discharge the final consignment. Both drivers and two terminal employees (a forklift operator and warehouseman) began unloading the trailer at approximately 12 noon and finished at 4:30 p.m., after which, the drivers left the facility with the trailer empty.

The senior driver told the Team that the wooden crate containing the source changers was the last item to be unloaded at the Patriot facility. He reported that as he pulled the crate away from the corner to allow the forklift to pick it up, he noticed that the crate was severely damaged and that several of the source changers had been forced out of the crate. As he picked up the source changers to return them to the crate, he noticed that the source changers had radioactive material labels (see Fig. 2.2).

The senior driver became alarmed at this discovery because the crate was not labeled as containing radioactive material, nor did the associated transport documents indicate that he was carrying such material. He immediately left the trailer to call his management at Covenant, Chattanooga, Tennessee, about this development.

Covenant managers advised the driver not to approach the crate until its contents could be confirmed. They then contacted the Nova Transportation Services Company in Compton, California, and were told by that company's officials that the source changers were empty and that no radioactive materials were involved in the shipment. Covenant managers relayed this information to the driver.

While the driver was making this inquiry, the Patriot forklift operator removed the crate from the trailer to examine it on the dock. He removed several source changers from the crate so that he could verify the number of source changers (Fig. 2.13); the forklift operator then stored the crate in the bonded freight enclosure in the warehouse and noted on the consignment record that the crate was damaged on arrival (Ref. 28).

The crate remained in storage in Patriot's bonded freight enclosure from February 22 to March 8, 1990. According to interviews with Patriot employees, they passed by and worked in the vicinity of the crate in the normal course of business (Figs. 2.14 and 2.15). However, no employees needed to be close to the crate for any significant duration, with the following two exceptions:

1. The Patriot forklift operator indicated that he spent up to 45 minutes every day in the process area, which is about 6 feet from where the crate was stored. He further indicated that he was in close proximity to the crate when he attempted to repair it for shipment to the consignee, Amersham Corporation. He also reported handling one of the source changers several times during this period to show the device to various other employees.

   On March 8, 1990, the same Patriot forklift operator loaded the crate onto a trailer for delivery to Amersham Corporation.

2. U.S. Customs Service inspectors daily inspected the bonded area, but the crate went unnoticed until on or about February 28, 1990, when a U.S. Customs Inspector closely inspected the crate for about 15 minutes because she noticed that it was obviously damaged. Noting that source changers were labeled as containing radioactive material, she expressed her concern about the condition of the crate and its contents to Patriot managers. They informed her that the source changers were empty and did not contain any radioactive material. She reported advising Patriot managers that the crate should be repaired and moved out of the area as soon as possible. U.S. Customs Service documentation indicates that the crate cleared Customs on March 7, 1990 (Ref. 29).

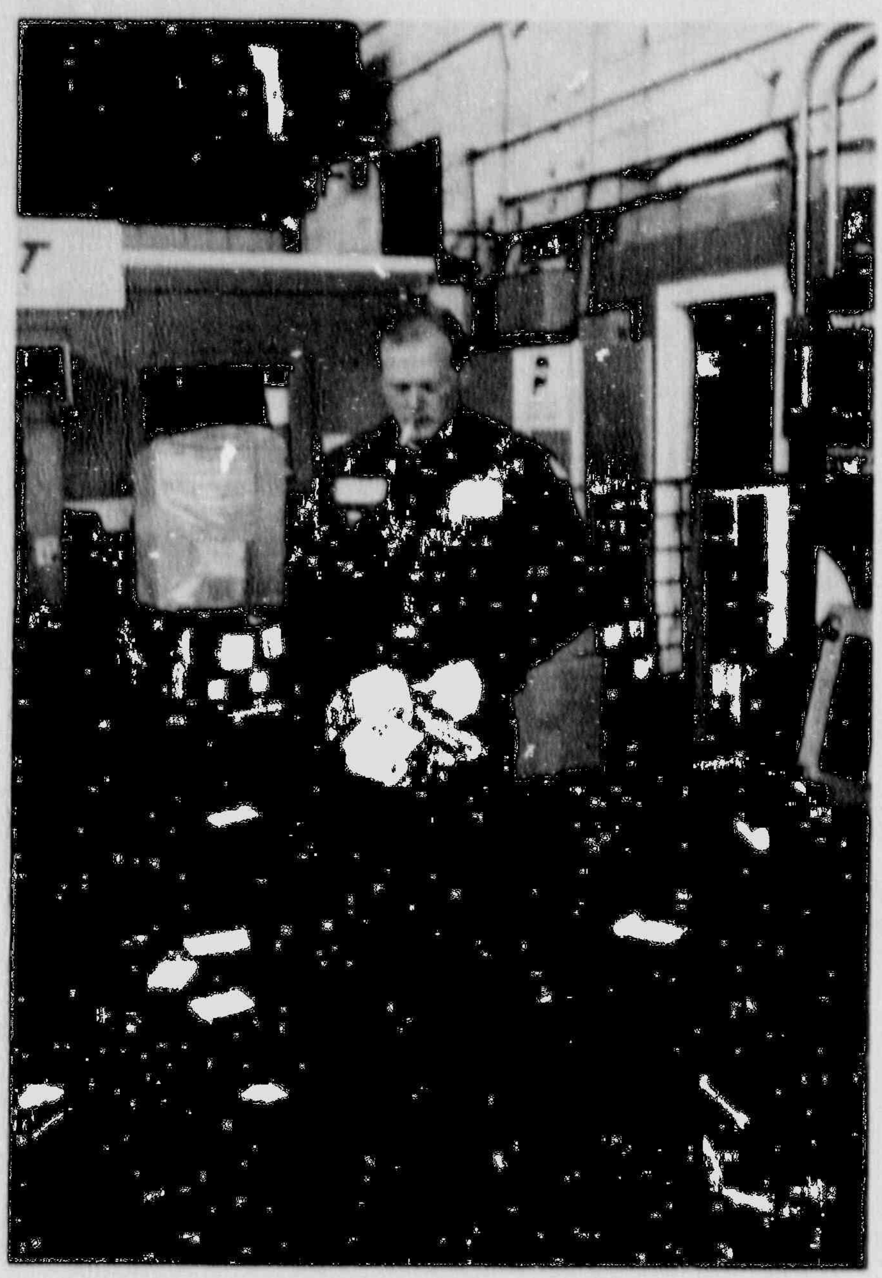


Figure 2.13 Forklift Operator Holding Source Changer

Figure 2.14 Bonded Area in Patriot Warehouse Where Crate Was Stored*

*Note Tire Tracks Indicating Forklift Traffic Pattern.

Figure 2.13 Forklift Operator Holding Source Changer

Figure 2.14 Bonded Area in Patriot Warehouse Where Crate Was Stored*

*Note Tire Tracks Indicating Forklift Traffic Pattern.

At approximately 2 p.m. on March 8, 1990, the Patriot forklift operator loaded the crate into the back of a 45-foot Patriot trailer for delivery to Amersham Corporation, in Burlington, Massachusetts, a distance of about 25 miles. The trailer was empty except for the crate containing the 14 source changers. The crate was not braced or tied down for the trip, which lasted approximately 30 minutes.

Upon arriving at Amersham, the driver opened the back door of the trailer and noticed that the crate had broken open and that the source changers were scattered over the floor of the trailer (Fig. 2.16). He proceeded to remove parts of the broken crate from the trailer and move some of the source changers closer together to facilitate unloading (Fig. 2.17). The driver then informed an Amersham technician of the delivery.

As the Amersham technician approached the trailer, he noticed that the audible alarming dosimeter he was wearing indicated increased radiation levels in the area. The technician immediately left the area and returned with a radiation survey instrument. As he approached the trailer, he noticed radiation levels of between 60 and 100 millirem per hour at an estimated 15 feet from the back of the trailer. He advised the driver to stay out of the area and left the dock to inform Amersham's RSO of the situation.

The RSO made further radiation measurements and promptly restricted access to the area. On the assumption that a source was probably not completely installed in a source changer, the RSO initiated efforts to reposition the source or to retrieve it, as necessary. By radiation measurements, the RSO was able to identify which one of the 14 source changers was emitting the radiation, after which it was moved from the trailer to the dock for further assessment.

Using a teletector to survey the levels of radiation, the RSO measured approximately 150 rem per hour at contact with the unshielded portion of the source changer. The RSO noted that the source changer was not locked with a padlock, but that a seal wire was threaded through the closure bolt.

Using source retrieval techniques and procedures, Amersham personnel opened the source changer for examination (Fig. 2.18). Initially, the source of radiation was not apparent. However, after removing a paper tag that was wedged into the source changer, Amersham personnel saw a small sealed source that had been severed from the pigtail (a cropped source) laying in the bottom of the unshielded portion of the source changer (Figs. 2.19 and 2.20). They estimated its dimensions to be 0.25 inch by 0.75 inch. A J-tube end cap was also laying on the bottom of the changer. The Amersham employees observed that end caps were not installed on either of the two source storage tubes.

Using remote handling tools and a portable shielding apparatus, Amersham personnel were able to remove the source from the source changer successfully and safely isolate it for closer examination and analysis. At 3:15 p.m., Amersham had complete control of the radioactive source.

Amersham's RSO notified NRC's Region I staff of the event at approximately 4:30 p.m. Region I staff advised the RSO to maintain control and accountability of all materials, including source changers, the source, relevant documentation,

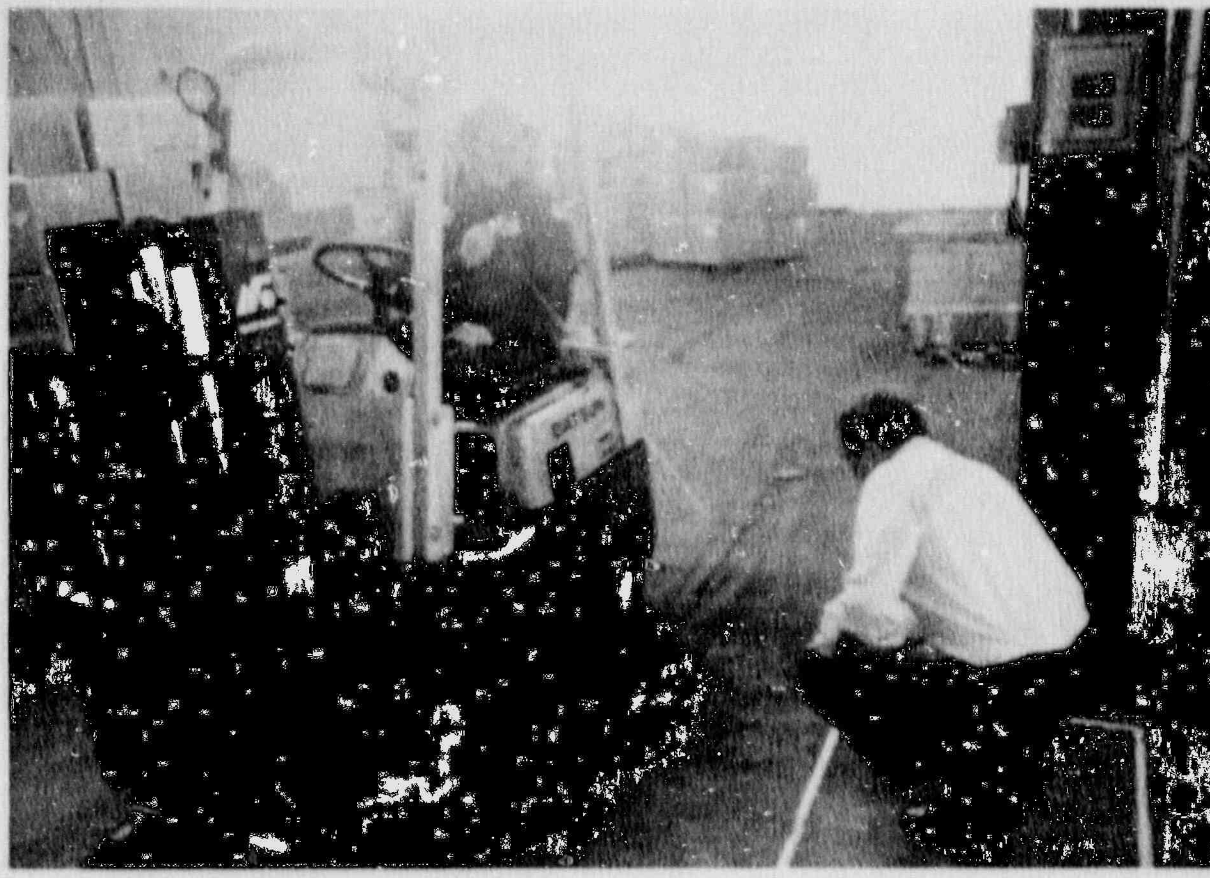


Figure 2.15 Distance from Crate in Patriot Warehouse to Traffic Pattern of Forklift

Figure 2.16 Source Changers Scattered Over Floor of Truck

Figure 2.15 Distance from Crate in Patriot Warehouse to Traffic Pattern of Forklift

Figure 2.16 Source Changers Scattered Over Floor of Truck

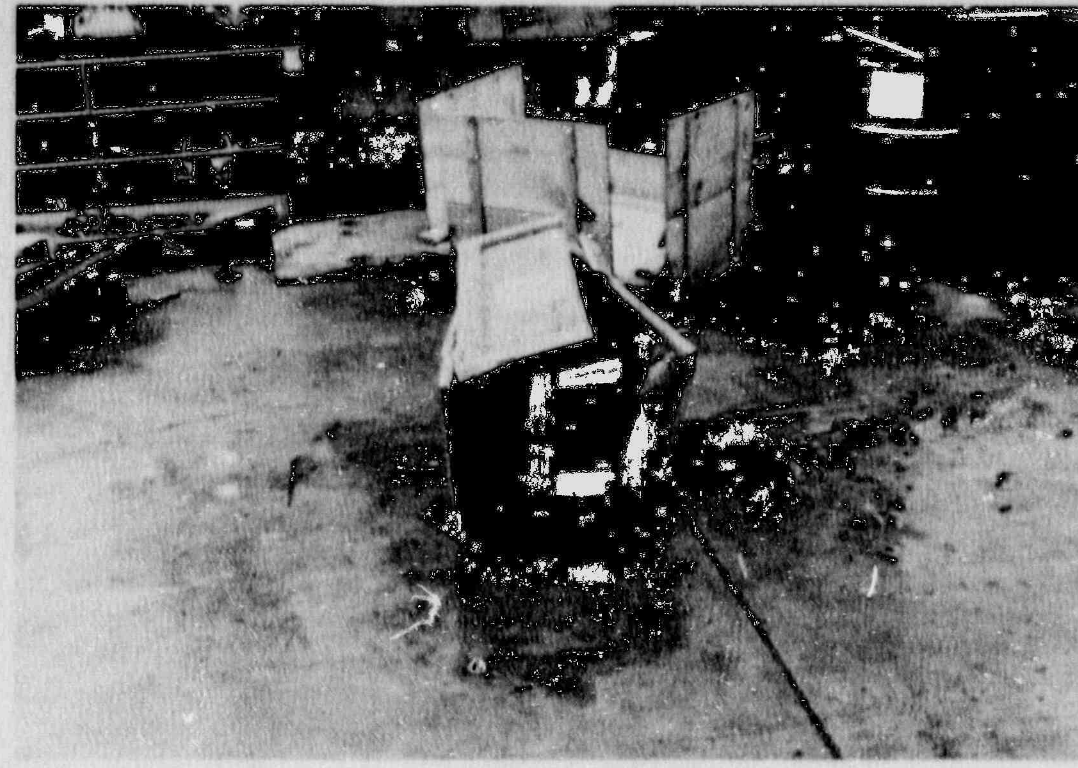


Figure 2.17 Damaged Crate As Received at Amersham

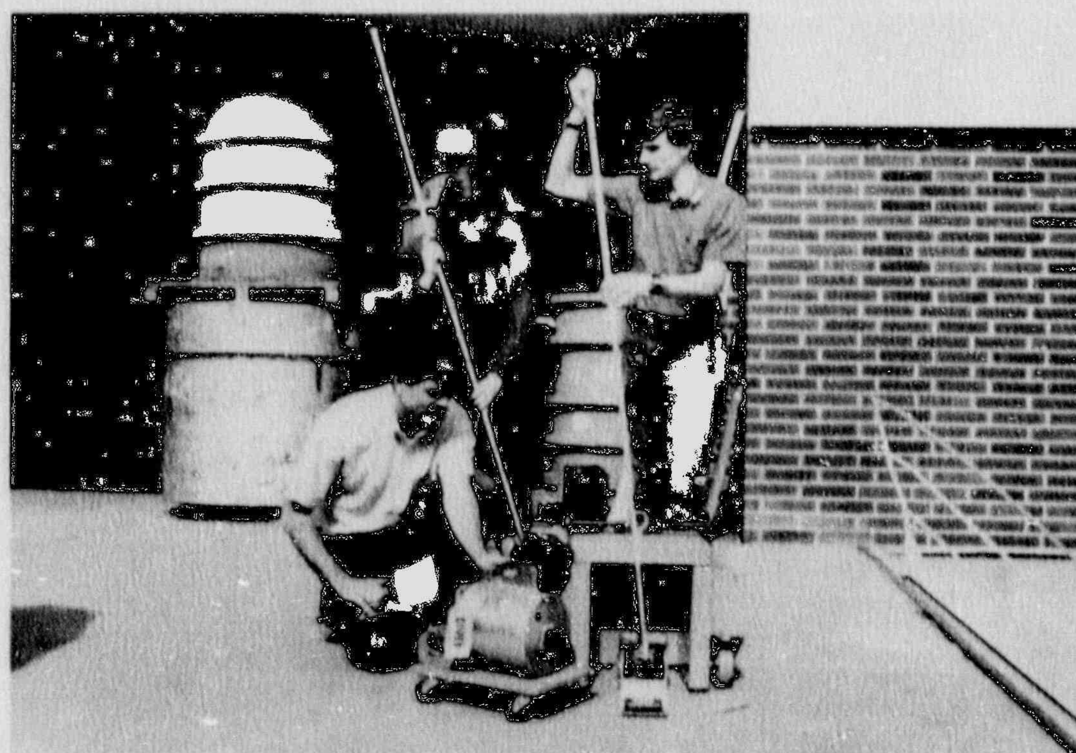


Figure 2.18 Simulated Source Retrieval

Figure 2.19 Source Changer Showing a Cap and Tag Wedged in the Unshielded Area

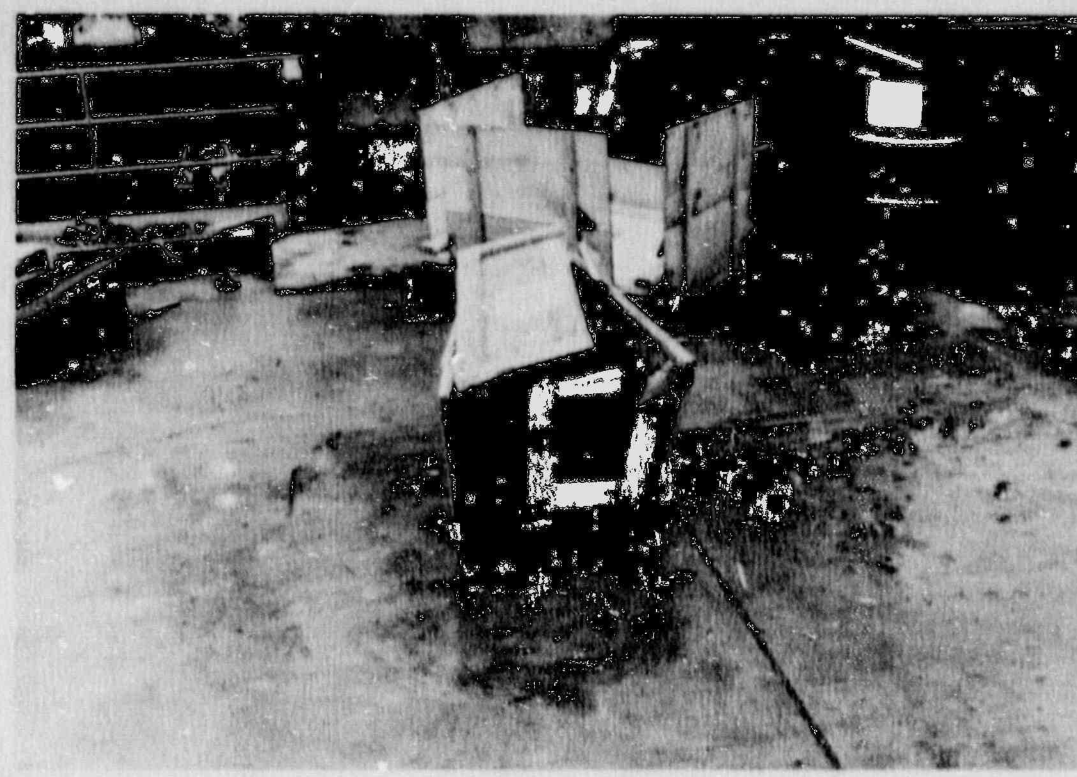


Figure 2.17 Damaged Crate As Received at Amersham

Figure 2.18 Simulated Source Retrieval

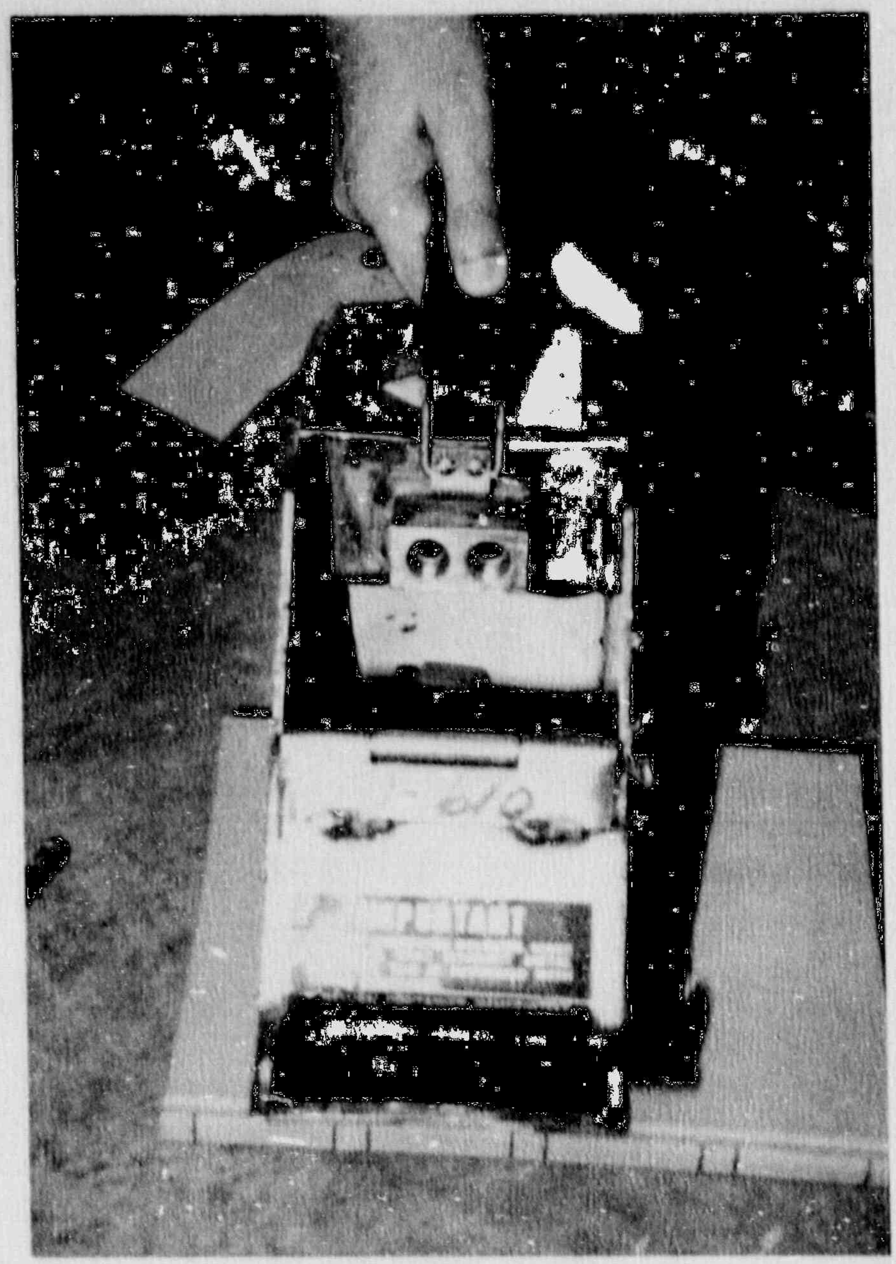


Figure 2.19 Source Changer Showing a Cap and Tag Wedged in the Unshielded Area

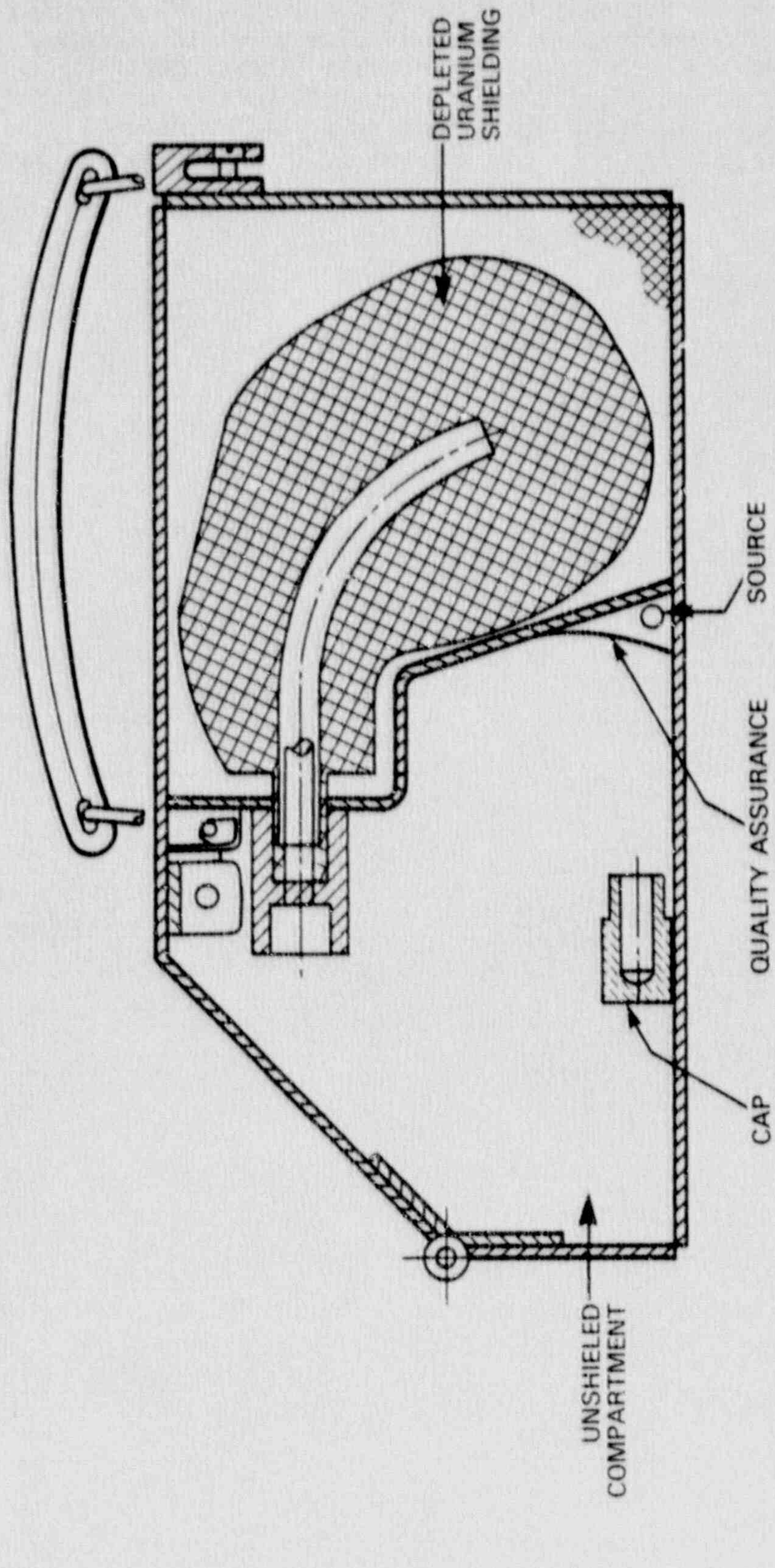


Figure 2.20 Source Changer Showing Location of Source in Unshielded Area

and the wooden crate, pending NRC review of the matter. A Confirmatory Action Letter to this effect was sent by NRC to Amersham on March 9, 1990 (Ref. 30).

On March 9, 1990, NRC's Region I management dispatched two inspectors to Amersham to perform a preliminary review of this event and to ensure that materials and documents were preserved for later investigation. On March 10, 1990, some members of the NRC Incident Investigation Team (Team) arrived in Boston to investigate the incident in that area, and on March 11, 1990, the remainder of the Team arrived in Los Angeles to investigate the incident in that area.

References*

1. Industrial Nuclear Corporation, "Radioactive Material Shipping Report," (Air Bill GEC-054990; Shipper's Export Declaration; and Invoice No. INC 0489558 M, attached) San Leandro, California, April 14, 1989. (F/N 04-117-90)

2. U.S. Nuclear Regulatory Commission, telephone interview conducted by Earl Easton with William E. Cain, Radiation Safety Officer, Industrial Nuclear Company, March 13, 1990. (F/N 04-053-90)

3. Chung Taek Park, Ministry of Science and Technology, Republic of Korea, letter to Ronald D. Hauber, U.S. Nuclear Regulatory Commission, March 20, 1990. (F/N 04-79-90)

4. Daeil Shipping Company, Ltd., Seoul, Korea, memorandum to John D. Pyun, President, Fidelity Transport Company, Norwalk, California, March 14, 1990 (memorandum is in Korean). (F/N 04-084-90)

5. K. Y. Kim, NDI Corporation, Seoul, Korea facsimile message to Amersham Corporation, Hong Kong, March 12, 1990. (F/N 04-084-90)

6. U.S. Embassy, Seoul, Republic of Korea, Status Report, fascimile message, March 20, 1990. (F/N 04-078-90)

7. U.S. Nuclear Regulatory Commission, Status Report Presented to the NRC by Representatives from Korea Institute of Nuclear Safety, Meeting at NRC Headquarters, Bethesda, Maryland, March 21, 1990. (F/N 04-099-90)

8. K. Y. Kim, NDI Corporation, Seoul, Korea, facsimile message to Amersham, Hong Kong, March 13, 1990. (F/N 04-035-90)

9. K. Y. Kim, NDI Corporation, Seoul, Korea, facsimile message to Amersham, Hong Kong, March 15, 1990. (F/N 04-057-90)

10. John Pyun, Fidelity Transport, Inc., Norwalk, California, facsimile message to John White, U.S. Nuclear Regulatory Commission, March 28, 1990. (F/N 04-142-90)

11. G. Jeong, Master of S.S. HANJIN MOKPO, "Master's Oath of Vessel in Foreign Trade," February 11, 1990. (F/N 04-091-04)

12. U.S. Customs Service, General Declaration for S.S. HANJIN MOKPO on arrival in Los Angeles, California, February 11, 1990. (F/N 04-092-90)

13. Hanjin Shipping Company, General Storage Place for S.S. HANJIN MOKPO (Voyage No. 092.E). (F/N 04-120-90)

*The file number in parenthesis at the end of some reference citations refers to the location of that reference in the Team's files for NUREG-1405. These files are available for inspection or copying for a fee at the NRC's Public Document Room, 2120 L Street, NW., Lower Level, Washington, D.C.

14. Robert Senseney, U.S. Department of State, facsimile message to Will Brown, U.S. Nuclear Regulatory Commission, Subject: Incident Involving a Radiation Source Transported from Korea, March 20, 1990. (F/N 04-100-04)

15. U.S. State Department Cable (Outgoing), STATE-076905, to American Embassy, Seoul, Republic of Korea, March 12, 1990. (F/N 04-141-90)

16. U.S. State Department Cable (Incoming), SEOUL-03157, to Secretary of State, Washington, D.C., March 21, 1990. (F/N 04-141-90)

17. U.S. State Department Cable (Outgoing), STATE-094322, to American Embassy, Seoul, Republic of Korea, March 26, 1990. (F/N 04-141-90)

18. U.S. State Department Cable (Incoming), SEOUL-03444, to Secretary of State, Washington, D.C., March 28, 1990. (F/N 04-141-90)

19. Hanjin Shipping Company, Seoul, Republic of Korea, Bill of Lading No. HJSCPUSA16149303, January 30, 1990. (F/N 04-096-90)

20. NDI Corporation, Commercial Invoice (No. ND-90002) and Packing List, Seoul, Republic of Korea, January 20, 1990. (F/N 04-095-90)

21. Nova Transportation Services Company, Compton, California, Container Freight Station Container Devanning Report for Container HJCU704673-1, February 14, 1990. (F/N 04-114-90)

22. Transportation Entry and Manifest of Goods Subject to U.S. Customs Service Inspection, Entry No. 067914512), February 14, 1990. (F/N 04-016-90)

23. Consignment Documents for Nu Tranz Trucking, Coraopolis, Pennsylvania; Port East Transfer Warehouse, Baltimore, Maryland; Evans Delivery Service, Philadelphia, Pennsylvania; and Patriot Trucking, Boston, Massachusetts. (F/N 04-122-90)

24. Covenant Transport Inc., Chattanooga, Tennessee, Route Sheet for truck No. 311; Trailer No. 48011, from February 16 to February 22, 1990. (F/N 04-116-90)

25. Covenant Transport, Inc., Chattanooga, Tennessee, Driver Trainee's Daily Log from February 17 to February 22, 1990. (F/N 02-116-90)

26. Covenant Transport, Inc., Chattanooga, Tennessee, Driver Trainee's Daily Log from February 16 to February 22, 1990. (F/N 04-116-90)

27. Covenant Transport, Inc., Chattanooga, Tennessee, Daily Log Composite as Developed by Senior Driver for the NRC Team, from February 16 to February 22, 1990. (F/N 04-119-90)

28. Covenant Transport, Inc, Chattanooga, Tennessee, Consignment Record 89642-4, February 16, 1990 (with notations dated February 22, 1990). (F/N 04-116-90)

29. International Specialists, Inc., Logan International Airport, Boston, Massachusetts, Delivery Order (HAWB No. UB0900171) stamped by U.S. Customs Service Inspector J. R. H 28276, March 7, 1990. (F/N 04-016-90)

30. Malcolm R. Knapp, U.S. Nuclear Regulatory Commission, Confirmatory Action Letter 1-90-007 to Ms. Cathleen M. Roughan, March 9, 1990. (F/N 04-021-90)

3 DESCRIPTION OF TEAM ACTIVITIES

3.1 Overview of the Team's Methodology

In its investigation of the inadvertent shipment of an unshielded radiographic source from Pusan, Republic of Korea, to Burlington, Massachusetts, in the United States, the Incident Investigation Team (Team) collected and evaluated information from documentation, photographs, measurements, tests, experiments, simulated conditions and situations, time and motion studies, and meetings and interviews, in person and by telephone. The Team collected and evaluated this information in order to determine the possible radiation exposures to individuals, the sequence of events, and the root causes of the incident.

Because various events related to this incident occurred over a large geographical area, the Team initially divided into two groups. One group conducted its investigation using Amersham's facility in Burlington, Massachusetts, as a base; the other group operated at various locations in California. After completing these field investigations, the Team reassembled at NRC headquarters, in Bethesda, Maryland.

The Team primarily obtained information about the sequence of the events from interviews, U.S. Customs Service documents, shipping records, drivers' log books, facsimile communications with Amersham's Hong Kong office, and U.S. State Department cables. On the basis of this information, the Team retraced the shipment of the source from its Korean end-user in Seoul through the Port of Los Angeles, across the continental United States, to its final destination in Burlington, Massachusetts (see Fig. 2.12). The Team also collected information on the original shipment of the source to Korea through correspondence with the affected parties in the Republic of Korea and with the source manufacturer in the United States.

Possible radiation exposures to individuals were determined from data gathered from interviews with the drivers and a review of their logs and from interviews with other individuals who may have been near the source. The Team gathered information from these interviews to develop time and motion histories for the affected individuals. These studies were used to determine when they approached and left the location of the source and how long they actually handled or were in the vicinity of the source changer. The results of the analysis of potential exposures to individuals is presented in Section 5 of this report. Details of the analysis are given in Section 6.

The source changers involved in the shipment, the wooden packing crate, and the source were quarantined on March 9, 1990, until they could be examined by the Team. On March 15, 1990, all materials involved in the incident, except for source changer SU-610 and its contents, were released for use by Amersham.

3.2 Interviews and Meetings

The Team placed a high priority on identifying and interviewing persons involved in the physical handling of the source changers or persons who came near them so that those with potentially significant radiation exposures could be tested promptly. The Team also deemed it important to contact those persons involved in the initial stages of the shipment as early as possible before their recollection of the incident had faded with the passage of time. The Team interviewed Federal and State officials to obtain information about regulatory control and surveillance of radioactive material shipments. All Team interviews and meetings are listed in Table 3.1.

Because this event involved shipping the radioactive source across the United States, the interviewees were distributed over a wide area. In order to conduct these interviews as quickly as possible, the Team divided into two groups. The West Coast Group (WCG), consisting of three Team members, focused its efforts primarily in California during the initial stages of the investigation. During its investigative activities in California, the WCG was accompanied, at its request, by a headquarters representative of the Department of Transportation. They concentrated on identifying those individuals involved in the early stages of the shipment within the United States. The WCG interviewed personnel involved with the shipment from the time it arrived at the Port of Los Angeles until it was received at the Patriot Shipping Company (Patriot) warehouse in Boston. The WCG conducted interviews in California and Texas. Subsequently, individual Team members interviewed personnel in Arizona, Pennsylvania, and Maryland. A primary objective of these interviews was to develop the time and motion histories needed to estimate possible exposures to individuals. Special attention was paid to identifying and interviewing the two Covenant Transport (Covenant) drivers who transported the source from California to Boston.

The East Coast Group (ECG), which initially consisted of four Team members, arrived in Burlington, Massachusetts, at approximately noon on Saturday, March 10, 1990. At that time, the ECG was briefed by two NRC Region I inspectors who had been dispatched to review the incident on March 9, 1990. The actual fact-finding began on the afternoon of March 10, 1990, when this group was given an overview of the event by Amersham management personnel. At that meeting, the ECG and representatives from Amersham discussed the activities relating to the discovery and retrieval of the source.

Because this incident began in Korea, the ECG requested Amersham's assistance in obtaining information about the source and the source changers from the Korean distributor, NDI Corporation, in Seoul. Amersham arranged to communicate requests for information to NDI Corporation through the Amersham office in Hong Kong.

Following the briefing, the ECG toured Amersham's loading dock and "hot cell" facility (i.e., a shielded room for storing radioactive materials that must be remotely handled), and visually examined the source changers, wooden packing crate, and the source.

The ECG spent Sunday, March 11, 1990, establishing a preliminary sequence of events, compiling a list of potential interviewees, estimating initial exposure doses, and coordinating efforts with the WCG. On March 12, 1990, one Team member from the ECG was dispatched to interview the second Covenant driver in El Paso, Texas. On March 13, 1990, this Team member joined the WCG to provide coordination between the two groups.

Interviews with Amersham employees began on the morning of March 12, 1990. The approach used for scheduling interviews was first to talk with those individuals directly involved in retrieving the source: the radiation safety officer (RSO), the hot lab supervisor, and a radiation technologist. The Team then interviewed the facility manager and the individual responsible for arranging export shipments. All of these interviews were recorded by stenographers and transcribed (see Table 3.1). A second radiation technologist involved in retrieving the source was interviewed by telephone from Apsen, Colorado. This interview was taped and transcribed.

On Tuesday, March 13, 1990, the ECG interviewed employees from the Patriot Trucking Company in Boston. They interviewed the employees who were involved in the unloading, handling, and reloading of the wooden crate that contained the source changers and talked to other warehouse employees who may have worked in the area where the crate was stored. All of the interviews with Patriot employees were recorded on tape and transcribed (see Table 3.1). A notice was posted in the Patriot warehouse requesting that anyone who had handled or worked near the crate contact the Team. No one else responded to the notice or was interviewed.

The ECG interviewed personnel from the U.S. Customs Service and the Commonwealth of Massachusetts between March 12 and March 16 to obtain any information they may have and to learn whether any U.S. Customs Service personnel were near the source. These interviews were conducted by telephone, recorded on tape, and transcribed (see Table 3.1).

The ECG conducted a number of telephone interviews with INC personnel on March 14 and 15, 1990, in an effort to determine the characteristics of the source. The interviews were documented by written notes (see Table 3.1). The methods used by the Team to determine the composition and activity of the source are described in Section 4.

On March 13, 1990, the WCG interviewed personnel of Hanjin shipping at Hanjin's San Pedro, California, terminal. The WCG also observed the unloading of containers from a Hanjin ship similar to the S.S. HANJIN MOKPO and traced the route of the container from unloading until it left the Hanjin terminal. On this same date, the WCG interviewed a U.S. Customs Service inspector regarding that agency's involvement with the shipment.

On March 14, a representative from the State of California, Division of Occupational Safety and Health, joined the WCG as they interviewed personnel from the Nova Container Freight Station (Nova CFS) in Compton, California. They interviewed every individual involved with unloading the ocean container and moving the crate into the Covenant transport trailer and reviewed the circumstances of the temporary storage of the crate. The WCG also interviewed all Nova personnel who may have come in close proximity to the crate while it was in temporary storage there. They developed a plot plan of those areas of the Nova warehouse that could have been affected by radiation (see Fig. 6.1).

On March 15, the WCG interviewed two U.S. Department of Agriculture inspectors, one of whom boarded the S.S. HANJIN MOKPO while it was in the harbor. On the same date, Hanjin Shipping Company personnel were contacted for the second time about the construction of seagoing containers and to arrange for Team members to board the S.S. HANJIN MOKPO on March 25, 1990, when it next docked in the Port of Los Angeles.

Additionally, the WCG interviewed U.S. Coast Guard personnel at their Marine Safety Office, Los Angeles-Long Beach, to determine the actual dates that the S.S. HANJIN MOKPO was in port, any potential exposure of U.S. Coast Guard personnel during the stay of the exposed source in the port area, and the required protocol and procedures for docking a vessel at the Port of Los Angeles.

The WCG also interviewed the President of Fidelity Transport, Incorporated, a non-vessel operating common carrier and freight consolidator, that contracted with Daeil Shipping Company, Seoul, to arrange the handling and transport of the crate of source changers from Los Angeles to Boston. At the interview, the president conveyed the results of Daeil Shipping Company's review of the sequence of events in Korea that were related to the incident.

After the Team reassembled in NRC headquarters, they interviewed representatives of the U.S. Department of Transportation and the NRC materials licensing staff, Office of Nuclear Material Safety and Safeguards. The purpose of these interviews was to identify the adequacy of regulatory controls and surveillance of radioactive material shipments and the process and requirements for approving and using sealed sources and radiographic devices. These interviews, conducted between March 21 and March 23, were recorded by stenographers and transcribed (see Table 3.1).

On March 22, 1990, a Team member, accompanied by two State of Maryland inspectors, interviewed personnel at the Port East Transfer, Inc., warehouse in Baltimore, Maryland, to determine which individuals were involved with unloading freight from the Covenant trailer at this warehouse. They measured and inspected the Port East facility to evaluate whether warehouse employees or truck drivers making deliveries could have potentially been exposed to radiation emitted from the shipment.

On March 25, 1990, two Team members met the S.S. HANJIN MOKPO as it docked at the Hanjin Shipping Company dock, at San Pedro, California. The Team members observed the unloading of the ship and conducted a time and motion study of the unloading of a container that was stowed in the same position on the ship as the container had been stowed that held the crate of source changers involved in the incident.

On March 30, 1990, a Team member interviewed personnel at the Nu Tranz Freight Systems, Inc. (Nu Tranz), warehouse to determine which of them were involved in unloading freight from the Covenant trailer at this location. The WCG measured and inspected the Nu Tranz facility to obtain information for estimating radiation exposures of Nu Tranz employees and delivery drivers. On April 11, 1990, a visit was made to Evans Delivery Service, Philadelphia, Pennsylvania, to obtain similar information about potentially exposed individuals.

3.3 Tests, Measurements, Simulations, and Experiments

During the investigation, the Team conducted or supervised a number of measurements and tests to obtain data needed to analyze this incident.

The Team --

- Measured the thickness and dimensions of the Covenant truck cab and the trailer used to transport the source to determine what shielding they provided (see Sec. 5) and developed a scaled drawing of the tractor-trailer rig used for the cross-country trip.

- Obtained the radiation profile for individual empty source changers to determine applicable shipping categories (see Sec.7).

- Repacked all 14 source changers in the original wooden shipping crate and measured the subsequent radiation profile to determine the applicable shipping category for the loaded crate (see Sec. 7).

- Determined the angle of tilt (end to end) required to cause a cropped source, that is, a source with the "pigtail" removed, to slide out of a source changer into an unshielded position.

- Developed plot plans for the Amersham loading dock and the Patriot and Nova warehouses based on measurements made by the Team.

- Witnessed Amersham's tests in its source certification laboratory to determine source activity and obtain gamma pulse height spectra to verify source composition (see Sec. 4).

3.4 NRC's Regulatory Actions: Quarantined Equipment

On March 9, 1990, NRC's Region I staff issued a Confirmatory Action Letter (CAL) to ensure that Amersham Corporation would maintain all material associated with the shipment in its as-received condition for inspection by the NRC. This material included 14 Model 500-SU source changers and accessories, the wooden shipping crate, and the source itself. The CAL stated NRC's understanding that Amersham Corporation would also assemble all pertinent shipping and handling documentation available to them for review by the NRC.

After the ECG arrived at Amersham on March 10, 1990, its members visually examined each of the source changers for physical damage resulting from their shipment from Korea. They photographed each source changer to preserve a visual record of its condition and labels and inspected the wooden crate to determine its condition and any role it played in the incident. They also examined the source and characterized it independently by test to determine its manufacturer, activity, and physical composition (see Sec. 4).

The Team requested that a radiation survey to detect contamination and a baroscopic examination to determine the inadvertent presence of a source be conducted on each of the source changers before they were returned to service. These test results showed that contamination levels were less than 0.001 microcurie on the surface of the changers and that no sources were present in any of the source changers. On March 15, 1990, all materials referred to in the CAL, except for source changer serial number SU-610 and the items found in it, were released from quarantine for use by Amersham. Amersham agreed to keep the source available to the NRC until the investigation was completed.

On March 27 and 28, the Team interviewed U.S. Customs Service inspectors in Nogales, Arizona, to obtain information about a similar incident that had previously occurred.

Table 3.1 Interviews and Meetings Conducted by the Incident Investigation Team

Date	Local Time	Meeting/Interview	Documentation Method*†
U.S. Nuclear Regulatory Commission			
3/10/90	12:30 p.m.	Debriefing by NRC Region I staff	(NR)
Amersham Corporation Personnel (Burlington, MA)			
3/10/90	1:30 p.m.	Briefing by licensee on event	(NR)
3/12/90	9:20 a.m.	Interview of radiation safety officer	(ST)
3/12/90	10:30 a.m.	Interview of hot lab supervisor	(ST)
3/12/90	1:20 p.m.	Interview of radiation technologist (A)	(ST)
3/12/90	2:00 p.m.	Interview of export specialist	(ST)
3/12/90	3:20 p.m.	Interview of corporate manufacturing manager	(ST)
3/12/90	8:30 p.m.	Interview of radiation technologist (B)	(TT)
3/15/90	4:15 p.m.	Interview of radiation safety officer	(TT)
3/16/90	11:00 a.m.	Exit meeting with Amersham staff	(NR)
Covenant Truck Drivers			
3/12/90	9:00 a.m.	Interview of senior driver (San Bernardino, CA)	(N)
3/13/90	9:00 a.m.	Interview of driver trainee (El Paso, TX)	(N)
3/14/90	10:00 a.m.	Reinterview of senior driver (San Bernardino, CA)	(N)
Patriot Trucking Company Personnel (Boston, MA)			
3/13/90	10:00 a.m.	Interview of vice president	(TT)
3/13/90	10:20 a.m.	Interview of truck driver	(TT)
3/13/90	10:00 a.m.	Interview of loading dock supervisor	(TT)
3/13/90	11:30 a.m.	Interview of dock hand	(TT)
Marine Terminal Corporation Personnel (San Pedro, CA)			
3/13/90	2:30 p.m.	Interview of gate manager, Hanjin Shipping Co., San Pedro, CA, terminal	(N)
3/13/90	3:30 p.m.	Interview of terminal manager, Hanjin Shipping Co., San Pedro, CA, terminal	(N)

Table 3.1 (continued)

Date	Local Time	Meeting/Interview	Documentation Method*†
Hanjin Shipping Company Personnel (San Pedro, CA)			
3/13/90	3:45 p.m.	Interview of yard manager	(N)
Nova Container Freight Station (CFS) Personnel (Compton, CA)			
3/14/90	11:45 a.m.	Interview of CFS operations manager	(N)
3/14/90	11:45 a.m.	Interview of CFS warehouse manager	(N)
3/14/90	2:30 p.m.	Interview of shipping clerk	(N)
3/14/90	4:10 p.m.	Interview of shipping supervisor	(N)
3/14/90	5:00 p.m.	Interview of receiving unloader (A)	(N)
3/14/90	5:15 p.m.	Interview of receiving unloader (B)	(N)
3/14/90	5:45 p.m.	Interview of checker	(N)
3/14/90	6:15 p.m.	Interview of Nova truck driver	(N)
3/14/90	6:30 p.m.	Interview of receiving clerk/checker	(N)
3/14/90	6:45 p.m.	Interview of shipping loader (A)	(N)
3/14/90	7:00 p.m.	Interview of shipping loader (B)	(N)
U.S. Customs Service personnel (Los Angeles, CA)			
3/13/90	1:30 p.m.	Interview of Customs inspector	(N)
3/15/90	11:00 a.m.	Interview of Customs supervisor	(N)
U.S. Customs Service personnel (Boston, MA)			
3/12/90	12:05 p.m.	Interview of Customs inspector (A)	(N)
3/15/90	3:30 p.m.	Interview of Customs supervisor (A)	(PT)
3/15/90	4:00 p.m.	Interview of Customs supervisor (B)	(PT)
3/15/90	4:40 p.m.	Interview of Customs inspector (B)	(PT)
3/15/90	4:50 p.m.	Interview of Customs inspector (A)	(PT)
3/15/90	8:30 p.m.	Interview of Customs inspector (C)	(PT)
3/16/90	12:10 p.m.	Interview of Customs inspector (A)	(TT)
State of Massachusetts personnel (Boston, MA)			
3/15/90	10:15 a.m.	Interview of radiation protection program director	(PT)
3/15/90	11:00 a.m.	Interview of radiation protection program inspector	(PT)
Industrial Nuclear Company personnel (San Leandro, CA)			
3/14/90	2:30 p.m.	Interview of radiation protection officer	(PN)
3/15/90	12:30 p.m.	Interview of radiation protection officer	(PN)

Table 3.1 (continued)

Date	Local Time	Meeting/Interview	Documentation Method*†
Department of Agriculture personnel			
3/15/90	3:00 p.m.	Interview of plant protection quarantine inspector (A)	(N)
3/15/90	3:15 p.m.	Interview of plant protection quarantine inspector (B)	(N)
Department of Transportation personnel (Washington, D.C.)			
3/21/90	10:15 a.m.	Meeting with Director, Office of Hazardous Material Transportation; Chief, Enforcement Division; Chief, Radioactive Materials Branch; and Enforcement Specialist	(ST)
3/21/90	1:30 p.m.	Meeting with Office of Motor Carriers; Chief, HAZMAT Program Division; and Director, Field Operations	(ST)
3/22/90	10:00 a.m.	Meeting with U.S. Coast Guard, Marine Technical and HAZMAT Division, Mechanical Engineer; Chief, Port Operations Branch, and, Chief, HAZMAT Section	(ST)
U.S. Coast Guard personnel (Marine Safety Officer-Los Angeles/Long Beach, CA)			
3/15/90	9:30 a.m.	Meeting with Port Safety and Security Division personnel	(N)
Fidelity Transport, Incorporated, Personnel, (Norwalk, CA)			
3/15/90	2:00 p.m.	Interview with president	(N)
Port East Transfer, Inc., personnel (Baltimore, MD)			
3/22/90	1:45 p.m.	Interview of corporate vice president	(N)
3/22/90	2:05 p.m.	Interview of warehouse manager	(N)
3/22/90	2:30 p.m.	Interview of forklift operator	(N)
Covenant Management and Dispatch personnel (Chattanooga, TN)			
3/22/90	2:00 p.m.	Interview of operations manager	(PN)
3/28/90	3:00 p.m.	Interview of dispatcher	(PN)
NRC Headquarters personnel			
3/23/90	11:00 a.m.	Interview of licensing specialist on sealed sources and devices, Office of Nuclear Material Safety and Safeguards	(TT)

Table 3.1 (continued)

Date	Local Time	Meeting/Interview	Documentation Method*†
U.S. Customs Service personnel (Nogales, AZ)			
3/27/90	2:15 p.m.	Interview of Customs inspector	(N)
3/27/90	4:00 p.m.	Interview of Senior Customs inspector	(N)
3/28/90	1:00 p.m.	Reinterview of Senior Customs inspector	(N)
Joffroy Warehouse, Inc., Personnel (Nogales, AZ)			
3/28/90	8:15 a.m.	Interview of warehouse manager	(N)
G. Mendez and Company Custom House Broker (Nogales, AZ)			
3/28/90	11:00 a.m.	Interview of customs broker	(N)
William F. Joffroy Custom House Brokers, Inc. (Nogales, AZ)			
3/28/90	11:45 a.m.	Interview of assistant customs broker	(N)
Oak Ridge Associated Universities, Medical and Health Sciences Division (Oak Ridge, TN)			
3/29/90	2:00 p.m.	Interview with chief of radiation medicine	(PN)
Nu Tranz Freight Systems, Inc., personnel (Coraopolis, PA)			
3/30/90	9:45 a.m.	Interview of terminal manager	(N)
3/30/90	10:15 a.m.	Interview of assistant terminal manager	(N)
3/30/90	10:35 a.m.	Interview of truck driver/warehousemen	(N)
Evans Delivery Service personnel (Philadelphia, PA)			
4/11/90	1:20 p.m.	Interview of corporate vice president	(N)
4/11/90	1:45 p.m.	Interview of warehouseman (A)	(N)
4/11/90	2:15 p.m.	Interview of warehouseman (B)	(N)

* All notes and transcripts are available for inspection in the NRC Public Document Room, 2120 L Street (lower level), NW., Washington, D.C.

† DOCUMENTATION METHOD
NR - not recorded
ST - recorded by stenographer; transcribed
TT - taped; transcribed
PT - taped phone conversation, transcribed
PN - phone conversation, notes
N - notes

4 SOURCE CHARACTERIZATION

One of the Incident Investigation Team's (Team) first priorities was to determine the isotopic composition and activity of the source. The activity is the strength of the source measured in curies. The Team needed reliable data to make timely and accurate estimates of radiation exposures for individuals who were involved with the shipment.

When the source arrived at the Amersham Corporation (Amersham) facility on March 8, 1990, it had no manufacturer's identification markings or serial number. The cable device (or pigtail) for the source, which ordinarily is inscribed with a serial number, had been removed from the capsule enclosing the source (Fig. 4.1). On the basis of a visual inspection of the source capsule, the Amersham staff determined that the source was not one of their designs. Because the source was found in a source changer shipped from Korea, the Team could not determine whether the source was manufactured domestically or abroad.

This section of the report describes the methods used to determine the isotopic composition, activity, and origin of the radioactive source involved in the incident. Table 4.1 summarizes the significant events involved in characterizing the source.

4.1 Determination of the Source's Manufacturer

On Saturday, March 10, 1990, the Amersham staff briefed the Team on the incident and showed them the source in the hot cell. During the briefing, the Amersham staff was not able to positively identify the source design or manufacturer. They were certain, however, that the source was not manufactured by Amersham. One Amersham employee identified Industrial Nuclear Company (INC), located in San Leandro, California, as a possible manufacturer of the source. To confirm whether INC was the source's manufacturer, Amersham had requested on March 9 that INC provide them with a dummy source of INC design for visual comparison.

On Saturday, March 10, the Team requested that Amersham contact its Korean distributor, NDI Corporation (NDI), to identify the end-user of each of the 14 source changers shipped to the Amersham facility on March 8 (Ref. 1). NDI was also asked to identify, if possible, the end-user for source changer serial number (S/N) SU-610. On Monday, March 12, NDI Corporation identified the Korean end-user of source changer S/N SU-610 as Korea Industrial Testing Company, Ltd. (KIT) (Ref. 2). NDI Corporation tentatively identified the manufacturer of the source as INC of San Leandro, California.

The dummy source Amersham had requested from INC arrived at Amersham on March 12. A visual comparison of the two sources identified INC as the probable manufacturer. Dummy source capsules supplied by Amersham and INC are shown in Figures 4.2 and 4.3. The dummy source capsule supplied by INC is identical to the one involved in the incident.

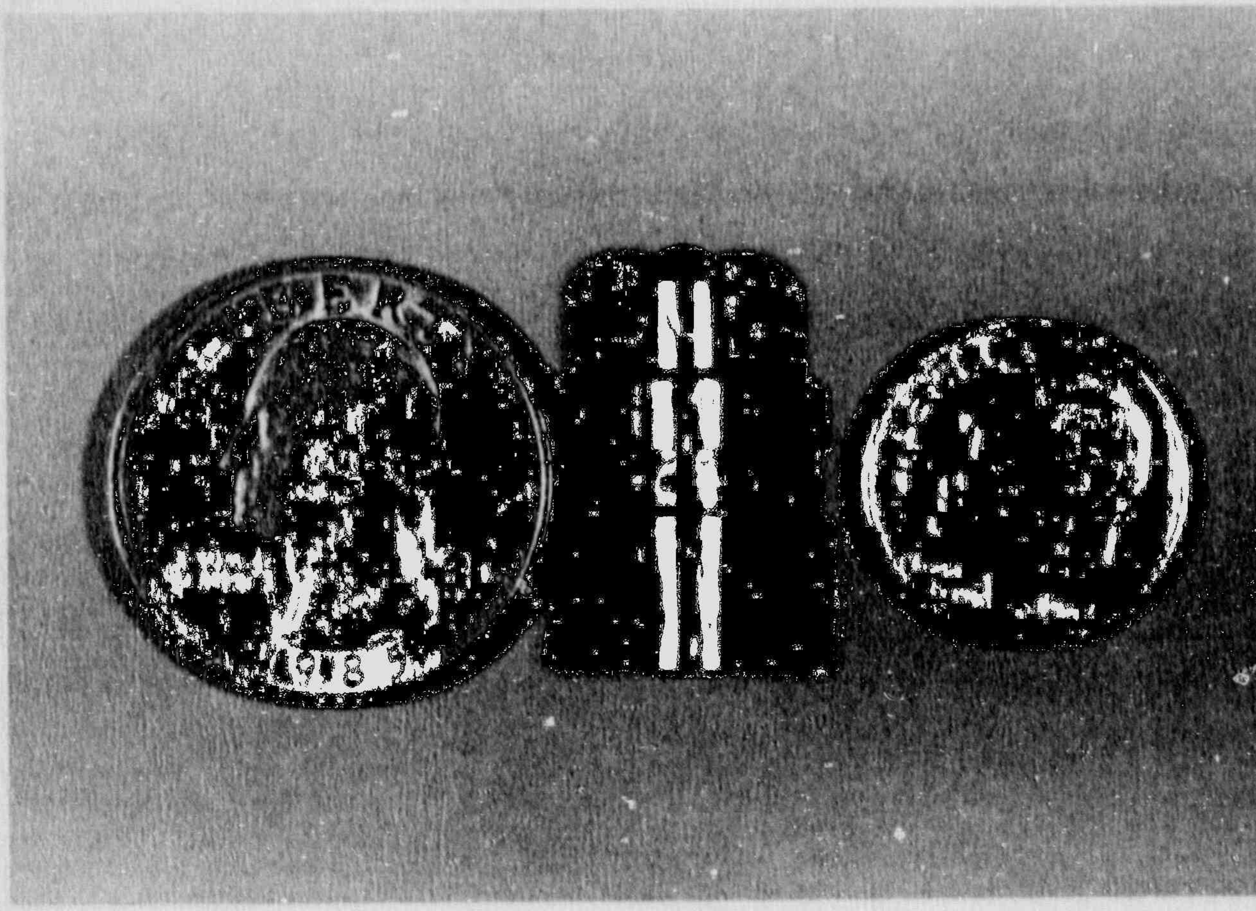


Figure 4.1 Representation of Industrial Nuclear Corporation Model No. 8 Iridium-192 Sealed Source #1062.

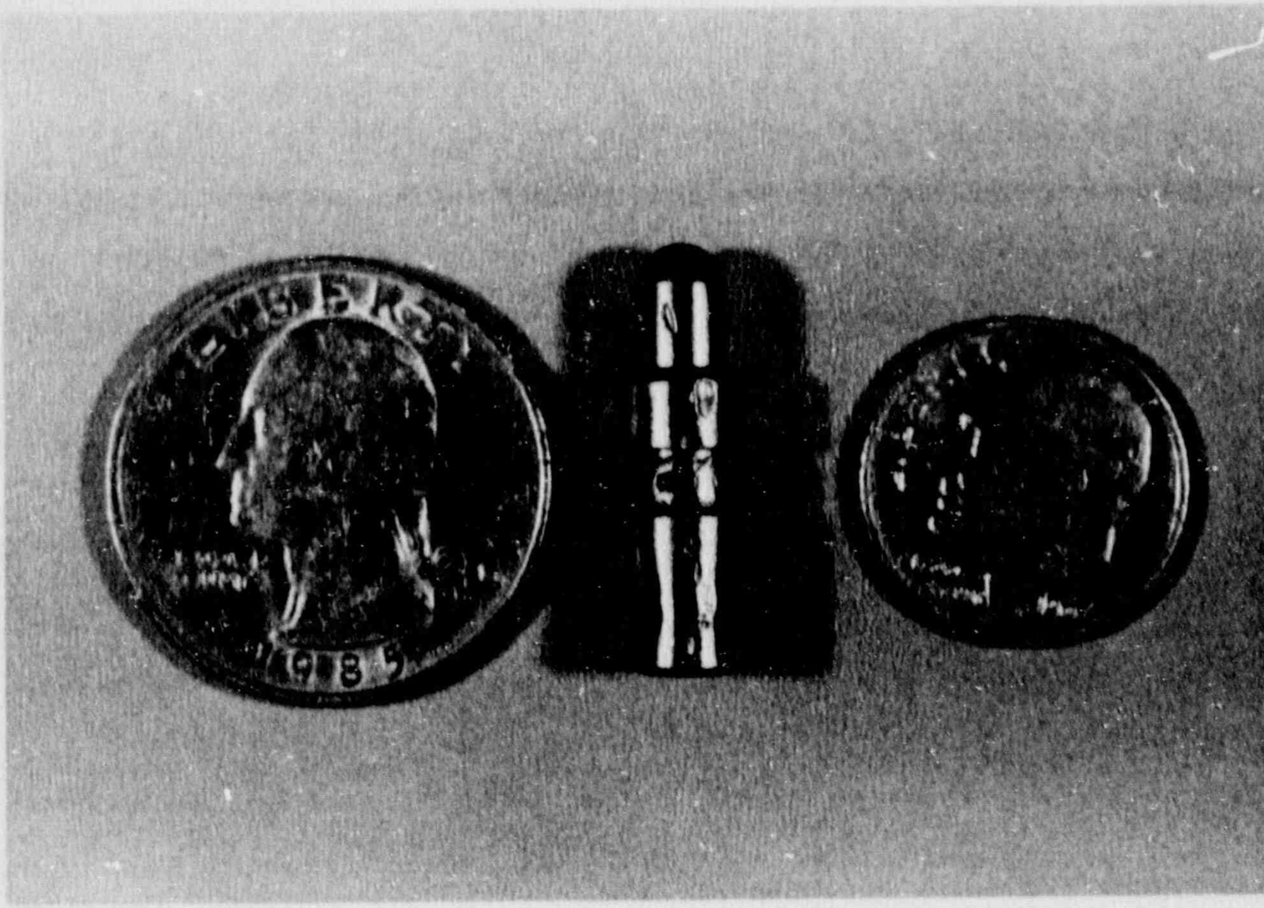


Figure 4.1 Representation of Industrial Nuclear Corporation Model No. 8 Iridium-192 Sealed Source #1062.

Table 4.1 Sequence of Significant Events Involved in Characterizing the Source

Dates in 1990	Events
March 8	Amersham estimates radioactivity as 7 curies based on measurements made during source retrieval.
March 9	Amersham revises its estimate to 3 curies based on measurements in the hot cell. A half-value layer test indicates the source to be composed of iridium-192 (Ir-192).
March 10	The NRC Incident Investigation Team (Team) arrives on site. The Team makes initial exposure estimates based on a 3-curie Ir-192 source.
March 12	A visual comparison of the unidentified source with a dummy source revealed Industrial Nuclear Company (INC) as the probable manufacturer.
March 13	INC provided the Team with a list of 10 candidate sources supplied to Korea having activities in the 2- to 4-curie range as of March 14. The list included an INC Model 8 source, serial number (S/N) 1062. Amersham staff repeats the hot cell measurement in the presence of the Team members. They determine source activity to be 1.92 curies.
March 14	Amersham performs a more accurate measurement of source activity in a source certification laboratory. Activity is determined to be 2.40 curies. Amersham confirms the source to be Ir-192 by a gamma pulse height analysis.
March 15	The Korean end-user identifies the source by manufacturer (INC) as S/N 1062. INC's decay curve indicates that the source activity is 2.49 curies on March 14.
March 20	The Korean Government confirms the identity of the source as an INC source, S/N 1062.

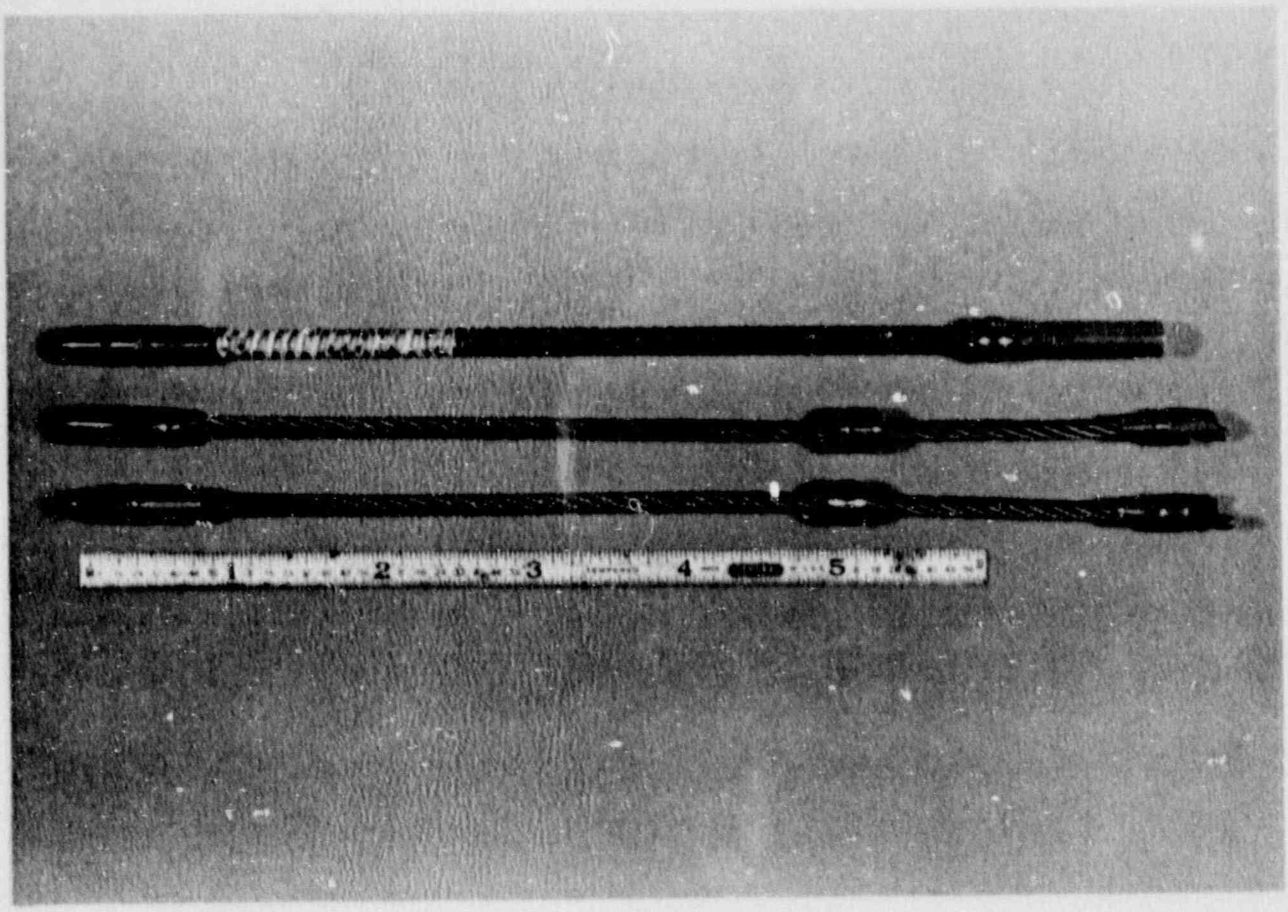


Figure 4.2 Top: Amersham Model No. A424-9 Iridium Source with Teteflex Cable and Connector (right end)
Middle: Amersham Model No. A2A Iridium Source with Aircraft Cable and Connector (right end)
Bottom: Industrial Nuclear Corporation Model No. 8 Iridium-192 Source.
(Note: Stop Ball on Cables Designed to Prevent Inadvertent Removal of Source From Source Changer.)

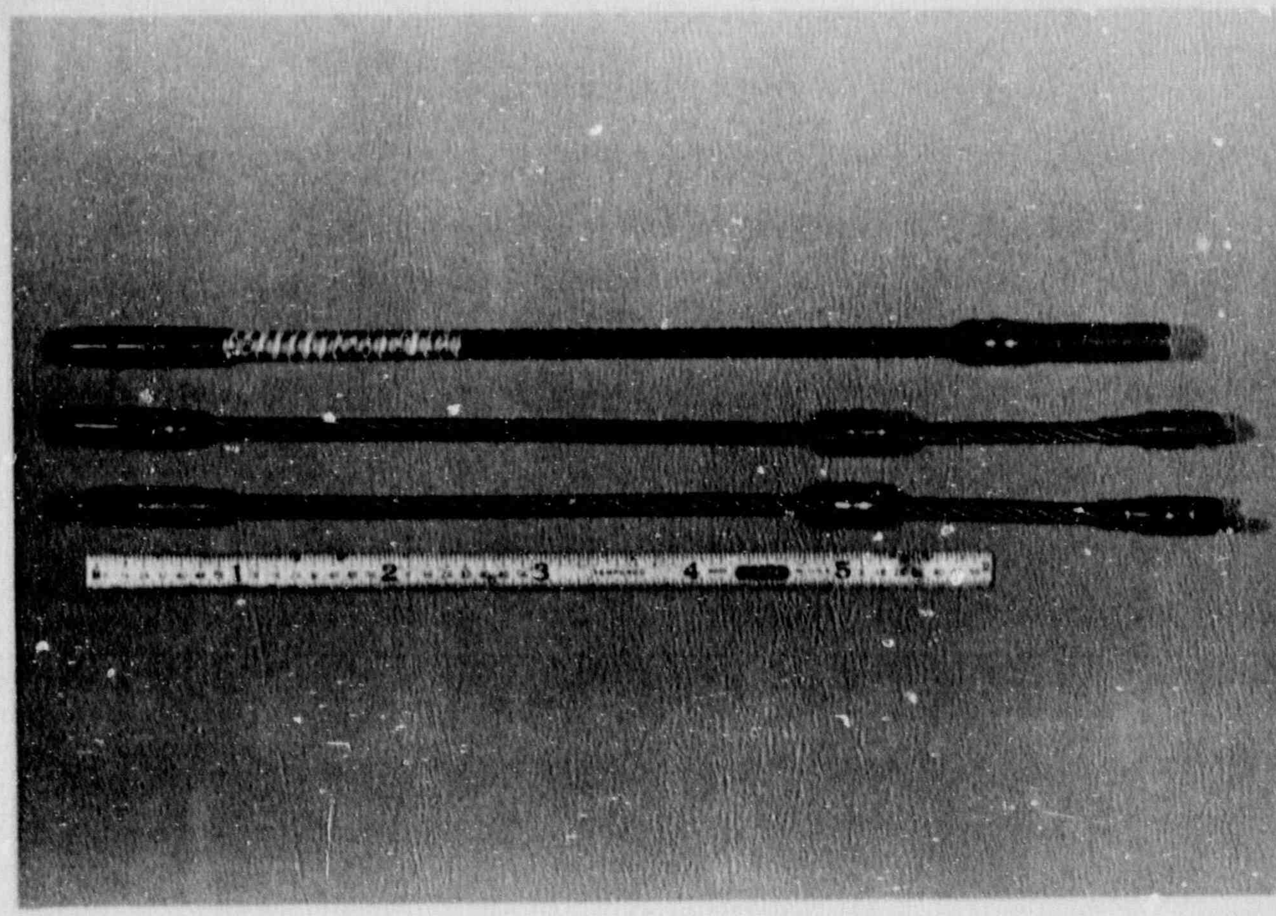


Figure 4.2 **Top:** Amersham Model No. A424-9 Iridium Source with Teteflex Cable and Connector (right end)
Middle: Amersham Model No. A2A Iridium Source with Aircraft Cable and Connector (right end)
Bottom: Industrial Nuclear Corporation Model No. 8 Iridium-192 Source.
(Note: Stop Ball on Cables Designed to Prevent Inadvertent Removal of Source From Source Changer.)

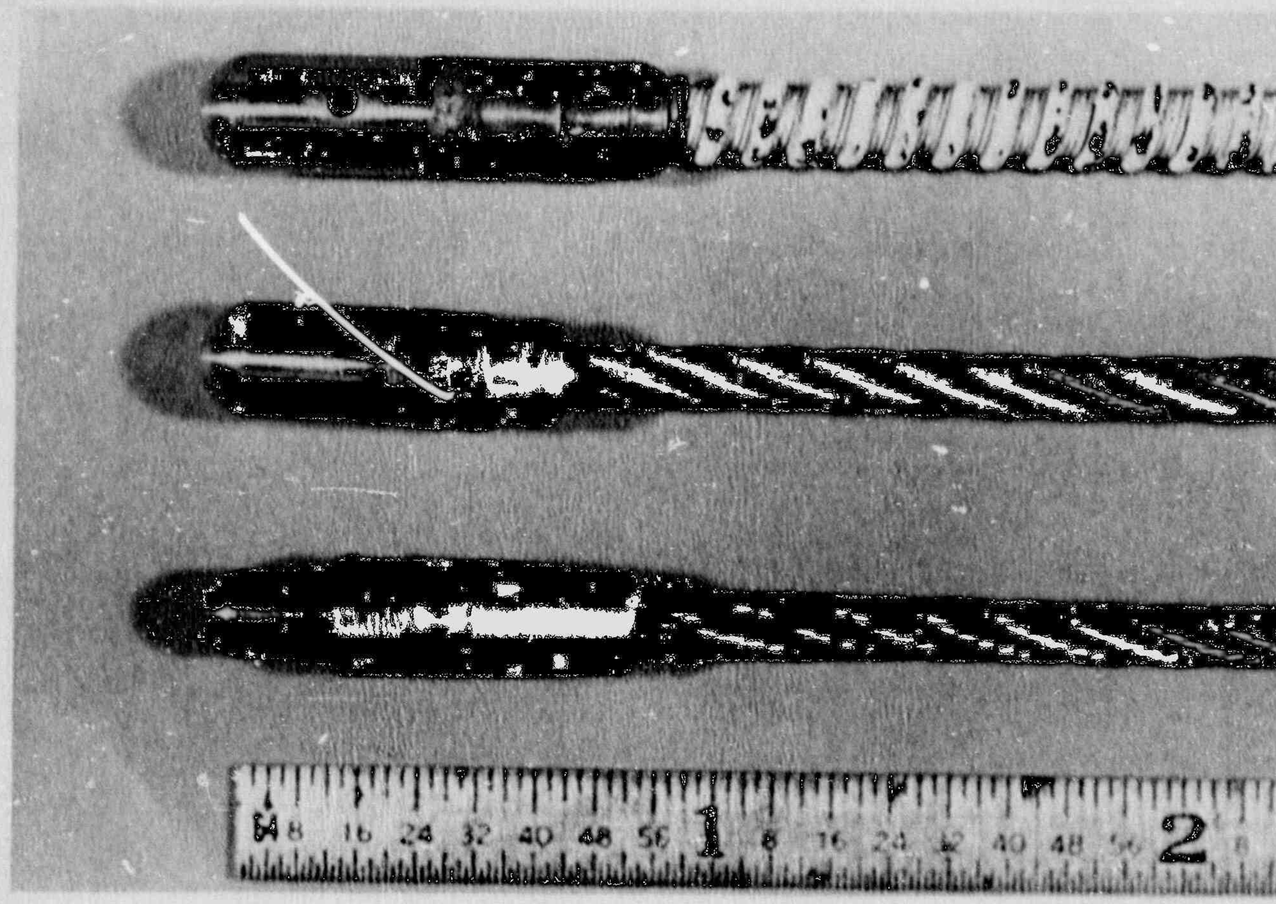


Figure 4.3 Enlargement of Figure 4.2 Showing Close-up of Sources. Hole Drilled Through Source Denotes that Source is a Dummy. Note Difference in Design of Bottom Source.

Figure 4.3 Enlargement of Figure 4.2 Showing Close-up of Sources. Hole Drilled Through Source Denotes that Source is a Dummy. Note Difference in Design of Bottom Source.

On Tuesday, March 13, the Team requested that the Radiation Safety Officer (RSO) at INC compile and send by telefacsimile any records related to the shipment of sources to Korea that would have decayed to a strength of between 2 to 4 curies by March 13, 1990 (Ref. 3). The 2- to 4-curie range for source activity was based on measurements made for the Team by Amersham on March 10. Those measurements indicated a source activity of approximately 3 curies. INC initially identified three 56-curie iridium sources (S/N 1060, 1061, and 1062) manufactured on April 13, 1989, as probable candidate sources. These sources would have had a residual activity of 2.49 curies on March 13, 1990. Seven additional sources were later identified by INC which, on March 13, would have had activities ranging from 1.65 to 2.0 curies (Table 4.2). On March 14, INC provided the Team with the model number, dimensions, decay chart, and serial number of each of the candidate sources (Ref. 4).

On Thursday, March 15, NDI Corporation identified the source as a 56-curie source, S/N 1062, shipped to KIT on April 24, 1989, by INC (Ref. 5).

In a related effort to identify the source, the Team requested on March 13 that the NRC's International Programs staff arrange to contact INC's Korean distributor, Boo Kyung Sa Ltd., to determine which, if any, of the sources identified by INC were shipped to KIT, the reported end-user (Ref. 6). In a response to the Team's request on March 20, 1990, the Korean Ministry of Science and Technology identified the source sent to KIT as S/N 1062 (Ref. 7).

Table 4.2 Sources Shipped to Korea by Industrial Nuclear Company with Activities of 2 to 4 Curies on March 14, 1990

Serial Number	Model Number	Date of Manufacture	Initial Activity in Curies	Activity on March 14, 1990
1030	8	3/17/89	53	1.83
1031	8	3/17/89	53	1.83
1032	8	3/17/89	53	1.83
1033	8	3/17/89	53	1.83
1035	7	3/23/89	55	2.0
1036	7	3/17/89	55	2.0
1060	7	4/13/89	56	2.49
1061	8	4/13/89	56	2.49
1062	8	4/13/89	56	2.49
1063	8	4/13/89	37	1.65

As a result of these activities, the Team was able to establish the model number, serial number, composition, date of manufacture, and initial activity of the source from data supplied by the manufacturer, which enabled the Team to evaluate the potential doses received by individuals.

4.2 Measurement of Source Composition and Activity

The Team sought to determine the composition and radioactivity of the source by direct measurement in the event that the source manufacturer could not be identified in a timely manner. Amersham's initial estimate of the source's radioactivity was based on measurements conducted while the source was still in the unshielded compartment of the source changer. Based on survey readings on the surface of the source changer of 150 rem per hour, the source activity was estimated to be approximately 7 curies on March 8, 1990. Amersham staff retrieved the source from the unshielded compartment of source changer S/N SU-610 and placed it in a small hot cell on March 8, 1990.

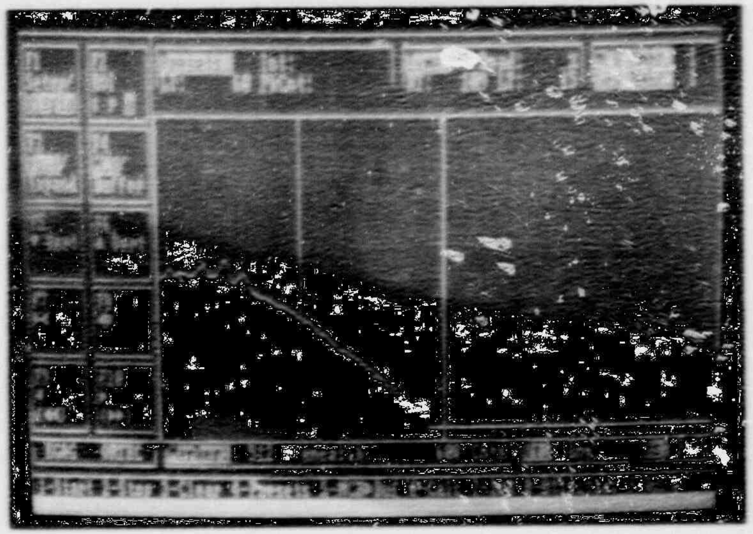
On March 9, the Amersham RSO measured the source activity to be about 3 curies and conducted a half-value layer test with lead to identify the composition of the source. A half-value test consists of determining the thickness of a specific metal, in this case, lead, which, when placed between the source and detector, reduces the observed gamma count rate to one-half its original value. The half-value thicknesses of various metals have been established for the radioisotopes used to manufacture sources. For Ir-192, the lead half-value thickness is approximately 0.2 inch. The half-value layer test performed by the Amersham staff indicated that the radioisotope in question was Ir-192. The initial dose estimates made by the Team, which arrived at Amersham on March 10, were based on these early measurements made by Amersham.

Before March 15, 1990, the Team was uncertain about whether the serial number of the source could be determined. The Team requested through NRC's Region I office that the source be shipped to Brookhaven National Laboratory (BNL) for analysis. However, BNL was unable to respond to the Team's request in a timely manner. At that point, Amersham volunteered to conduct a series of more accurate tests to determine the composition and activity of the source. Amersham fastened a source cable, that is, a "pigtail," onto the source so that it could be transferred to and examined in their source certification laboratory. The radioactivity of the source was then measured at 70.7 centimeters from an ion chamber and compared against a standard cobalt-60 source of approximately the same strength. Based on this measurement, the activity of the source on March 14, 1990, was determined to be 2.40 curies (Refs. 8 and 9).

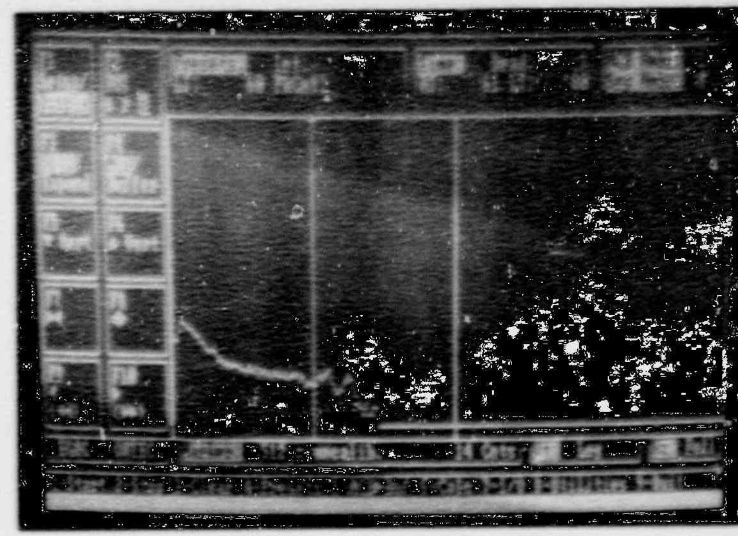
Amersham also conducted a gamma pulse height analysis of the source to verify its composition. The spectrum obtained from the source was compared with reference standards for iridium-192, cesium-137, and cobalt-60. Figure 4.4 shows the spectra of the three standard sources and the spectrum of the unidentified Korean source. On the basis of this gamma-pulse height analysis and the results of the earlier half-value thickness test, the Team concluded that the radioisotopic composition of the source was unquestionably Ir-192.

4.3 Summary

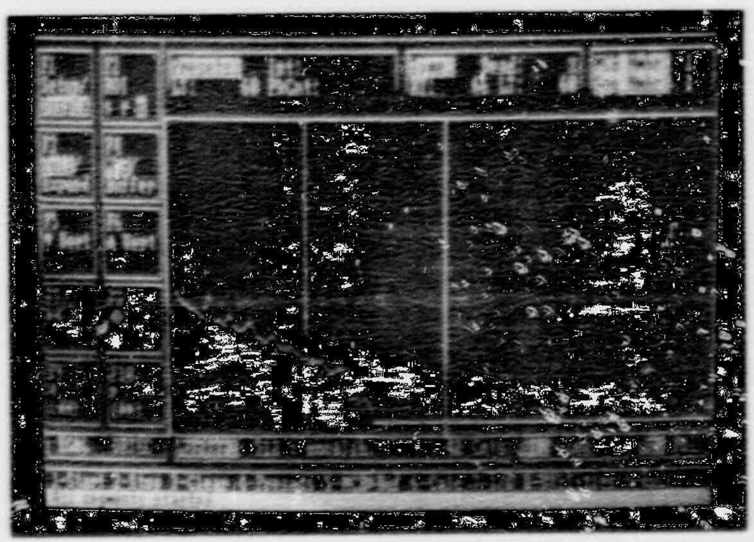
On the basis of the foregoing investigations and measurements, the Team determined that the source in question was originally a 56-curie, Ir-192 source, S/N 1062, which was manufactured on April 13, 1989, by INC, of San Leandro, California. On April 24, 1989, INC shipped the source to KIT. When the source reentered the United States on February 11, 1990, it had an activity of approximately 3.25 curies. On March 8, 1990, the day the source arrived at the Amersham facility, it had a strength of approximately 2.57 curies.



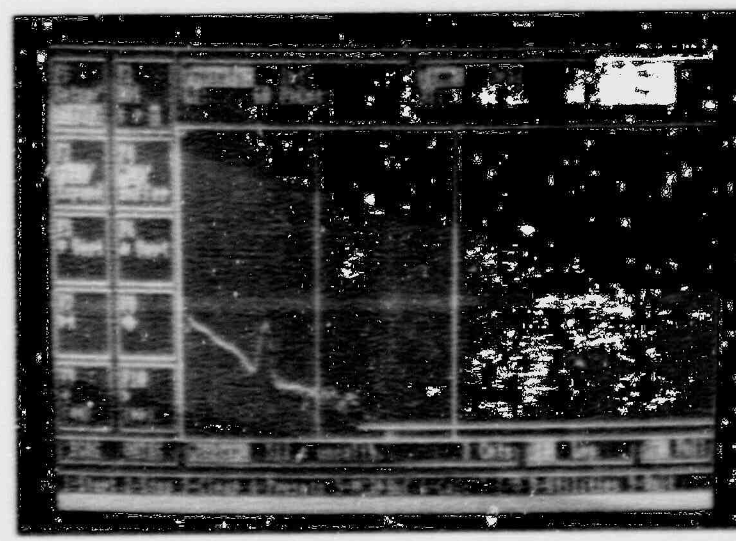
Korean Source Spectrum as Seen Through
5/8 Inch of Lead Shielding



Co^{60} Standard Source Spectrum



Ir^{192} Standard Source Spectrum

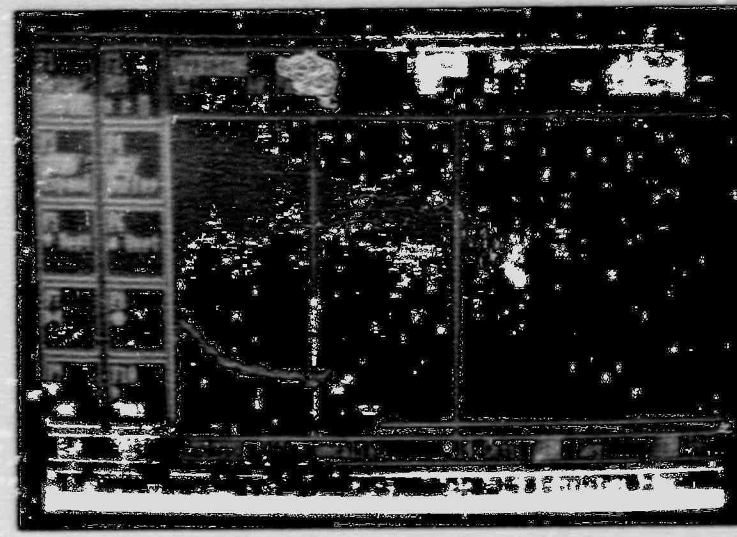


Cs^{137} Standard Source Spectrum

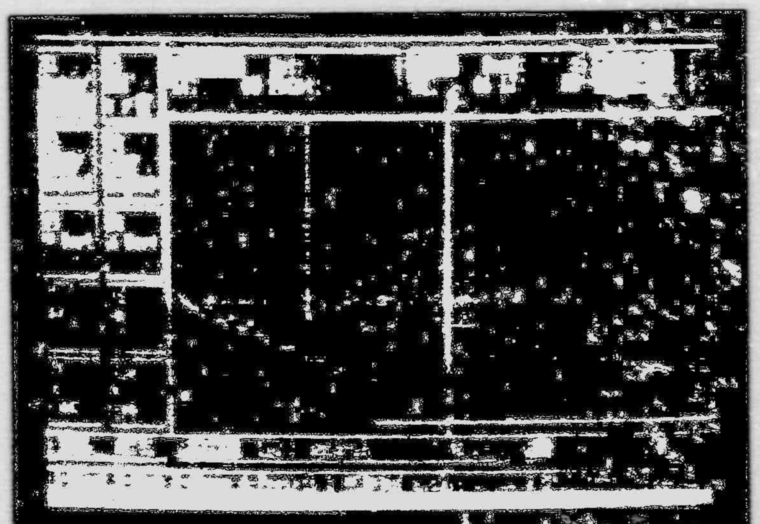
The Spectra Obtained from the Korean Source Compared to Standards for Co^{60}, Cs^{137} and Ir^{192}.

Figure 4.4 Gamma Pulse Height Analysis of Korean Source

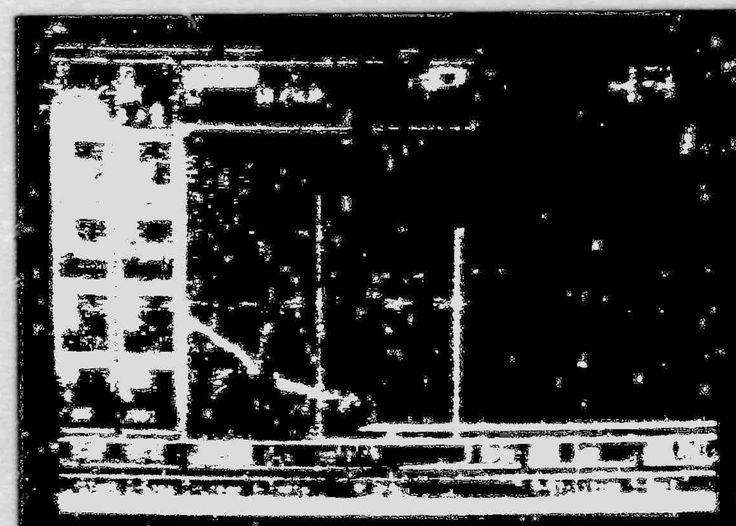
Korean Source Spectrum as Seen Through
5/8 Inch of Lead Shielding



Co^{60} Standard Source Spectrum



Ir^{192} Standard Source Spectrum



Cs^{137} Standard Source Spectrum

The Spectra Obtained from the Korean Source Compared to Standards for Co^{60}, Cs^{137} and Ir^{192}.

Figure 4.4 Gamma Pulse Height Analysis of Korean Source

References*

1. W. McDaniel, Amersham Corporation, Burlington, Massachusetts, transmittal to Tony Lawson, Amersham Corporation, Hong Kong, dated March 10, 1990. (04-27-90)

2. Tony Lawson, Amersham Corporation, Hong Kong, transmittal to W. McDaniel, Amersham Corporation, Burlington, Massachusetts, March 12, 1990. (04-22-90)

3. E. Easton, U.S. Nuclear Regulatory Commission, record of telephone conversation with W. Cain, Radiation Safety Officer, Industrial Nuclear Company, San Leandro, California, March 13, 1990. (04-053-90)

4. W. Cain, Industrial Nuclear Company, transmittal to E. Easton, U.S. Nuclear Regulatory Commission, Subject: "Ir-192 Decay Charts & Source Data," March 14, 1990. (04-051-90)

5. S. Lau, Amersham Corporation, Hong Kong, transmittal to W. McDaniel, Amersham Corporation, Burlington, Massachusetts, Subject: "Container Problems," March 15, 1990. (04-057-90)

6. R. Hauber, U.S. Nuclear Regulatory Commission, letter to Chung-Taek Park, Korean Ministry of Science and Technology, March 13, 1990. (04-069-90)

7. Chung-Taek Park, Korean Ministry of Science and Technology, letter to R. Hauber, U.S. Nuclear Regulatory Commission, March 20, 1990. (04-079-90)

8. Ed Shaffer, Amersham Corporation Source Calibration Record, Subject: "Korean INC Source," March 14, 1990. (04-104-90)

9. William Ott, National Bureau of Standards, Department of Commerce, Report of Calibration for Cobalt-60 Source, December 26, 1983. (04-140-90)

*The file number in parenthesis at the end of some reference citations refers to the location of that reference in the Team's files for NUREG-1405. These files are available for inspection or copying for a fee at the NRC's Public Document Room, 2120 L Street, NW., Lower Level, Washington, D.C.

5 ANALYSIS OF POTENTIAL PERSONNEL EXPOSURES

The Incident Investigation Team (Team) estimated whole-body radiation doses for all persons who were known or postulated to have been exposed to radiation during the transportation and storage of a possibly unshielded source from the time the source changer containing the source arrived on the S.S. HANJIN MOKPO at the Hanjin Shipping Company (Hanjin) dock in the Port of Los Angeles, California, on February 11, 1990, until the Amersham Corporation in Burlington, Massachusetts, received the source changer at 2:30 p.m. on March 8, 1990. Because the Team was unable to determine if the source was unshielded, estimates of radiation exposure were based on the assumption that the source was unshielded in the source changer from the time it left Korea until source-recovery operations were completed at Amersham.

5.1 Method for Estimating Potential Radiation Exposures

As described in Section 4, the unshielded source was determined to be a sealed source containing iridium-192 (Ir-192), serial number (S/N) 1062. This source (Model Number 8) was manufactured by Industrial Nuclear Company (INC) on April 13, 1989. According to INC's "Ir-192 Decay Chart and Source Data" sheet (App. B) for source S/N 1062, the source activity was 56 curies on April 13, 1989.

Ir-192 decays with a half-life of 74 days by electron capture to osmium-192 (4.7 percent) and by the emission of 0.67 million electron volt (MeV) and 0.54 MeV beta particles (beta negative decay) to platinum-192 (95.3 percent) (Ref. 1). The beta particles were absorbed by the source capsule and, therefore, presented no hazard to anyone during the handling and storage of the source changers in the transportation chain. Gamma photons are also emitted during Ir-192 decay, with energies between approximately 6 kilo electron volt (keV) and 1.4 MeV, resulting in a mean gamma photon energy of approximately 800 keV. However, in terms of gamma abundance (i.e., output) the predominant energy range for the gamma photon radiation is between 300 keV and 600 keV. Consequently gamma radiation emitted by Ir-192 is quite penetrating in all materials of relative low density. Higher density materials, such as steel, that could have shielded the Ir-192 source during its shipment and storage in the United States, were either non-existent or, when present, were too thin to effectively attenuate most of the radiation reaching occupied areas. For example, nearly two inches of steel would be required to reduce the radiation intensity from the Ir-192 source by 90 percent.

Radiation dose estimates for all individuals evaluated during the investigation were based on exposure rates that were calculated for selected distances to occupied areas from an unshielded Ir-192 source, corrected for radioactive decay and for attenuation in materials surrounding the source (where the composition and thickness of these materials were known). These materials included the steel case enclosing the source changer, and the metal walls of the ocean cargo container and tractor-trailer (truck), where applicable. Where the composition and thickness of shielding materials could not be determined, the Team assumed that no attenuation occurred. Because of the relatively large magnitude of certain errors associated with the analysis of radiation exposures to individuals, the correction factor for converting exposure in roentgens to absorbed dose in rads to muscle (0.958), was not applied (Ref. 2). The biological dose (rem) for gamma radiation is essentially equal to the calculated absorbed dose (rad). Therefore, all doses are reported in units of one-thousandth of a rem, that is, millirem.

Exposure rates from the unshielded source were calculated for the following dates: January 29, 1990, February 11, 14, 16, 19, 22, and 28, 1990, and March 8, 1990. These dates correspond to reference dates when the source crate was handled during shipment or receipt and to mid-points of calendar periods when the crate was either in storage or in transit (Table 5.1).

The corrected activity (A_t) and the percent of activity remaining correspond to each date referenced in Table 5.1 and was computed from Equation 1 using a 74-day half-life and elapsed time in days since April 13, 1989, when the source was originally certified as containing 56 curies. The unshielded radiation exposure rate (R) in roentgen per hour at 1 foot from the decayed source for each date was calculated from Equation 2 by multiplying the decay corrected number of curies of Ir-192 present on that date by the radiation output of 5.2 roentgens per hour at 1 foot from a 1 curie Ir-192 source (Ref. 3). The reference exposure rate for each distance from the decayed source beyond 1 foot, computed by dividing the resultant value by the square of the distance from the source, was multiplied by the exposure time (T) in hours to obtain the exposure (E_d) in millirem using Equation 3.

$$A_t = A_o e^{-0.693t/T_{1/2}} \qquad \text{(Eq. 1)}$$

where A_t is the corrected source activity (curies) at day t
A_o is the source activity on April 13, 1989 (56 curies)
t is the elapsed time in days since April 13, 1989
$T_{1/2}$ is the half-life of iridium-192 (74 days)

$$R = 5.2\ A_t \qquad \text{(Eq. 2)}$$

where R is exposure rate in R/hr at 1 foot from an unshielded iridium-192 source of activity A_t

$$E_d = \frac{RT \times 10^3}{d^2} \qquad \text{(Eq. 3)}$$

where E_d is exposure in millirem at distance d
T is exposure time in hours
d is distance in feet from the unshielded iridium-192 source
10^3 is a factor converting rem to millirem

The Model 500-SU source changer consists of a welded stainless steel rectangular box, containing a depleted uranium (DU) shield encased in a compartment at the front of the changer and a separate unshielded cavity at the rear of the changer (see Fig. 2.19). The DU shield designed into the Model 500-SU source changer is

Table 5.1 Calculated Dose Rates (R/hr) at Selected Distances for 56-Curies (Ci) Ir-192 Source Certified April 13, 1989

Date:		01/29/90	02/11/90	02/14/90	02/16/90	02/19/90	02/22/90	02/28/90	03/08/90
Elapsed Time (days):		291	304	307	309	312	315	321	329
Approx. % Remaining:		6.55	5.80	5.64	5.53	5.38	5.23	4.95	4.59
Activitiy (Ci):		3.67	3.25	3.16	3.10	3.01	2.93	2.77	2.57
		Dose Rates (R/hr)							
Distance:	4"	171.7	152.0	147.8	145.0	141.0	137.1	129.6	120.2
	1'	19.1	16.9	16.4	16.1	15.7	15.2	14.4	13.4
	2'	4.77	4.22	4.10	4.03	3.92	3.81	3.60	3.34
	3'	2.12	1.88	1.82	1.79	1.74	1.69	1.60	1.48
	4'	1.19	1.05	1.03	1.01	0.98	0.95	0.90	0.84
	5'	0.76	0.68	0.66	0.64	0.63	0.61	0.58	0.53
	6'	0.53	0.47	0.46	0.45	0.44	0.42	0.40	0.37
	7'	0.39	0.34	0.34	0.33	0.32	0.31	0.29	0.27
	8'	0.30	0.26	0.26	0.25	0.24	0.24	0.23	0.21
	9'	0.24	0.21	0.20	0.20	0.19	0.19	0.18	0.17
	10'	0.19	0.17	0.16	0.16	0.16	0.15	0.14	0.13
	11'	0.16	0.14	0.14	0.13	0.13	0.13	0.12	0.11
	12'	0.13	0.12	0.11	0.11	0.11	0.11	0.10	0.09
	15'	0.08	0.08	0.07	0.07	0.07	0.07	0.06	0.06
	20'	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.03
	25'	0.03	0.03	0.03	0.03	0.03	0.02	0.02	0.02

of sufficient thickness to reduce the radiation intensity from an Ir-192 source in a shielded position to very low levels (reduction factor approximately one million). However, from the position of the source as found in the unshielded portion of the source changer and the angle subtended by the DU shield relative to the source, the Team expects that the source would have been partially or fully shielded by the source changer's DU in only one direction.

The potential shielding effect of various materials other than DU surrounding the Ir-192 source was evaluated from transmission curves (Ref. 4), and from mass attenuation coefficients for gamma photon energies between 300 and 600 keV (Ref. 5). The only other source changer material that provided any significant shielding was the 0.135-inch thick steel wall enclosing the source changer. The total mass attenuation coefficient for iron is approximately 0.10 cm^2/g (see Ref. 5). However, because all potential radiation exposures occurred under broad beam geometry conditions (which includes multiple compton photon scattering), the true mass absorption coefficient of approximately 0.03 cm^2/g was used (Ref. 6). This evaluation indicated that the source changer's steel case, with an assumed density of 7.86 g/cm^3, attenuated only about 10 percent of the radiation emitted by the unshielded source. Consequently, a transmission factor of 0.9, applied to account for gamma attenuation, was incorporated into Equation 3 to calculate the total estimated radiation exposure (see Eq. 4).

$$E_{d'} = 0.9\, E_d \qquad \text{(Eq. 4)}$$

where 0.9 is the transmission factor resulting from shielding by the 0.135-inch thick steel case enclosing the source changer

As explained earlier in this report, the wooden crate transported from Korea to Amersham contained 14 source changers. Upon its arrival at the Amersham facility, the wooden crate was found to be severely damaged, and source changers were scattered over the floor of the Patriot Shipping Company's (Patriot) trailer. Soil mark impressions left by the source changers on the crate floor indicated that the source changers were positioned at right angles to the long axis of the crate. From this information and from knowledge of the crate and source changer dimensions, the wooden crate, as packaged by the Korean shipper, had apparently contained one group of seven source changers on the floor of the crate while a second group of seven source changers had been stacked on top of the first group. However, the Team could not determine either the specific location or the directional orientation of the source changer containing the unshielded source (S/N SU-610) within the wooden crate.

Lack of knowledge concerning the actual location of the unshielded source changer within the crate, and the orientation of the crate in occupied areas during shipment and temporary storage of the source changers, prevented the Team from determining accurate levels of radiation exposure in those areas. This effort was further complicated in many cases by the absence of detailed information concerning the presence, location, and composition of other structural or equipment barriers that may have shielded persons in areas near the crate. Additional complications in estimating doses were caused by relatively large uncertainties associated with occupancy times and distances from the source crate for potentially exposed individuals.

Consequently, different scenarios can be developed to support various levels of radiation exposure that depend on the directional orientation and position assumed for the source changer containing the unshielded source. For example, if the source changer containing the source, or other adjacent empty source changers, were oriented such that one or more DU shields were positioned directly between the source and any persons occupying a specific area near the source crate, the radiation exposure of these persons would have been reduced to insignificant levels. However, estimates of radiation exposure were always based on a worst-case analysis, which assumed that the source was located in the crate nearest any occupied areas and that the source was unshielded by DU material in the same or adjacent source changers. Conservative assumptions were also used in estimating exposure times and distances to the source changer containing the unshielded source when such information was questionable or unavailable. The resulting reported exposures were therefore considered as potential upper limit estimates only. In several cases, it is reasonable to expect that persons exposed to the unshielded source could have received radiation doses significantly lower than those reported.

The Team noted that, with the exception of Amersham personnel (who wore personnel radiation monitors), only one individual (a Patriot Trucking Co. driver) was known to have been exposed to the unshielded source. All other individuals are only assumed to have been exposed because it is possible that the source remained in a shielded position until it was transported to Amersham by truck from the Patriot warehouse.

5.2 Estimates of Possible Radiation Exposures for the Public and Employees Who Shipped, Handled, and Inspected the Source Changers

The Team estimated potential doses of radiation exposure for persons in the general public who may have been exposed to the unshielded source during transportation and storage of the source changers from their arrival in the United States to their destination in Burlington, Massachusetts. The Team also estimated a possible dose of radiation exposure for each person who was involved with shipping, handling, and inspecting the source changers. Employees from the U.S. Customs Service, U.S. Department of Agriculture, and four carrier companies were involved:

1. Hanjin Shipping Company (Hanjin);

2. Nova Container Freight station (Nova);

3. Covenant Transport, Inc. (Covenant); and

4. Patriot Trucking, Inc. (Patriot).

The estimates of possible radiation exposure that any of these employees and members of the public may have received are presented in the following sections and tables. The biological significance of the possible radiation exposures in the ranges of those calculated for these individuals can be evaluated most simply by comparing their possible doses with radiation doses to the general population from natural and man-made sources of radiation. The average person's exposure from natural background and man-made sources of radiation normally present in the environment is 200 millirem per year. The exposure estimates may also be compared to the maximum whole-body dose of five rem per year allowed by the NRC for occupationally exposed individuals (Ref. 7). The biological significance of radiation effects are described in References 8, 9, and 10.

5.2.1 Estimated Exposures for Employees at the Hanjin Berthing Area

While the S.S. HANJIN MOKPO was docked at the Hanjin berth in Los Angeles, California, a U.S. Department of Agriculture Plant Protection Quarantine Officer boarded the ship to inspect its food provisions. Because this officer was inspecting an area two decks away from the cargo containing the source changers, the Team estimates that this officer received no significant radiation exposure.

Hanjin terminal employees unloaded the ship's cargo, loaded the crate of source changers onto a tractor-trailer chassis, and moved this chassis to another area of the terminal. The Team estimates that the exposure to radiation for any of these employees would have been less than 20 millirem.

5.2.2 Estimated Exposures for Nova Employees

Assuming a worst-case scenario, the Nova Container Freight Station (CFS) driver who moved the trailer containing the crate of source changers from the Hanjin Terminal to the Nova CFS in Compton, California, would have received a dose of approximately 40 millirem. But, assuming that the driver was partially shielded by the cargo in the trailer and the container wall, the Team estimates the driver would have received a dose of approximately 20 millirem.

Two unloaders, several forklift drivers, and a checker employed by Nova CFS spent several hours unloading the cargo from the trailer. The two unloaders, assuming a worst-case scenario, could have received a dose estimated to be approximately 330 millirem. Although the cargo would have partially shielded the unloaders from any radiation exposure while unloading, the Team cannot accurately determine the degree of shielding provided during the two-hour unloading operation.

The Team assumes that the Nova forklift operator was exposed to the crate of source changers for approximately 5 minutes and estimates that the operator's exposure was approximately 50 millirem. The checker estimates that he spent 5 to 10 minutes examining the damaged crate, which the Team estimates would have resulted in a maximum exposure of 70 millirem.

A Nova shipping clerk and shipping supervisor work near the area where the crate of source changers was stored. The Team estimates that their maximum exposure would have been approximately 230 millirem to 500 millirem, received in 19 hours over three days.

Nova forklift operators, cargo unloaders, cargo checkers, and shipping employees work in an area near storage space 28 in the Nova warehouse where the crate of source changers was stored. The Team estimates that the upper exposure limit for any of these Nova employees would be approximately 150 millirem each.

When the crate of source changers was moved from storage space 28 to the Covenant trailer for shipment across the United States, two loaders, a checker, and at least one forklift operator formed the crew. The Team estimates the exposure to members of this loading crew to range from 50 to 320 millirem.

Finally, on the basis of the receiving clerk's estimate that he spent 10 to 15 minutes examining the crate because of markings on the outside of the crate, the Team estimates that this clerk could have been exposed to approximately 400 millirem.

In summary, the Team estimates that the various Nova employees received radiation exposures ranging from 40 millirem to 470 millirem (Table 5.2).

5.2.3 Estimated Exposures for Covenant Employees

In addition to measuring probable distances that the Covenant drivers maintained from the source, the Team used information from the Covenant truck drivers' logs and evaluated the shielding effectiveness of the materials from which the truck was constructed before estimating the radiation exposures that the Covenant drivers received. The Team estimates that the senior driver received a dose of approximately 35 rem during the six-day trip across the United States, while the driver trainee, received from 21 rem to 27 rem (Table 5.3). The estimated dose for the senior driver is higher primarily because he spent more time in the sleeper berth than the driver trainee.

During the cross-country trip, some warehouse workers and members of the public may have received radiation exposures. Either of the drivers or any number of fuel station employees refueled the truck at refueling stops in Southern California; Amarillo, Texas; Oklahoma City, Oklahoma; and Hebron, Ohio. The Team estimates that the person refueling the truck at each stop received approximately 100 millirem. At truck weighing stations in Fontana, California, and in Maryland, the Team estimates that weight-scale workers and a Maryland State Trooper inspecting the truck received exposures of less than 40 millirem.

During food and rest stops in Holbrook, Arizona; Amarillo, Texas; Oklahoma City, Oklahoma; Terre Haute, Indiana; Hebron, Ohio; Frederick, Maryland; Connecticut; and Massachusetts; the Covenant truck was parked well away from normally occupied areas. However, during these stops, several trucks were parked from 10 to several hundred feet away for 10 minutes to 2 hours. The Team estimates that any occupant in these trucks would have received an exposure of no more than 300 millirem.

The Covenant drivers stopped to discharge three consignments. The first unloaded was at the Nu Tranz Freight Systems, Inc. (Nu Tranz), terminal in Coraopolis, Pennsylvania, the second at Port East Transfer, Inc. (Port East), Warehouse in Baltimore, Maryland, and the third at Evans Delivery Service in Philadelphia, Pennsylvania. Taking into account both the distance from the source and the shielding from the source that the cargo provided, the Team estimates that Nu Tranz and Port East employees would have received an insignificant radiation exposure. At Evans Delivery Service, the Covenant drivers and one terminal employee could have been within 12 feet of the source changers for up to 2 hours while unloading the trailer in a worst-case scenario. Under these circumstances, the Team estimates that they would have received a

Table 5.2 Potential Radiation Exposure of Nova Employees

Exposed Individual	Activity Causing Radiation Exposure	Avg. Distance From Source (ft)	Exposure* Rate (R/hr)	Assumed Exposure Time	Estimated† Dose (mrem) Each Activity	Total† Dose (mrem)
Truck driver	Driving truck	20	0.04	45 m	30	40
		10	0.16	6 m	10	
Cargo unloaders	Unloaded cargo container	15	0.07	2 h	130	330
	Near source crates	5	0.66	20 m	200	
Unloading forklift operator	Moved source to space 28	5	0.66	5 m		50
Unloading checker	Examined source crate	6	0.46	10 m		70
Shipping clerk	At shipping clerk desk	25	0.03	3 h	80	230
	Occupied loading dock	12	0.11	1 h - 30 m	150	
Shipping supervisor	At shipping clerk desk	25	0.03	3 h	80	230
	Occupied loading dock	12	0.11	1 h - 30 m	150	
Asst. shipping clerk	Occupied loading dock	12	0.11	1 h - 30 m		150
Receiving clerk	Examined source crates	3	1.79	15 m		400
Loading forklift operator	Moved source to Covenant trailer	5	0.64	5 m	50	200
	Occupied loading dock	12	0.11	1 h - 30 m	150	
Cargo loaders	Loaded source crate on on Covenant trailer	15	0.07	2 h	130	470
	Near source crate during loading	5	0.64	20 m	190	
	Occupied loading dock	12	0.11	1 h - 30 m	150	
Loading checker	Examined source crate	6	0.45	10 m	70	220
	Occupied loading dock	12	0.11	1 h - 30 m	150	

* Exposure rate from unshielded iridium-192 source containing 3.16 curie on 2/14/90; 3.10 curie on 2/16/90.

† Dose includes 10 percent attenuation in source changer 0.135-inch steel case.

Table 5.3 Potential Radiation Exposure of Covenant Truck Drivers

Occupied Position	Approx. Distance From Source (ft)	Exposure[a] Rate (R/hr)	Total Dose Covenant Sr. Driver Time (hr)	Millirem[b]	Total Dose Covenant Trainee Time (hr)	Millirem[b]
Driver seat	10	0.16	43.5	6260	26.5[c]	3820[c]
					30.0[d]	4320[d]
Passenger seat	10	0.16	5	720	28.0[c]	4030[c]
					4.5[d]	650[d]
Sleep booth	6	0.44	58	22970	19.0[c]	7520[c]
					50.0[d]	19800[d]
Sleeper front seats	10	0.16	0	0	36.5[c]	5260[c]
					18.0[d]	2590[d]
During unloading of cargo at Patriot warehouse	(e)	(e)	2.5	4900	1.8[c]	200[c]
Accumulated dose	--	--	--	34850	--	20830[c]
						27560[d]

a. Exposure rate from unshielded Ir-192 source containing 3.16 curie on 2/14/90.
b. Dose includes 10 percent attenuation in source changer 0.135-inch steel case.
c. Based on trip information provided by the senior Covenant driver.
d. Based on trip information provided by the Covenant driver trainee.
e. Variable exposure times and distances from unshielded source; see Table 5.4.

maximum exposure of 200 millirem, but it is also possible that the actual exposures were much less because the cargo provided shielding and because the individuals were unloading cargo at distances of up to 25 feet from the crate (Table 5.4).

After unloading the third consignment, the drivers spent the night at a truck service plaza near Exit 13, eastbound on Interstate 90. The Covenant truck was parked within 4 or 5 feet of two other trucks with sleeper berths that may have been occupied. Depending on the assumed distance from the Covenant truck and the number of hours the drivers in the adjacent trucks slept (see Section 6.3.2 of this report), they could have received a dose from as low as 500 millirem to as high as 2200 millirem.

5.2.4 Estimated Exposures for Patriot Facility Employees and Others Near the Source

The two Covenant drivers discharged their final consignment at Patriot Trucking Company's (Patriot) facility at Logan Airport in Boston, Massachusetts. The drivers, a Patriot warehouseman, two Patriot forklift operators, a Patriot truck driver, and a U.S. Customs Service inspector were near or handled the crate of source changers at this facility. Using worst-case scenarios, the Team estimates that these persons received exposures at a variety of distances from the crate of source changers, as shown in Table 5.4 (see also Section 6.4). The maximum estimated exposures that these persons received were between approximately 200 millirem and 5600 millirem. Of these persons, only the Patriot truck driver was positively known to have received an actual radiation exposure from the unshielded source. The Team estimates that this person's exposure was approximately 550 millirem.

5.2.5 Estimated Exposures for Amersham Employees

Five Amersham Corporation (Amersham) employees were potentially exposed to the unshielded source upon its arrival at the Amersham facility: the radiation safety officer (RSO), two radiation technologists, a radiation safety specialist, and the hot lab supervisor. These employees wore whole body and extremity monitoring devices and pocket ion chambers to measure their radiation exposures. Amersham provided NRC a report stating that the maximum exposure any employee received was a whole body dose of 40 millirem and that the maximum extremity dose any employee received for the month was 100 millirem. The maximum pocket dosimeter reading reported was 20 millirem (Table 5.5).

5.3 Cytogenetic Evaluation Performed by Oak Ridge Associated Universities

In order to confirm the range of estimated radiation exposure to the five persons identified as having the highest potential for exposure, the NRC arranged for cytogenetic evaluation of these persons. The cytogenetic evaluation involved the examination of a randomly selected set of lymphocytes (a white blood cell) to determine how many in the set exhibit radiation-induced chromosome aberrations.

Arrangements were made with Oak Ridge Associated Universities (ORAU), Medical Sciences Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee, to supply blood specimen collection kits for each person. For the Patriot Driver, Patriot Operator, and USCS Inspector, the kits were supplied directly to the

Table 5.4 Potential Radiation Exposures at Patriot Warehouse

Exposed Indvidual	Activity Causing Radiation Exposure	Avg. Distance From Source (feet)	Exposure* Rate (R/hr)	Assumed Exposure Time	Estimated† Dose (mrem) Each Activity	Total† Dose (mrem)
Covenant senior driver	Unloaded cargo 14' - 8' from source	11	0.13	1 h - 45 m	200	
	Unloaded cargo 8' - 2' from source	5	0.61	15 m	140	
	Sat next to source crate	2	3.81	20 m	1140	
	Sat on source crate	1	15.2	10 m	2280	
	Handled source changers	1	15.2	5 m	1140	4900
Covenant driver trainee	Unloaded cargo 14' - 8' from source	11	0.13	1 h - 45 m		200
Patriot operator	Unloaded cargo 14' - 2' from source	8	0.24	1 h	220	
	Examined source crate	1	15.2	1 m	230	
	Removed crate from trailer	1	15.2	1 m	230	
	Removal and replacement of source changers	1	15.2	2 m	460	
	Source crate moved to bonded area	5	0.61	2 m	20	
	Occupied processing area	6	0.40	7 h - 30 m	2700	
	Removed and examined source changer	1	14.4	2 m	430	
	Repair of source crate	2	3.6	4 m	220	
	Stacked equipment near source crate	2	3.6	5 m	270	
	Near source crate	1	13.4	2 m	400	
	Source crate moved to Patriot truck	5	0.53	2 m	20	
	Cardboard placed under source crate	1	13.4	2 m	400	5600
Patriot Warehouseman	Unloaded cargo 14' - 8' from source	11	0.13	1 h - 45 m	200	
	Unloaded cargo 8' - 2' from source	5	0.61	45 m	140	
	Occupied processing area	6	0.40	30 m	180	
	Occupied bonded area	5	0.58	20 m	170	
	Touched and examined source crate	1	14.4	1 m	220	
	Cleaned floor near source crate	5	0.58	20 m	170	1080
USCS inspector	Examined source crate	2	3.60	15 m		810
Patriot truck driver	Inspected source crate	1	13.4	15 s	50	
	Near crate during loading	2	3.34	1 m	50	
	Transport to Amersham	50	0.005	30 m	<10	
	Removal of 2-3 source changers at	3	1.48	2 m	40	
	Amersham facility	1	13.4	2 m	400	550

* Exposure rate from unshielded Ir-192 source containing 2.93 curie on 2/22/90; 2.77 curie on 2/28/90; 2.57 curie on 3/8/90.
† Dose includes 10 percent attenuation in source changer 0.135 inch steel case.

Table 5.5 Radiation Exposures of Amersham Staff Based on Film Badge Readings

Radiation Technologist A	-	Whole Body	-	20 millirem
Radiation Safety Specialist	-	Whole Body	-	30 millirem
Radiation Technologist B	-	Whole Body	-	20 millirem
Radiation Safety Officer	-	Whole Body	-	15 millirem
Hot Lab Supervisor	-	Whole Body	-	40 millirem
Hot Lab Supervisor	-	Head	-	70 millirem
Hot Lab Supervisor	-	Left Wrist	-	30 millirem
Hot Lab Supervisor	-	Right Wrist	-	50 millirem
Hot Lab Supervisor	-	Left Hand	-	80 millirem
Hot Lab Supervisor	-	Right Hand	-	100 millirem

physicians they designated. For the Covenant Transportation senior driver and driver trainee, a Team member arranged for blood specimens to be collected at Loma Linda University Medical Center, Loma Linda, California, and Vista Hills Medical Center, El Paso, Texas, respectively. All five blood specimens were sent to ORAU for cytogenetic analysis to determine if any of the persons sustained any radiation-induced chromosome aberrations, a biological indicator of significant radiation exposure.

ORAU's procedure for cytogenetic evaluation involves sampling 500 first-division metaphases from blood lymphocyte cultures. In this study, the cultures were examined for dicentric frequencies, that is, chromosome aberrations. ORAU reported to the Team that dicentric frequencies ranging from 1.3 to 2.4 per thousand metaphases have been reported in population studies of 1141 non-irradiated adults having no known exposures to radiation other than background or rare chest or dental x-rays (Refs. 11, 12, and 13). Relative to this background, ORAU reported that the four persons exhibited between 0 and 1 dicentrics per 500 metaphases scored, indicating that they were within the range expected for non-irradiated persons. The only person known to have been actually exposed to the source exhibited 2 dicentrics per 500 metaphases scored, which is consistent with the estimated radiation exposure but not an indication of significant dose.

While such analysis is statistical in nature (i.e., based on a random selection of a single 500-cell sample from the millions of cells available), ORAU indicated that if any of these persons did receive exposure from the iridium-192 source, the resultant dose was too small to detect using standard cytogenetic methods. For perspective, ORAU calculated that a person receiving 30-rem exposure to iridium-192 (30,000 millirem) would probably exhibit a dicentric frequency of about 7 for 1000 cells scored. The results of the cytogenetic analysis are summarized in Table 5.6, where they are compared to the calculated radiation exposure estimates for five individuals who had the greatest suspected risk of exposure.

Table 5.6 Summary of Potential and Actual Radiation Exposure Estimates Determined by Calculation and Cytogenetic Evaluation

Individual	Potential Radiation Exposure Estimate	Actual Radiation Exposure Estimate	Cytogenetic Results Dicentrics/500 metaphases
Covenant Senior Driver	34850 mrem		0
Covenant Driver Trainee	27560 mrem		1
USCS Inspector	810 mrem		1
Patriot Driver		550 mrem	2
Patriot Operator	5600 mrem		1

References*

1. D.C. Kocher, Radioactive Decay Data Tables, A Handbook of Decay Data for Application to Radiation Dosimetry and Radiological Assessments, Technical Information Center, U.S. Department of Energy, 1981.

2. National Council on Radiation Protection and Measurements NCRP Report No. 69, "Dosimetry of X-Ray and Gamma-Ray Beams for Radiation Therapy in the Energy Range 10 keV to 50 MeV," Washington, D.C., December 15, 1981.

3. American National Standard N432, "Radiological Safety for the Design and Construction of Apparatus for Gamma Radiography," National Bureau of Standards Handbook 136, U.S. Government Printing Office, Washington, D.C., paragraph 8.1.2, 1981.)

4. National Council on Radiation Protection and Measurements, "Structural Shielding and Evaluation for Medical Use of X-Rays and Gamma Rays of Energies up to 10 MeV," NCRP Report No. 49, Washington, D.C. September 15, 1976.

5. B. Shleien and M. S. Terpilak, The Health Physics and Radiological Health Handbook, Nucleon Lecturn Associates, Inc., 1984.

6. G.J. Hine and G.L. Brownell, Radiation Dosimetry, Academic Press, Inc., New York, NY, 1956.

7. U. S. Code of Federal Regulations, "Standards for Protection Against Radiation," Part 20, Chapter 1, Title 10, "Energy".

8. Regulatory Guide 8.29, Instruction Concerning Risks from Occupational Radiation Exposure, U.S. Nuclear Regulatory Commission, Washington, D.C., July 1981.

9. Health Effects of Exposure to Low Levels of Ionizing Radiation, BEIR V, Committee on the Biological Effects of Ionizing Radiations, National Research Council, National Academy Press, Washington, D.C., 1990.

10. National Council for Radiation Protection and Measurements, NCRP Report No. 39, "Basic Radiation Protection Criteria", Washington, D.C., January 15, 1971.

11. L. G. Littlefield, Ph.D., Oak Ridge Associated Universities, ORAU, Oak Ridge, Tennessee, Memorandum to C. C. Lushbaugh, M.D., ORAU, Subject: "Cytogenetic Findings of March 21, 1990. (04-153-90)

12. L.G. Littlefield, Ph. D., Oak Ridge Associated Universities, Oak Ridge, Tennessee, Memorandum to C. C. Lushbaugh, M.D., ORAU, Subject: "Cytogenetic Dosimetry Evaluations," April 3, 1990. (04-165-90)

*The file number in parenthesis at the end of some reference citations refers to the location of that reference in the Team's files for NUREG-1405. These files are available for inspection or copying for a fee at the NRC's Public Document Room, 2120 L Street, NW., Lower Level, Washington, D.C.

13. L.G. Littlefield, Ph.D., Oak Ridge Associated Universities, Oak Ridge, Tennessee, Memorandum to C. C. Lushbaugh, M.D., ORAU, Subject: "Follow-up to NRC Requested Cytogenetic Studies," April 5, 1990. (04-165-90)

6 DETAILED ANALYSIS OF POTENTIAL AND ACTUAL RADIATION EXPOSURE ESTIMATES

Estimates of potential radiation exposures that the Team calculated for individuals who may have received radiation exposures from the radiographic source are described in detail in the following sections. Included in each section are the time, distance, and shielding factors and assumptions that were used in supporting each calculated dose estimate. As described in Section 5, each estimate of radiation exposure was based on generally conservative assumptions and, as a result, may be larger than doses actually received.

6.1 Potential Radiation Exposure of Personnel at Hanjin Berthing Area

The potential for radiation exposures was evaluated for personnel who worked in the Hanjin berthing area within the Port of Los Angeles. As described earlier, the ocean cargo container containing the wooden crate with the 14 source changers was unloaded from the S.S. HANJIN MOKPO on February 13, 1990. The container dimensions were 40 feet long by 8 feet wide by 8 feet 6 inches high. Shipping documents identified the weight and volume of each lot of cargo in the container. The location of the crate containing the source changers was estimated from the cargo volume and container dimensions to be approximately 10 feet from the container front wall and 30 feet from the container (rear) doors. The container had originally been loaded on the S.S. HANJIN MOKPO in Pusan, Korea, with the doors facing aft, 8.5 feet forward of the ship's superstructure area housing the crew's mess and living quarters. The container was the second in from the starboard side and eight feet above the deck.

While the ship was docked at the Hanjin berth, a U.S. Department of Agriculture (USDA) Plant Protection Quarantine (PPQ) Officer boarded to inspect the ship's food provisions. During most of the 1/2 hour inspection, the USDA-PPQ officer was in the superstructure at least two decks below and away from the cargo container containing the crate of source changers. The Team believes that no significant radiation exposure would have occurred owing to this officer's on-board activities.

To learn how the crate of source changers may have been unloaded, two Team members observed the unloading of similar containers from the S.S. HANJIN MOKPO after it returned to the Hanjin port terminal on March 25, 1990. In a typical unloading operation, one or two terminal employees spends a total of 9 minutes loosening, removing, and dropping lashing bars that hold the stacked ocean containers together (3 minutes at the rear of the container, 31 feet from the crate; 3 minutes at the front of the container, 10 feet from the crate; and 3 minutes across the aisle unlashing the rear of the next row of containers, 14 feet from the crate). According to Hanjin specifications, the container's doors are steel, 2 millimeters (0.08 inch) thick, and the body of the container is steel, 1.6 mm (0.06 inch) thick. The Hanjin load plan for the container indicates that it contained 18,413 kilograms of cargo in a volume of 44.15 m^3 (average density 0.417 gram/cm^3) filling the space between the source crate and the container rear doors. Considering the brief working time, the large distance between the source box and the container door, and the shielding effect afforded by the steel door and cargo, the exposure of any workers involved in the unloading operation would have been less than 20 millirem.

After the container was unlashed, it was removed by the terminal overhead crane from the S.S. HANJIN MOKPO and placed on a tractor-trailer chassis. During this unloading operation, a terminal employee in close proximity to the left front corner of the trailer typically spends about 3 minutes checking each container to ensure its proper placement on the chassis. Considering the location of the unshielded source in the container, 10 feet from the front when it was unloaded on February 13, 1990, the Team estimates that the worker would have received an exposure of less than 20 millirem.

The container, still on the trailer chassis, was then moved a few hundred yards by a tractor and parked at Space J-53 inside the Hanjin terminal, a large fenced and guarded yard with low occupancy. The exposure of the tractor driver during this brief move and parking operation would have been less than 20 millirem. It is unlikely that any personnel exposures occurred while the container was parked for two days at the Hanjin terminal because of the large size of the terminal yard, its low occupancy, and no need for anyone to be around the container until it was transferred to an unloading station.

6.2 Potential Radiation Exposure of Nova Personnel During Handling and Storage of Cargo

At 9 a.m. on February 14, 1990, a Nova Container Freight Station (Nova CFS) driver picked up the cargo container from Space J-53 at the Hanjin terminal. The driver estimated a driving time of 40 to 45 minutes from the Hanjin Terminal to the Nova CFS in Compton, California. During this period, the driver was approximately 19 feet from the crate of source changers. The driver took 4 to 6 minutes to connect and disconnect the tractor-trailer chassis at an estimated distance of 10 feet from the crate. Assuming that the driver was not shielded from the source by the container steel wall and the cargo between the crate of source changers and the front container wall, the driver's exposure would have been approximately 40 millirem. Assuming that the driver was partially shielded from the source by the cargo and the container wall, the driver's exposure was approximately 20 millirem.

Nova personnel began unloading the container at the receiving dock of Nova's CFS warehouse at approximately 10 a.m. on February 14, 1990. The unloading crew, two unloaders, several forklift drivers, and a checker, took an estimated 2 hours to remove all 30 feet of cargo from behind the crate. During this period, exposure times would have been largest for the two unloaders. Assuming (1) a 2-hour exposure at an average distance of 15 feet from the crate source changers, and (2) an additional 20-minute exposure at 5 feet from the source, the approximate exposure for the two unloaders could have been as high as 330 millirem. However, shielding from the cargo would have reduced radiation exposures of the unloading crew to less than 330 millirem under the above set of assumptions. Shielding from the cargo would have caused the radiation exposure from the source to vary from approximately background levels (i.e., total shielding of the source) near the container doors to radiation levels as high as 16.4 roentgens per hour at 1 foot from the crate (i.e., no shielding of the source by cargo). However, the actual reduction in exposure from the cargo shielding is difficult to estimate with any degree of accuracy because of the large variation in shielding over time as the cargo was being unloaded. Because of the potential for large errors involved in such an estimate, the Team ignored the shielding effect in estimating potential exposures of the NOVA personnel. Therefore, the exposure to the two unloaders is conservatively estimated to be approximately 330 millirem.

The crate of source changers was removed from the shipping container using a forklift and taken to warehouse Space No. 28 on the shipping side of the warehouse. Assuming a 5-minute exposure at a distance of 5 feet from the crate, the estimated exposure of the forklift driver while moving the crate to the storage area was approximately 50 millirem. The unloading checker noted that the crate had been damaged on receipt. The top of the plywood crate was partially lifted open and one side of the box had a hole, possibly caused by a forklift. No action was taken at this time to repair the crate. The checker estimated that he spent 5 to 10 minutes examining the damaged crate from a distance of 6 to 8 feet. Using these assumptions, the maximum exposure to the checker is estimated to be 70 millirem.

The crate of source changers was stored at NOVA CFS Space No. 28, which is approximately 8 feet by 24 feet (Fig. 6.1). Nova personnel indicated that the most likely storage location for the crate was near the front of Space 28, directly opposite the second door on the loading dock, and about 30 feet from the shipping clerk's desk. The crate remained in storage at that location for 54 hours, beginning at 12 noon on February 14, 1990, until it was loaded on a Covenant Transport, Inc. (Covenant), trailer for shipment at approximately 6 p.m. on February 16, 1990. The shipping clerk, who works an 8-hour day (8 a.m. to 4:30 p.m.), stated that she normally occupies the desk from 45 minutes to one hour each work day. The clerk spends most of her remaining hours working at various shipping doors. Assuming a worst case in which the shipping clerk spends all her time (19 hours total over three days) at the shipping desk, the maximum estimated exposure would be approximately 500 millirem. On the basis of a more realistic exposure time at the shipping desk of one hour a day for three days, the Team estimates that the shipping clerk's exposure was closer to 80 millirem. A similar estimate is noted for the shipping supervisor, who also spends 1 hour each day at the shipping desk and the remaining work hours at the shipping doors and other scattered locations inside the large area of the Nova warehouse.

The dock area in front of storage Space No. 28 is occupied continuously by warehouse workers (forklift operators, cargo unloaders, cargo checkers, a shipping clerk, an assistant shipping clerk, and a shipping supervisor) loading or checking cargo at the various doors. The traffic flow is such that a worker could be as close as a few feet or as far away as 150 feet or more from the location of the crate. The workers move in and out of the area continually and spend very brief times at any one location in front of the shipping doors. Under these conditions, it is reasonable to assume that any one worker would spend only a small fraction of a typical 8-hour work day at a location near the crate where radiation exposure levels were high. Assuming that workers would spend no more than 30 minutes per day at an average distance of 12 feet from the source crate, the Team estimates that the upper exposure limit of any one worker would be about 150 millirem. This estimated exposure is in addition to other exposures assigned to the two cargo loaders, the forklift operator, the loading checker, the shipping clerk, the assistant shipping clerk, and the shipping supervisor.

According to Nova's CFS Operations manager, the crate of source changers was taken from Space No. 28 at 6 p.m. on February 16, 1990, and moved by forklift to the receiving dock (the shipping dock was not available for loading) where it was loaded on a Covenant trailer. As mentioned earlier, the crate of source

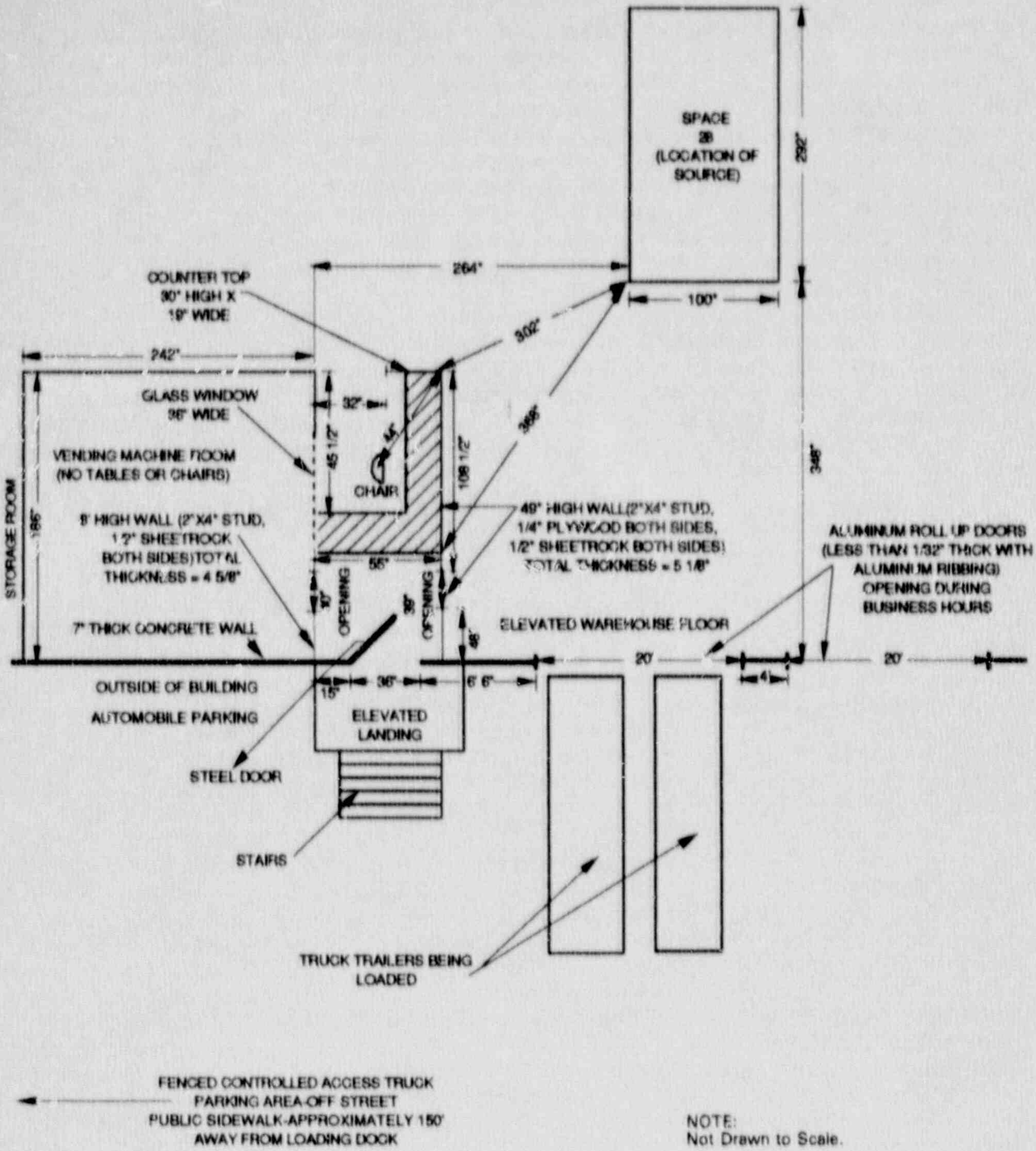


Figure 6.1 Affected Freight Storage and Loading Area of Nova Container Freight Station

changers was the first to be loaded onto the trailer for the eastbound shipment. Loading the trailer required two hours and was completed at about 8 p.m. Assuming the same exposure times and distances applied for the unloading crew, the Team estimates the exposure of the loading crew (two loaders, a checker, and a forklift operator) to range from 50 to 320 millirem. The Receiving Clerk stated that he examined the crate because of markings on the outside of the crate, but did not remember any damage. The Receiving Clerk estimated that he spent 10 to 15 minutes at a distance of approximately 3 feet from the crate. With these assumptions, the Receiving Clerk could have been exposed to approximately 400 millirem.

In summary, Nova personnel are estimated to have received radiation exposures ranging from approximately 40 millirem to 470 millirem. The highest exposures appear to have resulted from operations directly associated with the unloading and loading of the crate containing the source changers and cargo in the vicinity of the crate. A summary of these exposures is shown in Table 5.2.

6.3 Potential Radiation Exposure During Covenant Transport

6.3.1 Factors Used in Exposure Evaluation

The Team estimated the radiation doses received by the two Covenant truck drivers and other members of the public who may have been in the vicinity of the source changer crate during the six-day shipment across country on the basis of information from the trip logs ("Drivers' Daily Log") and information supplied to the Team by the drivers.

As described earlier, the crate containing the source changers had been loaded by Nova workers in the front right side of Covenant trailer No. 48011, facing the rear (passenger side) of tractor cab No. 311. Because the specific location of source changer No. SU-610 is unknown, the Team conservatively estimated radiation doses by assuming that the Ir-192 source was located immediately adjacent to either the front or side wall of the trailer, as appropriate. This source position would result in a direct line exposure of individuals without any intervening DU shielding.

The Team evaluated the shielding effectiveness of the construction materials in the Covenant truck. The cab sleeper wall is composed of thin fiberglass and aluminum, 0.065 inch as measured by Covenant. Based on measurements by Team members and on manufacturer specifications, the Team determined that the trailer wall was 3/4-inch thick plywood and 0.050-inch thick aluminum. These and other truck materials interposed between the source and the two truck drivers were considered to be ineffective as shielding materials. For example, based on a mass absorption coefficient for aluminum of approximately 0.03 cm^2/g and density of 2.7 g/cm^3 for the aluminum, its combined thickness of 0.15 inches (0.38 cm) would have attenuated only about 3.5 percent of the incident gamma radiation field. Therefore, the shielding effect of these materials was essentially ignored in the dose calculations.

6.3.2 Potential Radiation Exposures of Members of the Public

After the two Covenant drivers left the Nova CFS for the eastbound trip at 11:30 p.m. EST on February 16, 1990, they stopped twice near San Bernardino, California, for a few minutes each to weigh the truck. The drivers also stopped later in the trip (February 20, 1990) for about 15 minutes at a truck weighing station (New Market Scale House, I-70 East, in Maryland) for vehicle inspection and weight check by the Maryland State Police. No specific information was available concerning distances people occupied in relation to the crate containing the source changers for these stops. Using an exposure time of 15 minutes and assuming an average distance of 10 feet from the crate of source changers, weight scale workers and the Maryland State Trooper received exposures of less than 40 millirem.

To determine radiation exposures of the two Covenant truck drivers and other members of the public who were in the vicinity of the crate of source changers during the six-day trip, the Team evaluated information from trip logs ("Drivers' Daily Logs") and information the drivers supplied to the investigators.

On February 17, 1990, the Covenant drivers stopped for an estimated 20 minutes to refuel the truck in southern California. Similar times for refueling were noted during subsequent stops along the truck route in Amarillo, Texas; Oklahoma City, Oklahoma; and Hebron, Ohio. At these stops, either one of the drivers or fuel station employees refueled the truck. On the basis of these times and measured distances to the two truck fuel tanks, the Team estimates that the maximum individual exposures received at each stop were approximately 100 millirem.

The drivers made several stops for food and rest throughout the eastbound trip, including stops in Holbrook, Arizona; Amarillo, Texas; Oklahoma City, Oklahoma; Terre Haute, Indiana; Hebron, Ohio; near Frederick, Maryland; and in Connecticut, and Massachusetts. According to the senior Covenant driver, the truck was parked well away from diners and other normally occupied areas. At four of the rest stops (Holbrook, Arizona; Frederick, Maryland; and two stops in Connecticut), the truck was parked for only 10 to 30 minutes, several hundred feet away from other trucks. On two occasions (Hebron, Ohio, and Oklahoma City, Oklahoma), the truck was parked at estimated distances of 10 to 30 feet from other trucks. In other cases (Terre Haute, Indiana; Amarillo, Texas; and at a stop in Massachusetts), the truck was parked for up to 30 minutes at an unspecified distance from other trucks. Assuming worst-case conditions (exposure time of 2 hours and a source distance of 10 feet), the Team estimated that any truck occupants would have received exposures of no more than 300 millirem.

On February 19, 1990, at 10 p.m., the drivers arrived at the Nu Tranz Freight Systems, Inc. (Nu Tranz) terminal in Coraopolis, Pennsylvania, to discharge their first consignment. The drivers slept overnight in the truck at the Nu Tranz terminal to await unloading, which began at 9:00 a.m. on February 20, 1990. When the unloading was completed, the drivers departed Nu Tranz for the Port East Transfer, Inc. (Port East), Warehouse in Baltimore, Maryland, to unload their second consignment. The drivers arrived at the Port East facility at 8 p.m. the same day and slept overnight in the tractor before unloading commenced at 8 a.m. on February 21, 1990. The drivers parked the Covenant truck overnight, away from occupied areas in both the Nu Tranz and Port East terminals. The senior Covenant driver estimated that Nu Tranz and Port East terminal employees completed the unloading operation of the first and second consignments, respectively, within three hours each. The closest approach made by terminal employees unloading the first and second cargo consignment was estimated to be 25 feet from the source crate.

Taking into account both the distance from the source and the shielding provided by the cargo, radiation exposures of the Nu Tranz and Port East employees would have been insignificant.

At 2:30 p.m. on February 21, 1990, the drivers arrived at Evans Delivery Service in Philadelphia, Pennsylvania, to unload the third consignment. Both drivers and one terminal employee unloaded the trailer. The unloading started at a position in the trailer approximately 25 feet from the crate of source changers and was completed two hours later. While unloading, the two drivers and the terminal employee approached to within 12 feet of the source changers. Assuming that unloading personnel were 12 feet from the source crate for the entire two-hour period, the exposures received were conservatively estimated to be a maximum of 200 millirem. The actual exposures would have been much less owing to the shielding provided by the cargo and the actual unloading distances of up to 25 feet.

At 11 p.m. on February 21, 1990, the drivers spent the night at a truck service plaza near Exit 13, eastbound, on Interstate 90 in Massachusetts. The Covenant truck was parked between two other trucks with sleeper berths, which the senior driver thought were occupied, with 4 to 5 feet separating each truck. The Covenant drivers slept in their truck until 9:30 a.m. the next morning. When they awoke, on February 22, 1990, the two trucks parked adjacent to theirs were gone. The senior driver guessed that the drivers of these trucks had left at daybreak, 6:30 a.m. to 7 a.m.

To estimate the exposure that the drivers of these two trucks may have received, if they were occupied, the Team assumed that the unshielded source was located in the least favorable position relative to the closest adjacent truck (i.e., at the Covenant trailer side wall, approximately 8 feet from the closest sleeper-occupied position in the truck on the right) for 10 hours (11 p.m. to 9 a.m.). Under this assumption, the exposure to any adjacent truck occupants would be approximately 2200 millirem. If the adjacent truck had been parked only 8 hours next to the Covenant truck, the exposure would be reduced to approximately 1700 millirem. For any truck occupants parked on the opposite side of the Covenant truck, 12 feet from the source, the maximum estimated exposure would be approximately 1000 millirem in 10 hours or 800 millirem in 8 hours. Similar exposures (800 to 1000 millirem) would be expected in a different scenario that places the unshielded source in the center of the Covenant trailer (4 feet from each side wall). These dose estimates all assume that the adjacent trucks were parked parallel to the Covenant truck, so that the sleeper berths were closest to and directly opposite the unshielded source. In an alternate scenario, it is possible that the sleeper berths in both the Covenant and adjacent trucks were parked directly opposite one another (no offset of truck front to back). In this scenario, the unshielded source would have been positioned up to 15 feet from the adjacent truck sleeper berths; the resulting radiation exposures would then be reduced by about 75 percent. In summary, the dose assigned to any adjacent-truck occupants ranged between a minimum of 500 millirem (8 hours; 15 feet from source) to a maximum of 2200 millirem (10 hours; 8 feet from source).

6.3.3 Potential Radiation Exposures of Covenant Truck Drivers

Exposure times in areas occupied by the two drivers and distances to the occupied areas within the Covenant truck were used in estimating the radiation doses received by the two drivers. Team members measured the inside and outside dimensions between the front wall of the trailer (assumed location of the unshielded source) and various occupied areas in the tractor, including the front driver seat, the passenger seat (which converts into a bed), and the sleeper-berth (Fig. 6.2). An overall factor of 0.9 was applied in representing the transmission of gamma radiation emitted by the Ir-192 source along a path passing through the front wall of the trailer and rear wall of the tractor to the occupied areas.

The Covenant drivers' trip logs documented how much time each driver had spent driving, sleeping, and using the passenger seat in the truck (Fig. 6.2) while on duty and off duty. The trip-log form is divided into 15-minute units over a 24-hour period. However, the accuracy of the logs prepared by the senior driver and the driver trainee is limited to units of 30 minutes. At the request of the Team, the senior Covenant driver prepared trip logs showing daily activities for himself and for the driver trainee, while the trainee had logs describing only his own daily trip routine. A comparison of the two sets of logs for the trainee indicated markedly different estimates for time spent in the passenger seat and during rest periods in the sleeper-berth and sleeper front seats. Consequently, the Team prepared two dose estimates for the driver trainee.

Dose estimates for both drivers are shown in Table 5.3 for the entire six-day trip between Compton, California, and the Patriot facility in Boston, Massachusetts. The senior driver received a larger dose (about 35,000 millirem) than the driver trainee primarily because the senior driver spent more hours in the sleeper-berth, the area closest to the unshielded source. The estimated dose received by the driver trainee is between 21,000 and 27,000 millirem. These two dissimilar dose estimates arise principally because of the differing occupancy periods provided to the Team.

6.4 Potential Radiation Exposures of Employees During Unloading, Loading, and Storage of Source Crate

On February 22, 1990, at 11:30 a.m., the two drivers arrived at the Patriot Trucking (Patriot) Company's facility at Logan Airport in Boston to discharge their final load. Both drivers and two terminal employees, a Patriot forklift operator and warehouseman, started unloading the trailer at 12 noon. According to the senior driver, approximately 1 hour and 45 minutes was spent in unloading cargo at 8 feet to 14 feet from the source crate (first unloading interval). After advancing to within 8 feet of the source crate, the Covenant driver trainee left the area and was no longer involved with the cargo unloading. Another 15 minutes was then required by the senior driver and Patriot employees to unload additional cargo located between a distance of 2 and 8 feet from the source crate (second unloading interval). Discounting shielding by the cargo, the radiation exposures of the drivers at an average distance of 11 feet from the source crate during the first unloading interval is estimated to be approximately 200 millirem. The estimated radiation

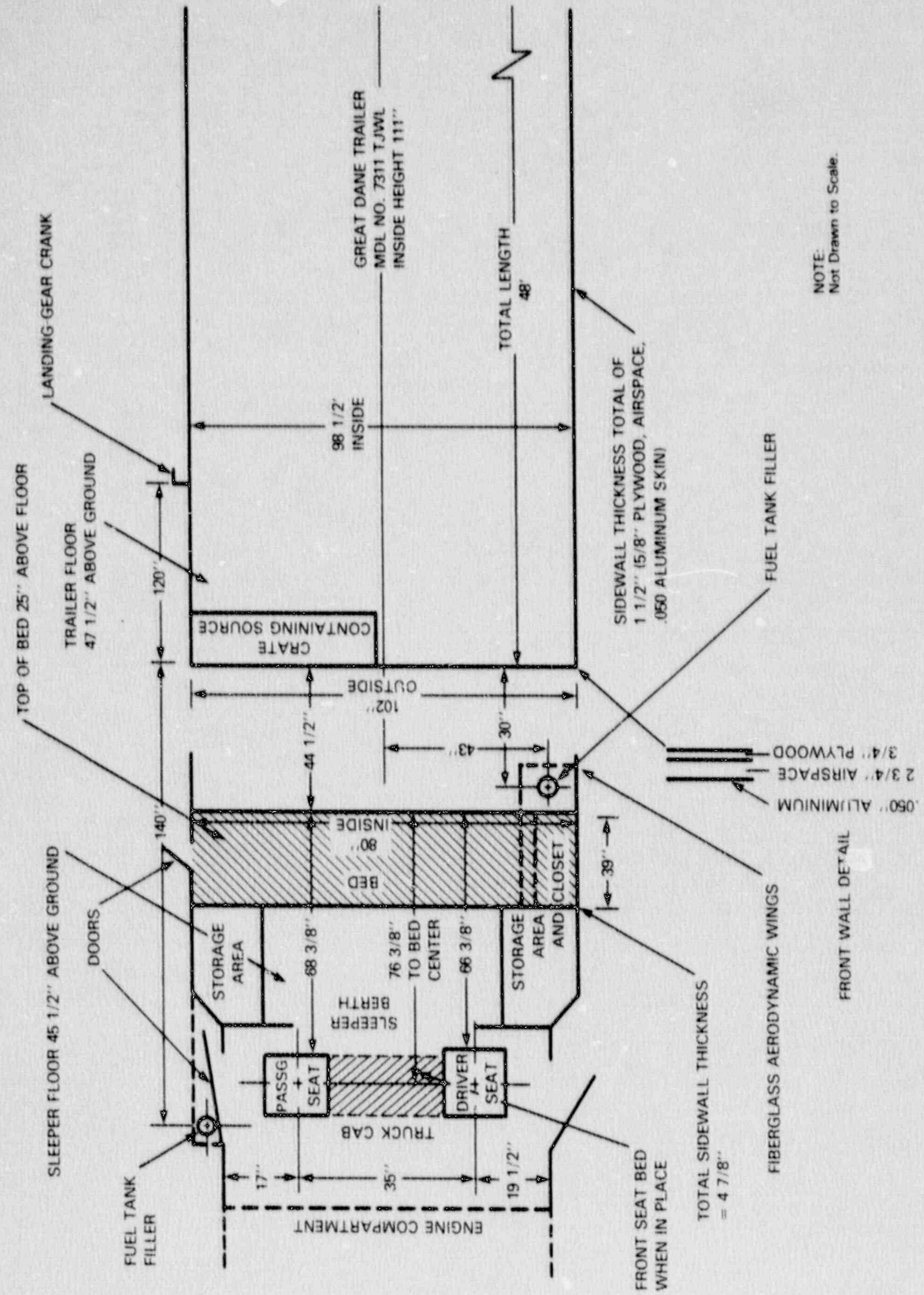


Figure 6.2 Covenant Truck Showing Proximity of Truck Cab and Sleeper to the Crate in the Trailer

exposure received by the senior driver at an average distance of 5 feet from the source box during the second unloading interval is approximately 140 millirem. Similar exposures were probably received by the Patriot warehouseman assisting the Covenant drivers. When unloading had proceeded to within 2 feet of the source crate, the senior driver sat on a shipping crate that was adjacent to the crate of source changers during a 20-minute rest break (third unloading interval). During this interval, the Team estimates that this driver could have received an exposure of approximately 1140 millirem.

According to the senior Covenant driver, when all remaining cargo in the trailer except for the crate of source changers had been removed, he sat for 10 minutes directly on the crate (fourth unloading interval). In a worst-case scenario, the source changer containing the unshielded source could have been located in a position near the top of the wooden crate. In this scenario, the closest possible distance between the unshielded source and the driver would have been approximately one foot. Under these conditions, the estimated exposure of the senior driver could have been nearly 2300 millirem.

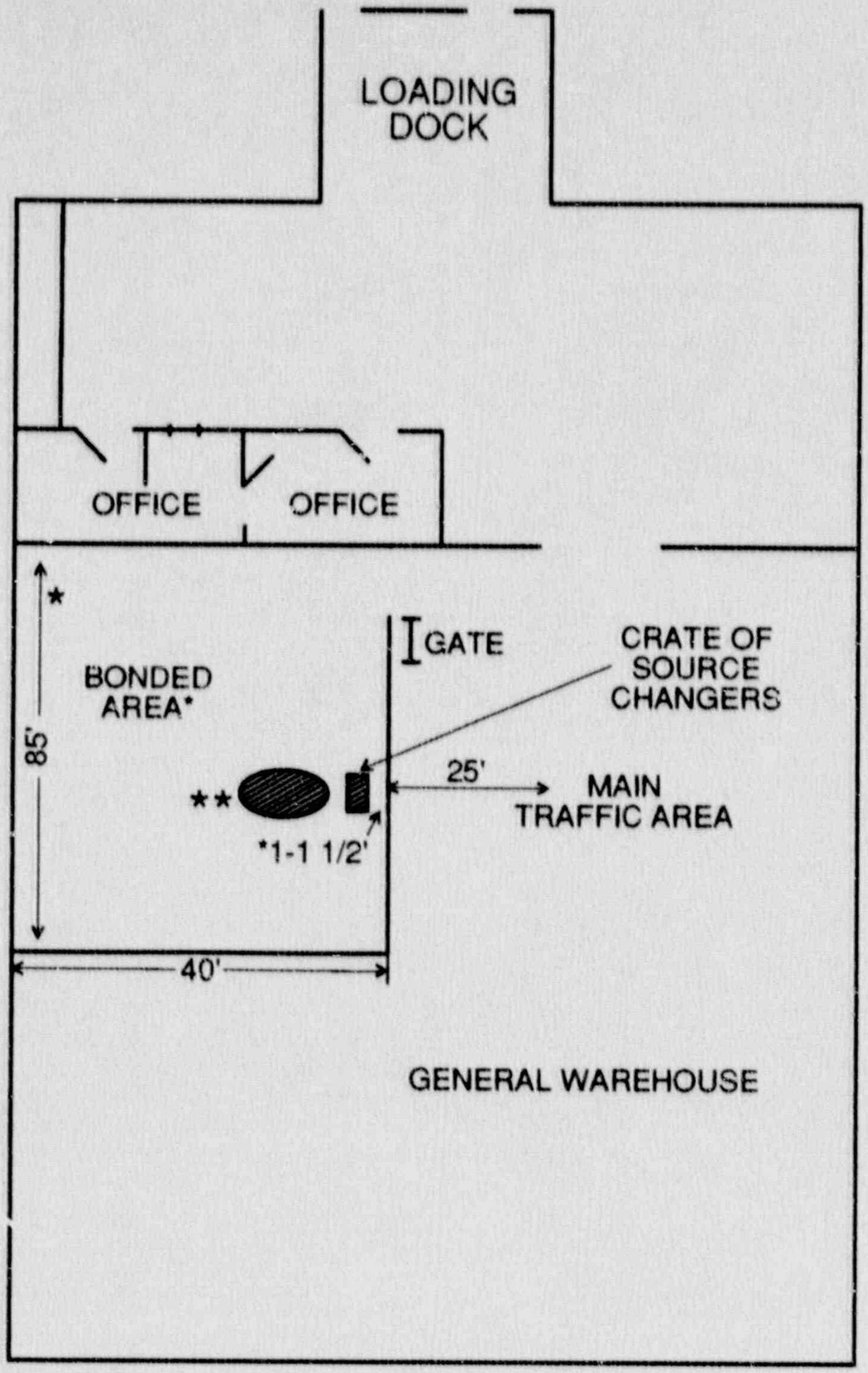
As the senior Covenant driver pulled the crate from the front of the trailer, he noticed that three to five source changers were laying loose on the floor between the crate and the front wall of the trailer. He estimated that he spent 4 to 5 minutes replacing several source changers in the crate. Assuming a worst case scenario in which the source changer containing the unshielded source was handled during the entire 5 minutes at an average distance of one foot, it is estimated that the senior Covenant driver could have received a maximum exposure of 1140 millirem.

The total estimated dose received by the senior driver during the entire unloading operation at the Patriot facility in a worst-case scenario using the above assumptions is approximately 4900 millirem. Because the Covenant driver trainee was not involved in the unloading of cargo near the crate of source changers, he probably received an exposure on the order of 200 millirem.

The potential radiation dose received by the Patriot forklift driver was evaluated from information provided by the operator during an NRC interview with the Team. The operator described several events involving his possible radiation exposure that began with the discovery of the damaged crate. Each of these events are briefly described below, along with estimated exposure times and distances to the source crate or changer, as appropriate.

The Patriot operator stated that he briefly examined the damaged source crate (1 minute at 1 foot). He then removed the crate from the trailer for closer inspection on the dock (1 minute at 1 to 2 feet). Some source changers were removed from the crate to enable the operator to count the source changers and then were returned to the crate (2 minutes at 1 foot). The wooden crate was moved by forklift to a bonded area in the Patriot warehouse (2 minutes at 5 feet) (Fig. 6.3).

While the wooden crate was stored in the bonded area, the Patriot operator spent an average of 1/2 to 3/4 hour each day for 10 days about 6 feet from the source crate (total 7.5 hours at 6 feet). On one occasion, a source changer was removed (2 minutes at 1 foot) by the operator for visual examination by another worker. On another occasion, some source changers were removed from



* Storage for U.S. Customs Clearance
** Forklift Unloading Area

NOTE:
Not Drawn to Scale.

Figure 6.3 Patriot Trucking Warehouse, Boston, Massachusetts

the crate and the crate repaired (4 minutes at 2 feet). The Patriot operator spent 3 hours stacking computer equipment in an area 1.5 feet to 24 feet from the source crate (5 minutes at 2 feet). On March 8, 1990, the Patriot operator spent 2 minutes near the crate while talking to the Patriot truck driver (2 minutes at 1 foot). The operator moved the crate of source changers with a forklift from the bonded storage area to the Patriot truck for shipment of the crate to Amersham (2 minutes at 5 feet). To prevent damage to the crate from a pool of water inside the Patriot trailer, the Patriot operator placed a protective cardboard under the crate (2 minutes at 1 foot).

With the exposure times and distances outlined above, the exposure that the Patriot operator could have received was conservatively estimated to be approximately 5600 millirem. This estimated exposure includes 220 millirem that the operator may have received during the three hours that he estimated was spent unloading the Covenant truck on February 22, 1990.

The Patriot warehouseman also spent some time near the crate of source changers while it was stored in the Patriot bonded area. The warehouseman estimated that on one occasion, he was working 6 feet from the crate for about 1/2 hour, and that on another occasion, he was 5 feet from the crate for 20 minutes. On yet another occasion, the warehouseman claimed he spent a total of 50 seconds in close contact with the crate (writing shipping numbers on the crate and examining it). Finally, the warehouseman said he cleaned the warehouse floor for 20 minutes at a distance of 5 feet from the source crate. On the basis of the above times and distances, the warehouseman could have received an exposure in the range of 700 to 800 millirem.

On February 28, 1990, a U.S. Customs Service inspector (USCS inspector) examined the damaged crate of source changers in the bonded area of the Patriot warehouse. The USCS inspector estimated that she spent 15 minutes examining the crate and its contents. Assuming a distance of 2 feet to the unshielded source, the USCS inspector may have received an exposure of approximately 810 millirem.

Before loading the box of source changers in the Patriot trailer, the Patriot truck driver inspected the crate at a distance of 1 foot for approximately 15 seconds. While the crate was being loaded on the truck, the driver was near (within 2 feet) the crate for another 1 minute. The crate was placed at the rear of the trailer, some 50 feet from the driver's seat in the tractor. The drive to Amersham took approximately 1/2 hour. On arrival at Amersham, the Patriot driver removed 2 to 3 source changers from the crate. The actual presence of the unshielded source was subsequently discovered by Amersham personnel.

According to the driver, he handled the source changers for approximately 15 seconds and was at distances of 3 to 5 feet from the source changers for an additional 2 minutes. In estimating the exposure to the driver, the Team conservatively assumed that the driver spent a total of 2 minutes each at distances of 1 foot and 3 feet from the source changer containing the unshielded source. From the above times and distances, the Team estimates that the Patriot driver received a maximum exposure of approximately 550 millirem.

Dose estimates for the Covenant drivers, U.S. Customs Service inspector, and Patriot employees exposed to the unshielded source during receipt, storage, and shipment of the source changers by Patriot are shown in Table 5.4. All previous estimates of radiation exposures of individuals were based on potential exposures resulting from the source that was assumed to have been unshielded. Unlike these earlier exposure estimates, the Team considers the dose estimate for the Patriot driver as real (i.e., the result of an actual exposure from an unshielded source).

6.5 Estimated Radiation Exposure of Amersham Employees

Five Amersham employees were exposed to the unshielded source upon its arrival at the Amersham facility. Amersham's RSO and a radiation safety specialist assisted the hot lab supervisor in the source retrieval operation. The Amersham personnel wore whole body badges and pocket ion chambers. The hot lab supervisor also wore extremity badges (head and left and right hands and wrists) while retrieving the source.

A dosimetry report dated March 13, 1990, provided to the NRC, indicated that the maximum exposure any individual received was a whole body dose of 40 millirem and that the maximum extremity dose any individual received was 100 millirem for the monthly period. The maximum pocket dosimeter reading noted was 20 millirem. The estimated radiation exposures for Amersham employees are shown in Table 5.5.

During source retrieval operations, two drivers of delivery vans (a United Parcel Service driver and a Nuclear Metal Corporation driver) approached the Amersham unloading dock on foot. Both drivers were stopped at distances of from 35 to 50 feet from the source, as shown in Figure 6.4, and instructed to use the front entrance of the building. Neither driver received an exposure of more than 0.2 millirem.

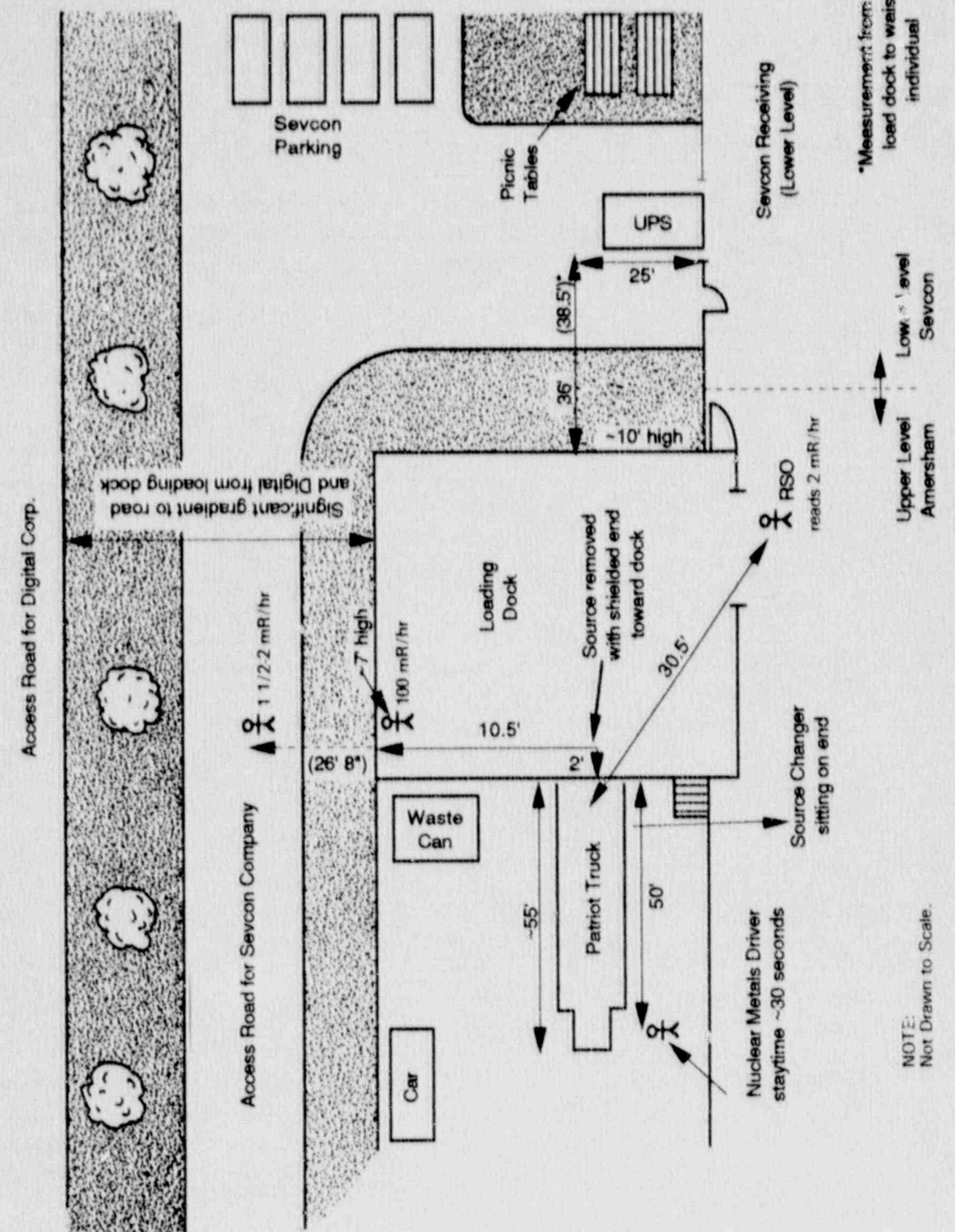


Figure 6.4 Plot Plan for Vicinity of Amersham Loading and Auxiliary Buildings

7 EVALUATION OF THE MODEL 500-SU SOURCE CHANGER AS A TRANSPORTATION PACKAGE

7.1 Introduction

The Team evaluated the Model 500-SU source changer as a transportation package because the incident involved the inadvertent shipment of an iridium-192 source in that type of package. The Team review of the package focused on three questions: Did the design of the Model 500-SU source changer contribute to the incident? Were the procedures for returning empty source changers to the supplier adequate and reasonably available to the end user? Did the way in which the Model 500-SU source changer was used contribute to the incident?

7.2 NRC Approvals for the Design of Model 500-SU Packages

The Model 500-SU source changer is designed for use both as a radiographic source changer and as a transport package for shipping iridium-192 (Ir-192) sources. The package is used primarily to transport radiography sources to end-users and for the return of spent sources to suppliers for disposal. The Model 500-SU source changer is authorized as a Type B transportation package by U.S. Nuclear Regulatory Commission (NRC) Certificate of Compliance 9006, Revision 9 (App. D). NRC requires that a Type B package, which is designed to withstand the accident conditions specified in NRC's regulations (10 CFR Part 71), be used to ship Ir-192 capsules with activity in excess of 20 curies. NRC licensees are authorized to use the source changer as a transportation package under the general license provisions of 10 CFR 71.12 of NRC's regulations. The general license provisions require that a licensee have a copy of the specific license, certificate of compliance, or other approval of the package and have the drawings and other documents referenced in the approval relating to the use and maintenance of the package and to actions to be taken before shipment. The Model 500-SU changer is also listed in NRC's registry of radioactive sealed sources and devices, along with its supporting safety evaluation report, which have been approved by the NRC and the Agreement States. The safety evaluation report for the Model 500-SU is included in Appendix E.

7.3 Description of Model 500-SU Source Changer Design

The Model 500-SU source changer consists primarily of a cast depleted uranium shield, housed in an outer 0.135-inch-thick Type 304 stainless steel case. The outer steel case is 11 inches long, 4.88 inches wide, and 5.56 inches high (Figs. 7.1 and 7.2). In addition to the uranium shielding, the outer steel case also houses an unshielded compartment that is used to hold the instruction manual and package accessories. Package accessories include such items as return shipment labels, seal wire, and source guide tubes. Users gain access to the package through a sloped-hinged cover lid. The package weighs approximately 65 pounds.

During shipment, the source holder assembly, consisting of a source capsule and attached cable or "pigtail," is inserted into one of two titanium source tubes.

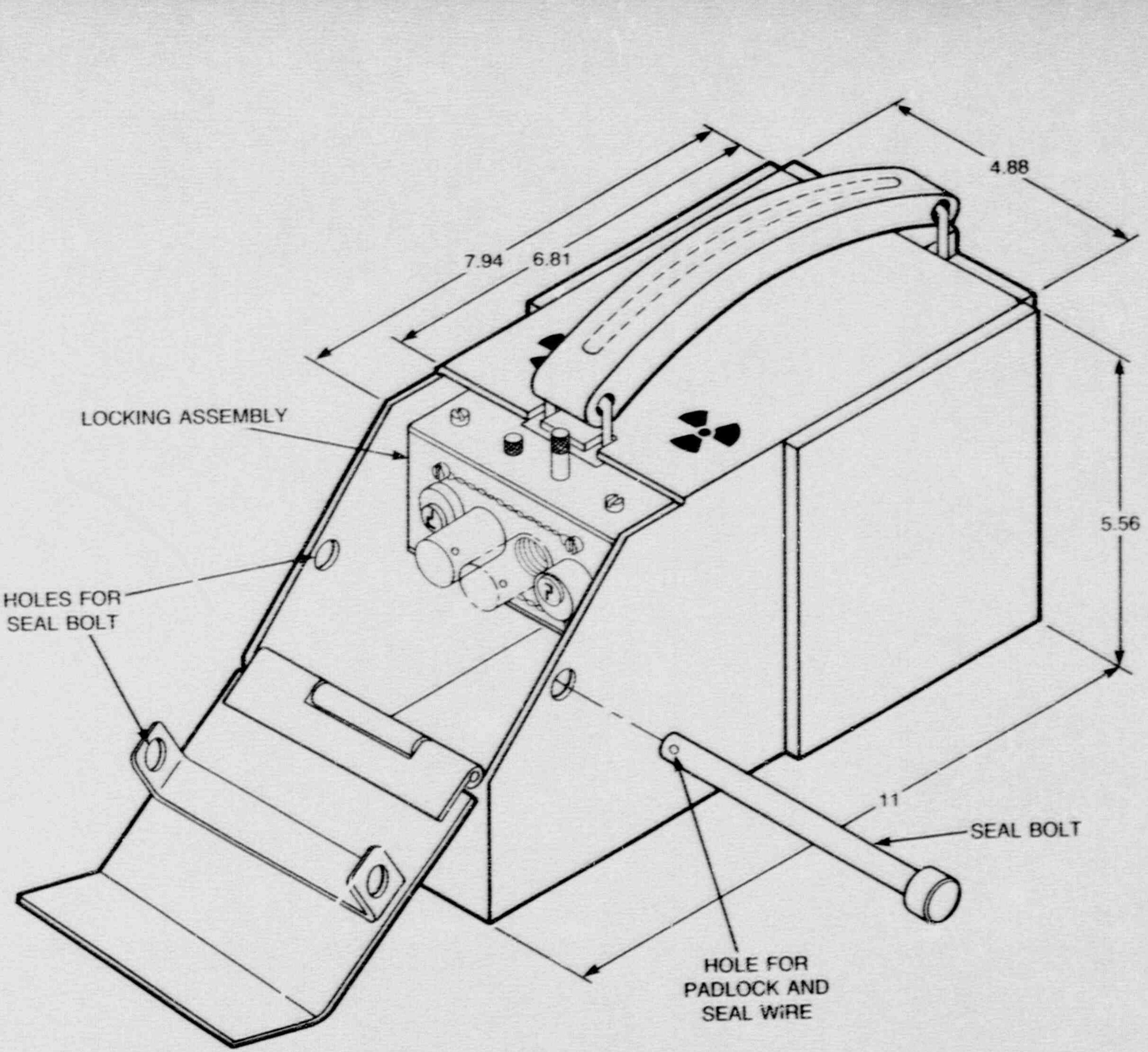


Figure 7.1 External View of Model 500-SU Source Changer

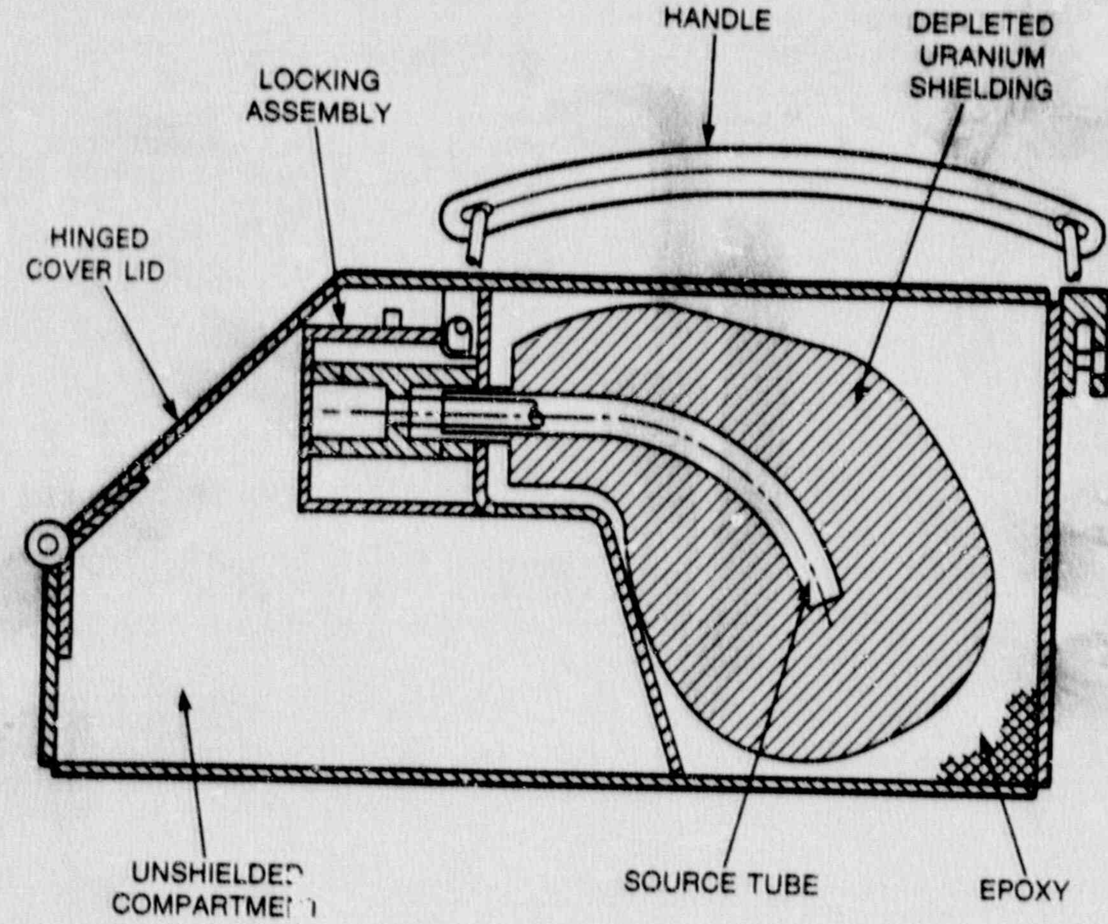


Figure 7.2 Cross Section of a Model 500-SU Source Changer

The source holder assembly is held in place in the shielded source tube by a locking assembly (Fig. 7.3).

The locking assembly consists of a lock slide, a latch pin, and a key-operated lock. The lock slide, by creating interference with a steel stop-ball on the pigtail, prevents movement of the source from the shielded position. The lock slide, held in position by a latch pin and key-operated lock, cannot be moved from the locked position until the key-operated lock is unlocked and the latch pin is depressed by inserting of a source guide tube into the lock-box assembly.

A threaded cap is then screwed into the lock-box to cover the source holder assembly. The cap cannot be installed unless the key lock is locked and the latch pin is depressed. Although NRC authorizes eight different caps in the current certificate, only two caps are in current use, a long cap and a short cap. The other caps are not used because the sources for which they were designed are no longer manufactured. To prevent caps from loosening during shipment, they are sealed together with wire threaded through holes in the caps and tightened.

The outer steel case is fastened with a padlock and seal wire at the end of a bolt that passes through the cover lid and body of the case. The seal wire provides the tamperproof device required in 10 CFR 71.43 of NRC regulations.

The Model 500-SU source changer is authorized for the shipment of up to 120 curies of Ir-192 in special encapsulated form. The NRC certificate specifies that the source capsule containing the Ir-192 must be attached to a pigtail and that use of the source holder assembly must be limited to those sources authorized in the table referenced in Revision 3 of the Safety Analysis Report for the Model 500-SU, March 31, 1986 (Appendix F). The Team learned that the source contained in changer SU-610 was a Model 8 Industrial Nuclear Company source. NRC does not currently authorize this source for use with the Model 500-SU source changer.

7.4 Team Observations on Source Changer Design

NRC Certificate of Compliance 9006, Revision 9, was revised on July 3, 1986, to require that all source changers have a locking assembly installed. No provision was made or requested to allow the continued use of an older unmodified package design, which did not contain the locking assembly. During the course of the investigation, the Team observed that none of the 14 source changers involved in the incident conformed with the drawings referenced in NRC Certificate of Compliance 9006, Revision 9, in that none contained a locking assembly. In addition, 6 of the 14 source changers were not constructed according to the dimensions specified in the certificate drawings. The upper body of these packages had been extended to accommodate longer threaded caps over the source holder assembly.

The request to modify the Model 500-SU design by adding a locking assembly was initiated by Amersham on March 31, 1986. The primary reason for adding the locking assembly is to prevent the inadvertent movement of the source from a shielded to an unshielded position while the pigtail is being connected to the drive cable that is used to extract the source.

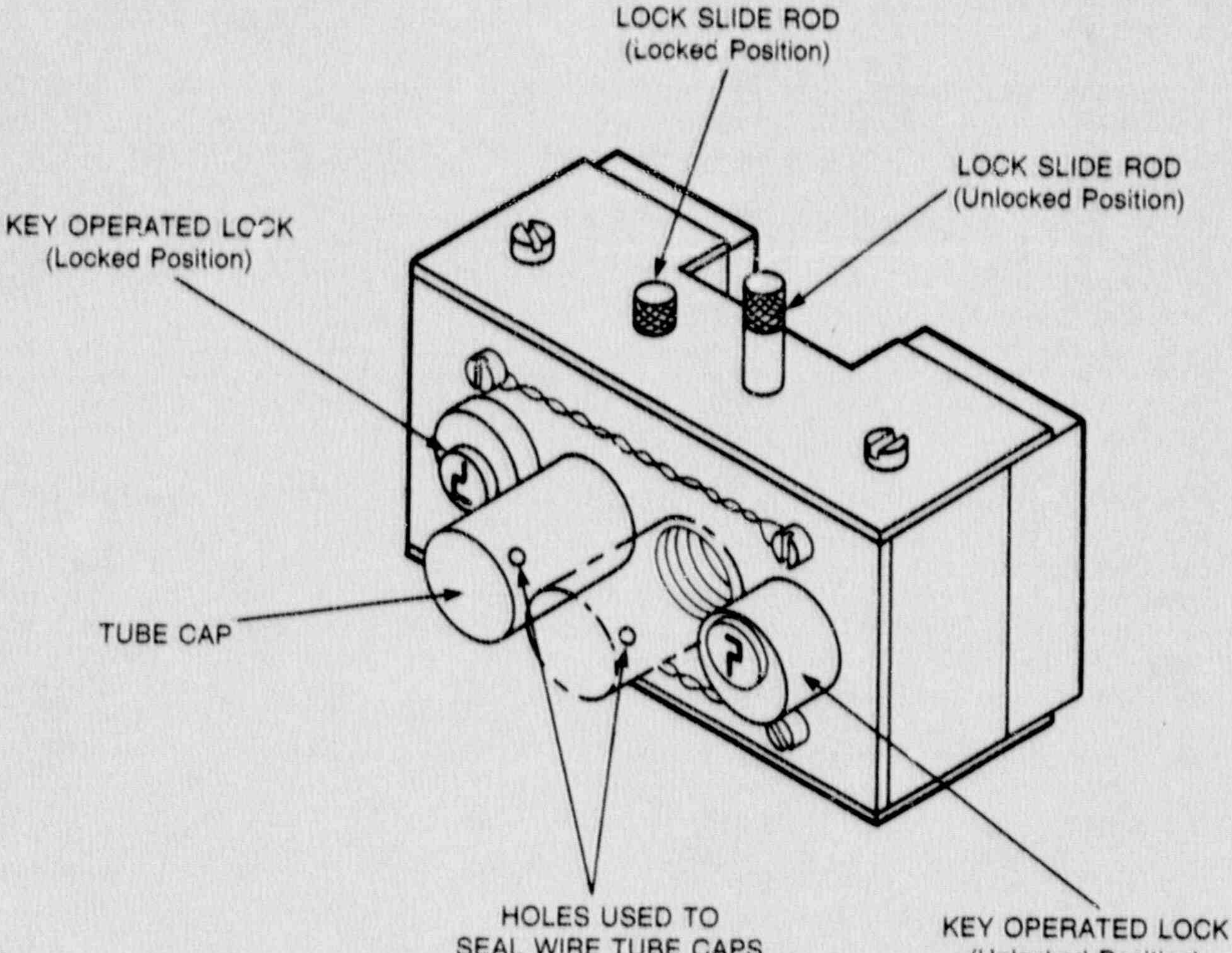


Figure 7.3 Locking Assembly for Model 500-SU Source Changer

The radiation safety officer (RSO) at Amersham Corporation estimated that approximately 120 Model 500-SU source changers were in use at the time of the incident. None of these changers had the locking assemblies installed. Although Amersham was in the process of modifying approximately 10 other source changers to include the locking assembly, none of them had been used for actual shipments at the time of the incident.

Six of the source changers involved in the incident had been modified to accommodate longer caps, a design change not reflected in the current NRC certificate. The source changer was initially designed so that the clearance between the cover lid and caps would not allow the caps to come off while the lid was closed. The lids, as modified, now permit sufficient clearance to allow the caps to come off. However, as noted above, the caps are required to be sealed together with wire during shipment to prevent their becoming loose. Had the caps been installed on the source tubes and wired together, there is no reason to believe that the source would have come out of the shielded position during handling and shipping.

Although the modifications observed were not authorized in the current certificate of compliance, the Team does not believe that they contributed to the incident. All the designs have features to prevent the source from coming out during shipment, such as a locking assembly or caps that can be wired together.

7.5 Role of Package Design in the Incident

The Team closely examined the 14 source changers involved in the incident. The only damage observed was that the leather handle straps on two of the changers were broken, although the Team could not determine whether the straps were broken during use or shipment. No dents, gouges, or other defects were observed on the outer casings that were not consistent with normal use.

Members of the Amersham staff said that all 14 source changers in this shipment were received with the outer cover lids closed (Ref. 1). The lids on 11 of the 14 changers were secured with pad locks and seal bolts. Two lids were closed only by the seal bolt. The lid on the changer containing the source was secured only with a seal bolt and a seal wire.

NDI Corporation could not confirm whether the caps were installed in the source changers in Korea before shipment to Amersham Corporation (Refs. 2 and 3). The caps in most of the source changers were not in place when the changers arrived at Amersham. When source changer SU-610 was opened to retrieve the source, the cap was discovered lying in the unshielded compartment. What is certain is that the cap, if it was originally installed in source changer SU-610, was not secured by a seal wire. In fact, no seal wire was found inside any of the source changers.

Nothing uncovered in the investigation indicates that the design of the Model 500-SU source changer did not meet standards for a Type B transport package. If the empty source changer had been prepared for shipment in the same manner required for loaded changers, an undetected authorized source would have been safely confined to a shielded position during handling and shipping. A source without a pigtail would probably remain in a shielded position, although a small likelihood exists that even with a cap in place, the source could move during shipping to a less shielded position inside the source tube. The Team established that a source, severed from its pigtail, can slide out of the tube entirely if the cap is missing and if the source changer is tilted towards the front opening, the end in which a source is inserted (see Sec. 7.8).

7.6 Adequacy and Availability of Procedures for Returning Empty Source Changers

Amersham Corporation includes an operations manual in every Model 500-SU source changer it ships (Ref. 4). The manual is placed in the unshielded compartment of the changer, along with any accessories needed to use the changer. The manual contains the only instructions for returning empty containers that Amersham routinely provides to both foreign and domestic end users. Amersham also provides a packet of more detailed information on shipping instructions to those users requesting it (Ref. 5). The Team could not determine whether the Korean end user requested or received this packet. Included in the operations manual that is routinely provided to end users are the following instructions for returning empty source changers:

> For the shipment of an empty source changer, assure that there is no source in the container. If the radiation level is below 0.5 mR/hr. at the surface, and there is no measurable radiation level at one meter from the container, no label is required. Mark the outside of the package with proper shipping name (Radioactive Material, articles manufactured from depleted uranium UN 2909). Mark the outside of the package:
>
> Exempt from specification packaging, shipping paper and certification, marking and labeling and exempt from the requirements of Part 175 per 49 CFR 173.421-1 and 49 CFR 173.424.
>
> Additionally, a notice must be enclosed in or on the package included with the packing list or otherwise forwarded with the package. This notice must include the name of the consignor or consignee and the statement:
>
> This package conforms to the conditions and limitations specified in 49 CFR 173.424 for excepted radioactive materials, articles manufactured from depleted uranium, UN 2909.

The manual is silent on what the shipper does should the radiation level at the surface of the source changer exceed 0.5 millirem per hour. The Team determined that the SU-610 source changer in the Korean shipment exceeded that level (see Sec. 8). A shipper would then presumably be expected to know that the source changers and crate must be labeled in accordance with Department of Transportation regulations, that the outside of the overpack must be marked "Inside packages comply with prescribed specification," and that the proper shipping name, "Radioactive Material, LSA, n.o.s., UN 2912," must be used in all shipping documentation. The absence of such specific instructions for empty source changers exceeding 0.5 millirem per hour may have been a contributing factor to their being offered as "excepted" packages.

The Amersham operations manual does not list specific procedures on how to determine whether a source changer is empty. Ordinarily, a visual examination of the source changer would be sufficient to verify the presence (or absence) of an authorized source. All sources authorized to be shipped in the Model 500-SU changer are required to have pigtails, the ends of which can be seen at the opening to the source tube upon visual examination. However, a visual examination would not have revealed the source involved in this incident because the pigtail had been completely removed from the source.

Another method that could be used to detect a source in the changer is a radiation survey at the surface of the changer. The individual changers were surveyed by NDI Corporation before shipment from Korea. To verify whether a surface survey would have detected the source, the Team requested that Amersham survey a source changer containing a 3-curie source placed in the shielded source tube. The surface readings at the surface of this changer were indistinguishable from readings obtained from the depleted uranium shield of an empty source changer. The Amersham RSO estimated that the minimum source activity detectable in the Model 500-SU source changer was about 4 curies (see Ref. 1). On the basis of this information, a surface radiation survey made when the source was shipped from Korea would not have detected the source unless it was located in the unshielded compartment of the source changer at the time of the survey.

Before shipment, this source could have been detected in only one of two ways: a physical probe of the source tubes or tight inventory controls. The operating procedures do not require that source tube caps be installed and wired together for empty shipments. Nor do they require that the cover lid be secured with a seal bolt and padlock for empty containers.

The information gathered by the Team indicates that instructions for returning an empty Model 500-SU source changer were made available to Korea Industrial Testing Co. Ltd. (KIT), the end-user, and to licensees of the Nuclear Regulatory Commission (see Ref. 1). While the instructions provided did not specify procedures for determining whether a source changer was empty, the Team believes that these instructions were adequate for determining whether an authorized source was present. Under ordinary circumstances; a simple visual inspection would have detected an authorized source because of its pigtail. The instructions did not caution users against placing a source without a pigtail in a source changer. Specific instructions requiring both a radiation survey and a probe of the source tubes may have prevented this incident. However, the Team is less certain that a requirement to install and seal caps with wire on empty packages, had it been followed, would have prevented the incident entirely. Even with the caps installed and sealed a source without a pigtail could still be present in a less shielded section of the source tube.

7.7 Improper Use of the Source Changer

During the course of the investigation, the Team received information from an employee of Industrial Nuclear Company (INC) that Korean end-users may be using source changers as storage devices for decaying sources (Ref. 6). To store a cropped source in a Model 500-SU source changer, the source changer would be turned on end. The source would then be dropped in the source tube and fall to a shielded position. After the source had decayed sufficiently, the source changer would be used to move the source to a disposal area.

The INC employee was not able to provide documentation of this practice, however. The information given to the team was based on conversations with Korean customers and distributors. The Team was able to verify that the Korean end-user involved in this incident, KIT, used the specific source changer involved in this incident (SU-610) for the temporary storage of spent sources (Ref. 7).

7.8 Role of the Wooden Crate in the Incident

The wooden crate was used to secure the 14 source changers in a single package for shipment. It was not intended to serve as a radiation barrier from an iridium source. The Model 500-SU source changer acts as the radiation barrier or containment for the source during shipment. To that extent, each of the source changers could have been shipped individually without the crate.

Damage to the crate during handling and shipment could have contributed directly to this incident because the "empty" source changers were most likely shipped without caps on the source tubes. If damage to the crate caused source changer SU-610 to overturn, the source inside the shielded compartment could have been dislodged from the source tube. Although the source was no longer contained inside the shielded compartment, it remained within the unshielded portion of the source changer only because the outside lid was fastened with a bolt and sealed with wire.

The Team conducted a simple experiment to determine the degree of tilt required to cause a source to come out of a Model 500-SU source changer. A dummy source, identical in size and weight to the Korean source, was inserted into the source tube of a Model 500-SU source changer. The rear end of the source changer was gradually raised to determine whether the source would come out and, if so, at what angle. The source slid out of the source tube when the rear of the changer was raised to approximately 70 degrees from horizontal.

The source could have been dislodged from the shielded position on several occasions during shipment. The wooden crate was reported to be damaged when it arrived at the Nova Container Freight Station in Compton, California, indicating that the crate may have been damaged when it was loaded on the ship in Korea. The crate could have been penetrated and overturned by a single blade of a forklift (Figs. 7.4 and 7.5). For example, if the forklift was moving a crate located in front of the crate with the source changers, it may have snagged and lifted the source changer crate by mistake. As the crate rose and began to tilt, the weight of the changers, 900 pounds, would have been shifted to the right and the back of the crate. This area of the crate was severely damaged upon its arrival at Amersham. Source changers could have tumbled from the crate after being tilted by the forklift blade.

The source could also have come out of the tube during cross-country shipment. A Covenant Trucking Company driver reported that he found several source changers outside of the crate when he arrived at the Patriot Trucking Company warehouse in Boston. The back and one side of the crate had become separated from the rest of the crate during shipment, creating a space for some of the source changers to tumble out.

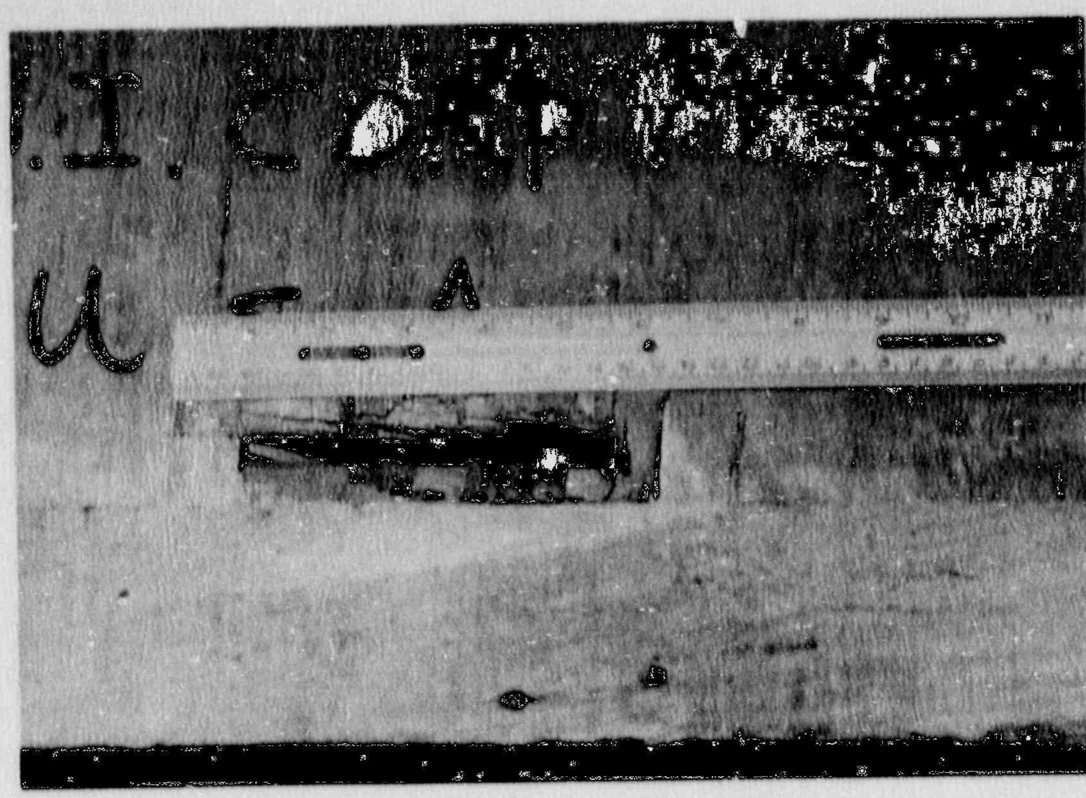


Figure 7.4 Presumed Forklift Blade Penetration

Figure 7.5 Presumed Damage to Crate from Forklift Mishandling

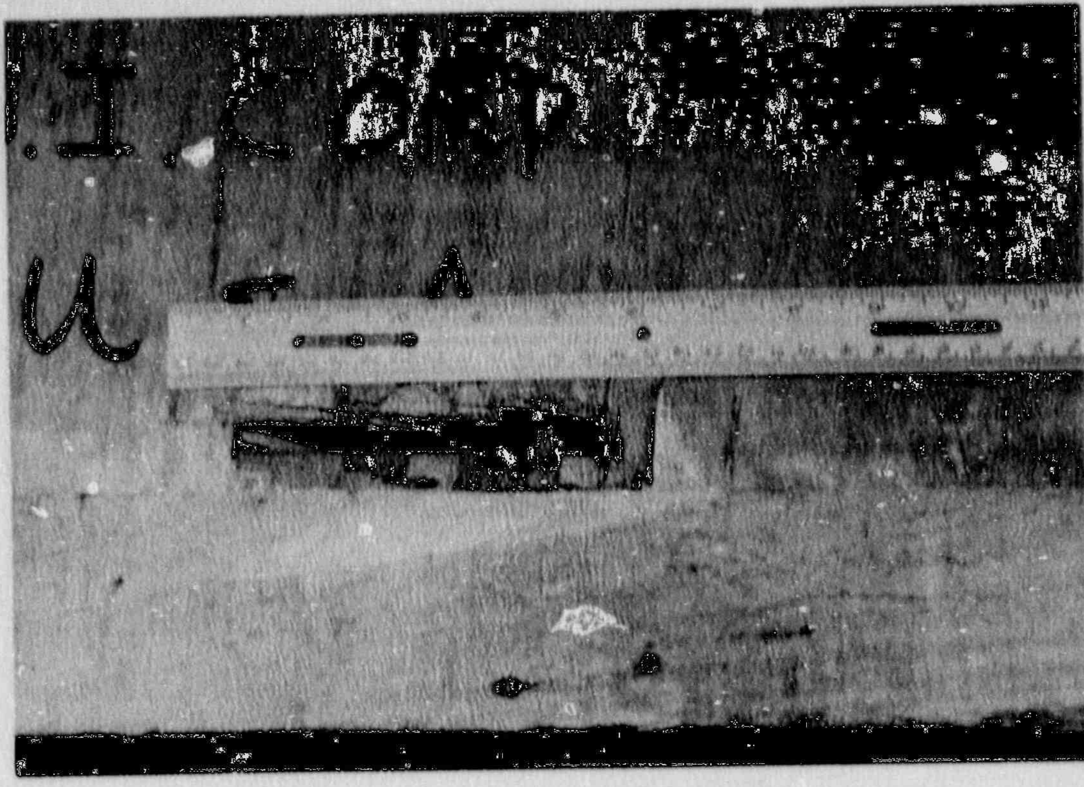


Figure 7.4 Presumed Forklift Blade Penetration

Figure 7.5 Presumed Damage to Crate from Forklift Mishandling

The source could also have come out when the crate was being transported to the Amersham facility in Burlington from the Patriot warehouse. When the shipment arrived at Amersham, the source changers were scattered on the trailer floor (see Fig. 2.16) and the wooden crate was turned upside down on several of the source changers. Based on the results of the cytogenetic studies, the Team believes this to be the most likely scenario.

The method by which the crate was placed in the Patriot truck with no blocking or bracing to hold it in place during transit could have contributed to the source becoming unshielded. It is probable that the source would have arrived at Amersham in the shielded position of the source changer had the crate not been overturned during transit.

7.9 Summary

The design of the Model 500-SU source changer was adequate to transport encapsulated iridium sources of up to 120 curies and was not a contributing cause to this incident. The Team uncovered no evidence to indicate that the source changer, if used according to the manufacturer's instructions, would not confine an authorized source to a shielded position during transport. The source changers themselves were not damaged during shipment.

Instructions for returning an empty Model 500-SU source changer were made available to KIT, the end-user. The instructions were adequate for determining whether a source changer contained an authorized source because a simple visual examination would detect the presence of a support cable, a "pigtail." Therefore, the instructions did not caution users against placing a source without a pigtail in the source changer. Specific instructions requiring both a radiation survey and a probe of the source tubes in a changer, if provided and implemented, may have prevented this incident.

References*

1. E. Easton and A. Grella, U.S. Nuclear Regulatory Commission, transcript of interview with C. Roughan, Radiation Safety Officer, Amersham Corporation, March 12, 1990. (04-125-90)

2 W. McDaniel, Amersham Corporation, Burlington, Massachusetts, transmittal to T. Lawson, Amersham Corporation, Hong Kong, March 12, 1990. (04-035-90)

3. K. Y. Kim, NDI Corporation, transmittal to T. Lawson, Amersham Corporation, Hong Kong, March 15, 1990. (04-057-90)

4. Amersham Corporation, Tech/Ops RPD, "AI Model 500-SU Source Changer Operation Manual," undated. (04-050-90)

5. Amersham Corporation, "Sample Transportation Instruction," February 9, 1990. (04-062-90)

6. E. Easton, U.S. Nuclear Regulatory Commission, record of telephone conversation with W. Cain, Radiation Safety Officer, Industrial Nuclear Company, San Leandro, California, March 13, 1990. (04-053-90)

7. T. Lawson, Amersham Corporation, Hong Kong, transmittal to W. McDaniel, Amersham Corporation, Burlington, Massachusetts, March 12, 1990. (04-22-90)

*The file number in parenthesis at the end of some reference citations refers to the location of that reference in the Team's files for NUREG-1405. These files are available for inspection or copying for a fee at the NRC's Public Document Room, 2120 L Street, NW., Lower Level, Washington, D.C.

8 APPLICABLE REGULATIONS

Regulations for transport of hazardous materials, including radioactive materials, are intended to ensure the safety of workers and the public and that property and the environment are adequately protected. To achieve this objective, the regulations rely principally on the proper packaging and identification of materials by shippers, rather than on extensive or elaborate operational controls by carriers. Both domestic and international organizations have promulgated regulations for packaging and transporting hazardous materials.

8.1 Responsible Regulatory Agencies and Organizations

8.1.1 Domestic: Memorandum of Understanding Between the U.S. Nuclear Regulatory Commission and the U.S. Department of Transportation

The U.S Nuclear Regulatory Commission (NRC) shares regulatory responsibility with the U.S. Department of Transportation (DOT) for transportation of radioactive materials, pursuant to the provisions of the Atomic Energy Act (Act), as amended. The Act mandates that the NRC regulate the use, possession, and transfer of licensed byproduct, source, and special nuclear material. Because of this overlap in statutory authority, the DOT and NRC have established a Memorandum of Understanding (MOU) that outlines in broad terms the areas each agency will regulate so as to avoid duplicative or conflicting regulations (Ref. 1). Generally, the DOT is responsible for the overall regulation of shippers and carriers and establishes packaging requirements for radioactive materials that qualify for use in Type A packages (see 49 CFR 173.403(cc)), whereas the NRC establishes standards for Type B packages (see Sec. 7.1.1 of this report). Under the MOU, the NRC has the lead responsibility for investigating transportation incidents involving packages of radioactive material regulated by NRC.

8.1.2 International Regulatory Organizations

The international transportation of hazardous materials is generally subject to regulations that have been established by international transport organizations for the relevant mode of transport. These regulations have been promulgated by the International Civil Aviation Organization (ICAO) for air, and the International Maritime Organization (IMO) for water, and the countries of origin and destination for hazardous materials shipments. Two international organizations, each composed of member-Government representatives, set standards that are used as a basis for the regulations established by the international transport organizations and by individual countries. These two organizations are the United Nations (UN) Group of Experts on the Transport of Dangerous Goods, a subagency of the UN Economic and Social Council, and the International Atomic Energy Agency (IAEA). All international transport organizations and most countries have incorporated the UN standards into their regulations. For UN Class 7, radioactive materials, the IAEA standards (Ref. 2) provide the technical basis for their regulations.

For international shipments by water, the regulations of the IMO are found in the International Maritime Dangerous Goods Code (IMDG Code). For import of radioactive materials packages into the U.S., the DOT requirements in 49 CFR 171.12(e) authorize compliance either with Title 49 requirements or with IAEA standards presented in Safety Series No. 6, "Regulations for the Safety Transport of Radioactive Materials," 1973 Revised Edition, as amended, provided that the country of origin has adopted those standards.

8.2 Requirements Applicable to the Shipments

The NRC and DOT regulations prescribe requirements applicable to shippers for classifying, describing, packaging, marking, and labeling of radioactive materials. In addition, DOT regulations require that importers of hazardous materials provide certain information to a foreign shipper and forwarding agent at the place of entry into the United States. DOT regulations also require carriers to report incidents involving hazardous materials (see App. G for additional information).

8.2.1 The Shipper

It is often difficult to identify the actual shipper for purposes of determining compliance with DOT hazardous materials regulations, particularly with respect to international shipments. In fact, Title 49 does not define "shipper." The term "any person who offers" is used throughout Title 49 when a shipper's responsibilities are listed. The DOT holds the position that more than one party can and often does perform the functions of a shipper (Ref. 3).

In this shipment, NDI Corporation (NDI) acted as the entity making the shipment from Seoul to Boston and was, therefore, responsible for ensuring that the material being offered was properly identified, classified, packaged, marked, and labeled. NDI was also responsible for preparing the required certification and shipping documentation. Daeil Shipping Company (Daeil) acted as carrier and shipping agency representing NDI and was responsible to NDI for the proper packaging, transportation, and delivery of the material.

While culpability may be shared in some cases, in this instance, the burden of ensuring that the source changers were appropriately identified and controlled as radioactive material rested principally with NDI.

8.2.2 The Carrier

The DOT regulations in 49 CFR 171.2(a) specify that "no person may offer or accept a hazardous material for transportation in commerce unless that material is properly classed, described, packaged, marked, labeled, and in condition for shipment as required or authorized by this subchapter...." The person who offered this shipment was NDI in the Republic of Korea, in concert with several agents. When the shipment of source changers entered the territorial waters of the United States, it was not in compliance with 49 CFR 171.2(a). NRC requirements in 10 CFR Part 71 were not directly relevant because the shipper was not under the jurisdiction of NRC.

Note that NRC regulations 10 CFR 30.13, 40.12, and 70.12, as well as equivalent regulations in Agreement States, exempt common and contract-carriers, brokers, freight forwarders, and warehousemen from any requirement to obtain a license to receive, possess, transport, or store in the course of transport, byproduct, source, and special nuclear material. In effect, therefore, none of the common carriers, brokers, or forwarders in the United States involved in the Korean shipment after it was unloaded from the S.S. HANJIN MOKPO were required to possess a license from NRC or an Agreement State.

8.2.3 Packaging

The DOT regulations authorize use of a Type A package to ship an iridium-192 source of less than 20 curies activity. Further, these regulations (49 CFR 173.415(c)) permit the use of any NRC-certified Type B packaging, such as the Model 500-SU source changer for use as a Type A package. For a more complete discussion of packaging, see Section 7 and Appendix G.

Whether or not the package contained a radiographic source, the Model 500-SU source changer was required to be a Type A package. However, the shipment of the source changers did not meet the requirements for a Type A package. It was offered for transport as an "excepted" package, but it did not meet the requirements for an "excepted" package either.

8.2.4 Marking and Labeling

To comply with DOT regulations, both the crate and the source changers inside the crate should have been appropriately labeled. The exterior of the crate should have been labeled with radioactive Yellow II labels and should have been marked as follows:

> "Radioactive materials, n.o.s.,* UN 2982" or
> "Radioactive materials, LSA,** n.o.s., UN 2912"

Neither of these labels or markings was present on the crate. However, the source changers bore Yellow II or III labels believed to be the original labels placed on the changers before they left Amersham Corporation (Amersham).

8.2.5 Shipping Documents

NDI in the Republic of Korea was responsible for preparing the original certification and shipping documents.

The shipping names that describe the contents of the package vary widely. Although none of the shipping names are in compliance with DOT regulations, their pervasive theme is that the package was empty. The Team observed the following descriptions on various shipping documents:

- "Transportation Empty, container of radioisotopes" (Fidelity Transport)
- "Radioisotopes" (Hanjin Shipping vessel manifest)

---
* n.o.s. means not otherwise specified
** LSA means low specific activity

- "Empty source changers, one box containing 14 source changers" (International Specialists, Inc.)

- "One box of transportation empty container of radioisotopes" (Daiel Shipping Co.)

- "Transportation Empty Container of Isotopes" (U.S. Customs, Transportation Entry Manifest)

While there is an "excepted" package provision in the DOT regulations, which might be applicable for other types of source changers, it is not applicable to the Model 500-SU source changers. This provision is for a "Radioactive material article, manufactured from depleted uranium, UN 2909" (see 49 CFR 173.424). As an "excepted package," it would be excepted from the required packaging, shipping papers, and certification, as well as the marking and labeling requirements of Title 49, provided that the surface dose rate did not exceed 0.5 millirem per hour and a certification notice was in or on the package. The Model 500-SU source changer did not meet either of these provisions. The dose rate at the surface exceeded 0.5 millirem per hour. On March 14, 1990, at Amersham's facility, the Team made confirmatory measurements using a calibrated survey meter (Ref. 4), indicating that empty source changer S/N SU-610 had dose rates of between 0.4 millirem and 1.4 millirem per hour, and that the crate, when loaded with the 14 empty source changers, had dose rates of between 0.3 millirem and 1.5 millirem per hour (Fig. 8.1 and 8.2).

The Team found no evidence that a certification statement was present in or on the crate of source changers when they arrived at Amersham. The markings that were present on the crate are illustrated in Figs. 8.3 and 8.4. Therefore, the shipping documents did not contain the required certification for the shipment as a Type A package.

8.2.6 The Importer

The NRC regulations in 10 CFR 110.23(a) provide a general license to any person to export almost all forms of byproduct material, except to certain countries. Similarly, 10 CFR 110.27(a)(3) authorizes any person to import byproduct material if the consignee is authorized to possess the material under a general or specific license that has been issued by the NRC or an Agreement State. Because Amersham Corporation (Amersham) holds such an NRC license, Amersham is authorized to import byproduct materials (i.e., radiographic sources). Also, pursuant to the exemptions contained in 10 CFR 40.13, Amersham is further authorized to import and export source material, that is, the depleted uranium contained in the Model 500-SU source changer as shielding.

Although Amersham was in full compliance with the NRC regulations cited for an importer, the Team noted certain deficiencies in the information Amersham provided the shipper.

The DOT regulations for the import and export of radioactive materials are specified in 49 CFR 171.12, "Import and export shipment." Subparagraph (a) requires that each person importing a hazardous material into the United States shall provide the shipper and the forwarding agent, at the place of entry into

Readings in Millirems per Hour (3/14/90)

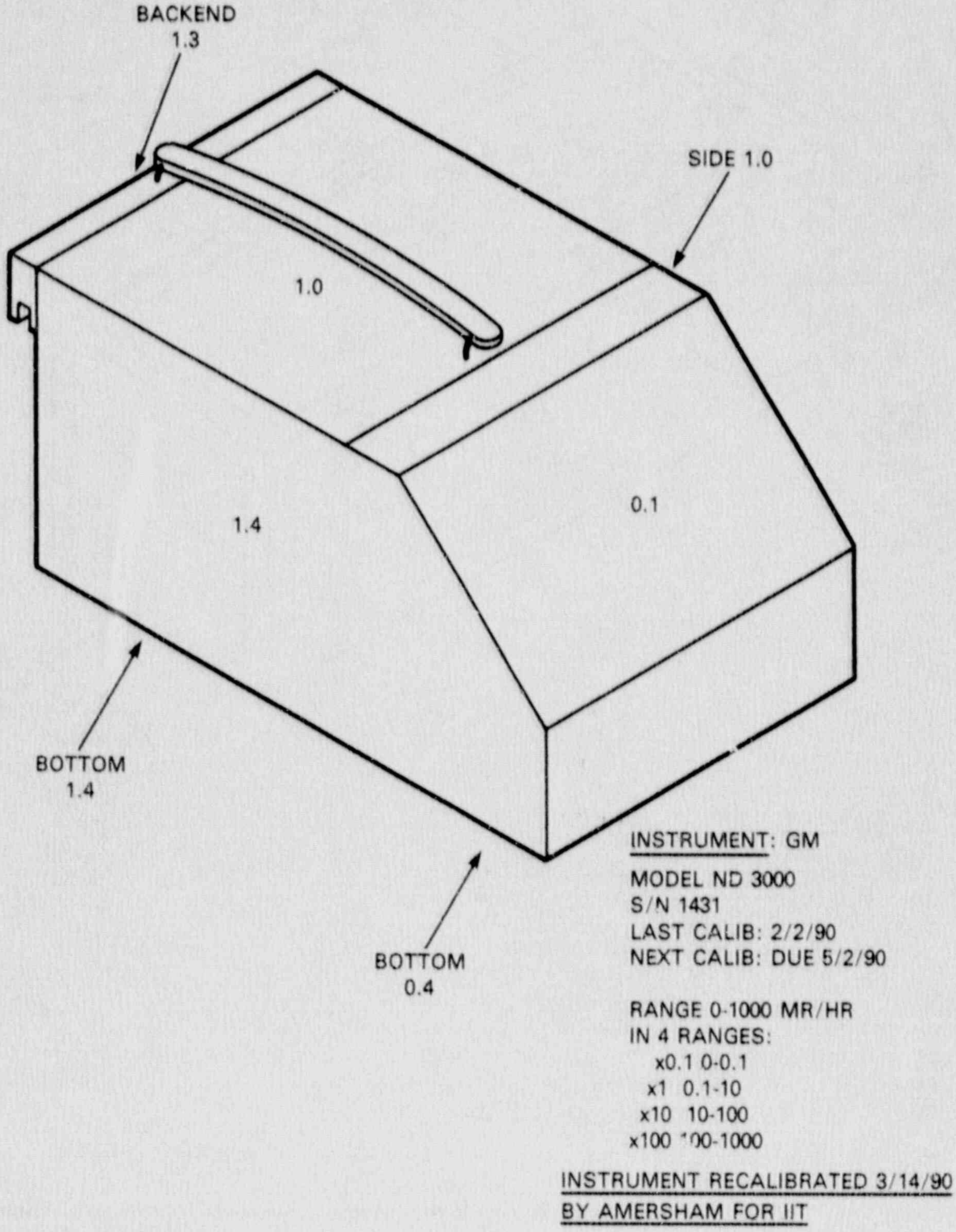
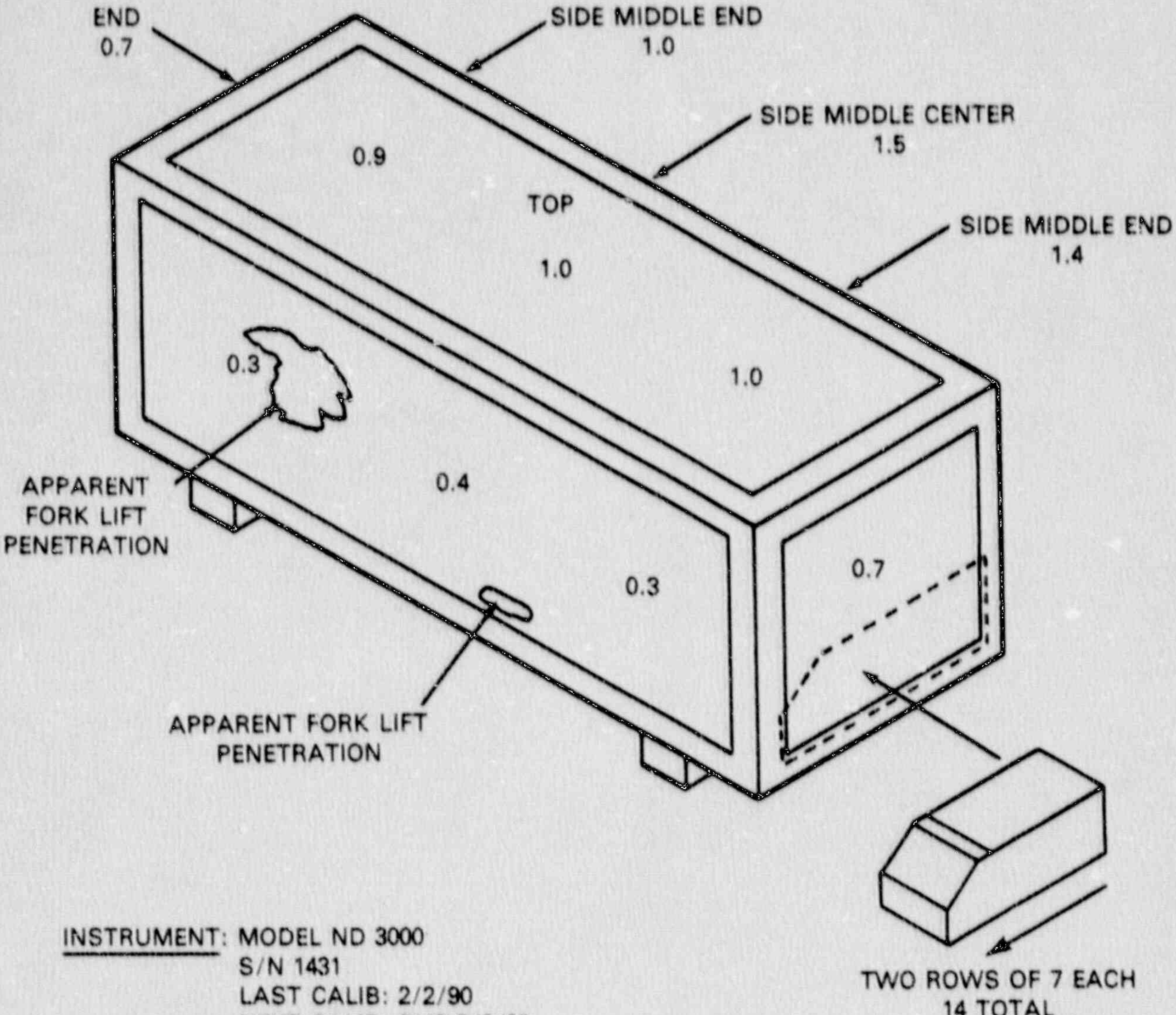


Figure 8.1 Radiation Profile of S/N 610 Model SU-500 Source Changer Without a Source

Readings in Millirems per Hour (3/14/90)



<u>INSTRUMENT:</u> MODEL ND 3000
S/N 1431
LAST CALIB: 2/2/90
NEXT CALIB: DUE 5/2/90

RANGE 0-1000 MR/HR
IN 4 SCALES:
x0.1 0-0.1
x1 0.1-10
x10 10-100
x100 100-1000

<u>INSTRUMENT RECALIBRATED 3/14/90</u>
<u>BY AMERSHAM FOR IIT</u>

Figure 8.2 **Radiation Profile of 14 SU-500 Source Changer Reloaded Into Original Shipping Crate with Source Changers Stacked in Two Rows of 7 Each with Sloped Ends. All Facing 90° Toward Side Having the Fork-Lift Penetration**

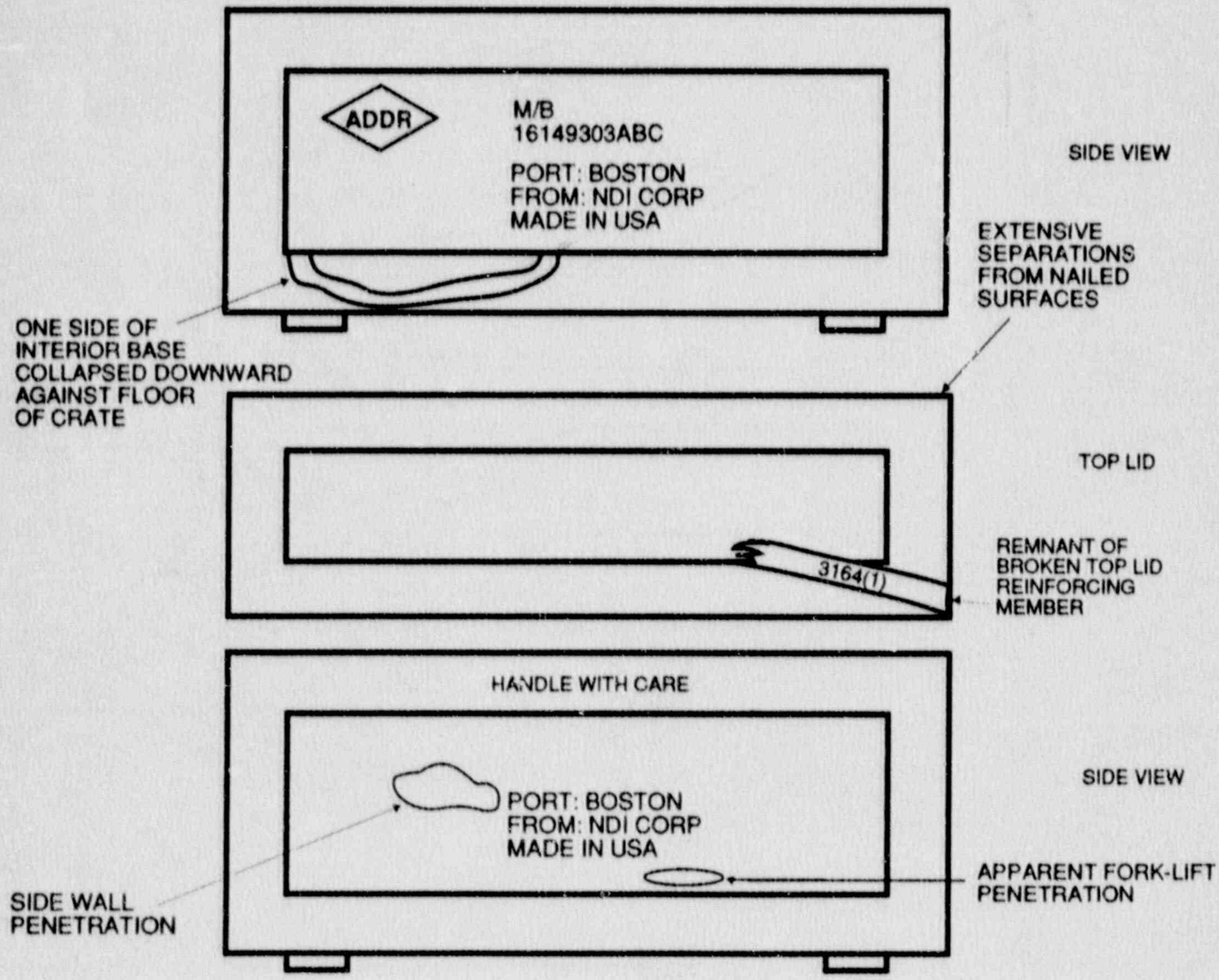


Figure 8.3 Markings on Damaged Crate Containing the 14 SU-500 Source Changers

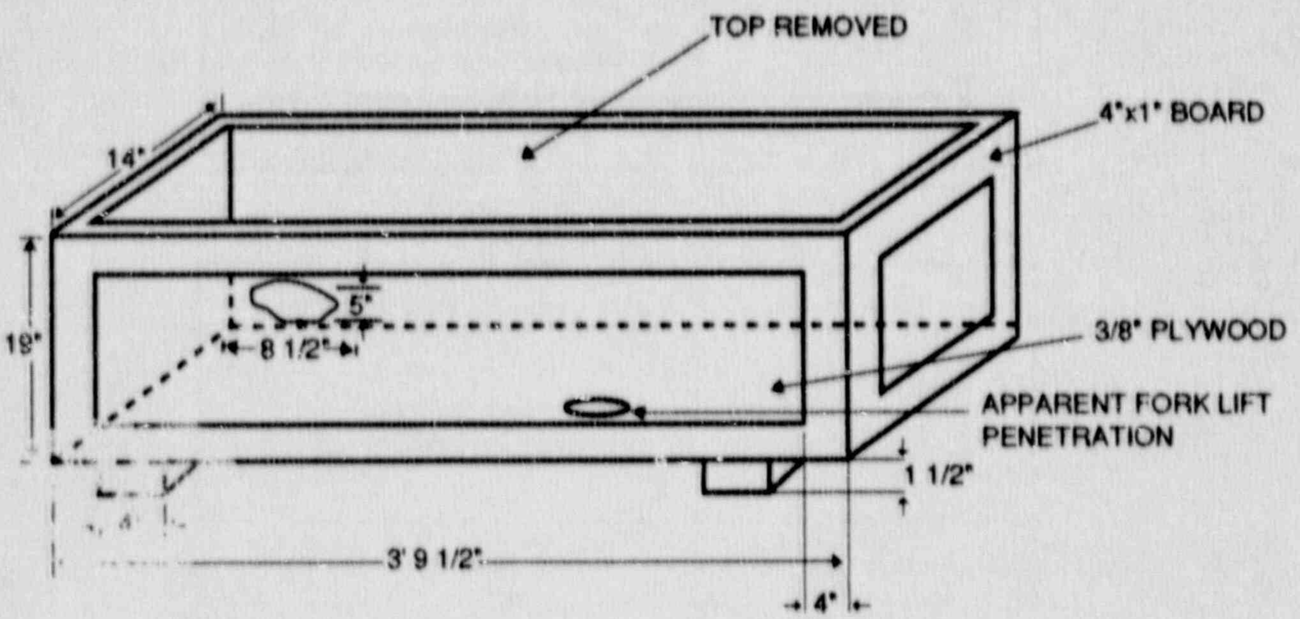


Figure 8.4 WOODEN CRATE SOURCE CHAN[illegible]ERS WERE DEL[illegible]ERED/SHIPPED IN

the United States, complete information as to the requirements of the DOT Hazardous Materials Regulations (HMR) that apply to the shipment within the United States.

On the basis of this requirement, DOT considers Amersham, the consignee of this shipment, to be the importer. On March 27, 1990, DOT requested (Ref. 5) that Amersham confirm that they were the importer and furnish information to indicate how they complied with 49 CFR 171.12(a). Amersham provided DOT with a copy of the instruction booklet that they routinely furnish to each recipient of a Model 500-SU source changer (Ref. 6).

The Team has examined the above instruction booklet and noted (see Sec. 7.6 of this report) that these instructions, although generally satisfactory, are deficient in that they are silent as to what procedures a shipper would follow in the event the surface dose rate of an empty Model 500-SU source changer exceeds the 0.5 millirem per hour limit for shipment as an "excepted" device containing depleted uranium. Also, the instructions do not provide details on how to determine if a source changer is empty.

The Team also confirmed that Amersham did not provide the freight forwarder in Los Angeles, the place of entry to the United States, information as required by 49 CFR 171.12(a). On March 7, 1990, Amersham did provide shipment information to their own customs broker/freight forwarder, International Specialists, Incorporated (ISI). In this case, the shipping document was annotated by ISI to make the following statement:

> Exempt from specification packing, shipping paper and certification marking and labeling and exempt from the requirements of Part 175 per 49 CFR 173.421.1 and 49 CFR 173.424, exempted from the [International Air Transport Association] IATA restricted article regulations (28th Edition) per paragraph 5.7.29, page 369.

The Team determined that the above statement was added by ISI at Amersham's request after Amersham had been notified by Patriot Trucking Company that source changers bearing "radioactive" labels had been observed in a damaged crate when it was unloaded from the Covenant Transport vehicle. This annotation was technically incorrect in that the package did not qualify as an excepted package and that the air transport mode was not involved.

8.2.7 Incident Reporting

Carriers are required to report to the DOT any incidents during transport of hazardous materials when there are fatalities, injuries involving hospitalization, $50,000 property damage, and, in the case of radioactive materials, "fire, breakage, spillage, or suspected radioactive contamination..." (49 CFR 171.15 and 171.16). In addition, an NRC licensee is required to report "any instance in which there is significant reduction in the effectiveness of any authorized packaging during use" (10 CFR 71.95). Package means the packaging together with its radioactive contents as prepared for transport. As discussed in Section 2, the Covenant senior truck driver informed his management of the damaged crate and radioactive labels, but because the shipping documents indicated that the packages were empty, they assured him that the package did not contain radioactive materials. Not until the package reached Amersham was the unshielded source detected. Under 10 CFR 20.403, a licensee is required to report to the NRC any events that "may have caused" significant whole body radiation exposure. Amersham's initial report was in compliance with this requirement.

8.3 Summary

The Team has concluded that the existing DOT regulations applicable to classification, packaging, marking, labeling, and shipping document descriptions for radioactive materials are adequate. To properly prepare the package for shipment, the Koreans should have verified that the "J-tubes" of the source changers were empty before shipment. Had these requirements been followed, the incident would not have occurred. The DOT requirement for importers to furnish information on import shipments to the foreign shipper and agents at the port of entry is ineffective because the information does not always get to the people preparing the package for shipment and agents are not equipped to use the information to correct discrepancies in shipments.

References*

1. U.S. Department of Transportation and U.S. Nuclear Regulatory Commission, "Transportation of Radioactive Materials; Memorandum of Understanding," Federal Register, Vol. 44, July 2, 1979, pp. 38690-38691.

2. International Atomic Energy Agency, "Regulations for the Safe Transport of Radioactive Materials, Safety Series No. 6, Revised Edition (as amended)" Vienna, Austria, 1973.

3. U.S. Nuclear Regulatory Commission, transcription of conversations between two members of the Team with Alan I. Roberts, Director, Office of Hazardous Materials Transportation, U.S. Department of Transportation, Washington, D.C., March 21, 1990. (04-160-90)

4. Amersham Corporation "Survey Meter Calibration Certificate" for the Model ND-3000 survey instrument, Serial No. 1431, Burlington, Massachusetts, March 15, 1990. (04-058-90)

5. U.S. Department of Transportation, letter from John J. O'Connell, Jr., Chief, Enforcement Division, Office of Hazardous Materials Transportation, to C. Roughan, Radiation Safety Officer, Amersham Corporation, Burlington, Massachusetts, March 27, 1990. (04-147-90)

6. Amersham Corporation, Burlington, Massachusetts, Tech/Ops RPD, "AI Model 500-SU Source Changer Operational Manual," undated. (04-015-90)

*The file number in parenthesis at the end of some reference citations refers to the location of that reference in the Team's files for NUREG-1405. These files are available for inspection or copying for a fee at the NRC's Public Document Room, 2120 L Street, NW., Lower Level, Washington, D.C.

9 RELATED EVENTS AND INFORMATION

9.1 Previous Shipments of Unauthorized Iridium-192 Sources in the Model 500-SU Source Changer

On two previous occasions, sources with severed pigtails were sent to Amersham Corporation from Korea in Model 500-SU source changers. On December 12, 1985, Amersham employees found a source with a severed pigtail in the shielded portion of a source changer while conducting wipe tests of units shipped from Korea (Ref. 1). These tests are performed by wiping the inner surfaces of source tubes with absorbent paper or cloth attached to the end of a wire. The paper or cloth is then surveyed to measure the level of removable surface contamination.

When an Amersham employee began to remove the wipe wire from the source tube, his survey meter went off scale. The source changer was moved to the sealed source hot cell and the radiation safety officer (RSO) was notified. (The RSO involved in this event has since left Amersham Corporation and was unavailable to be interviewed.) When the wipe wire was removed, a portion of a source holder cable, approximately four inches long, with a source on the end of it, was attached. Half of the cable pigtail had been removed. The source measured 600 millirem per hour at one foot. The activity of the source was estimated to be approximately 0.1 curie.

Amersham was unable to determine the serial number of the source changer involved in the 1985 event. Consequently, the Team was unable to identify the specific surface radiation survey performed by Amersham when the source changer was received. Such surveys could have confirmed that the source was in the shielded section of the source tube when the source changer arrived at Amersham.

Regardless, the Team believes that the source probably remained in a shielded position during shipment because (1) the source was retrieved from within the shielded portion of a source tube and (2) the remaining 4-inch portion of the pigtail was probably sufficiently long to keep the source in the shielded section of the source tube even without a tube cap. The Team could not determine whether tube caps had been screwed on the tubes and subsequently came off.

Another source was discovered on December 18, 1985, during wipe testing of the source tubes on other Model 500-SU source changers (Ref. 1). This source measured approximately 350 millirem per hour at one foot. The radioactivity of the source was estimated to be approximately 0.06 curie. The source was found in source changer number SU-630. A surface radiation survey of the source changer after its receipt indicated that the source was confined to the shielded compartment of the changer.

9.2 Contamination of Previous Shipments from Korea

At least nine Model 500-SU source changers were returned to Amersham from Korea between 1985 and 1989 with contaminated source tubes (Ref. 2). The contamination was confirmed to be iridium-192 (Ir-192) and ranged from 0.001 microcurie to 2 microcuries. What caused the surface of the source tubes to be contaminated is not known. Table 9.1 compares the number of contaminated source changers shipped from Korea with the total number of Model 500-SU source changers shipped from Korea from 1985 to 1989.

Table 9.1 Korean Shipments of Contaminated Model 500-SU Source Changers to Amersham Corporation

Year	Number of Source Changers Received from Korea	Number of Contaminated Source Chargers from Korea	Level of Contamination (Microcuries)
1985	43	3	0.005
1986	77	2	0.001-0.005
1987	111	2	0.001-0.005
1988	72	0	--
1989	76	2	0.005-2.0

9.3 Feasibility of Detecting the Importation of Unauthorized Radioactive Material

The only feasible way that an unshielded source in this shipment could have been detected en route is by a voluntary survey done by a carrier, by a random spot check conducted by Federal or local officials, or by a detection device installed at the point of entry into the United States. Based on interviews with hazardous material specialists from the U.S. Department of Transportation's (DOT's) Office of Motor Carrier Safety, this shipment would never have been surveyed because the crate was not labeled and marked as containing radioactive material (Refs. 3 and 4). Because of the large volume of these shipments, random spot-checks for radioactive and other hazardous materials are limited to packages labeled and marked for these categories.

In November or early December 1983, metal products contaminated with cobalt-60 were inadvertently imported into the United States from Mexico. As a result, the NRC commissioned a study to determine the feasibility of detecting the importation of unauthorized radioactive materials into the United States (Ref. 5). The study was aimed primarily at detecting the contamination of iron and steel scrap metal and metal products by nine radioactive isotopes currently and previously used in industry. (Ir-192 was one of the isotopes studied.) The threshold for detectability established in the study was an activity of 33.6 microcuries dispersed over a shipment of 24 boxes, each containing 100 pipe fittings contaminated with cobalt-60. The study concluded that off-the-shelf technology is available to detect this level of contamination.

A detector, such as those described in the study, could also have detected the Ir-192 source involved in the 1990 Korean incident if the source were in the unshielded compartment of the source changer when it arrived in the United States and even though the wooden crate was not labeled with a radioactive materials sticker. The triggering of a radiation detection alarm would probably have been cause for inspection of the crate, after which the unshielded source may have been discovered.

9.4 Unauthorized Importation of Source Changers into Arizona

At approximately 10 a.m., on March 22, 1990, a Mexican national, employed by Internacional de Energia Nuclear, a Mexican government electric generating utility, entered the United States from Mexico at Nogales, Arizona, in a pickup truck owned by the utility. The truck was carrying an unlabeled and unmarked 5-gallon shipping barrel. The driver of the truck initially attempted to pass through U.S. Customs Service and Immigration at the passenger vehicle entry portal, but was redirected to the U.S. Customs Service commercial inspection facility.

At the commercial facility, U.S. Customs Service inspectors opened the 5-gallon barrel and found a Gamma Industries (now owned by Amersham Corporation) Model C-10 source changer marked with a radioactive material symbol. U.S. Customs Service inspectors surveyed the barrel and determined that it was emitting radiation that was above background levels. The driver had no proper shipping papers to transport radioactive materials into the United States from Mexico; rather, he presented shipping documents to the Customs inspectors for a prior shipment of radiographic sources from Amersham Corporation to Mexico. The driver said that this was his first crossing into the United States with a source changer and that he was unaware of any requirements related to U.S. Customs Service or DOT regulations.

The Customs inspectors detained the truck driver, impounded the truck and the barrel, and contacted NRC's Region V Office and the State of Arizona (an NRC Agreement State). Region V, in turn, requested that the University of Arizona at Tuscon dispatch a health physicist (HP) to Nogales to evaluate the radiation levels emitted from the barrel. The HP measured 0.064 millirem per hour at the surface of the barrel. The source changer contained no radioactive sources; rather, the radiation being emitted was attributable to the depleted uranium shielding. Concurrent with this activity, the Region V Office notified the Team of the event and made arrangements to have U.S. Customs Service officials hold the barrel for inspection by a Team member.

On March 27 and 28, 1990, a Team member, accompanied by a State of Arizona health physicist, inspected the barrel and traced the history of shipments of radiographic sources and source changers from Amersham to Mexico and back to Amersham. During this investigation, the information obtained from the Amersham Corporation, U.S. Customs Service, and certain customs brokers in the United States and Mexico revealed that on at least six occasions over the preceding three years, radiographic sources were shipped to Internacional de Energia Nuclear by the Amersham Corporation. These shipments were all handled by the Rodolfo Joffroy Company, Nogales, Sonora, Mexico, a Mexican customs' broker, through its warehouse located in Nogales, Arizona. New sources destined for Mexico were shipped to the Joffroy warehouse in Nogales, Arizona, where they were held by Joffroy while import authorizations were obtained from the Mexican government. The sources were then trucked by Joffroy or by a Mexican utility company employee into Mexico.

The source changers were kept in Mexico until the next time new sources were to be picked up at the Joffroy warehouse in Nogales, Arizona. At that time, the Mexican utility employee would cross the border with the empty source changer and exchange it for a source changer shipped from Amersham with new sources. The returned source changer was then returned to the Amersham Corporation via Copper State Truck Lines.

These shipments were apparently made in violation of DOT's classification, marking, labeling, and documentation requirements for the transport of radioactive materials within the United States because they were never identified as shipments of empty radioactive material packages or as articles containing depleted uranium. Depending on their contamination and radiation levels, these items could have been exempted from meeting DOT Hazardous Material Regulations, but still would have to be properly classified and certified on the shipping documentation.

9.5 Partially Exposed Source in a Previous Shipment

In September 1983, Automation Industries (AI) shipped a Model 500-SU source changer containing a 25-curie Ir-192 source to a licensed user in Wisconsin. Although the AI records indicated that the surface radiation levels were in compliance with DOT regulations at the time of shipment, the dose rate at the surface of the source changer was found to be about 500 millirem per hour (the regulatory limit is 200 millirem per hour) (Ref. 6).

The excessive surface radiation was attributed to use of an incorrect extension tube or end cap. The actual end-cap was the wrong length for the pigtail and source that was shipped. Presumably, the pigtail was so short that when it was used with a long end-cap, the source was able to move to a partially unshielded position within the source tube. NRC's Region I investigated this incident and proposed a civil penalty, which was later withdrawn when AI went out of business.

References*

1. R. Kelly, Amersham Corporation, memorandum to V. J. Becker, Subject: "Iridium Shipping Containers from Korea," December 12, 19[illegible]5. (04-140-90)

2. U.S. Nuclear Regulatory Commission, W. Brown telephone conversation with C. Roughan, Amersham Corporation, Subject: "Prior Contamination of Model 500-SU Source Changers from Korea," April 6, 1990. (04-15-90)

3. U.S. Nuclear Regulatory Commission, A Grella and E. Easton, interview with A. Roberts, J. O'Connell, K. Blackwell, and M. Wangler, U.S. Department of Transportation, March 21, 1990. (04-160-90)

4. U.S. Nuclear Regulatory Commission, A Grella and E. Easton, interview with R. Bleakley and W. Byrd, U.S. Department of Transportation, March 21, 1990. (04-159-90)

5. R. Bee, "The Feasibility of Detecting the Import of Unauthorized Radioactive Materials into the United States," NUREG/CR-4357. (04-124-90)

6. U.S. Nuclear Regulatory Commission, "Enforcement Actions: Significant Actions Resolved, Quarterly Progress Report, October-December 1984," NUREG-0940, Volume 3, No. 4, February 1985, pg. 5-6, and II A-1 through II A-24.

*The file number in parenthesis at the end of some reference citations refers to the location of that reference in the Team's files for NUREG-1405. These files are available for inspection or copying for a fee at the NRC's Public Document Room, 2120 L Street, NW., Lower Level, Washington, D.C.

10 PRINCIPAL FINDINGS AND CONCLUSIONS

The inadvertent shipment of an iridium-192 source, within a reportedly empty source changer from Seoul, Korea, to Burlington, Massachusetts, is significant because the iridium-192 source, if unshielded, had the potential to cause high radiation exposure to members of the general public, in addition the following reasons:

- o Some users of radioactive materials in the Republic of Korea may not be cognizant of or do not comply with procedures and regulations for preparing and shipping radioactive material to and within the United States; and

- o Foreign shippers and forwarding agents at the point of entry into the United States are not always supplied with complete information on how to comply with U.S. Department of Transportation (DOT) regulations.

The Team has compiled the following list of principal findings and conclusions about the incident. The cause of the incident is stated in the first conclusion. Other conclusions are not presented in any particular order of significance.

1. The cause of the incident was that a stored source was inadvertently left in a source changer when the device was returned from the end-user to Amersham's Korean distributor for shipment. Neither the end-user, Korea Industrial Testing Company, Ltd. (KIT), nor the distributor (shipper) NDI Corporation (NDI), used effective methods to ensure that there was no source in the changer. The inability of the two parties to detect the source was exacerbated by the fact that the connecting cable, or pigtail, had been removed, that is, cropped from the source. (Events leading to the inclusion of the iridium-192 source in the shipment are also being investigated by the Ministry of Science and Technology, and the Korean Institute of Nuclear Safety, the responsible regulatory authorities in Korea. Their findings were not available at the time this report was published.)

2. The Team was able to identify the radiographic source as a 56-curie, iridium-192 source manufactured on April 13, 1989, by Industrial Nuclear Company, San Leandro, California. Using the manufacturer's decay curve for the iridium-192 source, the Team determined the source's activity at the times when potential exposures to individuals might have occurred. Independent measurements made of the source's activity at the Amersham Corporation facility were consistent with the values derived from the manufacturer's decay curve for the source.

3. While potential radiation exposure to the general public was possible, the number of individuals that could have been exposed was limited because

the shipment was maintained "in-bond" from its arrival in Los Angeles on February 11, 1990, to the time it cleared U.S. Customs Service in Boston on March 7, 1990. The transport vehicle carrying the shipment from Los Angeles to Boston was driven across country with infrequent stops of mostly short duration.

4. Although the maximum estimated potential whole-body radiation exposures range from 27 to 35 rem for the two long-distance drivers, and 0.5 to 5.6 rem for other individuals that may have been in close proximity to the source for extended periods of time, these estimates are not supported by cytogenetic studies done on the five individuals that had the highest potential for exposure. The cytogenetic data suggest that the source may have remained shielded so that no actual exposures occurred until the shipment was transferred from storage in Boston to Amersham's facility in Burlington, Massachusetts.

5. The safe handling and transportation of radioactive materials imported to the United States are highly dependent on the actions of foreign shippers and their agents to properly prepare packages for shipment, properly identify the contents, and accurately describe the contents in shipping documents. There are no DOT or NRC requirements for carriers or shipping agents to monitor or survey shipments during transit.

6. Carriers, freight forwarders, or shipping agents do not independently verify the accuracy of shipping documents for import shipments at the U.S. place of entry. Misclassified or mislabeled shipments are usually discovered by the receiving organization. There are no clear-cut requirements for a receiver to report to DOT or NRC instances where packages are not properly prepared for shipment or where the contents are not accurately identified. Current DOT regulations require carriers to report incidents where there is death, serious injury, or substantial property damage, breakage, spillage, or suspected radioactive contamination. NRC regulations require that licensees report any instance in which there is significant reduction in the effectiveness of any NRC-authorized packaging during use (10 CFR 71.95) if there is a high radiation level or contamination on packages when received (10 CFR 20.205), and for incidents in which there is the potential for significant exposure (10 CFR 20.403). The Team could not determine whether NRC regulations would have required Amersham to report previous instances where cropped sources had been inadvertently shipped from the Republic of Korea. Although the shipment was mislabeled and misidentified in these instances, the sources arrived within the shielded source tubes of the source changers. The Team could find no evidence that the instances were reported to either the NRC or DOT. The incident being investigated, where the source was received in an unshielded position was reported pursuant to NRC requirement, 10 CFR 20.403.

7. As an importer, Amersham was required to provide the shipper and the forwarding agent, at the place of entry into the United States, complete information on how to comply with DOT regulations. The instructions provided to the shipper by Amersham for classifying and preparing the source changers for shipment were incomplete. While instructions were

included for preparing the shipment of the source changers as an "excepted" package, no specific directions were provided for the case where the empty source changers did not meet the requirements for an "excepted" package. In spite of the inadvertent inclusion of an iridium-192 source, the shipment of empty source changers was improperly prepared for transport. Because the surface radiation level of the shipment exceeded 0.5 mrem/hr, it was required to be shipped within the United States as a Type A package. Lack of instructions for preparing a Type A package may have contributed to the misclassification of the package as an excepted package. However, proper classification of the shipment as Type A would probably not have prevented the incident.

8. Amersham's instructions for returning an empty Model 500-SU source changer were made available to NDI and KIT and were adequate for determining whether a source changer contained an authorized (i.e., uncropped) source, since a visual examination would detect the presence of a pigtail. However, in view of previous incidents involving the receipt by Amersham of cropped sources from the Republic of Korea, the instructions were deficient in that they did not anticipate that sources without pigtails might be stored in the source changer and not removed before shipment. Specific instructions requiring both a radiation survey and a probe of the source tubes, if implemented by the end-user, would have prevented this incident.

9. Amersham did not provide "shipper" instructions to the freight forwarder at the place of entry into the United States (Los Angeles), as required, but rather to its Customs broker in Boston. In this case, Amersham provided an erroneous instruction to transport the package as an "excepted" package.

10. The Team found no violation of NRC regulations with respect to the receipt of the source changer shipment at Amersham. NRC's regulations do not apply to the shipment of these source changers across the United States, other than 10 CFR Part 110.27, which specifies requirements for importing byproduct material. Shipment of the source changers within the United States was subject to DOT transportation regulations.

11. DOT regulations permit the use of an NRC-certified Type B package*, such as the Model 500-SU source changer, for shipment of a Type A** quantity, for example, either as empty (with the DU shielding) or with source totaling less than 20 Ci. However, DOT regulations are ambiguous as to whether an NRC-certified Type B package must be used in strict accordance with the NRC certificate for shipment of Type A quantities or whether the package need only comply with the general requirements for Type A packages in the DOT regulations. Thus, the Team could not determine whether the source involved in this incident could have been shipped in the Model 500-SU source changer as a Type A quantity, because the source (with or without the pigtail) is not authorized in the NRC certificate.

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* A Type B package is required to transport iridium-192 in encapsulated sources exceeding 20 curies.

** A Type A quantity for iridium-192 in encapsulated sources is less than 20 curies.

12. The 14 source changers involved in the incident did not conform to the drawings referenced in NRC Certificate of Compliance 9006, Revision No. 9, in that all of these source changers were constructed without a source cable locking assembly. In addition, 6 of the 14 source changers were not constructed according to the dimensions specified in the drawings referenced in the Certificate of Compliance. However, the Team determined that these discrepancies did not contribute to the cause of this incident.

APPENDIX A

Memorandum from James M. Taylor,
Executive Director for Operations,
to the Commission, March 9, 1990

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

MAR 9 1990

MEMORANDUM FOR: Chairman Carr
Commissioner Roberts
Commissioner Rogers
Commissioner Curtiss
Commissioner Remick

FROM: James M. Taylor
Executive Director
for Operations

SUBJECT: INVESTIGATION OF MARCH 8, 1990 EVENT INVOLVING CROSS COUNTRY TRANSPORTATION OF A RADIOGRAPHIC SOURCE FROM KOREA TO AMERSHAM CORPORATION IN BURLINGTON, MASSACHUSETTS WILL BE CONDUCTED BY AN INCIDENT INVESTIGATION TEAM (IIT)

On March 8, 1990, at about 4:00 p.m. an employee of Amersham Corporation, Burlington, Massachusetts, measured a radiation level of 100 mr/hr at the rear of a truck containing supposedly empty source changers which had been shipped from Korea to California, placed in a California warehouse, route trucked to Boston, left in a Boston warehouse, and then trucked to Amersham. The radiographic source, inadvertently imported from Korea, was included in one of fourteen supposedly empty source changers. The source was found outside of the shielded portion of the source changer but was still within the body of the changer. The source has been removed from the changer by Amersham employees and placed in a hot cell. The source, which is approximately the size of a pencil eraser, was measured to be 150 R/hr at a distance of six inches.

Note that in Section V.C of the June 8, 1979, Memorandum of Understanding between the Department of Transportation and the Nuclear Regulatory Commission, NRC will normally be the lead agency for investigating "all accidents, incidents, and instances of actual or suspected leakage involving packages of radioactive material regulated by the NRC." Accordingly, because of the nature and potential radiological health consequences of this event and the generic questions the event raises, I have requested AEOD to take the necessary action to send a six member IIT of technical experts to: (a) quickly resolve questions of radiation exposure; (b) determine what happened; (c) identify the probable cause as to why it happened; and (d) make appropriate findings and conclusions which would form the basis for any necessary follow-on actions.

The team will report directly to me and is comprised of: Willard B. Brown, Office of Nuclear Material Safety and Safeguards (NMSS), Team Leader; Alfred W. Grella, NMSS; Earl Easton, NMSS; John R. White, Region I; Phillip V. Joukoff, Region V; and David Skov, Region V. Enclosed is the charter for the IIT to use in the review of the event.

The licensee has agreed to preserve the equipment in an "as-found" state until the licensee and the NRC Team have had an opportunity to evaluate the event. The licensee's actions have been confirmed by the Regional Administrator in a Confirmatory Action Letter which will be issued on 3/9/90.

The IIT report will constitute the single NRC fact-finding investigation report. It is expected that the team report will be issued within 45 days from now.

James M. Taylor
Executive Director
for Operations

Enclosure:
As stated

cc: SECY
OGC
ACRS
GPA/PA
Regional Administrators

Enclosure

Incident Investigation Team (IIT) Charter

Inadvertent Import and Cross Country Transportation of a Radiographic Source from Korea to Amersham Industries, Burlington, MA

The IIT is to perform an investigation to accomplish the following:

1. Reconstruct the potential exposures to individuals who potentially were in close proximity to the radiographic source material during receipt, shipment and storage. The evaluation should include the following:

   - o Characterize the source term and geometry
   - o Reconstruction of the shipping/storage route
   - o Stay times during transit
   - o Time-motion studies of personnel potentially exposed
   - o Estimate actual exposure to individuals who had the potential for overexposure

2. Determine the root causes of the exposures including the following:

   - o Adequacy of the shipping container
   - o Adequacy of the shipping procedures including field surveys from port of entry to Amersham Industries
   - o The proximate cause of the source being unshielded during transit

3. Determine the adequacy of the licensees' response to this event.

4. Determine the adequacy of regulatory controls concerning this type of event.

APPENDIX B

Properties of Iridium and Iridium-Sealed Sources

APPENDIX B

PROPERTIES OF IRIDIUM AND IRIDIUM-SEALED SOURCES

Iridium is a hard, brittle, silvery metal usually found in nature in deposits of platinum- and osmium-bearing ores. It is produced primarily as a byproduct from the refining of other metals. Natural iridium has an atomic weight of 192.2 and has a number of stable isotopes. It has a relatively high melting point of 245°C.

The isotope used in radiography devices is iridium-192. Iridium-192 is produced by activating commercial iridium, which is 60 percent iridium-193 and 40 percent iridium-191, in a nuclear reactor. The resulting product is a mixture of approximately 40 percent iridium-192 and 60 percent iridium-194. The iridium-194, which has a half-life of 17 hours, decays to less than 2 percent of its original concentration in about four days. Iridium-192 has a half-life of 74 days. The decay chart for the iridium-192 source involved in the Korean incident is shown in Figure B.1.

Iridium-192 emits three principal gamma rays that are of interest in radiography. These gamma rays have principal energies of 311, 468, and 603 kilovolts.

Figures B.2 through B.4 give the decay scheme, dose rates versus distance, and half-value layers of iridium-192.

The iridium-192 used in radiographic devices as a source of radiation is encased in a metal capsule. The source capsule, made from stainless steel and welded to form a hermetic seal, is the principal means for preventing the radioactive material from dispersing (Fig. B.5). The source capsule must maintain its integrity and leak-tightness when subjected to certain test conditions in order to be approved by the U.S. Nuclear Regulatory Commission for transportation or for use as an industrial radiography source. The source capsule is generally attached to a source cable assembly or source "pigtail" assembly (Fig. B.6), to provide a coupling device for transferring the source between a shielded and an unshielded position or to a source changer for storage or transport.

INDUSTRIAL NUCLEAR COMPANY (INC)

Curies: 56 Date: 4/13/89 Ser. No.: 1062 Mod. No.: 8

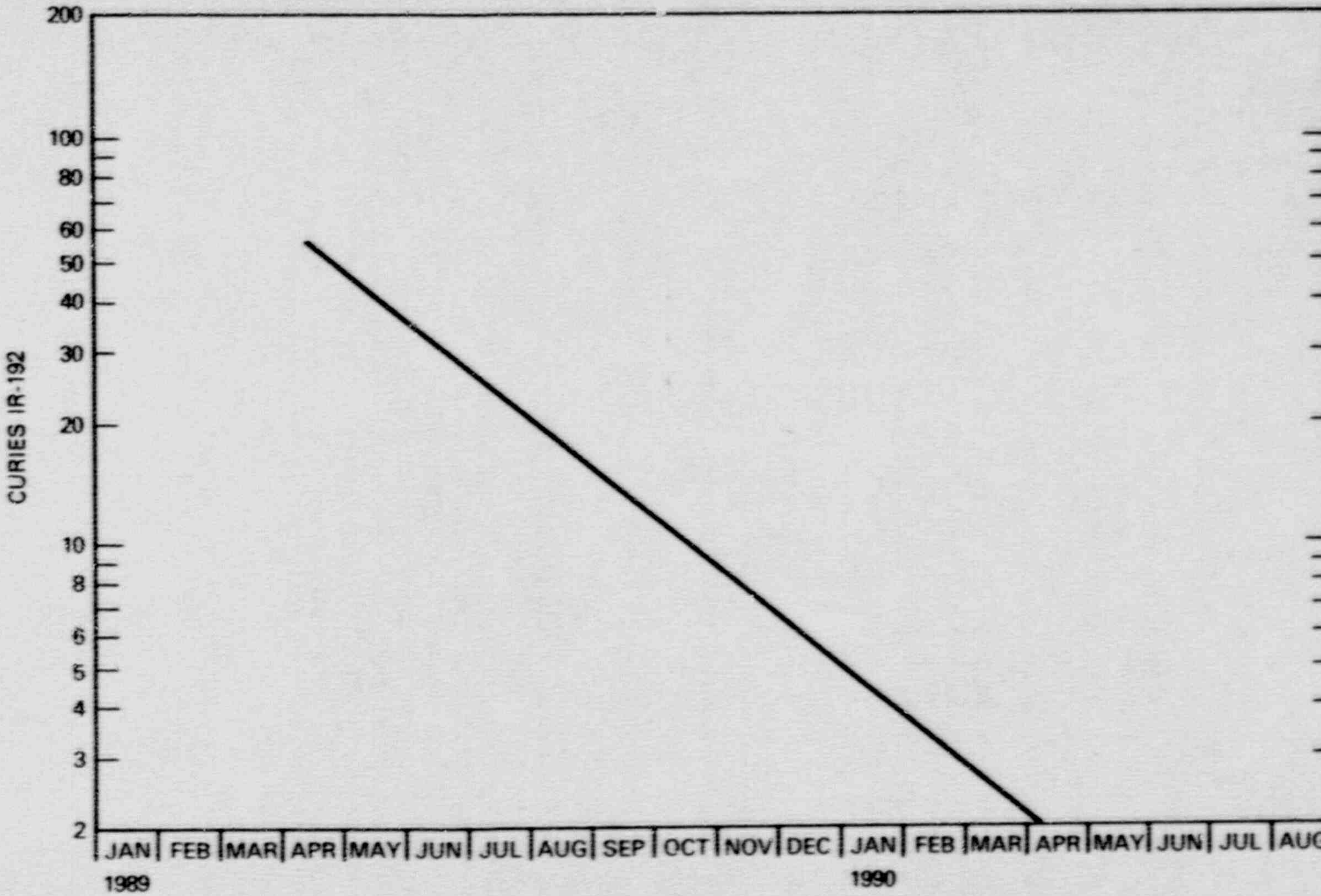


Figure B.1 IR-192 Decay Chart & Source Data (Adopted from INC certificate dated 4/13/89)

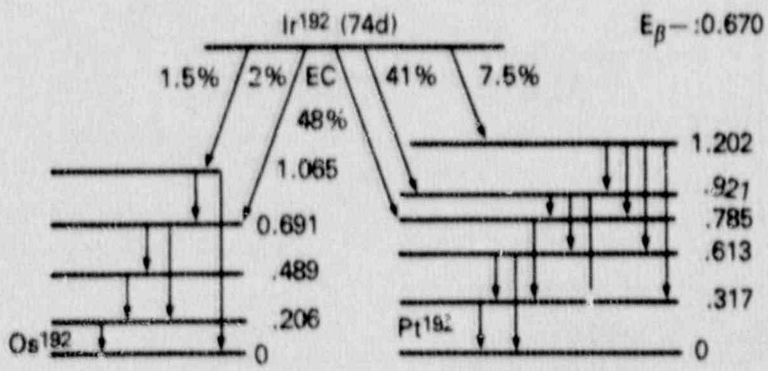


Figure B.2 Simplified Decay Scheme for Iridium-192

Dose Rates per Hour per Curie	
Distance	Iridium^{192}
1 FOOT	5.2 R
2 FEET	1.3 R
4 FEET	325 MR
8 FEET	81 MR
10 FEET	52 MR

Figure B.3 Iridium-192 Dose Rates vs. Distance

Material	Iridium-192	
	1/10 Value Layer*	1/2 Value Layer*
Lead	0.64 inch	0.19 inch
Steel	2.0 inches	0.61 inch
Concrete	6.2 inches	1.9 inches
Aluminum	5.2 inches	1.9 inches

*1/10 value and 1/2 valu layers are the thicknesses of material needed to reduce the radiation intensity (Roentgens/Hr.) to 1/10 and 1/2 of the original intensity, respectively.

Figure B.4 Thickness of Shielding To Reduce Iridium-192 Radiation

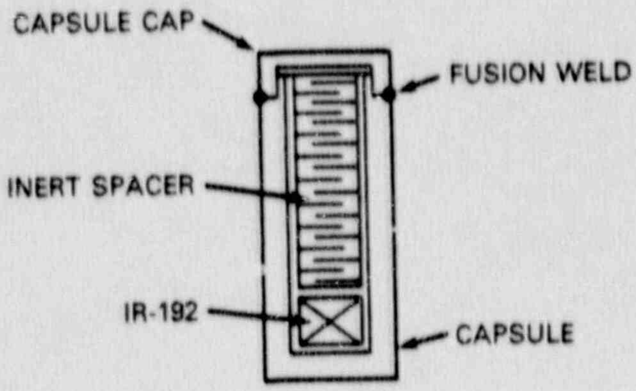


Figure B.5 Schematic of Typical Iridium-192 Radiographic Source Capsule

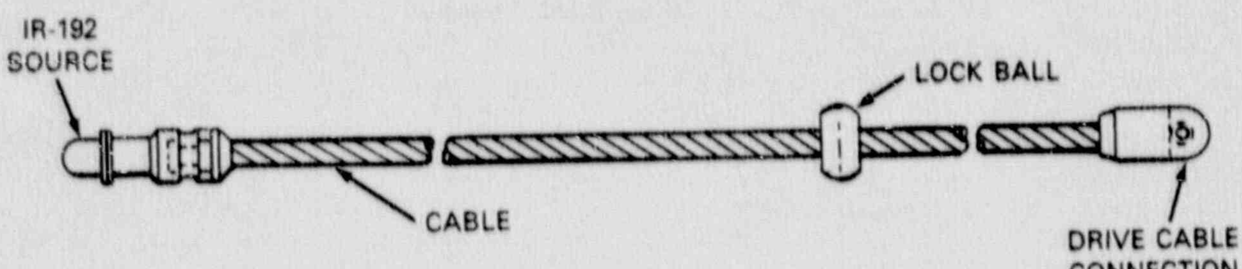


Figure B.6 Typical Source Holder Assembly

APPENDIX C

Event Chronology Table

Appendix C
Event Chronology Table

The following table concisely describes the events of this incident as they occurred, beginning with shipment of the source by its manufacturer through the time of its discovery at Amersham Corporation (Amersham) and subsequent analyses.

DATE	EVENT	COMMENT
04/18/89	Industrial Nuclear Company (INC) San Leandro, California, shipped a Model No. 8, 56-Curie Ir-192 source Serial Number (S/N) 1062 to its distributor, Boo Kyung Sa, Ltd., Seoul, Korea.	Source was shipped in an IR-50 source exchanger, an NRC-approved package.
04/24/89	Boo Kyung Sa, Ltd., supplied Korea Industrial Testing Company (KIT) with the Ir-192 source (S/N 1062).	
10/13/89	Amersham, Burlington, Massachusetts, shipped a Model No. G3, 64-curie, Ir-192 source to its distributor, NDI Corporation, Seoul, Korea.	The source was shipped in an Automation Industries 500-SU source changer (S/N SU-610), an NRC-approved package.
10/31/89	NDI Corporation supplied KIT with the Model 500-SU source changer (S/N SU-610) containing the Model No. G3 source.	The Model G3 source is designed to be used with Gamma Century SA exposure devices.
11/01/89 to 01/18/90	Sometime in this period, the 500-SU (S/N SU-610) source changer was used to store one or more "depleted" Ir-192 sources, including the INC Model No. 8 source (S/N 1062).	
01/18/90	NDI took possession of the 500-SU source changer (S/N SU-610) from KIT and brought the device to NDI's facility for storage. At this time, the Model No. 8 Ir-192 source (S/N 1062) was inadvertently left in the source changer when it was given to the NDI representative for return to Amersham, Burlington, Massachusetts. Neither NDI or KIT performed any radiation surveys of the device at KIT because the changer was believed to be empty.	

DATE	EVENT	COMMENT
01/20/90	Under arrangements made by NDI with their freight forwarder, Daeil Shipping Company, Ltd, a Non-Vessel Operating Common Carrier (NVOCC), the 500-SU source changer (S/N SU-610) and 13 other 500-SU source changers were transported by truck to U-Jin Packing Company, Seoul, Korea. U-Jin made a wooden shipping crate to enclose the 14 source changers for overseas transport.	Surveys performed by NDI indicated radiation levels between 0.03 and 0.5 millirem per hour in the area where the source changers were stored. Dose rates between 0.9 millirem and 1.2 millirem per hour were measured on the source changers.
01/21/90	The wooden crate containing the 14 Model 500-SU source changers was transported by truck from the U-Jin Packing Company in Seoul to the Dongbu Express Company, Pusan (a Container Freight Station).	
01/21/90 to 01/29/90	The wooden crate was loaded in a ocean cargo container (HJCU704673-1) for transport by a Hanjin Shipping Company vessel to Los Angeles, California.	The wooden crate may have sustained damage while being loaded into the ocean cargo container.
01/28/90	Container HJCU704673-1 was loaded aboard the S.S. HANJIN MOKPO, a Korean flagged and registered containerized cargo ship bound for Los Angeles.	
01/29/90	The S.S. HANJIN MOKPO departed Pusan for Los Angeles.	
02/09/90	The S.S. HANJIN MOKPO arrived off the coast of the Los Angeles-Long Beach area.	The ship remained at sea during a labor problem that involved marine pilots and the unavailability of the Hanjin Company's berth for docking.
02/11/90	The S.S.HANJIN MOKPO arrived at Hanjin Company's Berth 127.	
02/13/90	Container HJCU704673-1 was off-loaded from the ship onto a container trailer chassis and stored on Hanjin's terminal site in position J-053.	

DATE	EVENT	COMMENT
02/14/90	Under arrangements made by Daeil Shipping Company's U.S. agent, Fidelity Transport Company, NVOCC, container HJCU704673-1 was moved to the Nova Transportation Services Company's (Nova) CFS in Compton, California.	The container was opened and the cargo removed for shipment to its consignees. When the wooden crate containing the source changers was unloaded, damage to the crate was noticed and documented. U.S. Customs Service officials did not inspect the crate at Los Angeles. They considered the crate to be "in-bond" until cleared by the Boston District Customs Office.
02/16/90	A Covenant Transport, Inc. (Covenant) trailer was loaded with four east-bound consignments by Nova CFS, in the reverse order of scheduled delivery to facilitate unloading. Because the crate was part of the last consignment, it was the first item loaded into the trailer, and was positioned in the right-front corner.	
	Two drivers in a truck tractor from Covenant, a motor freight carrier contracted by the Nova CFS, picked up the trailer and left for the East Coast.	Snow prevented travel on Interstate 15. The drivers stayed overnight ay a motel in San Bernardino, California. California.
02/17/90	The drivers resumed eastbound travel.	Driving was continuous except for food and fuel breaks.
02/18/90	4 a.m.: Arrived Holbrook, Arizona; 11:30 a.m.: Arrived Amarillo, Texas; 4 p.m.: Arrived Oklahoma City, Oklahoma.	Continuous driving.
02/19/90	9 a.m.: Arrived Terre Haute, Indiana; 1:30 p.m.: Arrived Hebron, Ohio; 4 p.m.: Departed Hebron, Ohio; 10 p.m. Arrived Coraopolis, Pennsylvania at the (Nu Tranz Freight Systems, Inc. (Nu Tranz) warehouse.	The drivers slept onboard the truck at Nu Tranz terminal to await unloading of the first consignment.

DATE	EVENT	COMMENT
02/20/90	9 a.m.-11 a.m.: Nu Tranz employees unloaded the first consignment. Travel resumed at 11 a.m. 8 p.m.: Arrived at the Port East, Inc. (Port East) Warehouse in Baltimore, Maryland.	The drivers slept onboard the truck at the Port East terminal to await unloading of the second consignment.
02/21/90	8 a.m.-11 a.m.: Port East employees unloaded the second consignment. Travel resumed at 11 a.m.	
	2:30 p.m.: Arrived at Evans Delivery in Philadelphia, Pennsylvania. Both drivers and one Evans employee unloaded the third consignment. Travel resumed at 4:30 p.m.	
	7:30 p.m.: Stopped for a 30-minute break at Truck Service Plaza, approximately Exit 37, I-95 north in Connecticut.	
	10 p.m.: Arrived at a Truck Stop at Exit 13 Interstate 90 East in Massachusetts.	The drivers slept onboard the truck overnight.
2/22/90	9:30 a.m.: Resumed travel.	
	11:30 a.m.: Arrived at the Patriot Trucking Company (Patriot) Warehouse at Logan Airport in Boston, Massachusetts. Both drivers and two Patriot employees unloaded the fourth and last consignment.	
	When unloading the crate, the senior driver noticed that it was severely damaged and that some of the source changers had been knocked out of the crate. As he reloaded the source changers into the crate, he noticed the radioactive material labels and became concerned about the status of the shipment.	
	The Covenant driver contacted his management to advise them that the crate contained devices labeled as radioactive material.	

DATE	EVENT	COMMENT
	Covenant management personnel asked the NOVA officials about the contents of the shipment and were informed that the source changers were empty and did not contain radioactive materials. Covenant management so informed the driver, indicating that the cargo was not hazardous.	
	A Patriot fork-lift operator unloaded the wooden crate from the trailer and placed it in storage in the bonded freight enclosure.	
02/23/90 to 03/07/90	During this period, some Patriot employees and U.S. Customs Service inspectors reported occasionally passing near the wooden crate. A U.S. Customs Service inspector noticed the damage to the crate and the radioactive materials labels on the source changers on or about 2/28/90. The inspector subsequently asked Patriot management to remove the package as soon as possible.	
03/07/90	U.S. Customs Service officials cleared the wooden crate for delivery to Amersham.	
03/08/90	<u>2 p.m.</u>: The wooden crate was loaded aboard a Patriot tractor-trailer for delivery to Amersham, Burlington, Massachusetts.	The crate, unsecured, was the only freight loaded onboard the Patriot trailer.
	<u>2:30 p.m.</u>: The Patriot truck arrived at Amersham's Burlington, Massachusetts, facility. During the course of unloading, it was noticed that the crate had broken open during shipment. The source changers were scattered over the floor of the trailer. Radiation dose rates of 150 rem per hour were measured at the surface of source changer S/N SU-610.	After securing the source in a safe condition in a "hot cell" facility, Amersham's Radiation Safety Officer notified NRC Region I of the incident.
	Amersham determined that a sealed source had been erroneously included with the shipment of empty source changers; the sealed source was later	

DATE	EVENT	COMMENT
	identified as INC Source Model No. 8, S/N 1062. Subsequently, Amersham safely removed the sealed source from the source changer.	
03/09/90	NRC's Region I Office dispatched two region-based inspectors to perform a preliminary investigation of the incident. NRC's Region I also issued a Confirmatory Action Letter to Amersham, to ensure that all materials, records, and components associated with this incident were preserved for investigation by the NRC.	
03/10/90	Members of the NRC Incident Investigation Team (Team) arrived in Boston to begin the investigation of the incident in that area.	
03/11/90	Members of the NRC Team arrived in Los Angeles to begin the investigation of the incident in that area.	

APPENDIX D

NRC Certificate of Compliance No. 9006
for the Model AI 500-SU Source Changer

NRC FORM 618
10 CFR 71

CERTIFICATE OF COMPLIANCE FOR RADIOACTIVE MATERIALS PACKAGES

U.S. NUCLEAR REGULATORY COMMISSION

1. a. CERTIFICATE NUMBER	b. REVISION NUMBER	c. PACKAGE IDENTIFICATION NUMBER	d. PAGE NUMBER	e. TOTAL NUMBER PAGES
9006	9	USA/9006/B(U)	1	2

2. PREAMBLE

a. This certificate is issued to certify that the packaging and contents described in Item 5 below, meets the applicable safety standards set forth in Title 10, Code of Federal Regulations, Part 71, "Packaging and Transportation of Radioactive Material."

b. This certificate does not relieve the consignor from compliance with any requirement of the regulations of the U.S. Department of Transportation or other applicable regulatory agencies, including the government of any country through or into which the package will be transported.

3. THIS CERTIFICATE IS ISSUED ON THE BASIS OF A SAFETY ANALYSIS REPORT OF THE PACKAGE DESIGN OR APPLICATION

a. ISSUED TO (Name and Address)

Amersham Corporation
40 North Avenue
Burlington, MA 01803

b. TITLE AND IDENTIFICATION OF REPORT OR APPLICATION

Tech/Ops Inc. application dated March 31, 1986.

c. DOCKET NUMBER 71-9006

4. CONDITIONS

This certificate is conditional upon fulfilling the requirements of 10 CFR Part 71, as applicable, and the conditions specified below.

5.

(a) Packaging

(1) Model No.: AI 500 SU

(2) Description

A radiographic source changer consisting of a welded 10-gauge stainless steel box, approximately 5" wide x 6" high x 11" long. The source changer has a positive closure hinged flat plate cover and a depleted uranium shield. Two titanium tubes are positioned in the center of the depleted uranium and house the source capsules and the source cable assemblies. The two openings are closed by locking assemblies and threaded caps. The gross weight is approximately 65 pounds.

(3) Drawings

The packaging is constructed in accordance with Tech/Ops, Inc. Drawing Nos. AI500SU90, Sheets 1 through 7 of 7, Rev. B; AI500SU91, Sheets 1 and 2 of 2; AI500SU92; and optional Drawing No. AI500SU93, Rev. A.

(b) Contents

(1) Type and form of material

Iridium 192 as a sealed source which meets the requirements of special form radioactive material.

(2) Maximum quantity of material per package

120 curies

256

1007 on

Page 2 - Certificate No. 9006 - Revision No. 9 - Docket No. 71-9006

6. The source shall be positioned within the titanium tubing by a source cable assembly which meets the parameters shown in Tech/Ops, Inc. Drawing Nos. 42402-1, Rev. F, and 42402-4, Rev. B.

7. The name plate shall be fabricated of materials capable of resisting the fire test of 10 CFR Part 71 and maintaining its legibility.

8. The package authorized by this certificate is hereby approved for use under the general license provisions of 10 CFR §71.12.

9. Expiration date: May 31, 1990.

REFERENCES

Tech/Ops, Inc. application dated March 31, 1986.

FOR THE U.S. NUCLEAR REGULATORY COMMISSION

Charles E. MacDonald

Charles E. MacDonald, Chief
Transportation Certification Branch
Division of Fuel Cycle and
Material Safety, NMSS

Date: JUL 0 3 1986

257

10C6300

APPENDIX E

Safety Evaluation Report for the Model 500-SU
as a Radiographic Source Changer

REGISTRY OF RADIOACTIVE SEALED SOURCES AND DEVICES
SAFETY EVALUATION OF DEVICE
(AMENDED COPY)

DEVICE TYPE: Radiographic Source Changer

LABELING:

Attached to the exterior housing of the Model 500-SU source changer is a stainless steel labeling plate (10 gauge) which has markings etched 0.010 inch deep. These markings conform to the requirements of 10 CFR 20.203, 71 and 34 with Department of Transportation Title 49.

Further, each changer is accompanied by a set of user instructions and a source certificate with decay data, leak test certificate, and return shipping labels.

DIAGRAM:

See Attachment 1.

CONDITIONS OF NORMAL USE:

The Model 500-SU source changer is used primarily for the transfer of encapsulated radioactive sources to radiographic exposure devices. The source changer is designated to contain the radioactive sources during transfer and to prevent the field exchange of source.

PROTOTYPE TESTING:

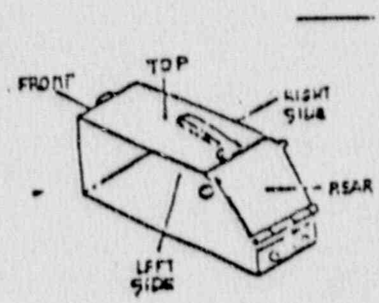
The Model 500-SU source changer was deemed acceptable for licensing purposes by the NRC on October 31, 1975. Tech/Ops performs a shielding comparative test and dimensional test on source assemblies to be used in the device to demonstrate that they will be compatible with the source changer.

DEVICE TYPE: Radiographic Source Changer

EXTERNAL RADIATION LEVELS:

A radiation profile performed by the manufacturer with a 34 curie source in the storage position showed a maximum radiation reading of 15 mR/hr at the surface of the device. Additionally, the manufacturer reported the following dose rates. These values are acceptable pursuant to 10 CFR Part 20 and 34.21.

MODEL 500 SU SOURCE CHANG
SERIAL NUMBER 529



ACTIVITY OF 50.5 CURIES OF IRIDIUM 192
MAXIMUM RADIATION INTENSITY (mR/hr)

	At Surface	At One Meter From Surface	At Surface	At One Meter From Surface
TOP	26	≤1.0	28	≤1.0
FRONT SIDE	34	≤1.0	34	≤1.0
RIGHT SIDE	38	≤1.0	26	≤1.0
REAR SIDE	22	≤1.0	26	≤1.0
LEFT SIDE	32	≤1.0	50	≤1.0
BOTTOM	52	≤1.0	42	≤1.0

REGISTRY OF RADIOACTIVE SEALED SOURCES AND DEVICES
SAFETY EVALUATION OF DEVICE
(AMENDED COPY)

NO: NR-628-D-171-S DATE: MAR 24 1986 PAGE: 5 of 6

DEVICE TYPE: Radiographic Source Changer

QUALITY ASSURANCE AND CONTROL:

Tech/Ops quality assurance and control program already has been deemed acceptable for licensing purposes.

LIMITATIONS AND/OR CONDITIONS OF USE:

- The device shall be distributed only to persons specifically licensed by the NRC or an Agreement State.
- The device/source shall be leak tested at six (6) month intervals using techniques capable of detecting 0.005 microcurie of removable contamination.
- Handling, storage, use, transfer, and disposal: To be determined by the licensing authority. In view that these sealed sources exhibit high surface dose rates when unshielded, these sealed sources should be handled only by experienced licensed personnel using adequate remote handling equipment and procedures.
- This registration sheet and the information contained within the references shall not be changed without the written consent of the NRC.
- Reviewer Note: This device was manufactured and distributed by Automation Industries (AI). Tech/Ops purchased the rights to all AI equipment and is now manufacturing and servicing the equipment. AI is no longer in business.

REGISTRY OF RADIOACTIVE SEALED SOURCES AND DEVICES
SAFETY EVALUATION OF DEVICE
(AMENDED COPY)

DEVICE TYPE: Radiographic Source Changer

SAFETY ANALYSIS SUMMARY:

Based on our review of the information and test data cited below, we continue to conclude that the Model 500-SU source changer design is acceptable for licensing purposes. Furthermore, we conclude that the device would be expected to maintain its containment integrity for normal conditions of use and accidental conditions which might occur during uses specified in this certificate.

REFERENCES:

The following supporting documents for the 500-SU source changer are hereby incorporated by reference and are made a part of this registry document:

- Supersedes registration sheet NR-628-D-171-S dated October 17,1984.
- Tech/Ops letters of amendment dated June 11, 1984 and August 12, 1985 with enclosures thereto.

ISSUING AGENCY:

U. S. Nuclear Regulatory Commission

DATE: MAR 24 [illegible] REVIEWER: Steve Baggett

DATE: MAR 24 [illegible] CONCURRENCE: Francis R. Hillman

REGISTRY OF RADIOACTIVE SEALED SOURCES AND DEVICES
SAFETY EVALUATION OF DEVICE
(AMENDED COPY)

No: NR-628-D-171-S DATE: MAR 24 1986

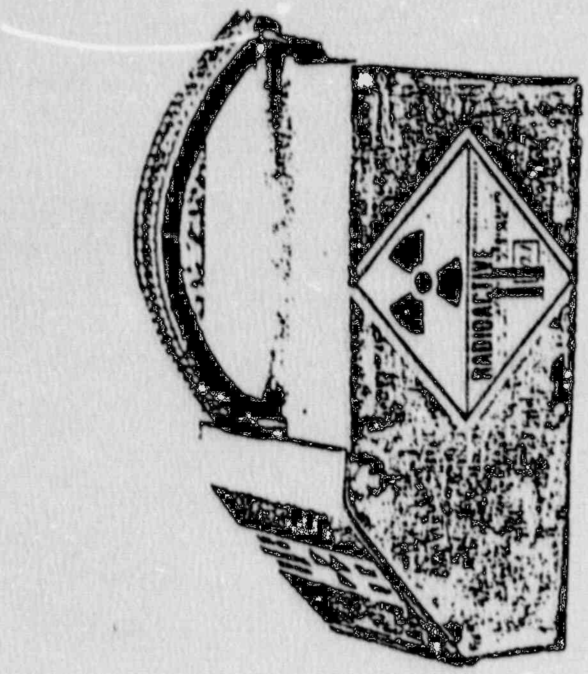
Table 1

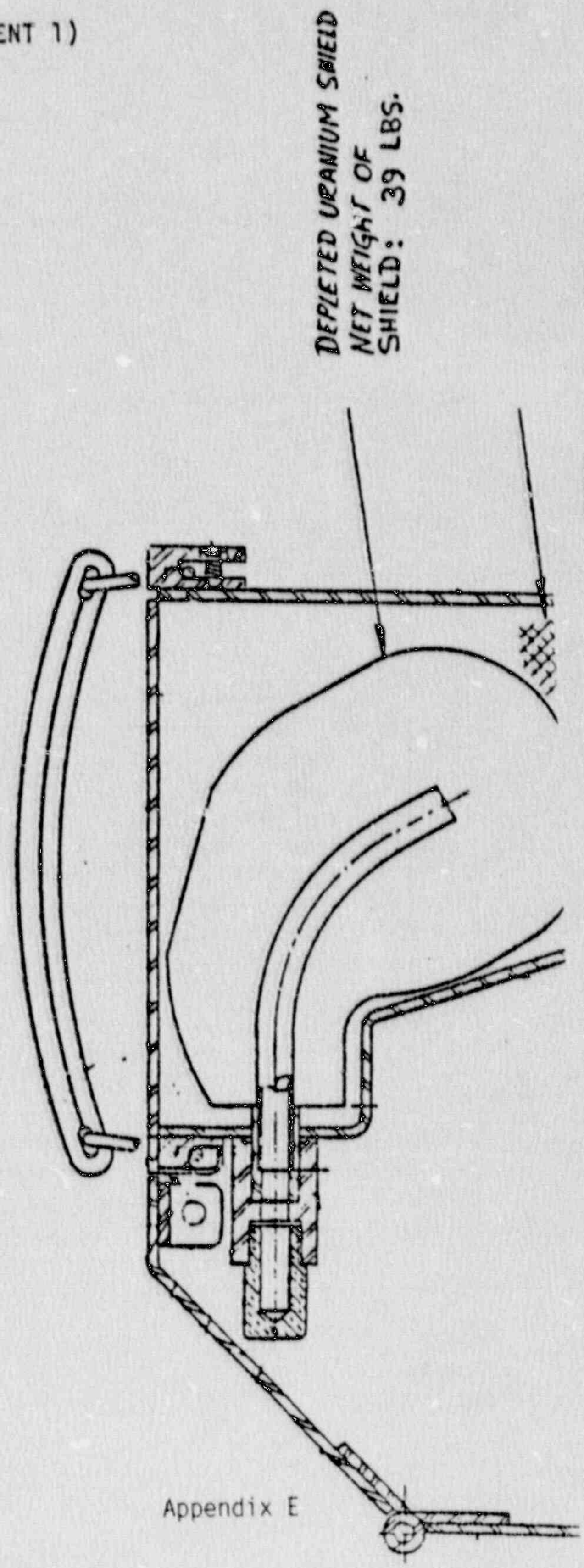
Source Assemblies and Radiographic Exposure Devices Compatible for Use with the Model 500 SU Source Changer

Source Assembly Model No.	Radiographic Exposure Device Model No.
A424-1	402,404, 412 489, 490, 491, 496 498, 498A, 524 525, 532, 533, 699
A424-9	402, 660, 713, 796
814	520
848	Gamma Industries Century Spec 2-T Gulf Nuclear 20V
866	520
39990; A10 130013; A11	100A series, 10A, 20A 30BA, 40 BA
41706; B2 41706; B3	50B series, 51B, 52B 53B, 110AB
41708; C2 41708; C3	60C series,61C 62C, 63C
41309; H1	151H, 152H, 153H
41045; J1	161J, 162J, 163J
200-520-004; N2 200-520-010; N3 200-520-008; N4 200-520-011; N5	520
36910; T1 36910; T2	490, 498, 533
200-660-09; T3	660, 664
36910; T5	533, 490, 498
200-660-009; T6	660, 664
39998; G1 39998; G2	Gamma Century "35" Gulf Nuclear V20
39998; G3	Gamma Century - SA
39998; G5	Gamma Century-"35" Gulf Nuclear V20
39998; G6	Gamma Century - SA
39998; SR	Sinco Ray Du-100P
500120;CR	Cumberland Res CRC-120

NO.: NR-628-D-171-S DATE: MAR 24 1986

(ATTACHMENT 1)





REGISTRY OF RADIOACTIVE SEALED SOURCES AND DEVICES
SAFETY EVALUATION OF DEVICE
(AMENDED COPY)

NO: NR-628-D-171-S DATE: MAR 24 1986 PAGE: 1 of 6

DEVICE TYPE: Radiographic Source Changer

MODEL: 500-SU

MANUFACTURER/DISTRIBUTOR: Tech/Ops, Inc.
Radiation Products Division
40 North Avenue
Burlington, MA 01803

SEALED SOURCE MODEL DESIGNATION: Various (See Table 1 for delineation)

ISOTOPE:	MAXIMUM ACTIVITY:
Iridium-192	120 curies
Depleted Uranium (As shielding)	39 pounds (18 kilograms)

LEAK TEST FREQUENCY: 6 months

PRINCIPAL USE: (A) Industrial Radiography

CUSTOM DEVICE: ____YES ___X__NO

DEVICE TYPE: Radiographic Source Changer

DESCRIPTION:

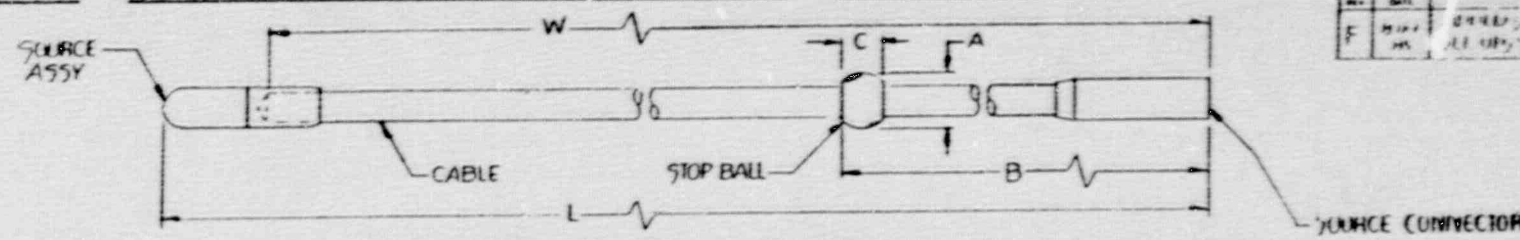
The Model 500-SU radiographic source changer consists of a welded stainless steel (10-gauge) rectangular box, approximately 5 inches wide and 6 inches high by 11 inches long and containing a depleted uranium shield encased in a welded compartment. The void space between the outer box and the 39 pound uranium shield is filled with high temperature solid epoxy. A hinged cover which is normally locked (key actuated) in place permits access to the internal compartment and two titanium tubes of 3/8 inch ± 1/64 inch inside diameter will accept pig assemblies (source capsule, locating ball and cable) of between 6-¼ to 7-7/16 inches long. In practice, one source tube is loaded and one is emptied to receive spent source. The various pig tails were accommodated by varying the bored depth of the 9/32 inch diameter recess in the lock box threaded seal caps up to 1-¼ inches in depth. This is to assure that all source assemblies will always be secured firmly into the dead-ended titanium shield tube. To prevent tampering a lead seal is provided through each titanium tube cap (one round, one hex head). The source changer has a gross weight of approximately 60 Lbs.

Effective with the issuance of this certificate and the transportation package certificate the 500-SU source changer hold down arrangement will be phased out with a modified key lock hold down mechanism. The source assembly is held in the shielded storage position by a "lockslide". The lockslide creates an interference with the stop ball, preventing its movement out of the shielded position. The lockslide is held in position by a latch pin and by a key operated lock. The lockslide cannot be moved from the lock position until both the key operated lock is unlocked and the latch pin is depressed by the insertion of a source guide tube into the lock body. With both interferences removed, the lockslide may be moved to the open position, allowing transfer of the source assembly. The addition of a second locking ball is necessary on some sources to correctly position and lock the source in the changer. The lockslide is only intended to keep the radiographer from complete removal of the source and maintain as much shielding of the source as possible. The continued use of the tube and caps will grantee that the source is held in the most shielded position. The end caps are given alpha character designation after the device model number. For example 500-SU(N), (B&N), (G) etc., side or back shielding plates may be welded on the device. This is necessary to allow all devices to be loaded with a 120 curie source. The addition of these shielding plates is necessitated by the lack of uniformity in the shielding.

The Model 500-SU source changer is suitable for changing the source assemblies into the devices as identified in Table 1. Identity of the source in a device is maintained using the source plate which is secured to the end of the lead seal wire.

APPENDIX F

Authorized Sources for Transport in the
Model 500-SU Source Changer

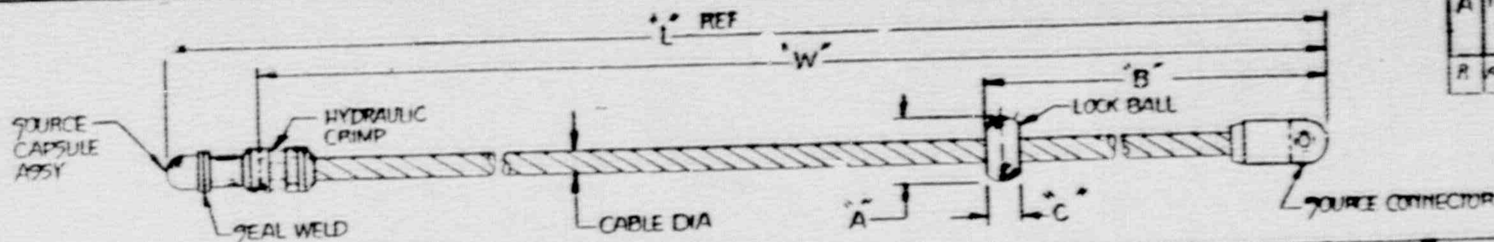


LOCATION COORDINATES	SOURCE ASSY MODEL NO.	RADIONUCLIDE	CAPACITY (CURIES)	SOURCE HOLDER DWG NO.	SOURCE CAPSULE ASSEMBLY	CABLE TYPE	SOURCE CONNECTOR DWG NO.	DIM. "L"	DIM. "W"	DIM. "B"	DIM. "C"	DIA "A"	DRIVE CABLE CONNECTOR DWG	EXPOSURE DEVICE USED IN	SOURCE CHANGER	REMARKS
1	A424-1	IR-192	240	A42401-1	60001 60004 OR 875	.187 D TELEFLEX	B55000-900	7.40	6.89	2.373	0.25	0.31	A55000-A	402 404 412 489 490 491 496 498 498A 534 Φ 539 532-Φ 533 Φ 699	414 820 650 855 500-SU(T)	Φ = USES DRIVE CABLE CONNECTOR B55000-2
2	A424-6	IR-192	120	A42406-1	60001 60004 OR 875	.187 D TELEFLEX	B55000-900	10.69	10.08	N.A.	N.A.	N.A.	A55000-A	511	414 650	
3	A424-9	IR-192	240	A42409-1	60001 60004 OR 875	.187 D TELEFLEX	B55000-900	7.19	6.58	1.225 2.06	0.25	0.31	A55000-A	402 660 713 796	414 820 650 855 500-SU(N)	2ND BALL ADDED (2.06)
4	A424-20	IR-192	240	A42420-1	60001 60004 OR 875	.187 D TELEFLEX	B55000-900	9.38	8.77	1.225	0.25	0.31	A55000-A	684	750 820 855	
5	68309	IR-192	120	B68309	68310	.187 D TELEFLEX	N.A.	AS SPECIFIED TO SUIT DEVICE		N.A.	N.A.	N.A.	N.A.	689	750 820	
6	814	IR-192	120	A81401	60001 60004 OR 875	.187 D TELEFLEX	B55000-900	6.94	6.33	1.625	0.25	0.31	A55000-A	A.I. 920	414 820 650 855 500-SU(N)	
7	848	IR-192	120	A84802	60020 60021 OR 875	.150 D FLEXIBLE SHAFTING	A86101	7.62	6.97	2.56	0.27	0.31	B86101-5	GI CENTURY SPEC 2T GN 20V	414, 500-SU(G) 650	
8	866	IR-192	120	A86602	60020 60021 OR 875	.150 D FLEXIBLE SHAFTING	A86101	6.72	6.06	1.44	0.27	0.31	B86101-5	A.I. 920	414, 500-SU(P) 650	

NOTE:
1. LETTER DESIGNATION WITH MODEL 500-SU SOURCE CHANGER [I.E. 500-SU(N)] INDICATES HOLDOWN CAP TO BE USED. SEE DRAWINGS SK2334-1 & SK2334-2 FOR DETAILS

SOURCE TABLE
42402-1
F

1-15



LOCATION COORDINATES	A SOURCE ASSEMBLY MODEL NO	B RADIONUCLIDE	C CAPACITY (CURIES)	D SOURCE HOLDER DWG NO	E SOURCE CAPSULE ASSY	F CABLE TYPE	G SOURCE CONNECTOR TYPE	H DIM "L"	J DIM "W"	K DIM "B"	L DIM "C"	M DIA "A"	N DRIVE CABLE CONNECTOR DWG NO	P EXPOSURE DEVICE USED IN	Q SOURCE CHANGER	R REMARKS
1	A.I. 39990; A10	IR-192	120	BSK2332-27	W8 OR W10	3/32 D 7x7	GAMMA UNSLOTTED	7.14	6.62	2.54	.264	.285	ASK2332-12	MODEL 100A SERIES 10A, 20A 30BA, 40BA	500-SU (N) 041026 OR 043859	
2	A.I. 130013; A11	IR-192	120	BSK2332-9	W8 OR W10	3/32 D 7x7	AUTOMATION SCREW	7.08	6.56	2.51	.264	.285	ASK2332-4			
3	A.I. 41706; B2	IR-192	120	BSK2332-14	W8 OR W10	3/32 D 7x7	AUTOMATION SCREW	12.21	11.69	2.26	.264	.285	ASK2332-4	MODEL 50B SERIES 51B, 52B, 53B 110 AB	041024 OR 043861 OR 500-SU(B+H)	
4	A.I 41706; B3	IR-192	120	BSK2332-28	W8 OR W10	3/32 D 7x7	GAMMA UNSLOTTED	12.33	11.81	2.26 7.15	.264	.285	ASK2332-12			2ND BALL ADDED (7.15)
5	A.I.41708; C2	IR-192	120	BSK2332-18	W8 OR W10	3/32 D 7x7	AUTOMATION SCREW	14.83	14.31	2.26	.264	.285	ASK2332-4	MODEL 60C SERIES 61C, 62C, 63C	041027 OR 043862 OR 500-SU(C+H)	
6	A.I.41702; C3	IR-192	120	BSK2332-29	W8 OR W10	3/32 D 7x7	GAMMA UNSLOTTED	14.96	14.44	2.32 9.77	.264	.285	ASK2332-12			2ND BALL ADDED (9.77)
7	A.I.41039; H1	IR-192	120	BSK2332-19	W8 OR W10	3/32 D 7x7	AUTOMATION SCREW	16.14	15.62	2.13 10.95	.264	.285	ASK2332-4	MODEL 151H, 152H, 153H	500-SU(H+N) OR 043864	2ND BALL ADDED (10.95)
8	A.I.41045; J1	IR-192	120	BSK2332-20	W8 OR W10	3/32 D 7x7	AUTOMATION SCREW	13.39	12.87	2.26 8.20	.264	.285	ASK2332-4	MODEL 161J, 162J, 163J	500-SU(J+N) OR 043863	2ND BALL ADDED (8.20)
9	A.I.200-520-009; N2	IR-192	120	BSK2332-37	W8 OR W10	1/8 D 7x7	A.I. TECH/OPS	7.13	6.61	1.78	.226	.290	ASK2332-5	MODEL 520	500-SU(N) OR 043868	
10	A.I.200-520-010; N3	IR-192	120	BSK2332-23	W8 OR W10	1/8 D 7x7	GAMMA SLOTTED	7.02	6.50	1.74	.226	.290	ASK2332-13			
11	A.I.200-520-008; N4	IR-192	120	BSK2332-31	W8 OR W10	1/8 D 7x7	AUTOMATION SCREW	6.96	6.44	1.61	.226	.290	ASK2332-4			
12	A.I.200-520-011; N5	IR-192	120	BSK2332-38	W8 OR W10	1/8 D 7x7	A.I. "SNAP-PIN"	6.98	6.46	1.64	.226	.290	ASK2332-51			
13	A.I. 36910; T1	IR-192	120	BSK2332-36	W8 OR W10	1/8 D 7x7	A.I. TECH/OPS	7.57	7.05	2.32	.226	.312	ASK2332-5	TECH/OPS MOD. 490, 498, 533	500-SU(T) OR 043866	
14	A.I. 36910; T2	IR-192	120	BSK2332-24	W8 OR W10	1/8 D 7x7	GAMMA SLOTTED	7.46	6.94	2.26	.226	.312	ASK2332-13			
15	A.I.39998; G1	IR-192	120	BSK2332-30	W8 OR W10	1/8 D 7x7	GAMMA UNSLOTTED	7.08	6.56	1.96	.226	.290	ASK2332-12	GAMMA CENTURY "S"	500-SU (N) OR 043867	
16	A.I.39998; G2	IR-192	120	BSK2332-25	W8 OR W10	1/8 D 7x7	GAMMA SLOTTED	7.08	6.96	1.96	.226	.290	ASK2332-13	GULF NUCLEAR V20		
17	A.I.39998; G3	IR-192	120	BSK2332-26	W8 OR W10	1/8 D 7x7	GAMMA SLOTTED	7.96	7.44	2.80	.226	.290	ASK2332-13	GAMMA CENTURY-SA	500-SU (G) OR 043867	

NOTES:

1. LETTER DESIGNATION WITH MODEL 500-SU SOURCE CHANGER [i.e. 500-SU(N)] INDICATES HOLDOWN CAP TO BE USED. SEE DRAWINGS SK2334-1 & SK2334-2 FOR DETAILS

Tech/Ops RADIATION PRODUCTS DIVISION

SOURCE TABLE (AUTOMATION INDUSTRIES)

C 42402-4

1-16

APPENDIX G

Regulations Applicable to Transportation of Radiographic Sources

1 U.S. Nuclear Regulatory Commission Regulations

The NRC regulations for transportation of radioactive materials are codified in Title 10, Code of Federal Regulations, Part 71 (10 CFR Part 71). These requirements provide the technical standards for the review and approval of packages to be used to transport quantities of radioactive material qualifying for Type B packages. A provision in 10 CFR 71.5(a), however, effectively requires that all licensees (who transport or who deliver to a carrier for transport), follow DOT's 49 CFR hazardous materials regulations (HMR) in Title 49 with respect to classification, packaging, marking, labeling, shipping papers, incident reporting, carriage, placarding, and so forth, even for quantities not requiring a Type B packaging. As a result of this regulation, NRC inspectors routinely inspect NRC licensees for compliance with both DOT (Title 49) and NRC (10 CFR Part 71) requirements. The general license provisions of 10 CFR 71.12 require licensees to use NRC-certified packages in accordance with the conditions specified in the NRC certificate (see Sec. 7 of this report). In addition, 10 CFR 71.87 requires that the licensee determine that the contents of the package are proper for the package being used. (This requirement is also found in DOT regulations, 49 CFR 173.475(a)). For shippers and carriers in intrastate commerce not subject to DOT jurisdiction, most States adopt and enforce 49 CFR HMR. In NRC Agreement States, 10 CFR Part 71 has been adopted.

The NRC regulations in 10 CFR 110.23(a) provide a general license to any person to export almost all forms of byproduct material, except to certain countries. Similarly, 10 CFR 110.27(a)(3), authorizes any person to import byproduct material if the consignee is authorized to possess the material under a general or specific license that has been issued by the NRC and an Agreement State.

Under 10 CFR 20.205, licensees receiving a Type B quantity of material are required to monitor packages for radiation levels and contamination. Licensees are required to report to the NRC excessive surface contamination or external radiation exceeding regulatory limits. This regulation is unclear as to whether these reports are required in those instances where a survey was performed, but was not required, that is, when it was performed on a Type A or an excepted package and exceeded the limits. Because this shipment did not involve a Type B quantity, monitoring was not explicitly required.

2 U.S. Department of Transportation

U.S. Department of Transportation (DOT) is responsible, under the authority provided to it in the Hazardous Materials Transportation Act (HMTA) and earlier legislation to regulate the safe transportation of hazardous materials in interstate and foreign commerce.* The DOT Hazardous Materials Regulations

* U.S. Congress, "Transportation Safety Act of 1974," 93rd Congress, H.R. 15223, Pub.L. 96-633, 49 USC 1801, January 3, 1975.

(HMR) are codified in Title 49, Code of Federal Regulations, Parts 100-178 (49 CFR 100-178). Essentially, Title 49 prescribes requirements for the appropriate classification, packaging, marking, and labeling of packages and for certifying and communicating information to carriers about the shipment of hazardous materials. Title 49 also prescribes DOT requirements for carriage by rail, air, water, and highway, Parts 174, 175, 176, and 177, respectively.

2.1 Package Types Required for Radioactive Materials

The three types of required packaging for radioactive materials, are --

1. "excepted packages," for which there are essentially no prescriptive requirements;

2. Type A packaging, which is designed to safely retain its contents during normal conditions of transport; and

3. Type B packaging, which is expected to safely retain its contents during both normal and severe accident conditions.

The regulatory criteria for Type A and Type B packaging are based on design and testing or evaluation of the package against performance standards, rather than on prescriptive hardware specifications. However, whereas most Type A packages are essentially "self-approved" by the user and acceptable unilaterally around the world, Type B package designs must be approved by a regulatory authority (such as the U.S. Nuclear Regulatory Commission), and, for some international shipments, the competent authorities of the countries involved in the shipment. The competent authority for the United States is the DOT.

2.2 Type A or B Package With a Source

For a transport package containing an iridium-192 (Ir-192) source exceeding 20 curies (Ci), DOT regulations require that a Type B package be used, usually in the form of an NRC-certified package (for a discussion of packaging for sources, see Sec. 7 of this report). When a source changer contains Ir-192 sources of less than 20 Ci of activity, the regulations authorize use of a Type A package. Because the Ir-192 source in this incident was less than 20 Ci, the regulations authorized a Type A package. DOT regulations 49 CFR 173.415(c)) permit the use of any NRC-certified Type B packaging, such as the Model 500-SU source changer, for use as a Type A package. However, DOT regulations are silent on the specific conditions under which Type B packaging may be used for a Type A shipment. DOT regulations are also ambiguous as to whether the Type A package would have to meet the terms and conditions of the NRC certificate or would need only to comply with the DOT's standard requirement for all packages (49 CFR 173.24).

2.3 Excepted packages

An "excepted" package, although still subject to regulation, is essentially excepted from most of the requirements, such as marking, labeling, specified packaging, and shipping papers. Two such "excepted" categories are "Radioactive material, empty package" and "Radioactive material, article manufactured from depleted uranium." Certain conditions must be met in order for either "excepted": category to apply, including --

1. The maximum surface radiation must not exceed 0.5 millirem per hour.

2. The shipment must be "certified as being acceptable for transportation by having a notice enclosed in or on the package, included with the packing list, or otherwise shipped with the package" (49 CFR 173.421-1(a)).

2.4 Survey Requirements

The transportation regulations do not require carriers to monitor or survey packages or shipments for radiation or contamination during shipment. DOT requires that shippers, before each shipment, "ensure by examination or appropriate test, that ...external radiation and contamination are within the allowable limits...," Title 49, Code of Federal Regulations, Parts 173.475(a)(9). In the Korean shipment of source changers, the organization most directly responsible for ensuring that no sources were present in the Model 500-SU source changer before it was shipped, as well as for surveying it to determine that radiation levels were within acceptable limits, was the shipper, NDI Corporation (NDI). KIT was responsible for ensuring that the source changer was empty when it was presented to NDI even though NDI rather than KIT was the shipper.

2.5 Communication Requirements

In addition to the packaging requirements, an extensive system of communications requirements are embodied in the DOT regulations. They are intended to ensure that the appropriate information about the hazards of the material in the shipment are available to carriers that handle the shipment, to civil authorities, and to the general public in the event of an emergency involving the package. This information includes marking and labeling the package and preparing and certifying shipping documentation. Communications requirements are minimal for excepted radioactive material packages.

2.6 Carrier Requirements

The requirements imposed on carriers are generally not extensive, but do include the following:

1. blocking and bracing packages within a vehicle;

2. controlling stowage to separate packages with high radiation levels from people;

3. ensuring possession of and easy access to the shipping documents for hazardous materials within a vehicle; and,

4. placarding certain shipments with radioactive materials placards.

2.7 The Role of Agents, Brokers, and Freight Forwarders

The transportation of goods in commerce frequently involves middlemen, such as freight forwarders, brokers, and warehousemen. Such middlemen are frequently involved in the domestic transportation of hazardous materials, and are always involved in international shipments. They act as agents for shippers or receivers, serving to expedite the movement of shipments, arrange for carriers, expedite paperwork, and in some cases prepare packaging, expedite customs clearances, etc. A number of these middlemen were involved in the Korean shipment: Daeil Shipping Company, Fidelity Transportation, Inc., and International Specialists, Inc.

Accordingly, it is often difficult to identify the actual shipper for purposes of determining noncompliance with the DOT HMR, particularly with respect to international shipments. DOT hazardous materials regulations in Title 49 do not define "shipper." The term "any person who offers" is used throughout Title 49 when a shipper's responsibilities are listed. The DOT holds the position that more than one party can and often does perform the functions of a shipper (see Sec. 8, Ref. 3). In investigating violations, DOT often finds that more than one party is culpable for noncompliance with the HMR, but DOT also holds that there are varying degrees of culpability.

In this shipment, NDI acted as the entity making the shipment from Seoul to Boston and was, therefore, responsibile for ensuring that the material being offered was properly identified, classified, packaged, marked, and labeled. NDI was also responsible for preparing the required certification and shipping documentation. Daeil acted as carrier and shipping agent representing NDI, responsible to NDI for the proper packaging, transportation, and delivery of the material.

While culpability may be shared in some cases, in this instance, the burden of ensuring that the source changers were appropriately identified and controlled as radioactive material rested principally with NDI.

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11. ABSTRACT (200 words or less)

Amersham Corporation, Burlington, Massachusetts, a licensee of the U.S. Nuclear Regulatory Commission (NRC), authorized to manufacture and distribute iridium-192 and cobalt-60 source assemblies for use in radiography equipment, received a shipment of 14 source changers on March 8, 1990, that were being returned from their product distributor, NDI Corporation in Seoul, Korea. One source changer contained a small sealed source in an unshielded location. Amersham employees retrieved the source, secured it in a hot cell, and notified NRC's Region I. Subsequently, NRC dispatched an Incident Investigation Team to perform a comprehensive review of this incident and determine the potential for exposure to those who handled the source changer and to members of the general public. This report describes the incident and the methodology used in the investigation and presents the Team's findings and conclusions.

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

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