RESPONSE AND CLEANUP OF UNINTENTIONAL DISPERSAL OF AN IRIDIUM-192 RADIOGRAPHY SOURCE

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ABSTRACT

This paper presents technical, regulatory and logistical challenges encountered during the emergency response to an accidentally dispersed radiography source at a large oil refinery. Selected approaches to each challenge and unanticipated observations are also shared.

During radiographic operations inside a 5 m (17 ft) diameter by 21 m (70 ft) long steel tank, an iridium-192 (^{192}Ir) source came into contact with an energized welding head and was subsequently dispersed into countless discrete particles. Initial survey readings were reported outside the tank, and subsequently confirmed, to be in excess of 10 Sv/hr (1000 rem/hr). Complicating the event was the fact that the radiographer was inside the tank during the accident and the unshielded source was within a few feet of the only egress point. In addition to the radiation exposure challenges in the immediate area of the tank, the response team had to address offsite contamination. The accident occurred at a facility employing thousands of workers untrained in radiological hazards. Radioactive contamination and dose rates were in a condition very similar to what would be expected with a radiography source that used in a Radiological Dispersal Device (RDD). The lessons learned during the response to this event may provide a basis for similar future emergency responses to intentional or unintentional dispersal of radioactive sources in areas with untrained occupational personnel or the public.

INTRODUCTION

During radiographic operations, the radiographer inside the tank reported seeing a flash of light in the vicinity of the radiography camera. It is speculated that the radiography drive mechanism and source holder came into contact with an energized welding system and was exposed to a high voltage arc.

The rapid heating and expansion of the source capsule resulted in a breach of the source jackets and an explosive distribution of the capsule contents. The source had been encapsulated in a dual layer jacket of stainless steel, .002 and .003 inches in thickness. The source material had been configured in a wafer like matrix that was fragile and easily disintegrated. The large steel tank provided a physical barrier and effectively contained a large portion of the dispersed source material. The portion of the source that was not contained was later tracked to a distance of several hundred meters from the tank. If the accident had occurred outside the confines of the tank, the dispersal of the material could have been even more widespread. The presence of discrete particles was not immediately recognized, as they were masked by elevated radiation levels in the general area. The particles were generally not visible and could only be located by radiation detection equipment. Even at the significant activity levels, extreme care and deliberate survey techniques were necessary to detect individual particles.

Initial Personnel Extraction

After the metal source jackets were breached, the majority of the source became disconnected from the drive tube and could not be retracted into the radiography camera. The radiographer who was inside the tank during the source breach was at a distance of approximately 50 ft (15 m) from the source. After several attempts at retracting the source he noticed the radiation levels remained higher than expected. His initial belief was that the source had simply become disconnected. That an actual breach of the source jackets had occurred was not discovered for several hours.

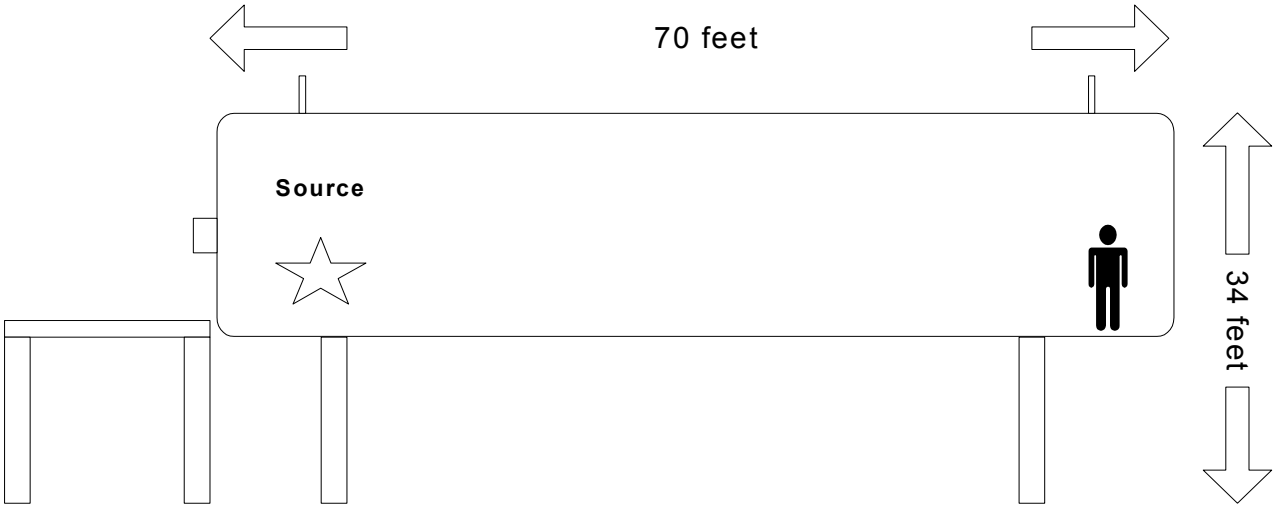

Fig. 1 Relation of radiographer, source and tank F5.

Efforts to assist by the radiographer from outside the tank were hampered due to radiation levels outside the tank greater than 10 Sv/hr (1000 rem/hr). The radiographer inside the tank was able to maintain communications via radio until the battery was drained after about two hours. The radiographer inside the tank was wearing a self-reading dosimeter and was accumulating dose at a rate of approximately 1mSv/hr (100 mrem/hr). His combined internal and external dose was subsequently estimated to be approximately 30 mSv (3 rem).

A fortunate factor during this event was the onsite presence of a senior Health and Safety Manager with extensive nuclear power plant experience. He was able to quickly assess and respond to this highly unusual situation for an oil refinery. This unique skill set would not likely be available in a public environment with a similar accident. Upon notification of the event he directed the prompt recovery of the individual from the tank. His observation of radiation fields around the tank initiated the suspicion of the possibility of a source breach. After the radiographer exited the tank, existing emergency procedures and training were followed and the radiographer was surveyed prior to release from the site. At this point it was confirmed that the source had been breached.

Early Source Recovery Activities

Initial efforts at retrieving the source were focused on the standard recovery of a disconnected source. Knowledge of the magnitude and degree of the source capsule failure and resulting contamination increased over the next two days. This delay was due to conditions created by the elevated radiation levels and their interference with the detection of discrete particles around the tank opening. After 2 days of retrieval efforts with remote grippers and tongs, efforts were suspended. As the understanding of the problem improved, additional help was secured and a larger source recovery team with additional physical and personnel resources was brought to the site.

Upon arrival of the source recovery team, multiple recovery tasks were put into place immediately. Immediate tasks included:

- Establishing an incident command organization
- Issuance of a formal stop work order
- Definition and agreement on short term and long-term priorities
- Identification and assignment of available resources both onsite and offsite
- Determination of cause of source dispersal
- Sharing the information on the incident with the two other radiography firms onsite
- Physical stabilization of the site from imminent severe weather
- Estimation of offsite doses
- Communication with and training of hundreds of non-radiation workers
- Definition of alternatives to cope with offsite contamination
- Implementation of new license requirements
- Standardization of radiological survey techniques by multiple teams
- Recovery and isolation of the dispersed source
- Consolidation of unorganized survey data and information obtained in the initial days
- Decontamination of the tank
- Controlling radioactive contamination in the outside environment

The distraction of negotiating potential financial liability concerns and establishing contract terms for emergency work was necessary, but naturally took a second priority to the technical effort. Pre existing emergency response contracts would have eliminated this distraction.

Source Term and Iridium-192 Characteristics

Attempts were made to account for the original activity in the camera. During this process it was learned that the quantity of radioactive material on the license and source certificates referred to "effective" curies not "physical" curies. Since iridium is a very dense material at 22.4 g/cm ^{3}, sources are prepared with extra activity to account for self-absorption within the source capsule. This extra factor varies with specific nuclides. In the case of ^{192}Ir it is estimated to be a factor of around 1.8. In this situation, the 35 Curie (1.3 TBq) source became approximately 63 Curies (2.3 TBq) when it was dispersed.

^{192}Ir decays with a 74-day half life and has abundant beta and gamma emissions. Figure 2 (from ICRP 30) shows the decay scheme for ^{192m}Ir metastable (m2). There is another metastable state (m1) of much shorter half life (less than 2 minutes). Of significance is the longer half life of the metastable state (241 years), which reduces the benefit of time and decay of the shorter lived ^{192}Ir. The ratio of metastable ^{192m}Ir to ^{192}Ir was not determined. Based upon discussions with the source manufacturer, it is estimated ^{192m}Ir to be a single digit percent at time of production.

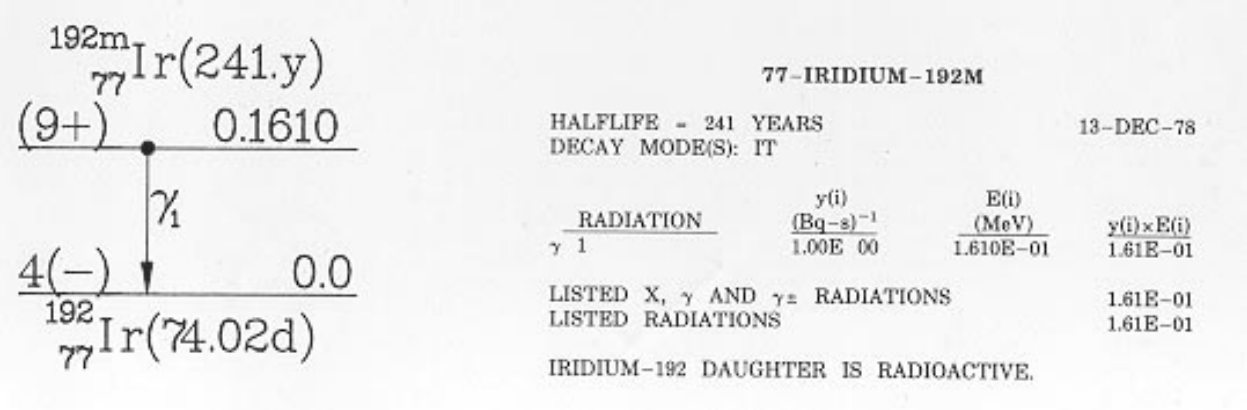

Fig. 2 Decay scheme of ^{192m}Ir from ICRP 30.

Detection and Measurement

Detection with beta-sensitive instruments and quantification by gamma spectroscopy was easily accomplished, but correlation of data required some review. Initial review showed that a wide range of direct survey results was being recorded in the same area by different survey teams. An investigation into these results revealed that differences were caused by variances in instrument response. Due to the numerous energetic beta emissions and gamma rays, a specific calibration factor was necessary for ^{192}Ir. Like this ^{192}Ir source, common radiography sources tend to be single nuclides (e.g., ^{60}Co or ^{137}Cs). Beyond the technical importance of this observation for characterization purposes, an incident command organization in a similar situation could be confused or develop lack confidence in survey teams when presented with conflicting survey data without explanation of variability in instrument response.

During discussions with the source manufacturer, it was learned that on rare occasions sources can have trace amounts of unintended contaminants such as ^{60}Co. When addressing

contamination from single nuclide sources, verification of source composition should be conducted to ensure that the expected nuclide is the only radionuclide present.

Particles were tenaciously adhered to surfaces at the site and were not effectively collected by standard smear techniques. At one point, over 2,000 disc smears were collected. All failed to indicate the presence of any discrete particles. Yet, contamination was observed in about half of the cases where protective clothing of the survey team was surveyed upon exiting the suspect area. Standard disc smears provided a convenient method that was somewhat reproducible between surveyors, but failed to replicate worker time and motion and the probability of subsequent personnel contamination events. The most effective means for locating discrete particles was direct survey after the ambient radiation levels were reduced, following the removal of the radiography camera and the bulk of the source from the area.

A comparison was conducted between the HPGe gamma spectroscopy system and the gas flow and scintillation gross counting systems. During this evaluation, it was determined that the gamma spectroscopy system had been calibrated for optimal efficiency of environmental samples with a typical planar or flat geometry as close as possible to the detector. Due to the high activity and small size of particles in the samples, the system was initially underreporting the actual activity by approximately 50%. The system was recalibrated with a source at a distance from the detector to minimize the geometrical effects of discrete sources. Once calibrated, the gamma spectroscopy system was used effectively to create several secondary ^{192}Ir standards to source check instruments.

An evaluation of the decay scheme indicated that 50 to 60 mg/cm^2 would be required to attenuate the energetic betas. This information was factored into protective clothing requirements. A fortunate condition at the site was the universal use of fire retardant clothing over personal clothing by all personnel onsite. This placed everyone in a double set of work clothes that provided protection against skin contamination and afforded additional attenuation of the beta particles, except for exposed skin.

Dispersion of Material Onsite

Dispersion of the material was caused by several transport mechanisms. The initial physical explosion of material caused dispersion of material into the tank shell. In the first few days, the exiting of the radiographer and retrieval of the camera from inside the tank provided a physical transport vehicle for material around the tank opening.

An air horn style ventilation exhaust system was operating on the tank during the period of the accident to help purge fumes generated from welding operations. This system was subsequently secured after the accident to reduce noise and improve efforts to communicate with the radiographer. Later, a calculation was made to estimate the airborne concentration in the tank during the event and to bound any possible downwind dose from the accident. The calculation was generated using in-vivo bioassay results, standard man breathing rates, retention functions from ICRP 30, tank air volume, duration of the post-accident ventilation period, actual meteorological conditions, and the air horn specification for nominal airflow rates. During the review of the manufacturer's quoted airflow rates, they seemed unrealistic. So, a field

measurement was conducted using the same plant air system and a new air horn. The observed flow rate was approximately half of what was expected. The observed value was used in subsequent airflow calculations. The results of the calculation suggested that the maximum dose was approximately 60 m (197 ft) downwind and was less than 10 μSv (1 mrem). One source of error in this calculation is the fact that the material was dispersed in the form of discrete particles and not as a uniform distributed aerosol. Future accident scenarios ought to consider this condition in their modeling.

Offsite Contamination Issues

During the initial hours following the accident, one individual transferred contamination to his vehicle and another individual had contamination detected on an arm of furniture at home. The levels were detectable but below USNRC Regulatory Guide 1.86 levels of 5,000 disintegrations per minute (83 Bq) per 100 cm ^{2} total and 1,000 disintegrations per minute (17 Bq) per 100 cm^2 removable. An important criterion to be established was at what level the team might reasonably stop pursuing potential offsite contamination. Other relevant regulatory guidance included the default parameters for license termination and the combined limit of 74,000 disintegrations per minute (1,233 Bq) per cm^2 (with less than 10% removable) for ^{192}Ir. Fortunately the offsite contamination was below both of these criteria. In other emergency situations, determination of practical release limits could present more of a challenge.

A related question associated with offsite contamination is whether to survey every location, which a potentially contaminated individual may have come into contact with. Hypothetically, an individual could have stopped at a gas station, school, market, airport, sports stadium, etc. before determining he or she was contaminated. Taking on the task of expanded offsite surveys may unnecessarily place strain on resources that could be more beneficial at the incident scene. In situations where contamination may be higher or beyond default values, decisions will have to be made quickly after considering the specific contaminant, decay scheme, toxicity characteristics, physical susceptibility to further dispersion, weather and allocation of response personnel and equipment resources.

Access Control and Non-Occupational Limits

Boundaries and access controls for the large affected area required special considerations. Initial conditions for posting of the radiography area were based on the maximum hourly limit of 2 mrem (20 μSv) in one hour as specified in 10CFR 20.1301. Since the source could not be readily retrieved or shielded, the secondary annual limit of 100 mrem (1 mSv) quickly became the limiting factor. Complicating the dose limit was the presence of large heat exchangers with NORM activity that could contribute dose indistinguishable from the iridium. A request was submitted to state regulators and approval was granted for authorization to operate with a non-occupational limit of up to 500 mrem (5 mSv) per year based upon the unusual circumstances. After the dose rates were decreased during the next few days, the limit reverted back to the standard 100 mrem (1 mSv) per year. Dosimetry was issued to personnel that required access to areas adjacent to the affected tank to aid in documenting dose.

In addition to surveys on the paved area under the tank, the large structures surrounding the affected tank required elevated surveys to be performed. Dose rates at elevated areas adjacent to the affected elevated tank were often found to be higher than those on the ground. This was due to shielding from plant structures and the shortest distance between two points. Tanks adjacent to the area were filled with water to provide shielding wherever possible.

Communications

Routine briefings were held twice per day, at 6:00 AM and 6:00 PM. All interested parties, including regulators, attended the meetings. Notes of each meeting were generated to clearly define issues, review plant status, and plan future activities. Later, the meeting notes in conjunction with log books provided valuable information for generation of the final report.

Several briefings were held with the work crews involved with the initial event – those that supported recovery operations or those uninvolved workers in surrounding areas that needed to understand new warning signs. A one-day orientation class for non-radiation workers was conducted to provide essential information and an opportunity for questions. Under the stress of emergency conditions it was difficult, but appropriate, to set aside personnel resources and time for communications with workers.

Contamination Controls and Decontamination

The recovery of the dispersed source was complicated by several factors. The general area dose rates around the primary area were a few mSv (hundreds of mrem) per hour. Since the event dispersed some of the material outside the tank, no physical structure was available to contain the loose contamination or support personnel access control. Although some particles were detected hundreds of meters from the tank, the majority of the removable gamma contamination levels were limited to an area within approximately 10 m (33 ft) around the tank. The presence of thousands of discrete particles required frequent surveys of response personnel to prevent excessive skin exposures. Selection of the recovery method and tooling was based upon high dose rates, high contamination levels, a relatively large area that was contaminated, limited access to the tank interior, and the unexpected difficulty in removing the contamination. Often the discrete particles were firmly affixed to most surfaces and could not be decontaminated by typical methods. The most successful tool to remove contamination from concrete and paved surfaces proved to be a hammer and a chisel.

After retrieval of the camera, gross decontamination of the work platform was conducted. High Efficiency Particulate Absorber (HEPA) vacuums were used for collecting loose material. Shadow shields were used on the platform around the tank opening to reduce worker exposures. A remote camera system was installed to evaluate the interior of the tank and provide videotapes to offsite support engineers. A modified vacuum system with a small in-line drop out tank for debris collection was fabricated to provide for gross cleaning inside the tank (fig. 3). The in-line tank had an outer annulus that was filled with cement for additional shielding (fig. 4). Fittings between vacuum system and drop out tank were designed with quick disconnect fittings in order to reduce personnel exposures. Initial efforts with the camera failed to visibly detect the source particles, so the vacuum head was connected to a radiation detector with a remote readout. As

the radiation levels increased with placement of the vacuum head, the vacuum system would be turned on to retrieve loose debris. Retrieval of the source material was confirmed by monitoring the increasing radiation levels in the vacuum debris collection tanks.

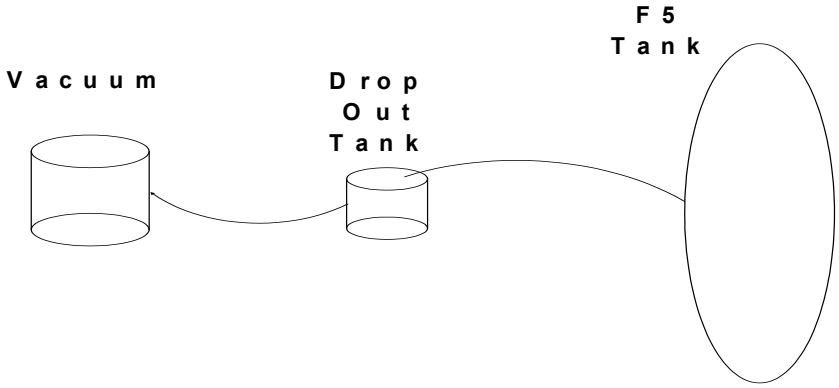

Fig. 3 Configuration of HEPA vacuum, drop out tank and affected tank F5

The next decontamination phase included a high-pressure water wash of the system to remove loose material. The rinse water was collected in portable tanks. A new personnel access hole was cut into the tank and physical interferences such as scaffolding and tools were removed. Grinding and sanding of the primary welding lead contact point removed a significant portion of the residual source. The final decontamination process employed a heated acidic rinse to remove the residue.

Fig. 4 Drop out debris Ttank with annulus for Ccement shielding

To accommodate the recovered sources and secondary waste, "sea land" containers were used to provide an informal but effective temporary radioactive waste storage facility. The higher activity material was positioned in the center of 3 side-by-side sealand containers.

Automated personnel contamination monitors were used to screen personnel working in or around the affected area. Personnel were required to use the monitors when exiting the work area, or at least twice per day when working around the perimeter. Personnel wore their work clothes through the monitors to give indication of the extent of contamination and as an aid in providing data for possible skin dose exposures. A lung phantom was constructed to aid in setting alarms on the personnel monitor. The personnel monitor was able to effectively perform rapid in vivo bioassays in less than 10 seconds. Although three dozen contaminated shoes were detected, the contamination monitors detected no contamination events on bare skin. Radiation frisking instruments were placed in each plant control room, and the operations staff performed a frisk of hands and feet prior to entering control rooms after tours.

Since the radiography source jacket had been breached, the source was no longer considered to be special form. A 2R container was required to package and ship the damaged source off site for inspection.

CONCLUSION AND LESSSONS LEARNED

Lessons learned from this project include details of the decay of ^{192}Ir, including impact of the longer half life of ^{192m}Ir and the practice over packing radiography source activity to account for self-absorption. In addition to the technical challenges of cleanup of the dispersed radioactive material, administrative challenges included communication with thousands of non-occupational workers in areas adjacent to the affected area using terminology with which they were not familiar. The low dose limit of 100 mrem (1 mSv) per year for non-occupational personnel was very difficult to maintain. The presence of low-level dose rates from NORM complicated monitoring programs. Early recognition of the extent of the problem was essential to isolate the affected area and minimize the spread of contamination. The cleanup was completed with a collective personnel exposure of approximately 2.5 rem (25 mSv).

- The financial impact of the event included
- Direct cost of remediation contractors
- Training and labor costs for non radiation workers
- Cost of diverting client's personnel from scheduled maintenance tasks
- Loss of production until area could be released
- Decontamination costs and repair or replacement of damaged equipment

REFERENCES

1 Code of Federal Regulations Title 10 Part 20 section 1301.

2 Code of Federal Regulations Title 10 Part 20 subpart E.

3 "Limits for Intakes of Radionuclides by Workers- Supplement to Part 2," International Commission on Radiation Protection (1977-1981).