RADIOLOGICAL EMERGENCY EXPERIENCE IN AN INDUSTRIAL PLUTONIUM PLANT

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"..... Truth is discovered by way of experience"

--Roger Bacon

As long as man exists, there will be accidents. Even the most elaborate safety rules and regulations won't entirely prevent industrial accidents. There is always an element of the unforeseen, which will confound the best laid plans of man.

Manufacturers and users of radioactive materials are not exempt from industrial accidents. In fact, industrial type accidents in radioactive materials plants are often complicated by the radiation hazards. What would ordinarily be a trival accident in a non-nuclear plant, may become a serious problem in a nuclear plant, because of an invisible amount of contamination.

NUMEC has had four serious accidents at its Plutonium Plant. Our facility, the world's first commercial Plutonium Laboratory, is located near Leechburg, Pennsylvania. We should mention that the plant operated for five years before the first accident occurred. We will describe each accident, what our emergency response was and how we recovered from the accident. At the end of the article, we will summarize what we have learned about preventing accidents, minimizing contamination complications and assuring good response to future emergencies.

1. Dry Box Explosion, January 17, 1966

At 2:05 p.m. a glove box exploded, when a technician struck a sparker inside the box to light a propane torch. Apparently the torch leaked, after a new cylinder was attached. The explosion blew out the box gloves and knocked the technician to the floor. Hot gases from the open glove ports singed the operator's eye brows and produced minor first degree burns, but he had no other physical injury.

The technician spread contamination, when he ran out of the room with box gloves still on his arms. Alpha contamination ranged up to 100,000 c/m on the technician's hair, face and chest. A nose smear, taken before showering, measured 50,000 d/m. He was decontaminated at the plutonium plant to less than 1000 c/m. The remaining skin contamination resisted further decon efforts.

Fully protected emergency personnel entered the contaminated room within minutes to put out fires started in the affected glove box. They placed covers on open ports, surveyed the area and sealed off the room. Alpha floor activity in the accident vicinity ranged up to 300,000 c/m/100 cm^2. Air samples, running during the accident, indicated 10-20 minute concentrations up to 1.1×10^{-7} uCi/ml or the equivalent of 367 MPC-hours (considering $^{241}AmO_2$ as the contaminant. At the time of the accident we assumed $^{239}PuO_2$ and thought the exposure was more than 900 MPC-hours).

After attending to the exposed technician, our most immediate problem was identifying other potentially contaminated personnel. One hundred and fifty employees were present in the plant, and since contamination was spread through the plant, we were not sure who was exposed. Every one was monitored externally and shepherded into the plant cafeteria. Nasal smears, taken on all personnel, showed that only the involved technician had been seriously exposed.

Our Health Physics Laboratory became "buried" by the incident, because it was in the controlled area and blocked off by contamination. To count early samples we moved counting equipment from our Apollo, Pennsylvania Uranium Plant.

After decontamination, the exposed technician was released to go home. We supplied him with feces and urine containers and instructed him to collect all excretions. His bioassay data is displayed in Figure 1.

The next day, we learned that Pittsburgh's Presbyterian-University Hospital had received a thin NaI crystal for its Whole Body Counter. Since this permitted plutonium evaluation, we arranged to have our technician counted that evening.

Because assessing the plutonium burden depended on measuring ^{241}Am and multiplying by the ^{239}Pu to ^{241}Am ratio, the initial estimate of the technician's lung burden was 0.4 uCi. We had assumed a "normal" ratio of 20 to 1. Based on this data, the technician was admitted to the hospital and DTPA was administered intravenously.

The third day, a sample of the incident contamination was subjected to alpha spectrometry. The actual ^{239}Pu/^{241}Am ratio turned out to be 3/17. This decreased the burden estimate considerably. However, the DTPA treatment did dramatically increase the urine and feces excretion. By the seventh day, the body burden had fallen to .002 uCi ^{241}Am. The medical aspects of the exposure were discussed by N. Wald and A. Brodsky[1].

Plant decontamination began the day of the explosion. But, because we had never dealt with such wide spread contamination, much confusion and re-contamination occurred. We had to learn while doing. It took three weeks to complete the decontamination. Later, we were able to handle much worse facility decontamination with relative ease.

2. Peroxide Glove Box Explosion, November 30, 1966

At 2:05 a.m. during a heat "kill", a peroxide filtrate glass tank overpressured and shattered. Two opposing glove box windows blew out, knocking an operator off his feet. Pieces of glass, acting like shrapnel, pierced surrounding glove boxes. $^{239}Pu/^{241}Am$ contaminated H_2O_2 solution splashed the operator's face. Exploding glass fragments cut his right hand. Figure 2 shows the glove box damage. A helper was standing off to one side and escaped both injury and serious exposure.

The operator immediately ran to the change room and showered. He thoroughly washed out his eyes, saving them from possible peroxide burns. He showered for ten minutes. Later, the shower hold tank was assayed at 23 millicuries of $^{239}Pu/^{241}Am$.

When the accident occurred, only three operators and a guard were present. The operator's helper alerted the guard, who called out emergency personnel. Health Physics personnel began arriving 35 minutes after the explosion.

At this time, after long showering, contamination on the operator's face and hands ranged from 250,000 to 2,000,000 c/m/60 cm^2. He was then wrapped in blankets and placed in a plastic cocoon. This was very successful in preventing contamination of the ambulance. While waiting for the ambulance, Health and Safety personnel washed out the operator's eyes and bandaged the hand wounds, which were bleeding profusely.

We took the operator to a local hospital, so that the resident surgeon could examine his injuries. This had been arranged in our emergency plans. We had run a training course for doctors and nurses at this hospital to teach contaminated personnel handling. We received good cooperation during the incident. The surgeon sutured the wounds to prevent additional bleeding. While there, NUMEC Health Physics personnel attempted further decontamination, but only succeeded in reducing levels by half. It was then decided to move the patient to Presbyterian-University Hospital in Pittsburgh, where they were better equipped to handle the case.

Further decontamination was carried out at the Presbyterian Hospital morgue. Morgue facilities are well suited for this kind of contaminated patient handling. All cleaning fluids are easily saved. Table, floor and other surfaces are easily cleaned. And the morgue is usually near an ambulance entrance.

Skin contamination was very stubborn and it took several days to complete external decontamination.(2) Shaving all body hair caused a dramatic decrease in alpha meter readings. The contamination apparently attached strongly to the hair. A special chelating concoction finally brought down skin levels.

Body counting data showed possible a high body burden, so chelation therapy was begun 20 hours after the accident. Figure 3 shows the operator's gamma spectrum after 1-1/2 years. The first 24 hours elimination after DPTA was 1.96×10^5 d/m in the urine and 3.54×10^6 d/m in the feces.

A NUMEC radiochemist ran a $^{239}Pu/^{241}Am$ ratio within hours after the explosion. The peroxide solution activity was 25% ^{241}Am. Using this data, the initial body burden estimate was 0.92 uCi ^{241}Am and ^{239}Pu. Chelation treatments and excision of the hand wounds helped reduce the burden to about 0.3 uCi.

Although facility contamination was much more extensive and tenacious, decon efforts were better organized than for the first accident and it took about three weeks to restore the plant to normal operation. We found that personnel traffic must be carefully controlled to prevent recontamination of cleaned areas. We used double change lines (and double sets of protective clothing) very successfully in the decontamination.

3. <u>Iridium-192 Hot Cell Release, January 13, 1967</u>

NUMEC encapsulates ^{192}Ir sources for radiographic cameras. The iridium pellets are usually received in aluminum capsules, which are dissolved off in caustic solution.

This particular morning, however, the capsules were of an aluminum alloy and would not dissolve. The lead Hot Cell technician decided to cut the capsule open. Without consulting the Hot Cell Engineer, he set up to make the cut. It occurred to him that there was a possibility of contamination release. So he placed a 2 inch exhaust hose, near the cut off wheel. Suction was obtained by using one of the three cell exhaust ducts. The technician thought the air flow through the 2 inch hose would be improved, if he blocked off the other two exhaust ducts. So he did. This action completely eliminated the cell's negative pressure.

During the cut, the abrasive wheel penetrated the fuel portion of the capsule. More than 75 curies were dispersed in fine particules. The small diameter hose exhaust failed completely to capture the high speed particules generated by the high RPM, cut off wheel. Figure 4 from the Industrial Ventilation Manual shows why. Air velocity falls off rapidly with distance from the exhaust opening.

The airborne contamination drifted out through the slave arm manipulators and other cell penetrations. Completely unaware of the release, the technician and his helper worked for an hour in the ^{192}Ir cloud. Only upon leaving for lunch through the change room and monitoring themselves, did they discover the contamination. They called the Health and Safety technician, who instructed them to shower. The fully protected Health Physics technician made entrance to the Hot Cell area, found high levels of contamination, retrieved air samples, and sealed off the cell area doors with tape. Although contamination levels were great enough to generate 20 mr/hr on all horizontal surfaces, the general air samples did not show corresponding air concentrations. One hundred and twenty-five MPC-hours was the maximum exposure measured at a sampling location. In light of the actual cell operator's exposure, the iridium cloud must have had a very steep concentration gradient. We have found this sharp disparity in our other operations by using personal air samplers.(4)

After showering, the hot cell technicians were monitored by a Health Physicist. He noticed gamma radiation levels of several mr/hr from the chest of each exposed technician. There was no appreciable difference in level when the beta window was closed, and no contamination could be smeared from the chest skin. The Health Physicist concluded that a large lung deposition had occurred and arranged for body counting at Presbyterian Hospital. The despostion and retention patterns of these cases have been discussed by Brodsky.[5,6]

To give you some idea of the rather sensational levels inhaled, both technicians had to be counted standing outside the body counter to keep the crystal from jamming, and the first fecal samples measured 20 mr/hr and 8 mr/hr with a gamma survey meter. The biological half life turned out to be longer than 300 days, but the short physical half life of ^{192}Ir (74.4 days) limited the lung doses to 45 and 14 rems, respectively to the lead technician and his helper. This illustrates an important point: where relative toxicity is low or half life is short, what might seem a real "barn burner" of an exposure, nearly always is less serious than the quieter exposures to ^{239}Pu or other long lived, highly toxic radionuclides.

Cleaning up the Hot Cell spill proved interesting. Unlike the alpha activity spills, where, when protected against inhalation and contamination, recovery personnel may stay indefinitely, we had to control clean up crews carefully to limit gamma exposure. The Hot Cell exhaust filters emitted radiation up to 15 R/hr and were a real problem to change. We managed by placing shields and writing a detailed procedure for the change.

The cell interior was much too contaminated for personnel entry; levels were several hundred R/hr, even after the intact Ir-192 pellets were shielded. The first operational problem was unblocking the cell ducts and restoring negative pressure. This was done, using the manipulators and a great deal of patience. Gross cell clean up was done with the manipulators. When levels reached several R/hour, personnel entry was possible. Teams for cell entry were organized from employees with low radiation histories. We constructed an isolation room at the cell entrance for outer coverall removal and contamination survey. Decontamination of the Hot Cell service area was accomplished in a week, but it was six weeks before the Hot Cell itself was restored to pre-incident levels.

4. Hand Amputation, December 14, 1967

A technician amputated his right hand while operating a milling machine in a plutonium glove box. The accident occurred when the technician's box glove was caught in the 4 inch cutter tool of a clausing milling machine, dragging his hand through the cutter. Figure 5 shows the milling machine. He was reaching past the cutter to adjust an N_2 hose. The hose is used for blowing chips away from a 3 inch milling tool, mounted 10 inches back on the same spindle.

Ordinary procedure called for fixing the N_2 hose while the machine was turned off. The milling machine had been run safely for two years by withdrawing the hands from the glove box and operating the machine with an outside foot switch.

The technician ran some 200 feet to a second floor first aid room. A Health and Safety technician and an engineer applied a tourniquet, stopped the bleeding and called a physician. An alpha survey showed that contamination was limited to the severed wrist.

After receiving medical attention, the technician was transported to Presbyterian Hospital. NUMEC personnel bagged the hand out of the glove box and took it, packed in ice, to the hospital. The hand was decontaminated and grafted back on the arm. About 10 microcuries was estimated by gamma scanning to be left on the hand. Brodsky is reporting separately on the Health Physics evaluation at the hospital.(7) Unfortunately, when warmth failed to return to the hand, it was surgically removed several days later. Less than 0.01 microcuries of plutonium and americium remained in the technician's body, as verified by gamma scanning of the stump, whole body counting and detailed bioassay.

NUMEC Health Physicists deconned the amputated hand. The grossly contaminated hand presented an interesting problem. Since gamma levels from the doubly bagged hand were several mr/hr, we were sure several millicuries of plutonium were inside the bag. We had the hand at the hospital morgue, when the surgeon decided to re-attach the hand. A ventilated hood was not available, the contents of the bag were relatively dry and dusty and there was not time to take the hand to a safe place for cleaning. We solved the potential radioactive dust problem by injecting saline solution into the bag and thoroughly wetting the interior. After that, we cut open the bag, without contamination release, and carefully deconned the hand with surgical soap. Our efforts achieved at least a factor of 10 reduction in contamination.

No significant release resulted in the Plutonium Plant. No unusual airborne radioactivity was measured in the immediate area. Only about 30,000 c/m could be detected on the affected glove port and this was quickly cleaned up. We found a complete absence of floor contamination. Although everyone in the production area was surveyed, we found no one contaminated, except the wounded technician.

Lessons Learned

Something of value can be retrieved from every accident. This lesson learned no matter how unimportant it may seem, may be the thing which saves a life or prevents another accident. Keeping this in mind, we have listed below some of the things we have learned from our accidents:

1. Each new operation should be reviewed for safe procedures and conditions.

This is best done by a committee composed of senior technical and safety professionals. Even from a production viewpoint, it's better to over review, than possibly omit some important point. One accident's lost time and costs pays for a lot of review.

2. Nuclear facilities should be compartmentalized to reduce the spread of contamination. Where a large fabrication area is an absolute necessity, room ventilation should be controlled so that airborne radioactivity does not spread contamination throughout a facility.

3. Of course, there should be emergency plans. But, some points which may be overlooked are:

   a. Telephone numbers and call out lists must be constantly updated.

   b. Local hospital personnel must be trained in handling contaminated personnel.

   c. Radiation measurements, such as isotope ratios, neutron activation analsis, etc, which may be used in an emergency, must be worked out ahead of time and regularly practiced.

   d. There must be a clear delineation of authority for post accident situations. Otherwise, duplication of effort, crucial omissions and working at cross purposes occurs.

   e. Radiation instruments must exist in the emergency cabinet as well as in the emergency procedures. You should not count on using routine instruments for emergencies. Too often, they are lost to contamination. Emergency instruments must be regularly calibrated and maintained. A weekly inspection is not too frequent.

   f. Training of emergency personnel must include First Aid. Skill in Health Physics does not guarantee that you know how to stop bleeding or give respiration assistance.

   g. The emergency measurement laboratory and control center locations must be planned to prevent loss of access because of radiation or contamination. You might not be able to improvise, as we did.

4. Trained, level headed professionals present after an accident are more important than elaborate plans. Every accident we have had has contained some element which we did not foresee. But, thus far, on the spot judgments have been good, and no serious errors have resulted.

5. The time to beware is when the basic use of a facility changes, as when a solely research laboratory takes on production work. Procedures, equipment, personnel and time scales change so rapidly that conditions for accidents develop.

6. All safety precautions ordinarily applied to machine tools must be followed when the machinery is in a glove box. In fact, one should be conservative in prescribing safeguards, providing only that the safeguards are not so cumbersome that their use is avoided by operating personnel.

7. A glove box is a confined volume. A very little flammable material can quickly create an explosive mixture in a box. Due attention must be paid to adequate air change rate in a box, limiting flammable material and providing readily used fire protection.

8. In nearly every accident, the situation initially appears worse than it really is. If you keep your head, what appears, at first, to be an impossible situation will soon become resolvable.

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