MAJOR HEALTH PHYSICS EXPERIENCES DURING 15 YEARS OF REACTOR TESTING

J. R. HORAN
United States Atomic Energy Commission Health, and Safety Division,
Idaho Falls, Idaho, United States of America

Abstract—The case histories of the major incidents involving the uncontrolled release of radioactive materials and radiation exposure to personnel will be reviewed. The most serious incidents in the 15-year operating history of the National Reactor Testing Station will be presented in an ascending order of seriousness using the following categories:

1. Property damage.
2. In-plant contamination.
3. Environmental contamination.
4. Inhalation exposure.
5. External total body exposure.
6. Radiation injury.
7. Maximum credible accident.

THE National Reactor Testing Station (NRTS) of the United States Atomic Energy Commission is a complex of facilities for nuclear reactor development extending over 900 square miles of public land in the north-western part of the United States. Since establishment of the NRTS in 1949, hundreds of millions of dollars and man-hours have been devoted to its primary mission to develop economic nuclear power and other peacetime uses of atomic energy. More experimental reactors of more advanced and different types have been built at this desert location than in any other equivalent area—a total of 42 to date.

The long-promised day of economic nuclear power is at hand. In the past year, we achieved the economic breakthrough of using large-scale reactors for commercial electrical power. As a result of rapid progress in research, technology, and operating experience, the United States today is years ahead of its planned nuclear power program. As of January 1, 1966, 22 nuclear power plants were operating or under construction with a total capacity in excess of 5000 MWe. During the first half of this year, orders were placed by various utilities for constructing 21 new nuclear power plants with a capacity in excess of 14,000 MWe. This means that more than 50% of the new electrical generating capacity in the United States has been assigned to nuclear power plants.

This new technology, now being applied in the United States and a few other nations, will be available to the world. Already European utilities are on the verge of placing an outburst of nuclear plant orders comparable to that experienced in the United States. A recent forecast of the nuclear power market abroad for the next 20 years provides the following consensus forecast of installed nuclear capacity. The free world in the next decade from 1970 to 1980 is expected to see nuclear power grow from approximately 22 millions of electrical kilowatts to approximately 200 millions of kilowatts and reaching approximately 400 millions of kilowatts by 1985. In the words of the late Dr. H. J. Bhabha of India at the Third International Conference on the Peaceful Uses of Atomic Energy, "There is no form of power as expensive as *no power*, i.e. doing without power altogether. . . . We know now that atomic power has come to stay." Because of the widespread concern about radiation due to the military birth of the atom, it is worthwhile to consider the experience at the National Reactor Testing Station where new concepts and new ideas for nuclear power have been developed. I am quite confident that a review of this experience will result in an overwhelming vote of confidence in the safety of design and the meticulous care which is taken in the construction and operation of nuclear facilities. The many barriers which are used to protect people against injury and equipment against damage provide evidence that serious accidents are quite improbable. But if a serious accident does occur, the engineered safeguards are adequate to protect personnel outside the radiation control zones.

Safety is the first law of nature. By nature every organism tends to conserve life and the faculties with which it is endowed. The character and magnitude of the hazards which could arise with the improper use of nuclear energy required that a framework of safety protection be established from the beginning. This philosophy was new to industry, which was to see every phase of the research, development, and operation of the peaceful development of uses of the atom tempered by a judicious concern for occupational and public safety. Experience shows that any quantity of radioactive materials can be handled safely. The safety experience record has been phenomenal.

The emergence of nuclear power as an important factor in the world's economy has brought both public interest and concern—interest in the economic benefits and concern about safety. The lack of basic knowledge, particularly lack of understanding of the essence and the extent of the danger, breeds fear. Unfortunately, this fear can deter the continued development of nuclear energy despite the promise it holds for mankind.

The health physics profession is committed to the prevention of injury from radiation and reducing the impact of damage which may result from any radiation incident. While we can be proud of the past record, we realize that our skill and our best efforts cannot be sufficient to prevent all accidents. Therefore, let us study the accident experience at a major establishment where all phases of reactor design, construction, maintenance, modification, and operation have been performed in research and testing of practically all types of reactors.

The case histories of all the incidents and accidents involving radioactive material or its release to the working environment or radiation exposure to personnel suggest the following general categories of incidents in an ascending order of seriousness:

1. Property damage.
2. In-plant contamination.
3. Environmental contamination.
4. Inhalation exposure.
5. External total body exposure.
6. Radiation injury.
7. Maximum credible accident.

As a health physicist, I have followed the innate pessimism of my profession by selecting the most serious incident of each type for analysis. While a number of the incidents may qualify for several of the categories listed, each will be reviewed under the most serious category for which it may qualify. Most of this detailed information has not appeared previously in the open literature.

1. PROPERTY DAMAGE (JULY 23, 1957)

A railroad flatcar was being used to transfer a spent air-cooled reactor core from a hot cell to a storage area. While a 25-ton capacity crane was moving the highly radioactive core from the flatcar to the storage pit, the boom started to lower causing the load radius to increase excessively. As the operator attempted to arrest this motion, the crane over-balanced and turned over on its side. The 13.5-ton core struck the ground with a swinging motion bending the flanges, and the core subassembly struck the ground on its side. The impact broke the core supports from the plug. No fuel was involved; the core was not reuseable. Although much of the material was salvable, the damage was estimated at $105,000. Except for superficial cuts sustained by the crane operator, there were no injuries. The estimated radiation exposure to three personnel directly involved in salvage work was less than 300 mr. The maximum radiation level from the core was 5 R/hr at 2 m. Contributing causes to the accident were the following:

The crane was being operated near its maximum capacity with a boom radius of about 4 m and an angle of approximately 63 degrees. The crane was being operated blindly with hydraulic controls. Because of the high radiation fields, the front window of the cab was covered with a sheet of lead and about a ton of lead brick had been added to shield the operator who was guided by a rigger. Finally, the operator had failed to lock the boom in position.

2. IN-PLANT CONTAMINATION (OCTOBER 5, 1957)

During the testing of an experimental air-cooled fuel sample, a fire of undetermined origin occurred in the charcoal filter in the off-gas line. The heat caused a gasket to fail at a flange, releasing burning charcoal dust which spread radioactively contaminated air throughout the reactor building. Air monitors alarmed; the reactor was scrammed; and personnel were evacuated. High levels of air activity persisted for approximately 30 min and then gradually decreased in intensity. The flames in the charcoal filter subsided when airflow to the experiment was shut off and the fire was extinguished with carbon dioxide. It is believed that the fire was caused by the spontaneous ignition of oil which had leaked into the charcoal bed during nonoperating periods.

The total loss chargeable to the fire was \$22,000, of which \$400 was due to the direct fire damage to the filter, \$2400 for decontamination, and \$19,600 chargeable to the downtime of the reactor. Although 11 employees, at one location in the reactor building, were without respiratory protection during the early phase of the incident, there was no significant exposure either from radioactive materials or other toxic materials.

It is interesting to note that the total fire loss in the 17 years of NRTS operations to date has been approximately \$68,000. The current valuation of the facilities is in excess of a half-billion dollars.

3. ENVIRONMENTAL CONTAMINATION (NOVEMBER 18, 1958)

During the startup of the HTRE-III experimental air-cooled reactor, faulty instrumentation resulted in a power burst which seriously damaged a number of fuel elements. An estimated 15,000 curies of fresh fission products were discharged through a 60-m stack under inversion conditions, contaminating approximately 600 hectares of desert land. There was no contamination to the farming areas beyond the Testing Station since the winds were from the northeast and the nearest off-site boundary in the downwind direction is more than 50 km away. Ground surveys indicated maximum readings of 0.15 mr/hr 1 m above the surface. Assuming that iodine-133 was the primary contaminant, this would be approximately 20 $\mu Ci/m^2$. The estimated maximum infinity dose from inhalation due to cloud passage would be approximately 5 mr. The financial loss as a result of property damage was estimated at \$1,100,000.

4. INHALATION EXPOSURE (MARCH 20, 1958)

A criticality incident occurred in a chemical processing plant during the transfer of a waste solution to permanent storage. Earlier chemical separations had been performed in a hot cell on a fresh fuel element. During cleanup of the process equipment, a momentary pressure surge caused vapor to be released through partially opened valves in the solution addition lines. These lines had not been used for six months. The associated valves were stuck in a partially opened position which was not detected by manual checks. Interestingly enough, at least five similar operations had been performed previously without incident despite the same existing conditions. Evidently, the precise process circumstances for the radioactive release did not exist during the prior transfers.

Approximately 1 curie of iodine-131 was released into the operating corridor. Originally, it was believed that iodine inhalation exposures would be insignificant, and the early urine samples supported this evaluation. However, the following day it became evident that at least two individuals had received high inhalation exposures. At approximately 20 hr post incident, stable iodine was administered, reducing the total dose to the thyroid by a maximum of 10%. Eleven individuals received thyroid inhalation exposures ranging from 12 to 220 rad. Six individuals exceeded the maximum permissible dose of 30 rad per year, with the two highest exposures being 200 and 220 rad, respectively. Iodine-131 uptake in the thyroid varied from 2 to 40 μCi. As a precautionary measure, all 11 individuals were placed on work restrictions, varying from two weeks to eight months. The highest external radiation exposure, as a result of submersion in the radioactive cloud, was approximately 1 R.

5. EXTERNAL TOTAL BODY EXPOSURE (OCTOBER 16, 1959)

A criticality incident occurred in the process equipment waste collection tank of a chemical processing plant used for recovering highly enriched uranium. The incident resulted from accidental transfer of about 200 liters of uranyl nitrate solution containing about 34 kg of enriched uranium (91% U-235) from critically safe process storage tanks to a geometrically unsafe tank through a line normally used for waste transfers. Although no specific instances of maloperation were discovered, several unsafe conditions were found which contributed substantially to the incident. An estimated 4×10^{19} fissions occurred in a waste tank located 17 m below grade and shielded by $1\frac{1}{3}$ m of concrete. Of the 21 persons directly involved in the incident, seven received external exposure to radiation as a result of the passage of a radioactive cloud through drains and vents into the inhabited areas; but none received whole-body exposure to penetrating radiation in excess of the annual permissible dose of 12 r. However, two individuals received skin doses from soft radiation of 50 and 32 rem, respectively. No medical treatment was required for any of the exposed individuals.

Although this was the first criticality incident at the NRTS, it was the twelfth such event in the United States. It is of interest to note this was the first such incident where personnel were wearing film badges. Another interesting aspect is that two days prior to the incident, personnel neutron threshold detectors had been installed in 95% of the badges for the 400 employees working in the Chemical Processing Plant. Ironically, only four of the personnel involved in the incident were equipped with this new monitoring device.

There was no significant property damage as a result of the excursion. The total loss chargeable to the incident was approximately \$60,000 to recover the contaminated uranium solution.

Approximately two years later, on January 25, 1961, a second criticality incident occurred at the same facility. The lessons learned during the earlier incident proved very profitable. The maximum exposure was less than 55 mrem, or less than the daily exposure guide.

6. RADIATION INJURY (JULY 27, 1955)

Following shutdown of a prototype propulsion reactor, maintenance personnel entered an equipment compartment to grind open the access ports to the heat exchanger for visual inspection. To reduce radiation exposure from corrosion and fission products within the exchangers, the units had been partially filled with water and pressurized. On grinding through the last weld, a mild blast of air was released from one of the contaminated heat exchangers impinging on a laborer. About a week later, this employee reported to the dispensary with a draining ear and was treated for an ear infection. Three days later upon the completion of another work assignment in a contaminated area, the same employee received a routine contamination check with a Geiger counter. This survey revealed radiation levels of from 2 to 20 mr/hr on the left side of his head. Examination and treatment at the dispensary resulted in the removal of a 70-micron particle with a radiation field of approximately 1 r/hr at 3 cm. This intense radiation field had damaged tissue in a local area sufficient to perforate the eardrum. Following the removal of the radioactive particle, the employee was hospitalized for observation.

The extremely minute particle had a gamma ray spectrum which indicated aged fission products which resulted in a beta-ray exposure in the thousands of roentgens to an extremely limited area of the ear. The injury resulted in 12 days of lost time; however, the individual has fully recovered except for a 10% loss of hearing in the one ear and is still employed at the project. The person involved was a new employee who had received routine indoctrination in basic radiation protection. Among the items which contributed to the injury were the following: failure to wear protective covering of the head, failure to shower and monitor following work in a highly contaminated area, and the lack of portal monitors at the exits to the plant. Those items which contributed to the incident were subsequently corrected.

During the seventeen years of NRTS operation, over 140,000,000 manhours of work have been performed with 275 lost-time injuries experienced. Only one of these—described above—was caused by radiation. Almost 300 times as many injuries resulted from gravity than from radiation.

7. MAXIMUM CREDIBLE ACCIDENT (JANUARY 3, 1961)

A 3 MW electrical prototype reactor known as the SL-1 underwent a nuclear excursion during a maintenance shutdown. The excursion destroyed the reactor, fatally injured three operators, and resulted in property damage estimated at $4,400,000. The accident was caused by a single event which covered a time interval of only 30 sec. An experienced military technician, knowing the hazards involved, deliberately withdrew the 39 kg central control rod to a height of 51 cm instead of making a 6 mm adjustment as dictated by the standard operating procedure. The reactor was capable of reaching criticality with this one rod withdrawn approximately 40 cm. A total nuclear energy release of 130 ± 10 MW-sec occurred. Five percent of the fuel in the center 16 fuel elements attained vaporization temperature of 2060°C. Altogether approximately 20% of the reactor core was destroyed.

The rapid formation of 34 atm of steam in the pressure vessel accelerated a 2 m column of water above the core and slammed it into the thick top head of the pressure vessel at an approximate velocity of 50 m/sec, producing a phenomenon known as a "water hammer". The impact of the compressed water produced a peak pressure of about 680 atm and transferred momentum to the pressure vessel itself which sheared the connecting piping and lifted the vessel approximately 3 m into the air. About 3 sec after the initiating event, the incident was over, and the vessel had fallen back onto its support cylinder. Based upon the best available data, approximately 5% of the gross fission products (estimated at 5×10^5 Ci) was ejected from the pressure vessel.

Large amounts of radioactive particles were released inside the reactor building. The cylindrical reactor building was made of steel plate, most of which had a thickness of 6.4 mm. The building was 13 m in diameter with an overall height of 16 m. Access to the building was provided by ordinary doors. The building was not a pressure-type containment shell, as would have been used for a reactor located in populated areas. Nevertheless, the building did contain almost all of the radioactive particles released by the explosion. Essentially all of the released material, with the exception of iodine-131 and the noble gases, fell out within the 1.2-hectare plot which contained the reactor and its support buildings. It was estimated that $\frac{1}{2}$ Ci of cesium-137 and $\frac{1}{10}$ Ci of strontium-90 were released from the building. In fact, more contamination was spread in the vicinity of the reactor by human and vehicular traffic during the subsequent rescue operations than by the accident itself. Air and vegetation sampling indicated that approximately 10 Ci of iodine-131 were released during the first 16 hr and approximately 70 Ci over the remaining 30-day period. Continuous air samples during this period indicated that the infinity thyroid dose for an adult at the nearest populated center 7 km was approximately 35 mrad which was slightly greater than 1% of the radiation protection guide value for off-site population which was in effect at that time.

Of interest is the fact that four of the health physicists involved in the early rescue operation became the first members of the profession to be decorated for heroism. Along with three other individuals, these men were presented with bronze medals by the Carnegie Hero Fund Commission for their attempt to rescue the three casualties after the accident. Rescue operations which involved short-term exposures in radiation fields up to 800 R/hr resulted in an integrated gamma exposure of 375 R to a total of 263 personnel of which 14 individuals received total body radiation exposures in excess of 5 R with the highest exposure being 27 R. The highest infinity thyroid dose from iodine-131 was 5.5 rad.

During operations over the following three-week period, all activities were performed under rigid exposure control procedures which involved an additional 300 individuals. During this interval, there were no injuries nor did a single individual exceed the guide value of 3 R per quarter.

The decision was made to demolish the reactor building and to restore the general area to a useable condition. It may be of interest that in the reactor room only one light bulb had been broken, despite the pressure shock and the number of missiles which peppered the area. The site cleanup resulted in removal of approximately 2500 m^3 of shielding gravel, contaminated equipment, and decontamination materials to a special burial ground. This material contained an estimated 22,000 Ci of fission products.

In speculating on the impact which the SL-1 accident could have had upon the public if the reactor had been located in a populated area, it would have been unlikely that any person would have unavoidably received a radiation exposure greater than that allowed on an annual basis. However, control measures would most likely have been necessary in a milk-producing area as a protective action to prevent ingestion exposure via the milk-chain.

SUMMARY

These examples of the most serious incidents over the years at the National Reactor Testing Station have been presented to support the thesis that even the most serious accidents experienced at a major testing establishment have not produced exposure or injury to personnel outside the immediate radiation control zone. It has been demonstrated that man can work with and control the hazards resulting from the use of any quantity of radioactive materials.

As the world enters the nuclear power era, the health physicist has been the first to accept the challenge given by the late President Kennedy, "Regardless of the scope of modern research and development, safety is the primary purpose and most important product of today's scientists."

REFERENCES

1. W. L. GINKEL *et al.* Nuclear incident at the Idaho Chemical Processing Plant. IDO-10035, 2-15-60.
2. J. W. LATCHUM *et al.* Nuclear incident at the Idaho Chemical Processing Plant. 1-25-61, La-54-61A.
3. Final Report of SL-1 Recovery Operation, May 1961 through July 1962. IDO-19311, July 27, 1962.
4. Statements to the SL-1 Board of Investigation by Combustion Engineering Incorporated and Argonne National Laboratory on the SL-1 Accident. IDO-19312, dated August 21, 1962.
5. J. R. HORAN and W. P. GAMMILL. The health physics aspects of the SL-1 accident, *Health Physics* **9**, 177–186 (1963).