CONF-8506148--6

MASTER

CHARACTERIZATION OF RADIOLOGICAL EMERGENCIES*

CONF-8506148--6

DE86 015921

Conrad V. Chester

Energy Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831

*Research sponsored by Martin Marietta Energy Systems, Inc. for the U.S. Department of Energy Under Contract No. DE-AC05-84OR21400. The views expressed are those of the author and do not necessarily represent those of the Department of Energy.

CHARACTERIZATION OF RADIOLOGICAL EMERGENCIES*

Conrad V. Chester

Energy Division
Oak Ridge National Laboratory
Oak Ridge, Tennessee 37831

ABSTRACT

Several severe radiological emergencies were reviewed to determine the likely range of conditions which must be coped with by a mobile teleoperator designed for emergencies. The events reviewed included accidents at TMI (1978), SL-1 (1961), Y-12 (1958), Bethesda (1982), Chalk River (1952 and 1958), and Lucens (1969). The important conditions were: radiation fields over 10,000 R/h, severe contamination, possible critical excursion, possible inert atmosphere, temperatures from 50°C to -20°C, 100% relative humidity, 60-cm-high obstacles, stairs, airlocks, darkness, and lack of electric power.

CHARACTERIZATION OF RADIOLOGICAL EMERGENCIES

Conrad V. Chester

Presented at the Workshop and Requirements of Mobile Teleoperators
for Radiological Response and Recovery
Dallas, Texas, June 24, 1986

CHARACTERIZATION OF RADIOLOGICAL EMERGENCIES

The purpose of this paper is to identify conditions which should be considered b, the designers of mobile teleoperator equipment intended for service in radiological emergencies. We will propose a definition of radiological emergency and a taxonomy of emergencies and mention examples of actual emergencies, some of which will be discussed in much more detail by other papers in this workshop. We will attempt to indicate the range of operating conditions that an equipment designer should consider as well as the type of operations that his machine might be expected to perform.

Definition of Radiological Emergencies

The following definition of radiological emergency is proposed:

"A radiological emergency exists when the actuality or potential exists for life or health (including long-term) -threatening amounts of radiation or radioactive material is in an environment where people can be exposed." A shorter way to phrase this might be that a radiological emergency exists when radiation is someplace it shouldn't be. As will be discussed later, not all radiological emergencies require the services of a mobile teleoperator.

Taxonomy of Radiological Emergencies

The following taxonomy or classification of radiological emergencies is proposed:

Criticality or potential criticality
Misplaced gamma source
Alpha active aerosol release (weapon accident)
Beta aerosol release (Kyshtym)
Beta-gamma aerosol release
High-level liquid leak or spill
Radioactive gas (Kr,I-Xe,or Rn) in atmosphere

We have not included accelerator accidents among radiological emergencies although they have been an important producer of radiation injuries in the past. The most acute danger from an accelerator can be eliminated by disconnecting its electric power. Any residual radioactivity in the target can be considered like any other gamma source.

Criticality accidents are an important class which have produced a number of fatalities. Very often they present emergency personnel with the possibility of additional critical excursions after the first one. Because of the potential for very large doses from critical accidents, great caution is needed in approaching a configuration of critical material of unknown reactivity. This is a good task for a remote teleoperator.

Misplaced gamma sources are another important producer of radiation injuries and deaths. The source can be radiographic sources, pieces of radioactive waste from a transport shipment, fragments from a re-entering reactor-powered earth satellite, or a variety of other radioactive materials and objects if the source is strong enough (e.g., tens of thousands of R/h). Recovery of the source once it is located, may be a task for a mobile teleoperator.

The release of an alpha active radioaerosol usually does not generate circumstances where a mobile teleoperator could be profitably applied. Humans with respiratory filters and possibly protective clothing are usually the most economical method of dealing with such an accident. An exception might be routine operations in a highly contaminated enclosure as for example in a plutonium fabricating facility. The time required to suit up men and then decontaminate them might more than offset the slower operation of a mobile teleoperator in such a facility.

A beta aerosol release and subsequent contamination such as occurred at Kyshtym in the Soviet Union about 1958 is very similar to an alpha aerosol release in terms of emergency operations. Workers can be fairly well protected with respirators and protective clothing. Large pure beta releases are very rare, with the Kyshtym incident being essentially unique.

Aerosol releases and subsequent contamination by gamma emitters or,beta gamma emitters such as fission products, provide perhaps the major opportunity for application of mobile teleoperators. If the gamma field is high enough, humans cannot work in such an area. The interior of the containment of unit 2 of Three Mile Island is possibly the outstanding example of such a circumstance.

A leak or spill of a very high level radioactive liquid could provide circumstances when a mobile teleoperator is safer and more economical to use in cleanup. A leak from a large tank of liquid high-level waste might produce such a circumstance. The consequences of such an event presently exist in the basement of the containment of Unit 2 at TMI.

A sealed volume with a large content of radioactive gas (krypton, iodine-xenon, or radon) may provide an environment where is advantageous to use a mobile teleoperator. Men would have to be suited up and then decontaminated in order to work in such an area. A machine which can remain in the area may be a more economical method of accomplishing tasks.

SOME EXAMPLES

(Bertini, 1980, Chester 1984)

In the past 40 years, there have been a variety of radiological accidents. The required considerable exposure to emergency personnel for rescue, recovery, and decontamination. Some of the more important of these accidents will be covered by individual speakers later in this workshop. We believe that they are highly illustrative of the conditions which would be faced by the users of a mobile teleoperator in future accidents.

Nuclear Incident at the SL-1 Reactor, January 3, 1961

This accident is the most serious in the United States in terms of fatalities (there were three) and may be first or second in terms of personnel exposure during recovery operations.

In January 3, 1961, a group of three re-connecting control rod drives on the SL-1 reactor inadvertently introduced a critical excursion, probably by manually withdrawing a control rod beyond a safe point. The ensuing steam explosion caused fatal mechanical trauma to all three operators. The critical excursion of over 10^{18} fissions produced a very high radiation field in the operating area at the top of the reactor, about ten thousand R/h immediately over the reactor, and several hundred R/h at the periphery of the operating area. The operating area was filled with a radioaerosol which was a severe respiratory hazard and subsequently contaminated adjoining buildings and some of the surrounding area.

Large radiation exposures were absorbed by rescue personnel in their efforts to recover the bodies of the operators. The bodies themselves were reading several hundred R/h. Subsequent efforts at reconaissance placing t.v. cameras and finally debris removal in recovery entailed further large exposures of recovery personnel.

Because of the maintenance activities on the reactor and removal of movable shielding from the top of the reactor and the steam explosions the operating area was very cluttered. The operating floor was only 6.3 meters (21 ft.) above the outside ground level could be entered only by either a crane-bay door at that level or a covered exterior stairway. Most present tracked-vehicle transporters would not have been able to negotiate the stairway and would have been capable only of limited movement on the operating floor due to clutter and debris.

The SL-1 incident can be taken as the archetype of a severe radiological accident. It entailed very high radiation fields difficult access, cluttered operating areas, severe contamination (including airborne radioaerosols), and time-urgency of the operation of recovering personnel and determining the state of the reactor.

Three Mile Island

The acccident at TMI was the result of a long improbable chain of mechanical failures and operator errors that culminated in heavy damage to the reactor core of Unit 2; flooding the basement of that unit with highly radioactive water; general contamination inside the containment;

and contamination inside the the auxiliary building. In addition, a deflagration of accumulated hydrogen occurred inside the containment producing a pressure spike of about 1.6 atmospheres (25 psi) which caused some mechanical damage to light structures such as sheet metal ducting. Negligible exposure occurred to operating personnel and the general public in the course of the accident. Recovery operations have involved considerable exposures to personnel but generally within Nuclear Regulatory Commission guidelines.

Three Mile Island certainly must qualify as the most expensive nuclear accident in history and may, before the cleanup is complete, entail cumulative personnel exposures approaching or exceeding those at the SL-1.

No personnel were in the containment at the time of the accident and there was no requirement for rescue. The time-urgent requirement was for information to determine the status inside the containment. Conditions in the containment shortly after the accident were about 50° centrigrade, 100% relative humidity, 3.4 kPa (0.5 psi) negative pressure, air atmosphere, some strontium, cesium, and iodine as airborne aerosols, and large amounts of radioactive krypton and xenon. This produced beta doses from the air of 500-600 R/h. Beta doses from surfaces could be as high as several 1000 R/h and were very often the exposure limiting factor.

Here the requirement was for reconnaissance equipment that was capable of television transmission with lights and sensors which could detect gamma and beta radiation over a wide range of dose rates. Mechanically the ability to climb over airlock thresholds was required, as well as to climb stairs and operate on a floor with some clutter on it. Ease of decontamination is an important requirement in this environment, at least initially. The requirement for a manipulator was relatively small and the ability to open and close airlock doors could have been very helpful. Also desirable was the ability to take smear samples and liquid samples.

As time went on the requirement to decontminate surfaces became paramount. The principal techniques were high-pressure water jet and stripable coatings.

The Y-12 Criticality Incident

In June, 1958, an inadvertent criticality occurred when an operator was draining a critically safe tank into a 200 liter (55 gal.) drum. The water had been used to leak test other critically safe tanks, and was being drained through one that unexpectedly contained some fully enriched uranyl nitrate solution. When about 58 liters of the solution had been run into the drum, the operators observed a bright blue light flash in the areas as though someone had struck a welding arc. Radiation alarms went off and the operators left the area. The operator standing closest to the tank received something over 400 rem and the other four operators in the area received lesser amounts. The reaction was not as violent as the Sl-1 incident. The excursion, which may have lasted as long as 20 minutes, produced something of the order of 10^{17} fissions. Very little of the fission products became airborne and got outside the tank.

The big problem in recovery was the unknown nuclear reactivity of the 200 liter (55 gal.) drum after an unknown amount of additional uranyl nitrate and water had flowed into it. A concern was the possible effect on reactivity of the system due to the neutron reflecting characteristics of the water in a man's body as he approached the tank. The required task was to poison the tank. This was finally accomplished by dropping a scroll of cadmium metal into the tank using a long pole. A remote manipulator would have been quite useful for this job in order to reduce the risk to the person who ultimately carried out the task. Additional capabilities of a teleoperator which would have been useful in this incident were radiation detection (particularly a neutron detector) a t.v. camera to determine the level of liquid in the drum and liquid sample-taking capability.

A Stuck Cesium Source at the Armed Forces Radiological Institute, Bethesda, Maryland, February, 1982

In early 1982, a cesium irradiation source became stuck in the raised position at the Armed Forces Radiological Institute in Bethesda, Maryland. The source was normally kept in a water-filled well. It was raised after a specimen, in this case a printed circuit board, was placed in the chamber for irradiation. The source was much too hot (10,000 R/h) to be approached even by a man moving very rapidly. The original design procedure for dealing with a stuck source was to flood the entire room and then manipulate the source with long-handled tools working from a boat floating above it. Flooding the room would have produced tens of thousands of liters of slightly contaminated water which would have presented a very difficult disposal problem in the Washington, DC area, not to mention the adverse publicity in today's political climate. The problem was finally solved by the PaR mobile manipulator HERMAN which was able to successfully enter the area by way of an elevator and cut the cable supporting the source using a specially fabricated tool. A few weeks were involved in the operation while the special tooling was fabricated and the operation was practiced on a mock-up.

The NRX Reactor Accident - Chalk River, Canada, December 12, 1952

The NRX Reactor was a 30-megawatt heavy-water-moderated, light-water-cooled experimental reactor installed at the Canadian Chalk River facility. On December 12, 1952, a combination of operator errors, design errors, and equipment failures resulted in coolant loss followed by an overheated and severely damaged core. Following failure of the integrity of the cooling system and contamination of the cooling water, approximately one million gallons of cooling water containing 10,000 curies of fission products were dumped into the basement of the building.

This produced radiation levels of 10 R/h in the basement with hot spots as high as 200 R/h and 100 mr/h in the control room. Cleanup required 1100 people with an aggregate exposure of 2,000 man rem. The maximum exposure to any one individual was 15 rem.

The NRU Reactor Accident, Chalk River, Canada, May 23, 1958

The NRU is a 200 megawatt thermal research reactor which was installed in the Chalk River facility in Canada. On May 23, 1958, the operators observed reactor trips and high fission product levels in the coolant. One fuel rod suffered moderate damage and one fuel rod was severely damaged, possibly due to a faulty rate of rise control switch. In an attempt to remove the severely damaged fuel rod from the reactor to a transfer flask, the rod became jammed in the flask in such a way that it could not be cooled. The rod caught fire and disintegrated with a large piece falling on the top of the reactor and a larger (3-ft) piece falling in the maintenance pit adjacent to the reactor. The operating crew managed to cover the burning pieces with sand to stop the fire.

Radiation levels were 50,000 R/h in the pit and from 10 to 1000 R/h on the top of the reactor. Subsequently, vertical surfaces in the building were measured as reading 0.5 R/h.

The sand and large pieces of fuel were pulled onto pallets with long-handled rakes and removed and eventually the interior of the building decontaminated. Six hundred to eight hundred men participated in the cleanup. Seven hundred man-rem of total exposure was accumulated. The maximum dose to any one individual was 19 rem.

Reactor Accidents at Lucens, Switzerland, January 21, 1969

The Lucens reactor was a 30 megawatt thermal experimental reactor sited in a rock cavern. It was heavy-water-moderated and carbon dioxide cooled. A breach in the seal of the carbon dioxide cooling system led to overheating of the fuel and melting of a fuel element. Fission products escaped from the cooling loop into the cavern raising the radiation level to a few hundred R/h. This decayed to a few hundred mr/h after 44 hours. After several days, the atmosphere in the cavern was vented through filters to the exterior. No radiation above permissible levels was released to the environment from this accident.

Future Trends

Many of the radiological emergencies in the past have resulted in large part from the inexperience of the people and institutions involved. In many cases, the accidents occurred at facilities where the main activity was development of nuclear power. As the technology matures, accidents of this type appear to be becoming less frequent. A good example is criticality accidents. There was a hiatus of almost 20 years in these accidents until the one in Argentina last year. As the technology has matured in the industrialized nations, the need for development and exploratory activities has decreased and with it the likelihood of accidents caused by inexperience.

Commercial nuclear power plants are a likely source of radiological emergencies with the possibility for sizeable exposures, both in level of dose rate or the number of people potentially at risk. If reprocessing and waste disposal resume in the United States, they will become potential sources of radiological emergencies.

It is much more likely that those parts of the developing world which are developing nuclear power will have radiological accidents. A major source of concern is the potential for political unrest in these areas and the consequent possibility of military or terrorist attacks on nuclear power reactors. These could result in emergencies involving very high radiation levels and over considerable areas.

OPERATING CONDITIONS

From the accidents just described and others which have occurred, it is possible to specify the range of operating conditions that could be encountered by emergency response and recovery forces in future accidents (these are listed in Table 1).

A high level of gamma radiation is the definitive condition of an accident where a mobile teleoperator can be used to great advantage. Radiation levels up to 10,00 R/h have been encountered (SL-1, Bethesda) over small areas in some accidents. High radiation levels are theoretically possible in accidents involving irradiation facilities, and in acts of war against large commercial power reactors. Doses of a few hundred R/h are encountered over larger areas.

Radiation accidents frequently involve high levels of contamination. Ease of decontamination is a very important property for any machine intended to serve in radiological emergencies.

Criticality accidents, particularly those involving solutions of fissionable material, always involve the potential for additional critical excursions as the systems cool or mechanical disturbances change the geometry of the fissionable material or reflectors around the critical assembly. A critical excursion can produce several hundred to tens of thousands of roentgens in its vicinity, including a lot of high energy neutrons which can introduce transient effects in solid state electronics. Control systems, in addition to being hardened against radiation, should be designed to handle transient radiation effects gracefully.

TABLE 1

OPERATING CONDITIONS

RADIATION: UP TO 10^4 R/H (SL-1, BETHESDA) IN SMALL AREAS; FEW HUNDRED R/H OVER LARGER AREAS

CONTAMINATION: SL-1, TMI

POSSIBLE CRITICALITY: Y-12, SL-1

INERT ATMOSPHERE: ROCKY FLATS DRY ROOM

TEMPERATURE EXTREMES: 50°C AT TMI
-20°C AT SLI

HUMIDITY: 100% AT TMI

CLUTTERED FLOOR: SL-1
(OR OUTDOOR TERRAIN)

STAIRS AND AIRLOCK THRESHOLD: SL-1

CLOSED AIRLOCK DOOR (UMBILICAL): TMI

NO ELECTRICITY

DARKNESS: TMI

One application for a mobile teleoperator would be routine maintenance operations in rooms filled with inert atmosphere as in certain types of fabrication and storage facilities for fissionable materials.

Temperature extremes may range from 50° centigrade inside the containment at Three Mile Island to lower than -20° centigrade encountered outside the SL-1 under normal conditions for January in Idaho.

High humidity coupled with high temperature can be expected inside the containment in a variety of accident scenarios involving light water reactors. Poor footing due to mechanical debris scattered on a floor or poor soil conditions outdoors, are very common in emergencies of all sorts. Any mobile system must be able to negotiate debris and difficult terrain.

A related problem is stairs. Most radiological operations are conducted in buildings with more than one story very often with the floor connected by stairways. The mobile system must be able to manage stairs. A related problem is that many airlocks have thresholds which must also be climbed over.

Many radiological operations are conducted inside some type of containment and the principal access through an airlock. In most emergencies an effort would be made to arrange some type of containment for the affected area of contamination. If the containment included an airlock for access, the machine must be capable of traversing the airlock and closing the door behind it. This would preclude the exclusive use of an umbilical cable for power and/or signal. If a machine is to be able to to enter an area and close a metal door behind it, it must have some form of onboard power and some system for getting command and sensor signals in and out of the containment area.

Loss of electric power and darkness have been experienced in radiological accidents and can be expected in the future. While a machine ought to be able to take advantage of electrical power if it exists in the area, it must also be capable of providing for own light and motive power.

REQUIRED OPERATIONS

A mobile teleoperator must be able to gain access to the area, conduct reconnaissance, carry out such operations as necessary to stabilize the system, and possibly begin the recovery. In order to do this it must have the requisite mobility to handle irregular terrain, climb stairs and traverse cluttered areas. To conduct reconaissance, it must be able as a minimum to transmit t.v. pictures and measure and transmit radiation levels.

A wide variety of tasks may be required to effect stabilization of the accident and begin the recovery operation. These are listed in Table 2 as possible manipulator tasks. These tasks were compiled from conversations with people who have conducted operations in radiological emergencies.

Rescue

Rescue capability in a mobile teleoperator is likely to be of little value in a radiological emergency. Getting a teleoperator into operation would be a task taking from hours, if the machine is available locally, to days if the machine has to be brought in from another facility. Human response in an emergency is likely to take several minutes to an hour. If any casualties are savable, the radiation levels cannot be too high. If the dose to the casualties is to be under 500 R, the dose to human rescuers will be tolerable. Fast-moving volunteers can extricate casualties an order of magnitude more quickly than any machine, reducing the dose to the casualties by a corresponding amount.

However, the recovery of bodies is likely to be a high priority task as it was at the SL-1 incident.

CONCLUSIONS

We have attempted to characterize some of the conditions which might be encountered by a mobile teleoperator intended for service in radiological emergencies. These conditions are based on experience with actual emergencies over the past 40 years. The most severe cicumstances have been very high radiation fields and difficulty of access to the area of the emergency, coupled with complete ignorance of the conditions existing in the emergency area. The fundamental requirement for the machines are mobility in difficult terrain, tolerance for radiation, tolerance for up to the 10^6 R of gamma radiation, and the ability to communicate to the emergency personnel the conditions existing in the emergency area. Only then can the tasks of mobile teleoperation begin.

TABLE 2

STABILIZATION AND RECOVERY MANIPULATOR TASKS

- OPEN AND CLOSE AIRLOCKS
- THROW SWITCHES
- TURN VALVES, HAND WHEELS AND DOOR KNOBS
- INSERT ELECTRIC PLUGS
- BREAK OR CUT HASPS AND PADLOCKS
- PICK UP OBJECTS OFF THE FLOOR OR FROM ELEVATED SURFACES
- PICK UP SAMPLES
- TAKE SURFACE SMEARS
- TAKE LIQUID SAMPLES
- STACK LEAD BRICKS (26 LB)
- CUT AND SEAL PIPES
- OPEN JUNCTION BOXES
- OPERATE A SCREWDRIVER AND SOCKET WRENCH
- OPERATE AN ABRASIVE SAW
- PRY WITH A PRY BAR
- PICK UP FLOOR PLATES

REFERENCES

Bertini, H. W., Descriptions of Selected Accidents that have Occurred at Nuclear Reactor Facilities, NL/NSIC-176, Oak Ridge National Laboratory, Oak Ridge, TN 37831, April 1980.

Chester, C. V., Improved Robotic Equipment for Radiological Emergencies, ORNL-6081, Oak Ridge National Laboratory, Oak Ridge, TN 37831, September 1984.