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ACCIDENTAL RADIATION EXCURSION AT THE OAK RIDGE Y-12 PLANT—II

HEALTH PHYSICS ASPECTS OF THE ACCIDENT*

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Abstract—The information presented here is one part of a series of four articles which collectively describe the accidental nuclear excursion which occurred June 16, 1958, in the Union Carbide Nuclear Company, Y-12 Plant at Oak Ridge, Tennessee. This discussion is submitted for publication in *Health Physics*, the official journal of the Health Physics Society in the interest of further dissemination of information concerning this unique event.

INTRODUCTION

ON June 16, 1958, the first known accidental and unscheduled nuclear chain reaction to occur in an industrial process facility took place in the Union Carbide Nuclear Company Y-12 facility for the recovery of enriched uranium from fuel fabrication scrap and other salvage.

In an incident of this type, the hazard of first concern is not a high order nuclear explosion, but instead the lethal radiation which accompanies the incident. Of secondary importance, but of real concern to those who must combat the hazard, are the radiation after-effects. This discussion proposes to generally describe the conditions encountered during the course of the Y-12 incident and the health physics measures taken to evaluate and regain control of the area.

BACKGROUND

To best understand the Y-12 situation, distinction should be made between chemical processing facilities for the preparation of "cold" enriched uranium, which has relatively little radioactivity, and those designed to recover uranium from "hot" irradiated reactor fuel by separation from the highly radioactive fission products. In the latter case, protection must be routinely provided against the ever-present radiation hazard. Accordingly, such operations are shielded and controlled remotely. These requirements provide, in addition, a certain measure of protection against nuclear accident consequences. In the case of "cold" material, such as that handled in the Y-12 facility, the radiation problem is not acute; thus, the materials and equipment are accessible as a matter of routine. Personnel, in large numbers, frequent the area with relatively free access.

For many years, a successful program of nuclear safety has been carried out in Y-12. This program, while obligated to the principle of preventing even a single nuclear excursion was, and remains, contingent upon human capabilities. Since safety is never absolute, the program assumed that a nuclear excursion could occur. Accordingly, plans were made to provide capabilities to detect and combat such an incident. This plan may be described as follows.

1. *Detection of incident and sounding of alarm*

Although physical damage could occur, one cannot depend upon fuming, boiling, explosion, or a blue glow or haze as the only means for

* The information presented here was taken generously from material gathered and prepared through the unselfish efforts of many people, who contributed to the preparation of report Y-1234, "Accidental Radiation Excursion at the Y-12 Plant".

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detection of a nuclear reaction. Further, prompt action must be taken with a minimum of time lost to make decisions. Accordingly, γ-sensitive radiation detectors have been installed in all areas wherein potential criticality hazards exist. The monitor system in Building 9212, the location of the incident, is composed of six permanently-mounted instruments, a siren system audible throughout the building, and an annunciator system which indicates the location of an activated monitor. Any one of the six monitors automatically actuates the alarm sirens when the dose rate at the instrument exceeds 3 mr/hr. The utility of such a system is the fact that the alarm so given indicates the presence of a radiation hazard and implements emergency action with a minimum of lost motion. It cannot predict a nuclear excursion, and thus is after-the-fact, but it may, through the establishment of a prompt alert, minimize subsequent personnel exposures.

2. *Evacuation of area*

In case of a monitor alarm, quick orderly evacuation by the most direct route away from the processing area is considered to be the best path for the majority of people to follow. In some cases, it may be possible to provide sufficiently flexible evacuation signals so that evacuation routes are *always away* from the scene of a nuclear reaction. In the subject case, however, the former procedure is used due to the complexity of the plant layout, leaving to chance the possibility that any given evacuation path could pass closer to the accident location. By prompt evacuation of the affected area to preselected assembly stations, control over the group is established in case of need for further action.

3. *Initial survey of area and personnel*

β-γ survey meters are maintained in pairs at three locations at the perimeter of the area of concern. Local emergency squads, trained in survey procedures and maintained routinely in all hazardous areas, assemble immediately upon monitor alarm. They collect the instruments provided and survey the assembly areas, moving personnel as necessary to keep them in a radiation zone of less than 5 mr/hr. These teams also check for gross personal contamination ($>$1 r/hr) using the available portable survey instruments. Persons found to be contaminated should have their contaminated clothing removed immediately and should be sent to shower without delay.

4. *Screening of personnel for significant exposures*

Upon verification of the occurrence of a nuclear incident, evacuation of personnel proceeds to selected secondary locations where survey teams monitor badges for indium foil activation and check personal contamination further. As a matter of routine procedure, indium foils have been placed in all security badges for the purpose of quick identification of those persons who may have been exposed to neutron radiation arising from a nuclear reaction. The intent of this procedure is to identify those cases of significant exposure, particularly any which may be serious or critical. Such cases may then be directed to the Medical Dispensary for treatment and/or observation. Facilities for decontamination are available in these locations if needed.

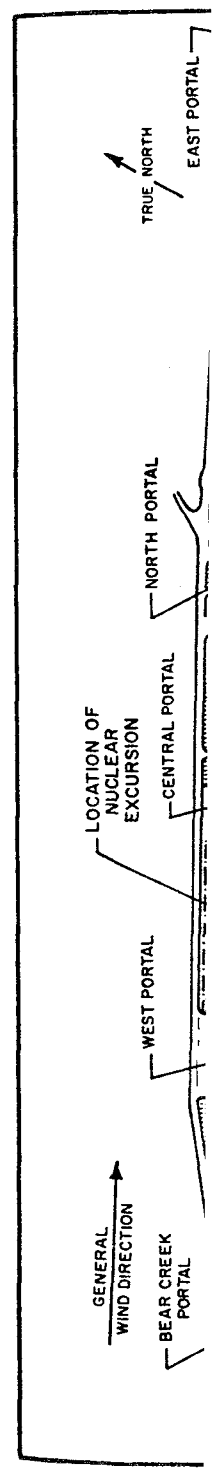
5. *Follow-up area survey and rehabilitation*

As soon as feasible after activation of the plant emergency plan, trained survey teams, which are made available locally and through pre-established mutual assistance plans with others, are dispatched to the radioactive area. These teams monitor toward the reaction location and establish boundary lines at 12.5 mr/hr and 125 mr/hr. Simultaneously, efforts are made to determine the extent of environmental contamination by direct measurements and by air-sampling. Areas found to be unaffected, or within permissible limits, are released for rehabilitation as the surveys progress. Continuing control is exercised over the area until the radiation intensities permit access to the immediate area and suitable disposition is made of the source.

CONDITIONS ENCOUNTERED AND MEASURES TAKEN FOLLOWING THE INCIDENT

Preliminary surveys

At approximately 2.05 p.m., June 16, 1958, sirens of the radiation monitoring system



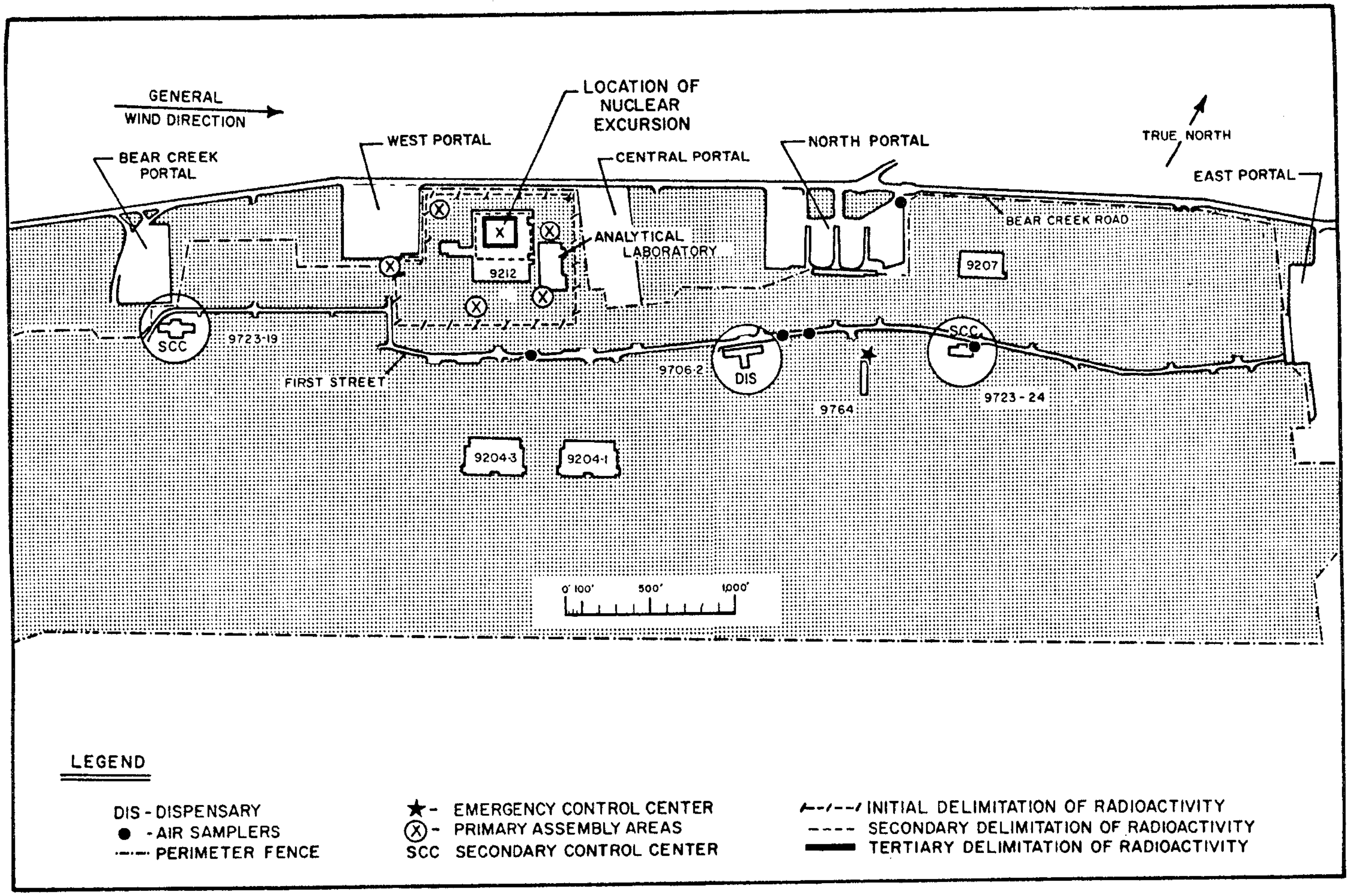


FIG. 1. Location of Y–12 Plant buildings pertinent to incident.

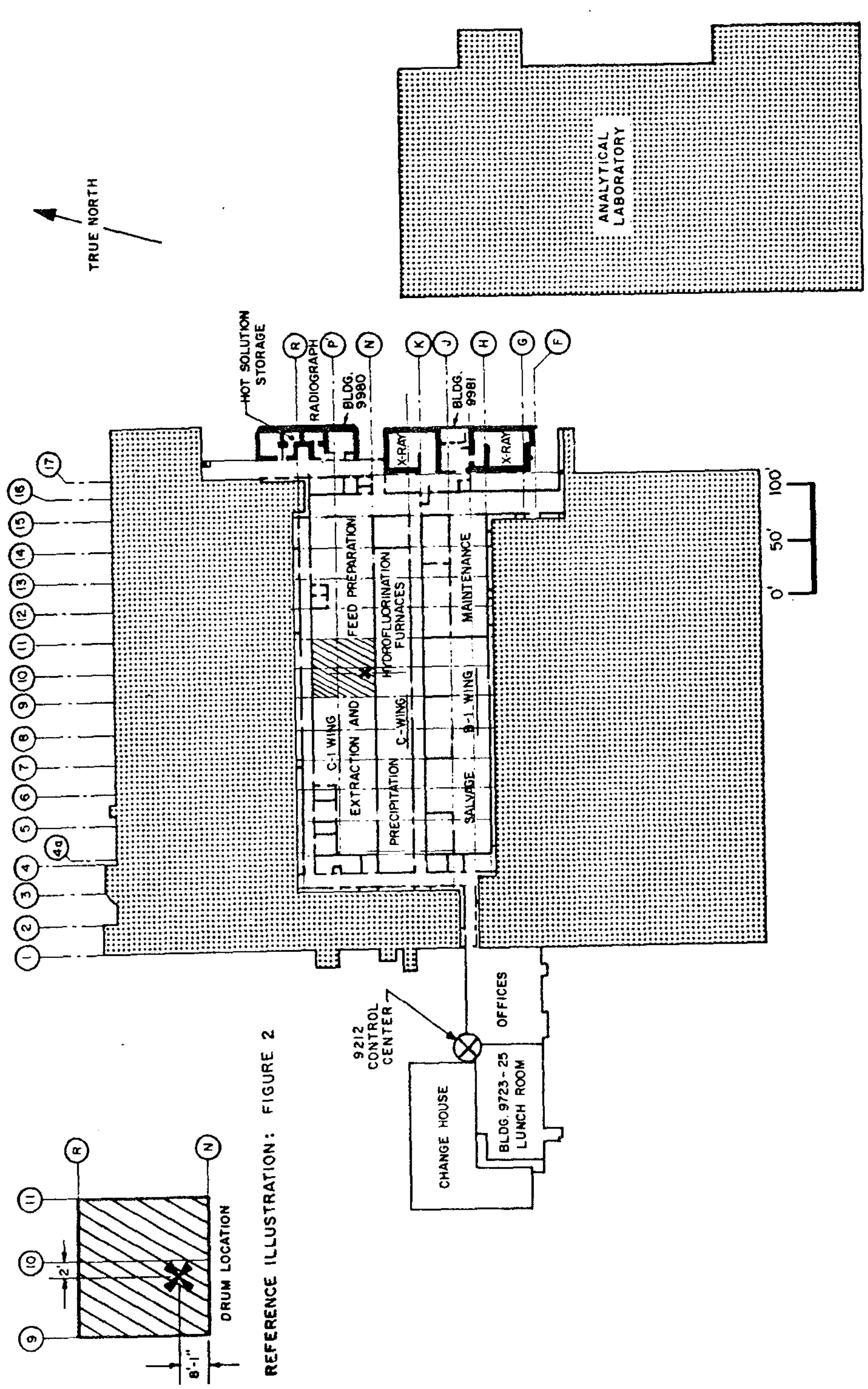


FIG. 2. Location of nuclear excursion, Building 9212.

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sounded the alarm in Building 9212, implementing the building evacuation plan. Immediately, process supervisors, equipped with emergency radiation survey meters detected, and confirmed by multiple readings, radiation intensities of more than 100 mr/hr at the building control center, a distance shown later to be about 350 ft from the location of the accident. The Plant Emergency Director, who was present at the time of the alarm, acted to put the plant emergency plan into effect, thus evacuation of personnel from primary assembly points to secondary control centers proceeded with little further delay (see Figs. 1 and 2 for locations).

The local emergency squad surveyed the west and north ends of the building, observing readings of from 50 to 100 mr/hr. During this same period, radiation was detected by laboratory supervisors at the north end of the analytical laboratory, approximately 400 ft east of the accident scene, at first fluctuating in intensity up to ≈1000 mr/hr and shortly thereafter up to 500 mr/hr. It is perhaps significant to observe that the building is oriented in such a manner that the corridors and operating areas extend in an east–west direction. It is reasonable to assume that less attenuation occurs to the east and west owing to lack of walls and absence of bulky operating equipment. The area is cross-walled and heavily equipped to the north and south.

The radiation detected up to this point made it clear that the incident had occurred within Building 9212 with the precise location yet to be determined. Continuing surveys along the outside of the perimeter fence recorded readings of up to 50 mr/hr for a period of about 20 min, after which time the levels dropped to 5–10 mr/hr.

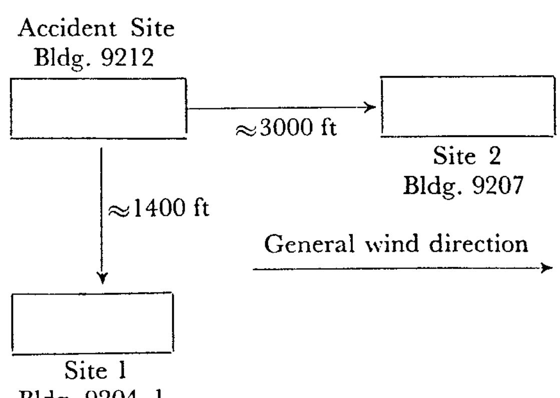
Survey of environs and detection of released activity

Radiation surveys were made of the plant area to obtain an overall evaluation of conditions. Within an hour after the incident, it was determined that there was no direct radiation or significant contamination outside the perimeter fencing, which forms the security area in which Building 9212 is located. This area, approximately 800 ft × 1000 ft, was subsequently marked off as the initial delimitation area.

Efforts were made to survey the environs and detect the release, or subsequent fallout of fission product activity. High-volume air samplers were set up outdoors at five locations ranging from ≈700 ft to ≈3000 ft downwind from the accident. Sampling was not begun until about 50 min after the incident and 20 min after the ventilation supply and exhaust fans for the area involved had been cut off. The samples, obtained by drawing air through Whatman no. 41 filters, were counted for α- and β-γ activity.

These samples indicated a maximum concentration of 2.5×10^{-11} $\mu c/cm^3$ β-γ activity as of the time of collection. This is well below the 10^{-9} $\mu c/cm^3$ permissible level of air-borne activity suggested by the National Committee on Radiation Protection.[1] As would be expected, no significant air-borne α-contamination was detected.

Some indication of air-borne contamination released to the atmosphere may be obtained from inspection of two continuously recording β-γ air monitors which were located as shown in the sketch below. These monitors are Geiger–Muller tube instruments measuring and recording the β-γ emission from particulates collected from an air stream on a fixed filter paper. The tubes are surrounded by the filter and are shielded by $1\frac{1}{2}$ in. of lead.



Both instruments detected the initial direct gamma radiation from the actual excursion and both showed subsequent increases in the level of atmospheric beta–gamma contamination. The

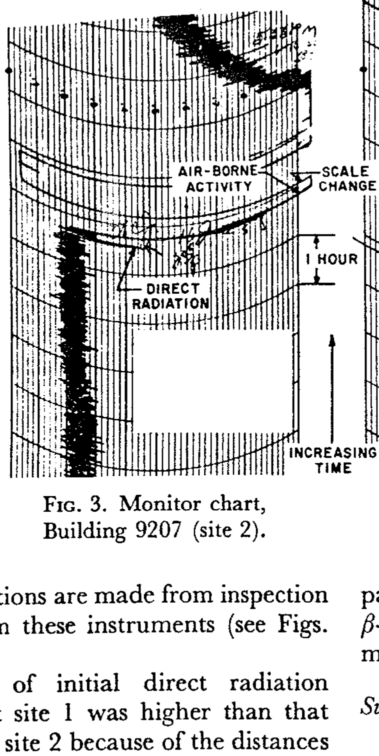


Fig. 3. Monitor chart, Building 9207 (site 2).

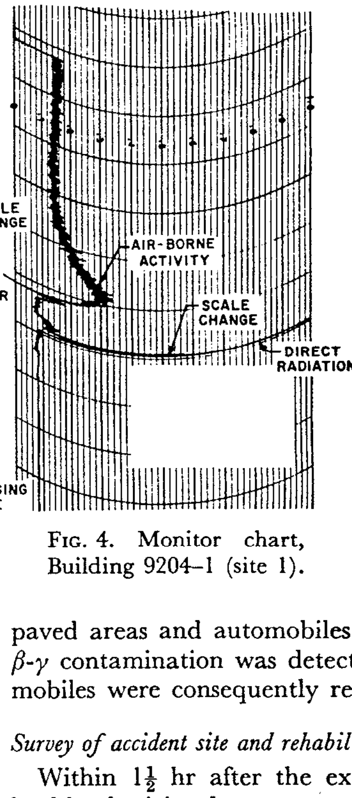


Fig. 4. Monitor chart, Building 9204–1 (site 1).

following observations are made from inspection of the charts from these instruments (see Figs. 3 and 4).

(1) The level of initial direct radiation recorded at site 1 was higher than that observed at site 2 because of the distances involved.

(2) The air-borne contamination, however, reached site 2 much sooner (10 min vs. $\approx$45 min) and in higher concentrations (considerably more than a factor of 3), since it was directly downwind.

(3) Because of the short half-lives of many of the fission products ($<$2 hr) and the relatively short length of exposure of any persons to the contaminated atmosphere, the concentrations detected constituted no acute hazard.

(4) Considering the favorable conditions of wind velocity and direction existing at the time and the levels of concentration detected, it can be stated, with a high degree of confidence, that no significant concentrations of these activities reached nearby populated areas.

Surveys were made of the parking lots along the north side of the plant site, these lots being located generally east and west of the accident area. Spot checks were made on the ground, paved areas and automobiles. No evidence of β-γ contamination was detected and the automobiles were consequently released.

Survey of accident site and rehabilitation of area

Within $1\frac{1}{2}$ hr after the excursion, teams of health physicists began approximating the site of the incident by a series of perimeter radiation surveys. The radiation and contamination levels encountered were quite low, ranging from 0.2 mr/hr at the boundary of the primary delimitation arc to 10 mr/hr at distances of approximately 200 ft from the drum. Although some spillage of materials had occurred in a few areas due to unattended operating equipment, no serious contamination levels were encountered. Boundary limits were adjusted to permit employes to re-enter all areas except those within the secondary delimitation boundary ($\approx$350 ft $\times$ 400 ft) shown in Fig. 1.

Some 3 hr after the incident, an emergency team undertook a cursory survey of the salvage area in which the reaction had occurred. The radiation dose rate itself at the southwest door of this area, a distance of approximately 100 ft from the drum, was 60 mr/hr. When the men emerged, after being in this location for about 10 min, the cannisters of their gas masks read from 10 to 15 mr/hr, indicating that significant concentrations of air-born
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Approximate position
20 ft east of drum
12 ft east of drum
8 ft east of drum
12 ft west of drum
8 ft west of drum
12 ft north of drum
8 ft north of drum
2 ft north of drum

concentrations of air-borne contamination still existed in the area. Radiation measurements, direct and by air-sampling, were continued in the zone proximate to the accident area. Within a few hours, it was possible to relax the restriction boundaries to that area indicated as the tertiary delimitation area in Fig. 1.

Control stations, manned by health physicists and stocked with the necessary items of protective equipment, were set up in the hallways to prevent unauthorized entry into this restricted area. Authorized persons were permitted to enter the controlled zone only in teams of two or more. Each team carried at least two radiation survey instruments. Required protective equipment included coveralls, shoe covers, stocking caps, rubber gloves, and either an MSA "All Service" mask with an ultra-filter or a U.S. Army assault mask M-9 with an M-11 canister. Each person wore direct-reading pocket dosimeters and a film badge and each was surveyed for personal contamination upon return from the controlled zone.

In order to prevent the spread of air-borne contamination from the controlled zone to other parts of the building, a small fan, which exhausted through a CWS filter, was turned on, thus maintaining the area under negative pressure.

A cadmium scroll was inserted into the drum by manipulation of a 10 ft pipe, which was adapted for the purpose. This action provided positive assurance of nuclear safety and permitted a more detailed survey of the area. Such a survey was undertaken with the following results being recorded about 9 hr after the excursion:

Approximate position	Reading* (r/hr)
20 ft east of drum	1.1
12 ft east of drum	4.7
8 ft east of drum	9.8
12 ft west of drum	3.6
8 ft west of drum	8.0
12 ft north of drum	3.6
8 ft north of drum	9.8
2 ft north of drum	81.0

"Wipes" or "smears" of the floor near the drum indicated that surface contamination had been confined to the immediate vicinity of the drum. The highest activity detected on these smears was 250 mrad/hr, direct reading from the smear itself, and 16,000 d/m per 100cm^2 α-contamination. Normal α-contamination usually ranges from 500–1000 d/m per 100cm^2. The fact that the active solution was confined to the drum itself was fortunate since widespread contamination would undoubtedly have seriously hampered reoccupation and rehabilitation of the area.

The drum of poisoned solution was allowed to sit intact until the morning of the second day following the accident. During this time, additional activity measurements of the drum were made. Some indication of the decay of radioactivity is shown below:

Date	Time	Reading (r/hr)	Position
June 16	10.32 p.m.	81	at 24 in., middle of drum
June 17	10.30 a.m.	100	at 3 in., middle of drum
June 18	10.00 a.m.	48	at 3 in., middle of drum

After the immediate nuclear hazard had been disposed of by the addition of cadmium, the problem of removing the highly radioactive solution from the operating area was approached. It was decided to install "safe" tankage in an available radiographic cell some 200 ft east of the drum location and to vacuum transfer the solution via stainless steel tubing into this system, where it would be allowed to decay prior to reprocessing. Monitoring services were provided during the preparation for transfer of the solution to the shielded safe storage vessel.

* All readings were taken with an ionization chamber instrument (cutie pie) approximately 3 ft above the floor with the exception of the last reading. The reading 2 ft from the drum was made at a height above the floor of approximately one-half the height of the drum.

Dosimeters, worn by persons installing the vacuum transfer line indicated that no persons received any appreciable γ-dose (i.e. less than 300 mr) while making these preparations.

On June 18, vacuum transfer of the solution from the drum to the safe containers was begun. Radiation intensities, a few inches from the line, varied from 50 mr/hr to 80 mr/hr during transfer of the solution. During flushing of the drum and line with water, the radiation intensity dropped from 38 mr/hr during the first 5 gal flushing to 5 mr/hr during the second 5 gal flushing. Following this action, the following conditions were noted:

Empty line at exterior surface: 1 mr/hr
Top of empty drum; exterior surface: 5 r/hr
Near bottom of drum, exterior surface: 30 r/hr
(due to sludge in drum)

After the active solution had been successfully transferred to shielded safe storage and the drum removed from the area, the boundaries of the control area were moved in to encompass only the operating wing itself ($\approx$50 ft $\times$ 400 ft). Contamination surveys and air samples were continued. By early afternoon of 18 June, approximately 2 days post-accident, it was determined that the exhaust ventilation fans could be turned on without significantly contaminating the surrounding areas. Subsequent air samples were well within permissible levels; personnel were then allowed to enter the accident area without respiratory protection.

Decontamination of the area proceeded as the area was released by the investigating authorities. Routine monitoring and smear surveys were made to help direct and evaluate the decontamination efforts. On 23 June, 1 week after the accident, all facilities were returned to normal operations.

SURVEY OF PERSONNEL FOR RADIATION EXPOSURES

Since 1955, strips of indium foil (approximately 1 g each) have been included in the security badges of all employees at Y-12. The purpose of these foils is to provide a quick positive means for segregating employees who receive a significant radiation dose in the course of a nuclear reaction. This determination is accomplished by the measurement of β- and γ-radiations from the radioactive In^{116} isotope which is produced by neutron irradiation of the stable In^{116} isotope in the foil.

Following assembly of personnel at the two secondary control centers, checking for neutron activation of the indium foil in their badges and for evidence of personal contamination was undertaken. Those persons whose badges gave evidence of possible high neutron doses were directed to the dispensary for further tests and medical attention. As a result of this process, twelve persons out of approximately 1200 surveyed were sent to the dispensary within 2 hr after the incident. The maximum reading observed during these checks was 60 mr/hr. In the five most significant cases, badge readings exceeded 20 mr/hr 2 hr after exposure.

In order to insure that exposure cases had not been overlooked, badges were collected at the gates when personnel were released and each badge was subsequently processed. In the course of these and the prior badge checks, about 4500 activity readings were made.

Those persons who were sent to the dispensary were checked for personal contamination, interviewed briefly, and their badges rechecked. Individuals showing evidence of β and γ body contamination were scrubbed at the dispensary decontamination facility with soap and water and mild acids.

No attempt will be made to further describe the details of the evaluation of personnel exposures since this information will be treated more fully in other parts of this series. Suffice it to say that the use of indium foil in the security badges made possible the early identification of employees who had been in the immediate vicinity of the reaction and facilitated their segregation from unexposed employees. A possible unmanageable flood of employees to the dispensary was thereby forestalled.

SUMMARY

The Y-12 critical incident was unique and began suddenly. Of particular note is the fact that the radioactive solution which comprised the reactor fuel was well contained within the reactor vessel, thus no extensive decontamination of persons or facilities was required. Further-

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the distribution of fission products to the environs was limited so that no serious complications were encountered in the plant area. The seriousness of the incident was lessened by the fact that no physical violence was involved in the reaction. Rehabilitation of the area and resumption of activities were possible in a minimum amount of time. Identification and segregation of all seriously-exposed personnel was accomplished with reasonable dispatch. In this respect, the use of indium foil as an identification medium was proven to be successful.

It should not be inferred that the conditions encountered in this incident are characteristic of the consequences to be expected as a result of future nuclear accidents. Rather, in view of a number of unique, fortunate circumstances which reduced the Y-12 problem significantly, it is reasonable to assume that consequences in other cases could be much more severe.

REFERENCES

1. *Maximum Permissible Amounts of Radioisotopes in the Human Body and Maximum Permissible Concentrations in Air and Water*, National Bureau of Standards, Handbook 52 (1953).