This barrel . . .

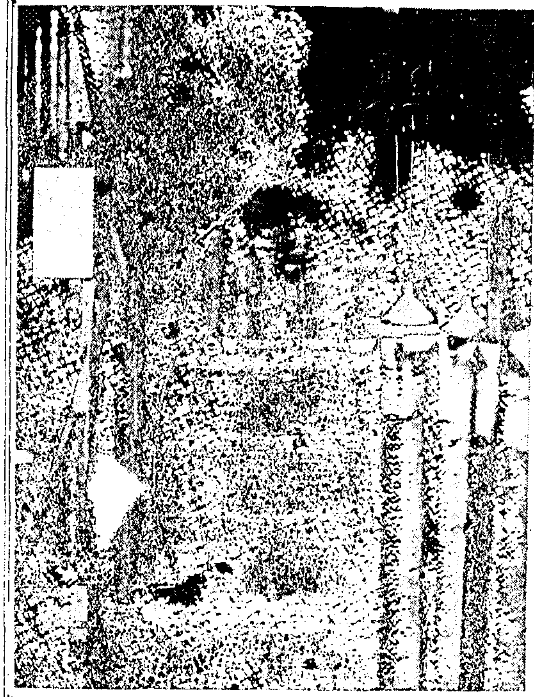

FIG. 1. Actual 55-gal drum in which excursion occurred. Critical amount of uranyl nitrate solution was introduced through plastic tube

. . . went critical in this system . . .

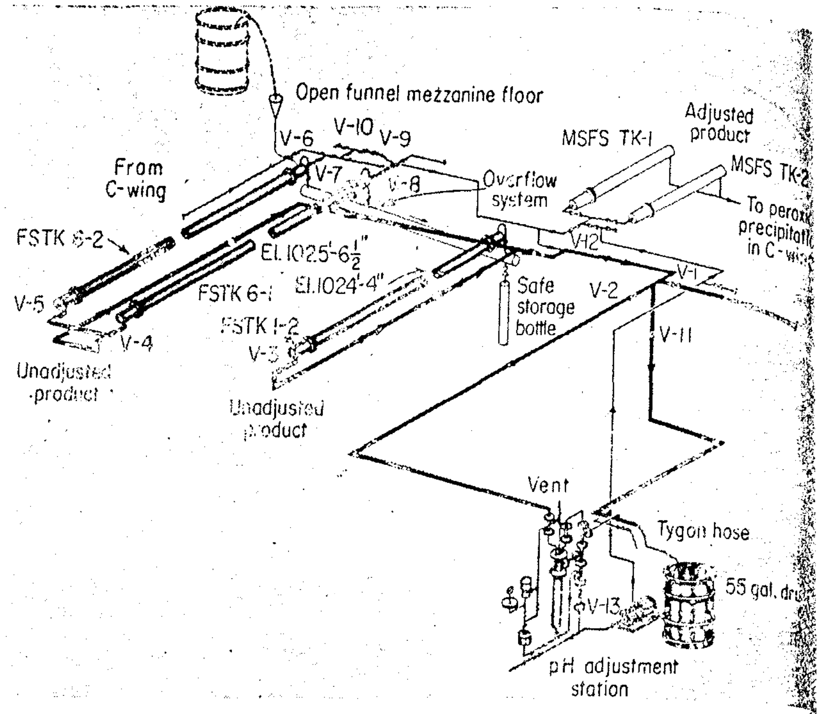

FIG. 2. Solution of 90%-enriched uranium was inadvertently introduced into "safe" tank FSTK 1-2 and piping connecting tanks 1-2, 6-1 and 6-2. Subsequently, 6-1 and 6-2 were filled with water through funnel for leak testing. When drain line was opened, enriched solution preceded water into drum

Oak Ridge Y-12 Accident

Adjoining are extracts from the final report (Y-1234, Y-12 Plant, Union Carbide Nuclear Co.) of the committee appointed to investigate an accidental radiation excursion at the Y-12 Plant. This incident was described as "the first nuclear excursion to have occurred in a uranium processing facility."

Publication of this report reflects the intention of NUCLEONICS to publish such information when it is available. Reports of two earlier incidents —Windscale and M. W. Kellogg —appeared in the December, 1957, NUCLEONICS, p. 41. In this way, it is hoped to contribute to the understanding of the nuclear industry by relaying experience gained and by enlightening the public.

AN ACCIDENTAL nuclear excursion occurred in the Y-12 Plant at approximately 2:05 p.m. on Monday, June 16, 1958. The following remarks summarize information obtained by the committee appointed to investigate the accident:

1. The site of the accidental nuclear excursion was a 55-gallon stainless steel drum located in the C-1 Wing of Building 9212 [Figs. 1–3] . . . .

2. On the basis of the available data, the following sequence of events is postulated as leading to the incident: a portion of enriched (~90% U^{235}) uranium-bearing solution, containing approximately 50 gm U^{235}/liter, flowed through a valved pipeline from an extraction product "safe" tank in B-1 Wing into C-1 Wing and partially filled "safe" tank 1-2 as well as the piping connecting tanks 1-2, 6-1 and 6-2 [Fig. 2] . . . .

Subsequent to this inadvertent transfer, tanks 6-1 and 6-2 were partially filled with water for purposes of routine leak testing following the monthly inventory clean-out.

When the valve on the drain line leading to the drum shown in [Fig. 1] was opened, the enriched uranium solution in tank 1-2 and the connecting piping preceded the water from tanks 6-1 and 6-2 into the drum causing the incident.

3. Following the initial nuclear burst which did not discharge the contents of the drum, the nuclear system appears to have oscillated. The reaction was ultimately stopped by the additional water flowing into the drum. Based upon an examination of the chart taken from a recording monitor located in another building and other indicative information, it is believed that the nuclear reaction lasted approximately twenty minutes.

4. Upon the sounding of the radiation monitor alarm siren, plant emergency procedures were put into effect.

By 5:00 p.m. of June 16, radiation survey teams established that the incident had in fact taken place in a drum located in C-1 Wing of Building 9212. At approximately 9:30 p.m., the drum was poisoned by the insertion of a cadmium scroll. Clean-up of all Building 9212 areas except C and C-1 Wings was begun during the night of June 16. During the night of June 17, a "safe" tankage facility was fabricated and installed in one of the Building 9212 shielded radiograph cells, and the contents of the drum were transferred to this improvised storage site during the afternoon of June 18. The empty drum was then transported to ORNL for analysis.

. . . Five men received medium radiation doses

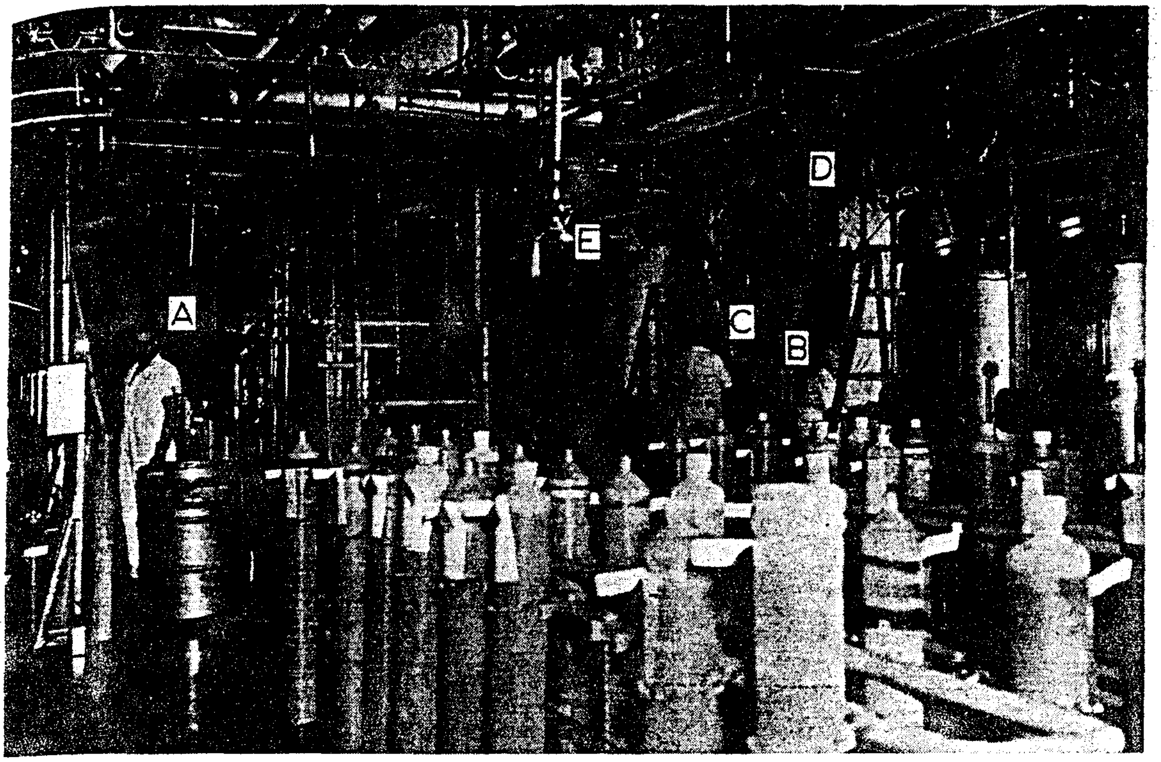

FIG. 3. Re-enactment of positions of employees receiving highest doses; employee A stood behind drum of reactant solution. Doses and distances from center of solution were: A—365 rad (461 rem), 6 ft; B—270 rad (341 rem), 15 ft; C—339 rad (428 rem), 17 ft; D—327 rad (413 rem), 16 ft; E—236 rad (298 rem), 22 ft

Excursion, June 16, 1958

Clean-up activities were continued, and by the morning of June 19, all recovery facilities with the exception of those in the central and east portion of C-1 Wing were put back in operation.

In the afternoon of June 20, a team consisting of members of the investigating committee, UCNC operations and development supervision moved into C-1 Wing and carried out a program of dismantling, sampling, inspection and hydraulic testing. As of June 23, after all available raw data had been gathered to the satisfaction of the investigating committee, all recovery facilities were returned to normal operations.

5. Eight Y-12 employees were in the vicinity of the drum at the time of the incident. Five men [were] exposed to what has been described as a medium dose of radiation by Dr. Marshall Brucer, Chairman, Medical Division, Oak Ridge Institute of Nuclear Studies. . . . The positions of these men are portrayed in [Fig. 3]. The other three men were exposed to [lower doses of 68.5 rad (86.5 rem), 68.5 rad and 22.8 rad (28.8 rem)].*

Following the accident, these men were hospitalized at the Oak Ridge Institute of Nuclear Studies where specialized medical attention was provided. The employees [receiving the low doses] were released from the hospital on June 26, 1958, and allowed to resume their normal activities. [The other five] were released on July 30, 1958.

6. The neutron and gamma radiation of personnel whose indium foil badges indicated significant exposure was determined by measuring the Na^{24} in the bodies of those exposed. This was done in two ways: (a) by counting blood samples, and (b) by counting the total body in a whole body counter. The neutron and gamma doses measured in a mock-up of the excursion, carried out in the ORNL Critical Experiments Laboratory on June 18, provided necessary data to which the Na^{24} values could be related. . . .

7. Although it is unlikely that any future accidental nuclear excursion would exactly duplicate the incident sustained at the Y-12 Plant, there are certain aspects which would be common to all incidents. . . .

Findings

Causes of the incident. It is believed that this accident was caused by a number of interdependent contributing circumstances. Although of uneven weight, no single happening can be said to be a principal contributor. . . .

1. The process phase in which the accident occurred was a temporary arrangement encompassing portions of a new installation in the startup stage (B-1 Wing), and an old installation in the shutdown stage (C-1 and C Wings). This arrangement was necessitated by delays in the activation of new facilities in B-1 Wing for the conversion of uranyl nitrate solution to uranium tetrafluoride.

This temporary arrangement of old facilities combined with part of a new installation was a compromise between the customary detailed design planning of valving, instrumentation, and other safeguards, and a requirement for maintaining production during this interim phase. Also, the responsibility for the uranyl nitrate to uranium tetrafluoride operation was thereby split among three different supervisors in three physically separated areas, instead of being under a single supervisor as would be the case in the completed B-1 Wing. Communications were considerably complicated by this situation.

2. At the time of the incident the uranium

* . . . First collision total dose [is] in rads and estimated RBE dose in rem, with an assumed RBE = 2 for fast-neutron dose.

processing areas had been concerned with the required monthly accounting of uranium in inventory, which necessitated a stoppage of operations. However, all operations were not stopped or started at the same time due to the complexity of the installation. The method of taking inventory varied with the form and concentration of the uranium. For example, where equipment contained dilute homogeneous solutions of uranium, a satisfactory accounting could be made by taking samples and computing the contents of known volumes.

In the process phase wherein the accident occurred, because of the high concentration of the uranium and the tendencies of the solutions to deposit uranium-bearing solids, more precise accounting is obtained by processing the contents of the 5-in.-diameter "safe" geometry tanks to uranium tetrafluoride just prior to the inventory period. In addition, it was recognized procedure to wash, dismantle and swab out these 5-in.-diameter "safe" tanks, collecting the washings in portable plastic "safe" bottles. . . .

As reassembled "safe" tanks were prone to leak at the tank ends when placed back in service after the monthly inventory cleanup, leak testing of reassembled tanks by filling with water, checking and draining prior to their return to operation, was practiced. Leak testing with water was among the . . . routine duties that were not formalized and were carried out under the discretion and supervision of the process foremen.

Although this leak testing had considerable utility, as practiced it deviated from the intent of two mandatory area procedural rules by the incorporation of a 55-gallon drum to collect water drained from "safe" tanks after the leak testing. These rules are:

(a) Process liquids are never to be transferred from a geometrically "safe" container to a geometrically "unsafe" container.

(b) "Unsafe" containers used to collect dilute liquids (such as mop water) must contain a charge of cadmium nitrate (a nuclear poison).

An unfortunate interpretation of the above rules was that they did not apply to the leak testing of the 5-in.-diameter "safe" tanks, since the tanks were clean and only water was used in the operation.

The significance of the foregoing, with regard to the accident, is that it furnished the mechanism whereby an "unsafe" geometry container (i.e., the 55-gallon drum) was separated from concentrated uranyl nitrate solutions by only a single valve (V-1).

3. The dismantling, cleaning, reassembly, and subsequent leak testing of the C-1 Wing "safe" tanks involved a number of different employees, including both maintenance personnel and chemical operators, and usually required several eight-hour shifts for completion. Under these circumstances, it is evident that good communications were necessary.

The leak testing practice included the following pertinent routine safeguards:

(a) The process foreman in charge assures himself, by reference to the operating log and by discussion with the preceding shift foreman, that the tanks to be tested have actually been disassembled, cleaned, and reassembled.

(b) The process foreman, either personally or through instructions to his operators, checks all valves connecting the tanks to be tested with other process areas and determines that their position is correct. In addition, the pneumatic liquid level indicators are checked to determine that the tanks are empty.

(c) During the draining of the leak test water from the "safe" tanks into a container (i.e., in this case a 55-gallon drum), an operator is stationed adjacent to the container to observe the flow of water, and safeguard against any unusual development. . . .

Early during the shift preceding the accident (11:00 p.m. Sunday, June 15, to 7:00 a.m. Monday, June 16), the process foreman (Foreman "Y") in charge of C-1 Wing noted that solution (wash water) was present in the 6-in. glass standpipe of the C-1 Wing *p*H adjustment station and directed one of the chemical operators to drain this liquid. At 5:00 a.m. Foreman "Y" again noted liquid in the glass standpipe and questioned the forementioned operator as to whether his previous order had been carried out. This operator stated that the standpipe had been drained. Upon investigation, Foreman "Y" found that solution was slowly leaking through valve V-2. Foreman "Y" tightened this valve, stopping the leak. . . . Foreman "Y" was aware at the time that the B-1 Wing secondary extraction systems were in operation producing uranyl nitrate product, but believed that the leak testing of the 6-1, 6-2, and 1-2 tanks had been completed on the previous Friday.

The closing of valve V-2 allowed the uranyl nitrate solution, which had been leaking into the *p*H adjustment station standpipe, to back up into the C-1 Wing "safe" geometry storage tanks. . . .

At 7:00 a.m., June 16, Foreman "X" relieved Foreman "Y." The accounts of whether Foreman "Y" notified Foreman "X" of the above mentioned uranyl nitrate leakage are conflicting. In any event, no mention was made of it in the operating log.

At 8:00 a.m., Foreman "W" came on duty. One of his jobs was to complete the leak testing of the C-1 "safe" tanks including tanks 6-1, 6-2, and 1-2. He assigned Operators "A" and "J" to this work. Foreman "W" was completely unaware of the circumstances of the uranyl nitrate leakage observed on the previous shift. He was, however, quite certain that the "safe" tanks 6-1, 6-2, and 1-2 had been dismantled and cleaned during the previous week and that no operations had been started in C-1 Wing since that time. This information had been logged and had also been given him on the preceding Friday by Foreman "U."

On the basis of this previous knowledge, Foreman "W" did not deem it necessary to check the tank level indicating panel nor did he attach any significance to the open or closed condition of valve V-3 at the bottom of tank 1-2 during his piping check. Being aware of the fact that B-1 Wing was in operation, he did, however, instruct Operator "J" to check valve V-1 in the line from B-1 Wing. Furthermore, Operator "A" was stationed at the 55-gallon drum during the "safe" tank draining operation.

Subsequent investigation indicated that valve V-3 at the bottom of tank 1-2 was open and that this tank contained a substantial quantity of concentrated uranyl nitrate solution. This solution had leaked from B-1 Wing through valve V-1 between Sunday night and 1:30 p.m. Monday when Operator "J" checked valve V-1 and applied pressure to the handle to assure positive closure.

4. Shortly before 2:00 p.m., the leak testing of tanks 6-2 and 6-1 having been performed by Operators "A" and "J," Operator "J" opened drain valve V-11 to empty these tanks into the 55-gallon drum and temporarily left the C-1 area. Operator "A" remained by the drum. At 2:05 p.m., an accidental nuclear excursion took place in the drum. Subsequent investigation has established the following facts:

(a) The excursion took place after the concentrated solution in the drum had reached a height of 9 inches.

(b) It appears that this solution came from tank 1-2 into which it had previously flowed from B-1 Wing. This was indicated by hydraulic tests. . . . which showed that liquid drains from tank 1-2 in preference to liquid in tanks 6-1 and 6-2; it was supported by chemical analysis . . . which showed the liquid in tanks 6-1 and 6-2 to have contained a negligible amount of uranium while a sample of residual solution removed from tank 1-2 contained approximately 35 g U^{235}/liter.

(c) The leak test water from tanks 6-1 and 6-2 followed the concentrated solution from tank 1-2 into the drum and approximately twenty minutes after the beginning of the excursion, when the level in the drum had reached a height of 14 to 16 inches, this additional water caused the nuclear reaction to subside.

5. Operator "A," an experienced man (one year of college training, six years in uranium processing operations), was adjacent to the 55-gallon drum observing the slow flow of liquid. The previously mentioned hydraulic experiments, performed after the accident, established that approximately a quarter of an hour was required for the liquid in the drum to reach the level at which it became critical. In addition, the yellow color of concentrated uranyl nitrate is distinctive and was well known to Operator "A." It would thus appear that Operator "A" had an opportunity to shut off the flow of solution prior to the accident.

Radiation alarm system. The utility of radiation detection instruments can be summarized by stating that they are important after an accident in indicating the radiation hazard then prevailing, but in general, they have no value in predicting that a nuclear excursion is imminent.

There were six radiation alarm monitors in the general area of Building 9212 which encompassed the site of the accident. These monitors actuated alarm sirens when the dose rate at the instrument exceeded 3 mr per hour. However, in tests subsequent to the accident, it was determined that a period of 3 to 5 seconds was required, after actuation of the radiation monitors,

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Oak Ridge Incident

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for the alarm sirens to reach audible speed. The first several seconds are the period of greatest danger to a criticality accident.

Since the emergency procedure specifies that personnel should leave by the nearest building exit and since the radiation monitors are not capable of pinpointing the site of an accident, the possibility exists that personnel could receive serious additional exposure if the source of radiation were near an exit. . . .

Conclusions

Causes of accident. This accident is not attributable to the action of any single individual, but rather, it arose out of a combination of circumstances involving the character of the facilities as well as the behavior of individuals.

An abstract, yet significant, contributing circumstance was the interim status of the enriched uranium recovery facilities as discussed in the section entitled "Findings." For example, the fact that the facilities for converting concentrated uranyl nitrate into uranium tetrafluoride were spread over three areas seriously compounded the communications problem. Furthermore, C-1 Wing had for years been operated under the principles of administrative batch control of nuclear safety. The extensive use during these years of equipment not of "nuclearly safe" dimensions due to its size and shape had previously conditioned plant personnel to the unchallenged acceptance of a 55-gallon drum in the leak testing of the C-1 Wing "safe" tanks with water.

In addition, the complete exchange of significant information among personnel was not assured, nor was the potential significance of several observations, now recognized as highly pertinent to the occurrence, adequately appreciated.

It is highly likely, if not certain, that the accident would not have occurred in the absence of any one of several factors. Among these are the use of the 55-gallon drum, the inadvertent flow of unidentified solution between areas, and the subsequent drainage of this solution into the 55-gallon drum without recognition of its composition.

It seems reasonable to conclude that the accident resulted largely from an accumulation of observable physical conditions which, though unknown in full to any individual at the time, should have prompted preventative action.

The committee also concludes that, although the environment in which this event took place and the performance of some individuals might have been improved, a nuclear accident will always be within the realm of possibility whenever potentially critical quantities of fissionable material are being handled.

Nature of accident. The accident took place as a result of the inadvertent introduction of concentrated uranyl nitrate solution into a 55-gallon drum. The energy release concomitant with the accident occurred during an interval of minutes in which the effective reactivity and the power level oscillated a number of times. The nuclear reaction was ultimately stopped by the additional flow of water into the drum. No solution was forcibly expelled from the drum during the power evolution, other than an aerosol. It is evident from a review of the accident that very slight differences in any one of several controlling factors could have resulted in an energy release several orders of magnitude greater than that observed. The energy release was however, about ten times greater than that resulting from previous accidents of this type.

Emergency procedures. The emergency procedures previously established to provide for incidents of this nature and magnitude are considered to have been adequate. The number of people involved over large areas, as might be expected, introduced a degree of confusion, causing some delay. However, work progressed, information was obtained and coordinated, and the basic principles of the emergency plan (that is, personnel evacuation, personnel monitoring, medical assistance, and radiation area isolation) progressed in a satisfactory manner.

Dosimetry. The sodium activation of the blood provided the best estimate of the radiation dose received by exposed personnel. The indium foil in the badges carried by the Y-12 employees enabled health physics personnel to quickly and efficiently identify highly exposed employees and make preliminary estimates of the magnitude of the doses.

Recommendations

It is recognized that extensive study and evaluation are required to improve existing radiation control practices and procedures if such action is to be taken without (a) establishing unduly rigid controls which would seriously interfere with operating efficiency, or (b) embarking on large expenditures for equipment and facilities which might be of only minor assistance in preventing or coping with a similar incident in the future. Accordingly, a study group, composed of representatives from AEC installations operated by the Union Carbide Nuclear Company and the Goodyear Atomic Corporation, has been established. Its mandate is to develop detailed recommendations regarding means of avoiding the occurrence of radiation emergencies and of providing adequate preparation for handling such emergencies if they do occur. Subjects being considered include: equipment design philosophy, operating procedures, nuclear safety education, radiation detection and warning devices, dosimetry, and emergency planning.

Nevertheless, the committee feels that, in keeping with the purpose of this investigation, the following general recommendations should be made at this time in the hope that they may be applicable and of value to other processors of fissionable materials.

Equipment design philosophy. Nuclear safety often can be enhanced without compromising economy by the extension of present control methods and, perhaps more significantly, by the utilization of other well-known nuclear concepts which thus far have not been extensively applied to production operations. Examples of these methods are included in the following recommendations:

1. Within the bounds of economic practicability, nuclear safety should be incorporated in the design of the equipment, taking full advantage of the characteristics of the material and process.

2. Within the same bounds of economic

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practicability, if materials of different isotopic enrichment are to be processed simultaneously or in campaigns in a single facility, the entire facility should be designed for the highest level of enrichment.

3. Transfers from a processing train which relies for nuclear safety on equipment construction to one which relies on administrative control should be avoided unless no practical alternative is available. These transfers, if made, must be conducted under extremely rigid control conditions. For example, no single analytical determination should be depended upon for the limitation of a batch size.

An investigation of the use of fixed neutron absorbers in process equipment to implement nuclear safety should be actively pursued. The properties to be investigated should include the necessary configuration and concentration of the absorbers and their mechanical and chemical stability. Information from such tests will allow future design decisions to be based on economic and technical considerations.

Operating procedures. The use of portable unsafe containers in operating areas incorporating "safe" processing equipment should be held to an absolute minimum.

The means of communication between shifts, between operating and maintenance groups, and between production and staff groups should be more highly formalized than is customary in the chemical industry.

Nuclear safety and health physics education. It is recommended that the importance of nuclear safety in fissionable materials processing plants be restated and re-emphasized periodically to all personnel working in the processing areas. Although primary dependence for nuclear safety lies in equipment or procedural restrictions, it is clear that only by creating a constant awareness of nuclear safety can unusual and unexpected circumstances be viewed in terms of their possible nuclear hazard.

Likewise, management and all plant personnel should be reinstructed periodically in the health physics aspects of potential nuclear emergencies.

Dosimetry and radiation detection. The incident has underlined the urgent need for personnel dosimeters at installations which handle fissionable materials. Records of dosimetric findings should be kept for each individual. Only by requiring that the best dosimetry available be employed routinely can one insure that accurate dose values will be obtained in case of accidents. It is recommended that a single personnel dosimeter packet be used.

1. The personnel dosimeter should be capable of measuring both the gamma and neutron dose. A film type badge dosimeter which fulfills these requirements is available. It contains the following: (a) A film sensitive to gamma energies ranging from a few milliroentgens to thousands of roentgens. (b) An NTA film pack and approximately 1 gram of sulfur for fast neutron detection. (c) Indium foil for rapid identification of individuals who received appreciable neutron doses. (d) Bare- and cadmium-covered gold foils for slow neutron detection (the gold permits scanning over several days).

Where economically feasible, Hurst threshold detectors in addition to appropriate gamma detectors should be located at the various danger points. The threshold detectors would be used to establish the spectral distribution of neutrons in the neighborhood of an accidental excursion and the gamma detectors would aid in establishing the ratio of the gamma and neutron yields.

2. Sampling procedures should be established to determine neutron activation of the persons and possessions of exposed individuals. The activation of blood sodium . . . is particularly valuable in this connection. A whole body counter should be used for the scanning of large numbers of people and for the rapid assay of large volumes of low level liquids.

3. A competent, well-informed health physics group, vested with a reasonable degree of authority, is vital in properly coping with the aftermath of a nuclear accident.

Emergency planning. Any facility concerned with the processing of fissionable materials should have a detailed emergency plan. This plan should closely coordinate all plant emergency activities and, in applicable areas, close interplant coordination should exist. Trained local and plant emergency squads should be maintained, and the emergency plan should be given thorough testing and periodic review to maintain its adequacy.

As a minimum, this plan should ensure that adequate provisions are made for the following points:

1. Immediate alerting and evacuation of personnel.
2. Adequate communications including an information control center.
3. Prompt location of the affected area.
4. Location, monitoring, decontamination, and medical treatment of personnel involved in the incident.
5. Control of re-entry to the affected areas.
6. Adequate identification for prompt access of emergency personnel.
7. Mobilization of adequate transportation facilities.

Approach of near critical solutions by personnel. The following recommendation is made governing the approach of a near critical solution of U^{235} by personnel. The recommendation is based on the analysis of the effect on the solution reactivity of the neutron reflection by a simulated human body. . . . A vessel containing solution in which a nuclear accident has recently occurred should be approached no nearer than five feet, and the number of persons at this distance should be limited to one. This person should be equipped with both neutron and beta-gamma survey meters, the former of a type which is operative in a high-level gamma-ray field. If only a gamma monitor is available, a person should remain at the 5-foot distance a maximum of 10 seconds to avoid possibly incurring significant radiation exposure. This exposure is in addition, of course, to that from the delayed gamma rays which may impose additional limitations on the minimum approach distance. It is emphasized that this recommendation is applicable only to incidents stemming from nuclear excursions in aqueous solutions of fissionable materials. It does, however, include a safety factor of more than two on the result of the analysis.