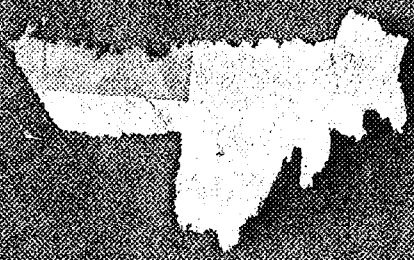
NUCLEAR SAFETY



A Quarterly Technical Progress Review

Prepared for DIVISION OF TECHNICAL INFORMATION, USAEC, by
Wm. B. COTTRELL, W. H. JORDAN, and ASSOCIATES, OAK RIDGE NATIONAL LABORATORY

June 1963

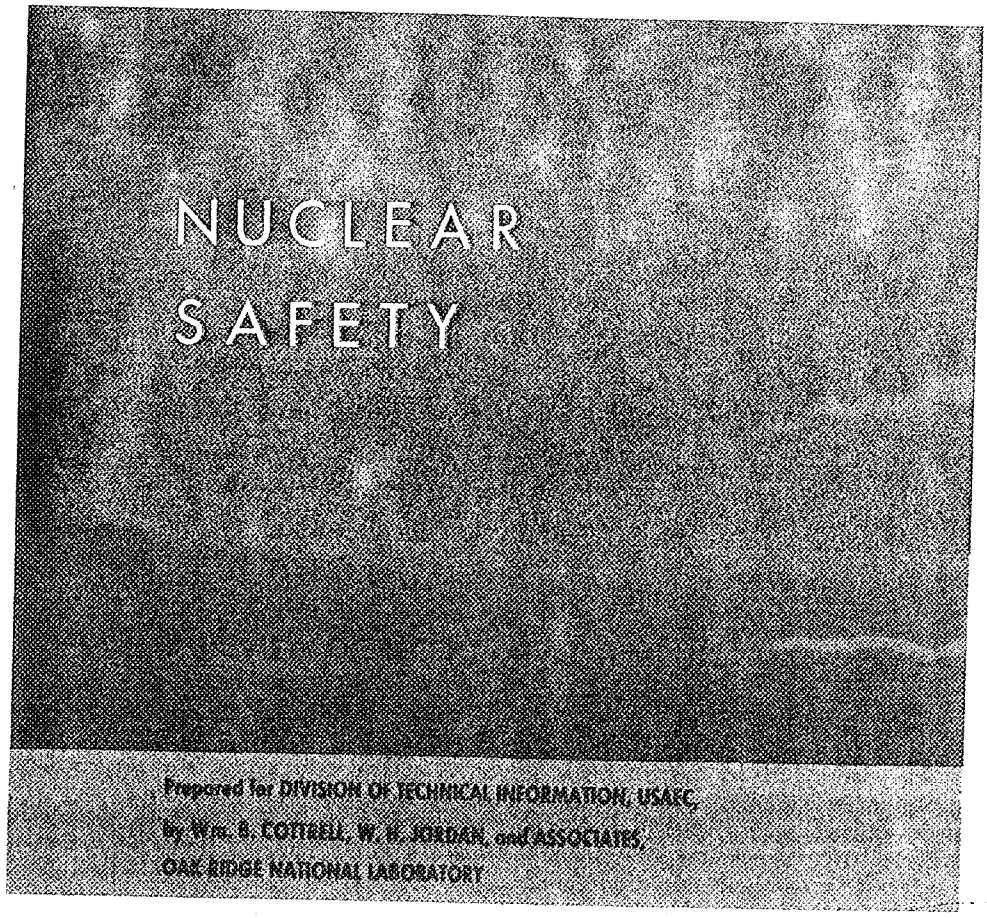
TURE ARTICLE:

Reliability of Reactor Control Systems

● VOLUME 4

● NUMBER 4

NUCLEAR SAFETY



Prepared for DIVISION OF TECHNICAL INFORMATION, USAEC,
by Wm. B. COTTRELL, W. H. JORDAN, and ASSOCIATES,
OAK RIDGE NATIONAL LABORATORY

JUNE 1963

VOLUME 4

NUMBER 4

ment of regulatory requirements at the level, and only in the detail that is really necessary from a safety standpoint, will continue to be an objective in operation of the ship.

Accidental Nuclear Excursion in Recuplex Operation at Hanford in April 1962

By D. Callihan

Criticality was accidentally achieved at about 11 a.m. on Saturday, Apr. 7, 1962, in essentially unshielded plutonium-recovery equipment at the Hanford Atomic Products Operation (HAPO) of the General Electric Company. A volume of plutonium solution, which had been separated from the uranium and fission products with which it was associated earlier, was drawn by vacuum into a cylindrical vessel where it became supercritical. Oscillations between supercritical and subcritical apparently followed during the succeeding 37 hr and generated 8×10^{17} fissions. Dosimetric observations showed that three employees near the site of the accident received exposures to neutron and gamma radiation totaling 110, 43, and 19 rem, respectively. No clinical symptoms attributable to these exposures have been observed. None of the 19 other persons in the building received more than 2 rem. These exposures are not inconsistent with the plausible power-vs.-time pattern of the excursion, which was developed from the nuclear properties of the materials concerned and an estimate of their quantity and their location. The power excursion caused no rupture of process lines or damage to equipment, and the plutonium contamination problem, which is normally present in these operations and requires that the equipment be provided with containment barriers, was in no way aggravated by the accident. The following discussion of the nuclear power excursion is a summary of the report[14] of the investigating committee that was appointed by the Manager, Hanford Operations Office, AEC, and was composed of staff members of the Hanford Operations Office and HAPO. The discussion also includes additional information obtained by personal communication with the Hanford staff.

It is interesting to observe that this is the fifth criticality accident to occur in chemical operations within the history of nuclear energy in the United States. The first of these was at the Oak Ridge Y-12 Plant[15–19] in mid-1958. Another occurred at the Los Alamos Scientific Laboratory,[20,21] and two occurred at the Idaho Chemical Processing Plant, National Reactor Testing Station.[22–25] In the first two accidents, operations with unirradiated fissile material were being directly performed by personnel, as was also true in the Hanford accident, whereas the Idaho accidents were in remotely operated well-shielded equipment for processing irradiated reactor fuel. Accordingly, the exposures to individuals in the vicinity of the Y-12 accident were as high as 461 rem; the exposure that resulted in a fatality at Los Alamos was estimated at 20,000 rem; and those in Idaho did not exceed 8 rem internal or 50 rem to the skin. It is equally interesting to note that all the accidents, and particularly those in directly operated equipment, occurred in fissile-material salvage processes where inventory uncertainties are more highly probable and where operations are less routine than in production operations.

Description of the Facility

The accident occurred in a multipurpose recovery system designated Recuplex. The equipment for this operation was located, in part, in Room 221, Building 234-5, as shown in Fig. VI-4. Of the equipment in Room 221, that located in the solvent-extraction hood is more germane to the review of the accident than is any other. Figure VI-5 is a photograph of a model of the solvent-extraction hood showing the three extraction columns, H-1, H-2, and H-3; a product-receiver tank, J-1; two solvent treatment tanks, K-1 and K-2, where additional purification of the plutonium was carried out; and a solution transfer tank, K-9. Although the other equipment shown in the model is not of importance to this discussion, its presence illustrates the necessary complexity of the equipment layout. One additional vessel, a waste receiver tank designated L-2, located in the reception and blending hood (Fig. VI-4) is referred to in this review. In this recovery system, plutonium was being salvaged from various waste streams arising both within the Hanford production complex and in offsite sources. The impurities from which the plu-

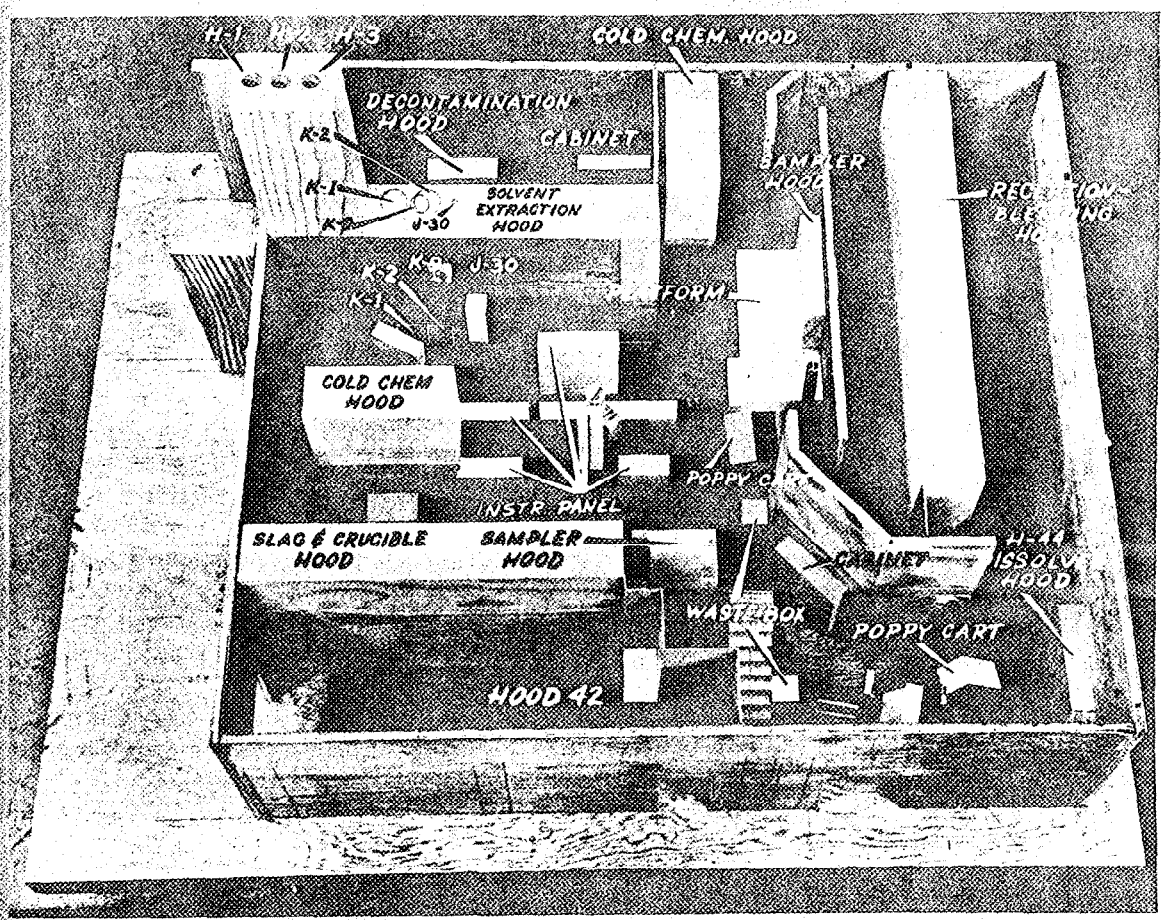


Fig. VI-4 Model of hood arrangement in Room 221 (Fig. IV-2 of Ref. 14 with additions to show positions of solvent-extraction columns H-1, H-2, and H-3 of Fig. VI-6).

tonium was separated were not uranium or fission products. The Recuplex system contained dissolvers, feed-preparation tanks, solvent-extraction contactors, and the miscellaneous auxiliary equipment necessary for chemical separations by solvent extraction. The organic extractant was tributyl phosphate (TBP) in carbon tetrachloride, which essentially quantitatively removed plutonium from the aqueous feed solution in the extraction column and, also essentially quantitatively, left the impurities behind. The impurities that were carried into the organic stream were washed back into an aqueous phase by scrub streams introduced at the bottom of the first extraction column. One of these scrub streams derived from the stripping column, where plutonium was returned to an aqueous phase, and was, in fact, a part of the product of the stripping column. In this recycling operation, plutonium was not only purified but was concentrated to about 100 g/liter prior to final discharge as Recuplex product.

Since plutonium adheres strongly to dibutyl phosphate (DBP), which is a decomposition product of TBP, a small amount of plutonium was carried out of the stripping column in the organic effluent. It was necessary to treat the effluent to remove this "unstrippable" plutonium and, at intervals, the DBP. This treatment for plutonium recovery was carried out in vessels auxiliary to the principal stream and consisted of an additional solvent extraction of the plutonium into an aqueous solution of ferrous ammonium sulfate, sulfamic acid, and nitric acid. Prior to achieving a plutonium concentration of 3 g/liter, this aqueous "cap" was transferred to subsequent process steps via the transfer tank K-9. It was in tank K-9 that the critical volume of plutonium solution

was accumulated. Tank K-9 was a cylindrical vessel about 18 in. in diameter with a capacity of 69 liters; its lateral wall was $\frac{3}{8}$-in.-thick pyrex glass; its top and bottom were steel plates. The bottom plate, which reflected neutrons into the solution, was 1 in. thick.

The natural hazards associated with processing plutonium require equipment containment to limit the dispersion of radioactive contamination arising in normal operations, such as the machining of the metal, or from accidental occurrences, such as the rupture of a liquid-carrying process line. Containment is often provided by compartments constructed of transparent materials, plastic or glass, and equipped with openings tightly fitted with long gloves to allow manipulations within the compartments. These are called "glove boxes" or "hoods," even though they may be the order of 100 ft long to accommodate extended process trains. The Recuplex system occupied several such hoods, including one for the solvent-extraction equipment in which tank K-9 was located. In some instances the hoods were equipped with relatively thin shields that were designed to protect the operators from the natural radioactivity of plutonium and its companion elements but which were not intended to protect against radiation arising in a nuclear accident of the magnitude discussed here.

Nuclear safety, i.e., protection from accidental achievement of criticality, was effected in the Recuplex process by imposing, individually, several of the usual limitations, such as those on chemical concentration and on the dimensions and shape of equipment, and, in some cases, by combinations of two or more of these. Some equipment, for example, was described as "geometrically unfavorable," meaning that the dimensional restrictions assured safety provided the plutonium content, or the plutonium concentration, did not exceed a predetermined value. Solutions of cadmium nitrate were added to the process stream in some instances. No solid neutron-absorbing materials, such as rings of borosilicate glass, were installed in the equipment. It is obvious that tank K-9 could not safely accommodate

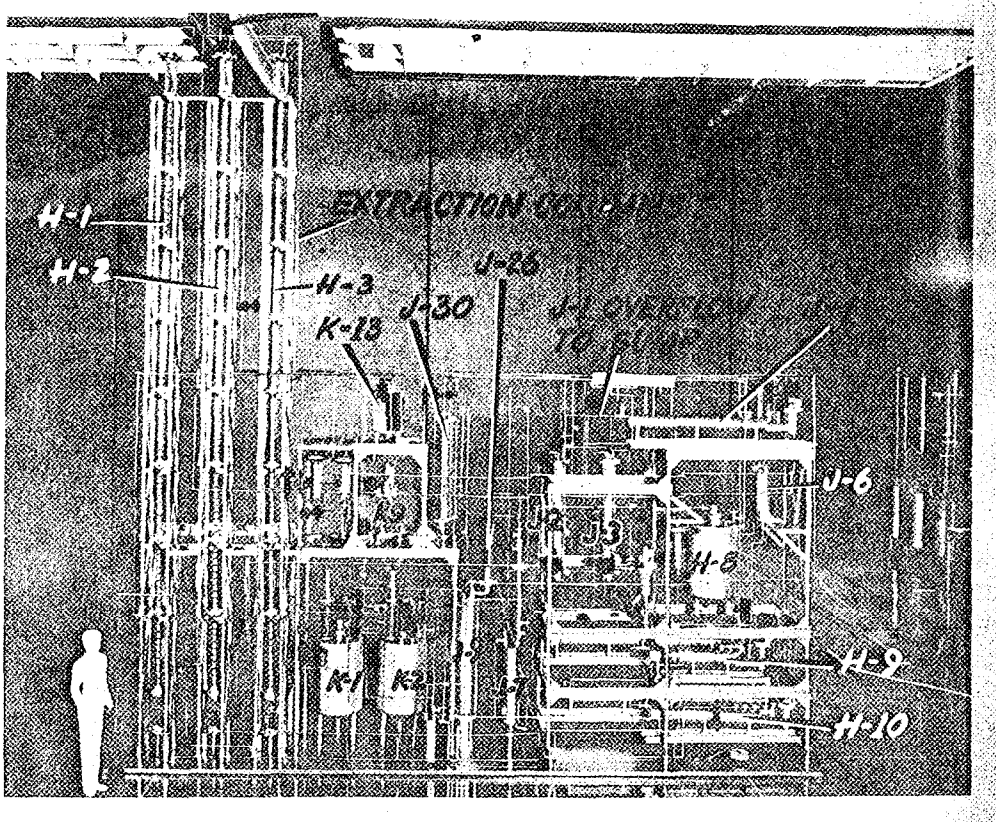


Fig. VI-5 Model of SE hood.

its full capacity of plutonium solution without concomitant restrictions, so, as noted above, the process design limited the plutonium concentration to 3 g/liter, which is well below the minimum concentration required for criticality in an aqueous solution. The concentration was administratively controlled by analyses at points immediately upstream of tank K-9.

Operations at the Time of the Accident

During a period of several weeks prior to the accident, the extraction section of the Recuplex process had been used for cleaning the hood in which that section was located. This housekeeping chore was demanded by an accumulation of liquid and solid materials, and some in-between phases, on the floor of the box. The accumulation apparently included both organic and aqueous solutions of plutonium and reagents from leaks in the process plumbing; there were also neoprene gloves and plastic containers that had been temporarily disposed of by dropping them to the floor. All in all, the result was a conglomerate mess that was somewhat rich in plutonium. Much foreign material had collected on the walls of the hood and thereby reduced visibility of the interior, a factor of some significance. The cleanup entailed adding successive volumes of aluminum nitrate solution and nitric acid to the floor. These solutions were sampled and analyzed and then transferred into tank K-9 in batches, with the size of the batch established by the analyses. Cadmium nitrate solution had previously been added to tank K-9 as a safety measure. The transfer from a sump in the floor to tank K-9 was by vacuum through a temporarily installed 1-in.-diameter plastic tube that was attached, through two valves, to the bottom of tank K-9 and had not yet been removed at the time of the accident, although the floor cleanup, per se, had been satisfactorily completed some days previously. There remained to be done, however, a necessary cleaning of the undissolved slurry materials from the extraction system itself before normal process operations could be resumed. Difficulties with plugged lines, flooding of columns, and system leaks were encountered in this cleanout, although the operation, which was not routine, had been described, as was the entire cleaning task, by procedures properly prepared prior to its commencement.

A piece of equipment of some importance was the geometrically favorable product-receiver tank, designated J-1, which was immediately downstream of the stripping column. It could receive solutions with plutonium concentrations of up to 100 g/liter from the column. For the past several years, tank J-1 had apparently been equipped with an overflow that spilled solution directly to the floor of the hood instead of into a catch tank, where an overflow of tank J-1 could have been detected, as was formerly true. That it could overflow directly to the floor in this manner was not known to the directly associated operating organization and was not reflected in the operating procedures. The reasons for allowing solution to accumulate knowingly outside the process piping were not made clear.

In one phase of the rather complex operations, it was necessary to use tank K-9 to transfer solutions of low plutonium content from the waste receiver tank L-2 to solvent treatment tank K-2. This transfer could be effected through either or both of two paths. Transfer by one of the paths was prescribed by operating procedures; transfer by the other path, although not prescribed, was not prohibited by the procedures. On occasion the latter path was employed because, in the opinion of some of the operators, the transfer could be made more expeditiously through it. Flow through this path was controlled by two valves in series, valves 431 and 543, Fig. VI-6. It is probable that not only was this unprescribed path used during the shift preceding the one in which the accident occurred but also that, at the conclusion of the transfer, both valves were inadvertently left open.

Between the two valves in the unspecified flow path was a tee to which was also connected, through a third valve (valve 944), the temporary plastic tube leading to the sump in the floor of the hood through which the floor-cleaning salvage solution had been removed. It was intended, of course, that this third valve be closed at all times except when removing liquid from the sump. The valve was found closed after the accident.

Immediately preceding the accident some 200 liters of organic solution containing about 2 g of plutonium per liter had been transferred via tank K-9 from one vessel (tank L-2) to another (tank K-2) preparatory to further removal of unstrippable plutonium. A few tens of liters of aqueous phase, probably quite lean

in plutonium, which had been collected unintentionally atop the organic solution in tank K-2, was then transferred by vacuum back to tank K-9. The next step, the addition of reagents to the 200 liters of organic solution, was interrupted by the excursion that was evidenced by a flash of blue light, the response of radiation detection instruments, the sound of emergency alarms, and, according to one observer, a sound resembling that of an electric arc. Evacuation of the area by personnel was immediate.

Cause of the Accident

In order to establish the cause of the accident, which obviously resulted from a critical accumulation of plutonium in tank K-9, it was necessary to ascertain the source of the plutonium and to postulate a reasonable method of transfer. From many pieces of information and observations, including examination of valve conditions and tests of their integrity, chemical analyses of samples from all process streams and vessels, reviews of records from continuously operating process instrumentation, and interrogation of operating personnel, the following reconstruction of events leading to the accident was derived. Even so there remain inconsistencies and uncertainties, some possibly caused by the delay in sampling enforced by the area being inaccessible.

The conclusions point to the presence of 45 to 46 liters of solution (determined from rings on the pyrex cylinder) in vessel K-9 at the 1400 to 1500 g of plutonium and was dilute in nitric acid and other chemicals. Within a few hours prior to th overflow of an est solution, having a about 45 g/liter (2 occurred from the and collected on presence of liquid was observed prio subsequently desc not as dark colore The cause of this have been becaus materials on the of the hood had r overflow of such been observed. Th floor was so comm at this time proba if it were identif requisite quantity established.

Mention has b presence of the p porarily installed the fact that one in Fig. VI-6) se K-9 was found ope of the tube was l one valve (944) fc must have been o to substantiate the tion of the accide being opened was sonnel. The valve quiring only a 9 full open to full the glove box, and manipulating anot

When reentry o was found vented quence, no doubt, three-way (vent v the activities whe assured. There i was under vacuu Therefore a plau ment of the soluti

A hypothesized release, support demands that th criticality was a possible upon th liters in the tim

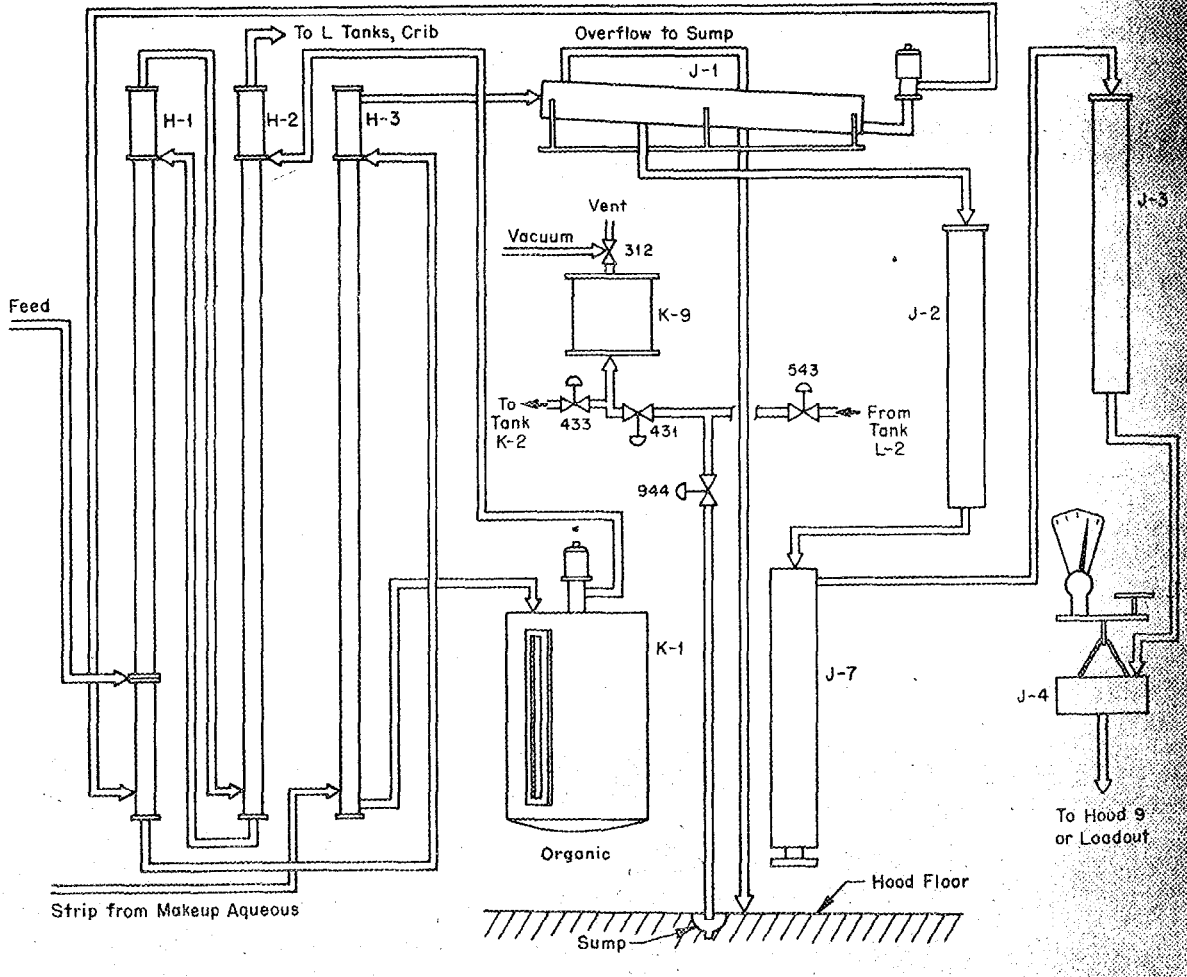


Fig. VI-6. Flow diagram of solvent-extraction process (Fig. IV-5 of Ref. 14 with additions to show

hours prior to the incident, an unobserved overflow of an estimated 48 liters of product solution, having a plutonium concentration of about 45 g/liter (2160 g of plutonium), probably occurred from the product-recovery tank J-1 and collected on the floor of the hood. The presence of liquid on the floor of the hood was observed prior to the incident, and it was subsequently described as being clean, i.e., not as dark colored as is plutonium solution. The cause of this error in identification may have been because the deposit of obscurant materials on the inside of the plastic walls of the hood had reduced visibility so that an overflow of such a quantity might not have been observed. The presence of liquid on the floor was so common that product solution there at this time probably elicited no concern, even if it were identified. A likely source of the requisite quantity of plutonium was therefore established.

Mention has been made of the continued presence of the plastic tube, which was temporarily installed for the hood cleanup, and of the fact that one of the two valves (valve 431 in Fig. VI-6) separating the tube from tank K-9 was found open after the accident. The end of the tube was located in the floor sump. The one valve (944) found closed after the accident must have been opened, at least momentarily, to substantiate the most reasonable reconstruction of the accident. No evidence of the valve being opened was presented by operating personnel. The valve was of a ball-plug type requiring only a 90° turn of a bar handle from full open to full closed. The handle was inside the glove box, and an accidental turn of it while manipulating another was unlikely but possible.

When reentry of the area was made, tank K-9 was found vented to the atmosphere, a consequence, no doubt, of remote manipulation of the three-way (vent vacuum K-9) valve (312) during the activities whereby the safety of reentry was assured. There is little question that tank K-9 was under vacuum at the time of the accident. Therefore a plausible path and means of movement of the solution existed.

A hypothesized power-vs.-time pattern of the release, supported by data and calculations, demands that the approach of the solution to criticality was at a much slower rate than that possible upon the addition of approximately 50 liters in the time available. Reasonable means existed, however, for further addition of reactivity in increments sufficiently small to account for the observations and analyses. This final increment of reactivity may have been provided through dilution of the larger volume by the aqueous cap of low-plutonium concentration, which actually was added to the believed-to-be-empty tank K-9; the increment of reactivity may have been added by deaeration of the contents of K-9 following the addition of the cap; or the reactivity increase may have resulted from settling of low-plutonium-containing organic material (carbon tetrachloride, a neutron absorber) from the plutonium solution. Any one or a combination of these three possibilities would be consistent with the findings.

Personnel Response and Exposure

Following the audible radiation alarm, prompt evacuation of personnel from the entire building was effected according to well-established emergency procedures. From the local assembly point, all personnel were transferred to the area first-aid building, where a "Quick Sort" examination* not only correctly identified the three employees who were shown later by more sophisticated dosimetry to have received doses greater than 2 rem but also excluded, with possibly one exception, all other personnel from the significant-exposure category. These three exposed employees were in the room containing the extraction hood and were at distances from the accident estimated to range from 5 to 26 ft. They, together with a fourth employee whose exposure was initially uncertain, were hospitalized. The fourth employee, who was later shown to have received an exposure of about 1 rem, was discharged the following day. The other three were discharged on the ninth day.

A complete medical report describing the radiation effects on the three individuals receiving the greatest exposure will not be issued until the completion of relatively long-term clinical tests. A variety of immediate clinical tests and radioactivity determinations (including blood pattern studies; testicular biopsies; and measurement of induced radioactivity in body fluids, in hair, in fingernails, and in toenails)

*In this test a Geiger-Müller tube is placed against the subject's abdomen; he bends his body over the tube, and neutron-induced activity in the body is detected.

gave results that were not inconsistent with exposures derived from physical dosimeters. There was some variance because the exposures occurred at short range and therefore varied from part to part of an individual. The presently reported whole-body exposures are, respectively, for the four individuals: (1) 63 r gamma and 24 rads neutron, (2) 23 r gamma and 10 rads neutron, (3) 13 r gamma and 3 rads neutron, and (4) 1.4 rem (estimated). A value of 2 was assigned to the fast-neutron relative biological efficiency of radiation (RBE) factor. No deleterious effects attributable to these exposures had been observed in any of the individuals at the time the report[14] of the incident was issued, August 1962. The dosimetric studies of the accident have been reported by Roesch.[26]

Behavior and Reconstruction of the Accident

It is of interest to review the physical behavior of the critical volume, the actions taken to suppress it, and the reconstruction of its cause and behavior. Radiation surveys in and around Building 234-5 during the hour following the excursion revealed (1) a persisting gamma-ray field and (2) the absence of alpha-particle contamination; the first signified continuation of the nuclear reaction, and the second implied the containment of the affected plutonium within the extraction hood. The continuation of the reaction was soon confirmed by measurements within the building of neutron and gamma fields as great as 0.25 rad/hr and 2.5 r/hr, respectively. Since within the next several hours the chain reaction appeared to be decreasing in intensity, it was decided to allow it to extinguish itself, as it did, about 37 hr after its initiation.

The most complete record of the history of the reaction was obtained from a recording neutron-sensing device located within another building about 350 ft from tank K-9. Although the recorder was off scale early in the period, a power pattern can be constructed. There was a rather sharp initial power peak of uncertain duration owing to the recorder being off scale until 28 min following the excursion (except for some indication of an increase in the neutron field above background during the first 1.5 min, which possibly defines an increasing multiplication of the ambient Pu^{240} neutron population as the solution approached criticality). In the second half-hour period the intensity decreased exponentially, and then it gradually further decreased during the next 34 hr (until 10 p.m. on April 8). It then decreased rapidly to background about 24 hr later. It is postulated that the volume became subcritical about midnight April 8 (37 hr after its initiation) and that background neutron multiplication continued for another 24 hr. Imposed on this pattern were many power oscillations.

Radiochemical analyses of liquid recovered from tank K-9 and the volume involved, determined from a ring around the pyrex cylinder, gave the energy release as 8.2×10^{17} fissions (6.4×10^{6} calories), of which about 20% appeared in the initial unrecorded, half-hour interval. The decay during this interval was assumed to be exponential from its inception, with the period observed during the second half-hour interval. This may be a gross, but unimportant, oversimplification. The pattern is not inconsistent, however, with the energy yield in the initial stages, as ascertained from personnel exposures and from dosimeters.

Cessation of the chain reaction by means then unknown demanded assurance, as a preliminary to contact action and investigation, that the chain reaction would not be restarted. At that time the exact location of the accident was not unequivocally fixed, the momentary observation of the glow having been not entirely definitive. The use of a robot to gather information and to effect remedial measures is perhaps the most fascinating part of the reconstruction. This mobile one-handed device with a closed-circuit television eye was operable from a point 100 ft distant and around some corridor corners from the extraction hood, and the operator was therefore provided with considerable radiation protection in the event the reaction started again. It was established that the reaction occurred in tank K-9, for example, by equipping the robot with a highly directional gamma-ray detector and demanding that he scan the hood. Tank K-9 was the only strong gamma-ray source observed. The robot also placed lights and instruments, read meters, moved equipment, and turned valves. The valve connecting tank K-9 to the vacuum header, for example, was turned to vent, and observations on detectors previously placed by the robot showed no resulting effect on the nearby neutron field. The culmination of many such actions was the reasonably assured safe entry

by personnel who, still by operations moderately remote, drained much of the liquid from tank K-9. Cadmium nitrate solution was added to all vessels in the Recuplex system not geometrically favorable, and all parts of the system were sampled.

Instrumentation was positioned (some by the robot) whereby the neutron field could be observed as the solution was removed from tank K-9 and an estimate could thereby be made of the critical volume of solution of that particular composition from an apparent neutron multiplication curve taken in reverse time. The conditions necessary for criticality in the cylinder were also calculated by reactor-physics computer codes based on reasonable plutonium concentrations and reflector conditions. The results of the calculations were normalized to the critical mass obtained from the neutron multiplication. These many considerations, not entirely internally consistent and suffering from unknowns in such basic parameters as the mass of plutonium involved [for example, about 130 g of plutonium in approximately 1 liter of organic solution was found in the tube connecting tank K-9 and valve 944 (Fig. VI-6), and solids bearing plutonium which might have been suspended during at least a part of the period were found on the bottom of the tank], allowed a formulation of a sequence of remarkably coherent events in view of the complexity of the normal process and, particularly, of the special-purpose operations in progress at the time.

The hypothesized sequence of events leading to and during the excursion is described in the following summary. Approximately 1500 g of plutonium in a solution with a concentration of less than 45 g of plutonium per liter was added to tank K-9 from the hood sump, and it occupied a subcritical volume. The slow addition of dilute nitric acid, bringing the total volume to perhaps 45 to 46 liters, gradually increased the reactivity and led to a small and slowly developing initial pulse of approximately 10^{16} fissions, consistent with personnel exposure. Repeated pulses were then formed, and each was terminated by the presence of radiolytic gas bubbles until, after about 20 min, boiling ensued (at 60°C under the pressure in tank K-9). As boiling proceeded to reduce the solution volume, the reactivity decreased, forcing a decline in power. Such a decline would be expected to be exponential and, if this analysis is correct, was in progress about the time the neutron recorder came back on scale. After 2 to 3 liters of solution had boiled off, the declining reactivity could no longer maintain bulk boiling; this condition developed about 1 hr after initiation of the reaction. Following termination of boiling, evaporative cooling and heat losses to the environment reduced the temperature and thereby added slight reactivity through the negative temperature coefficient and established a quasi-equilibrium condition that persisted until the solution reached ambient temperature. Then, with the source of reactivity no longer present, the system became subcritical owing to further evaporation which, in fact, continued until the evacuation system was valved off. Since the volume of the solution in tank K-9 at the time of personnel reentry was 39 liters, 6 or 7 liters were removed by boiling and evaporation.

The plutonium concentration of the solution removed from tank K-9 was approximately 35 g/liter. The plutonium content was 1365 g, an amount shown by reactor-physics calculations to be insufficient, by 140 to 160 g, for criticality in the volume of solution, 46 liters, believed in the tank at the time of the accident. This plutonium deficiency could be provided by the quantity found after the accident in the connecting tube attached to the bottom of K-9, and an interesting speculation accounted for its transfer from K-9, where it was required in solution to initiate the accident, to the small-diameter connecting tube. It is speculated that about 1 liter of an organic liquid having a density less than that of the aqueous plutonium solution was also pulled by vacuum from the sump into tank K-9 and floated on top of the aqueous solution. The source of this organic might have been the extractant (carbon tetrachloride and tributyl phosphate with possibly some dibutyl phosphate) from which the carbon tetrachloride had evaporated as it lay on the hood floor. The density of the organic increased as it picked up plutonium from the aqueous solution until, upon exceeding the density of the aqueous phase, the plutonium-laden organic settled finally into the connecting tube. The critical mass of plutonium in 45 liters of aqueous solution in tank K-9 with 1 liter of organic as a neutron reflector on top was calculated to be 1470 g; that of 46 liters of aqueous solution unreflected on top was about 1500 g. The transfer of plutonium from the

solution by this postulated mechanism may have been a factor contributing to the cessation of the nuclear reaction.

Restoration of Operations

Processes other than Recuplex occupying the same general area at Hanford were shut down at the time of the accident on April 7 as a precaution against personnel exposures that might arise from the continuing or aggravated nuclear reaction. Processes in buildings other than Building 234-5, i.e., those in buildings beyond a 1500-ft-radius exclusion area, were reactivated on April 16. Those within Building 234-5, except Recuplex, were restarted on April 30. As of April 1963, the Recuplex processing system had not been returned to service, and it will probably be replaced by a more modern salvage system.

Comments and Conclusions

The criticality accident that occurred in the Hanford operations in April 1962 is the latest of the remarkably few accidents of this kind which have occurred in the country's chemical and metallurgical processing of fissile materials. The fact that its consequences were not more severe is a tribute to a well-planned and well-organized emergency procedure whereby personnel evacuated the affected area in a prompt and orderly manner. As has been true in related instances elsewhere, the cause was not an unexpected physical or chemical phenomenon but, according to the most plausible reconstruction of events, was a combination of shortcomings, some in the design of the process and the equipment, some in supervision and administration, and some in the operation itself. The value of the accident to other operations is a reemphasis of the need for care and caution on the part of all persons concerned in order to more completely assure safe operations.

Although there were many items that contributed to the accident, it is difficult to single out dominant ones, particularly since there are uncertainties in the description of the way in which it happened. Measures that would correct many of these items can be read into the description of the occurrence. It is possible, in the opinion of this reviewer, to make two general comments. Salvage operations, because of the variety, nonuniformity, and uncertainty in the process materials, must be clearly prescribed and carefully carried out. This need is particularly apparent in those processes with fissile materials where the safety of the processing depends, in part, on parameters administratively controlled, such as the chemical concentration of process solutions, and, in part, on more firmly fixed controls, such as the dimensions of equipment. Transfers of material between these areas must be done carefully and with an understanding of the concomitant shift in the manner of assuring safety.

The second comment has to do with an apparently simple matter—good housekeeping—upon which all types of safety so strongly depend. It is rather apparent, in retrospect, that the recovery process was made difficult by poor visibility of operations, that the source of the plutonium existed unnoticed for the same reason, and that this particular cleanup was necessitated by a long-standing accumulation of waste materials.

MTR Fission-Break Incident

By R. A. Costner, Jr.

A fission break[27] occurred at the Materials Testing Reactor (MTR) on Nov. 13, 1962, because of the melting of a small portion of one of the 19 fuel plates in a single fuel element. There was a total loss[28] of about 0.7 g of U^{235}. The plate melted as a result of insufficient cooling caused by a restriction of the flow of the primary cooling water by debris that was later identified as a gasket material from the floating roof of the seal tank (a 17,000-gal water-supply tank). The reactor automatically shut itself down, and personnel were evacuated from the reactor building for 12 to 15 min. There were no significant personnel exposures and no consequences beyond the site boundary. A brief description of the MTR, as well as some aspects of its operation, was included in the March 1962 issue of *Nuclear Safety*.[29]

A fission-break incident that occurred at the Engineering Test Reactor (ETR) was reviewed in the June 1962 issue of *Nuclear Safety*.[30]

The Incident and Immediate Events

The reactor had been operating at 40 Mw since Nov. 2, 1962, except for five short-duration power reductions. On Nov. 13, 1962,