HW 74723

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HW-74723

Return to Betty Roberts
3760 Bldg, 300 Area
BNW

Health & Safety

HANFORD OPERATIONS

OFFICE

Richland, Washington

FINAL REPORT

of

ACCIDENTAL NUCLEAR EXCURSION

RECUPLEX OPERATION

234-5 FACILITY

Date of Incident:

April 7, 1962

Prepared by:

Investigation Committee

August 1962

MASTER

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DISCLAIMER

[redacted]

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APPENDICES

For ease in identifying sections of the report, pages have been numbered separately for each section. For example, Section III - Brief of Findings, will have page numbers III-1, III-2, etc., whereas Appendix 3 - Operating Procedures and Standards, will have page numbers 3-1, 3-2, etc.

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I. INTRODUCTION

On Saturday morning, April 7, 1962, at about 1059*, an accidental nuclear excursion occurred in the plutonium waste recovery facility (Recuplex) of the 234-5 Building. The facility, along with many other plants at Hanford, is operated by General Electric as prime contractor for the Commission. The nuclear excursion is the first to have occurred in any production facility at Hanford. This excursion did not result in any mechanical damage or spread of contamination. Three employees of the General Electric Company received overexposures to gamma and neutron radiation. None were fatally exposed; in each case the overexposure was recognized promptly, and following medical observation and testing the men were released to return to work.

In compliance with AEC Manual Chapter 0703, an AEC-HAPO committee composed of two AEC employees (one of whom was the Chairman) and five General Electric employees was appointed by the Manager, HOO, with the concurrence of the General Manager, HAPO, to conduct an investigation of the incident. The committee's purpose was to determine the cause, nature, and extent of the incident, and recommend action to be taken by others to minimize or preclude future incidents of this magnitude. A study of operating practices and operating conditions that appeared to exist prior to, during, and subsequent to the accident was made by the committee.

The committee believes that this report provides sufficient information to answer questions which may arise as a result of the criticality incident except those relating to its cause. Evidence obtained strongly indicates the cause, but it cannot be stated positively that the incident occurred in a certain manner. It is believed that this evidence cannot be secured.

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*Armed Forces time.

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II. AUTHORIZATION AND SCOPE OF INVESTIGATION

On April 9, 1962, the Manager, HOO, by memorandum (see Exhibit 12-A) appointed the following Investigation Committee:

Carl N. Zangar, Director, Health and Safety Division, HOO - Chairman
M. C. Leverett, Consulting Engineer, HLO, HAPO
C. C. Gamertsfelder, Technical Consultant, HLO, HAPO
P. F. Gast, Manager, Physics and Instrument Research and Development, HLO, HAPO
O. H. Greager, Manager, Research and Engineering, IPD, HAPO
W. N. Mobley, Manager, Manufacturing, FPD, HAPO
M. J. Rasmussen, Nuclear Chemist, Production Division, HOO

E. G. Pierick, Senior Engineer, CPD, HAPO, acted as secretary for the Committee and rendered valuable administrative and technical assistance.

The scope of the investigation as stated in an April 13, 1962 memorandum (see Exhibit 12-B) from the Investigation Committee to the Manager, HOO, is:

1. Cause of and responsibility for the incident.

2. Nature and extent (including costs) of the incident.

3. Recommendations for corrective action, if indicated.

4. Probability, amounts, and validity of claims against the Government to the extent this is practicable.

5. The effectiveness and appropriateness of actions taken to insure safety to personnel and Government property, and to restore the Recuplex Operation.

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III. BRIEF OF FINDINGS

The Investigation Committee, after examining a large body of evidence and after interviews with numerous persons finds as follows:

A. The accidental nuclear excursion in the Recuplex facility on April 7, 1962 occurred in a general purpose transfer tank, designated K-9, as the result of the presence in that tank of approximately 1400-1500 grams of plutonium contained in about 45-50 liters of dilute nitric acid containing other chemicals. The plutonium concentration of the solution was thus about 30 grams/liter.

B. The preferred explanation for the presence of this quantity of plutonium in K-9 is not completely consistent with all the technical evidence and all the testimony of witnesses. The preferred explanation is that about 48 liters of plutonium product solution (45 grams/liter plutonium concentration) overflowed from product receiver tank J-1 to the floor. This overflow occurred through a line, installed about three years ago, which led to the SE hood floor directly, rather than through catch tank J-5, as formerly. The fact that a J-1 overflow could not, therefore, be detected by the former method of observing a rise in the liquid level of J-5 was unknown to the immediately associated operating organization, and had not been taken into account in the operating procedures.

The product solution flowed across the floor of the solvent extraction (SE) hood, and was from there later partly sucked up into K-9 through a temporary line used in previous hood clean-up operations. In order for the solution to have entered K-9 via this temporary line, a valve (#944) in that line had to be opened and subsequently closed by human agency. The valve (#944) was found closed upon examination after the accident.

C. The strong plutonium solution from the floor mingled in K-9 with a smaller volume of dilute aqueous solution of plutonium. This dilute aqueous solution originated in Tank L-2 in the normal course of operations aimed at clean-up of organic solvent prior to discarding it.

D. That a significant overflow of plutonium solution occurred from J-1 to the floor is well supported by charts taken from recording instruments on the equipment.

The explanation is consistent also with postaccident measurements of the concentrations of plutonium in K-9, J-1, and L-2 (the tank which was the source of the dilute aqueous plutonium solution), assuming the two solutions were mixed in the ratio of approximately 1 part L-2 solution to 1.5 to 2 parts J-1 solution.

E. Both sulfate and hydrogen ion concentrations in J-1 itself are inconsistent (too high) with the mixing ratio calculated from the plutonium balance on J-1, K-9, and L-2 solutions. As noted in the text, it is at least partly justifiable to disregard this inconsistency.

The explanation also is not supported by the statements of the operators on duty just before or during the accident, since both of them state that they do not recall having manipulated valve #944 in any way during the period in question. Acceptance of this explanation implies that this testimony is false or that recollection of the manipulation has, indeed, been obliterated, perhaps by the shock of the event.

F. The tank in which criticality occurred is provided with essentially no shielding to protect operators of the equipment and other occupants of the building against escaping neutrons or gamma rays. Of the 22 persons in the building at the time, three were hospitalized for observation and treatment after the accident. These three were estimated to have received 110, 43, and 19 rem, respectively, in the accident. No other person received more than two rem. None of the three hospitalized persons have or had symptons definitely referable to radiation received in the accident, although laboratory tests show some effects due to radiation.

The occurrence of the accident on a Saturday when week-day employees were not present may have prevented additional significant radiation exposures.

G. There was no mechanical damage resulting from the excursion and no spread of alpha contamination. Fission product activity was detected in the atmosphere for a brief period after the accident, having been ejected up the ventilating stack, but quickly and harmlessly dispersed in the atmosphere.

H. The total number of fissions occurring between the time of initial criticality and final subcriticality about 37 hours later was about 8×10^{17}. The course of the reaction comprised an initial rapid rise to a peak rate of fission, a subsidence, a rise to one or more later peaks, and after a period of the order of half an hour, the onset of a long ($\sim$ 36 hours) period of declining rate of fission with minor fluctuations from the general trend. The peak power was probably limited by radiolytic gas evolution, and the final subcriticality was probably caused by loss of water, principally through evaporation.

I. The emergency plan was executed well. Personnel left the building immediately. Responsible management, both in HOO and HAPO, were rapidly notified of the event, even though the accident occurred on a weekend day. The Emergency Control Center was activated and staffed rapidly with top management, consultants, and specialists. Individuals thought possibly to be significantly exposed to radiation were identified immediately and put under medical supervision. Radiation doses received by all persons were quickly estimated. Control of entry and exit of personnel to and from the accident area was established early.

J. Public and press releases were effective. One press release was made within a few hours of the accident, and others as appropriate.

K. The procedures used in re-entry and in making the facility secure against a resumption of the chain reaction were developed and executed with meticulous attention to the prevention of exposure of personnel in the event of another excursion. The elaborate precautions taken were justified in view of the unknown state of the facility at the time.

L. The cost of the accident, including loss of production in Recuplex and in other areas which were shut down temporarily, is estimated to be at about $891,000.

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M. In the chain of events leading directly to the accident, the Committee finds no significant violation of a formal, written procedure. However, opening valve #944 was contrary to oral instruction, and to instructions implied in the supervisor's written communications to the operating crews.

N. The main events or conditions, not necessary to successful operation of the process, and in the causal chain leading to the accident are:

1. The immediately associated operating organization did not realize that a J-1 overflow would bypass J-5.

2. The operators did not observe or did not properly interpret the weight factor indication on J-1.

3. The temporary line from the sump to valve #944 had been allowed to stay in place after its usefulness was past. Secondarily, the procedure calling for the installation of this line did not call for its final removal. (However, an order had been issued for removal of the line and was awaiting routine execution.)

4. Valve #944 was operated, contrary to oral instructions.

5. Valve #431 was open. This was a result of use by the operator on the 12-8 shift of a method of transfer from L-2 to K-9 not contemplated in the design of the system, but not expressly forbidden by instruction.

6. K-9 was not geometrically favorable, and although the introduction into it of fixed nuclear poison had been considered, no such poison was present.

7. K-9 was not equipped with an alarm-sounding neutron counter which might signal the presence of too large quantities of Pu.

O. The facility had been designed originally as a pilot plant and later was converted to production. In some respects the facility is not well suited to production operations. This fact was recognized about three years ago, and this recognition led to authorization for a new facility a few days before the accident.

P. The equipment in Recuplex shows ample evidence of wear, corrosion, leakage, and repair. Although it does not appear that equipment deterioration per se played a primary role in causing the accident, it was the basic cause of the operations being carried out at the time of the accident, and resulted in frequent recourse to nonroutine procedures.

Q. The facility was a difficult one to operate, and the operations were by nature of varying and complex character. The organization and manning were appropriate to a routine operation. Engineering coverage was normally available only during week-day operations.

R. Although the Recuplex facility had a "three-faults-to-cause-an-accident" philosophy, conditions of operation and design at the time of the accident were such that the opening of a single valve caused a nuclear excursion.

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IV. DESCRIPTION OF PLANT AND PROCESS

The Recuplex facility is a multipurpose plutonium recovery operation that is located in the 234-5 Building, 200-W Area, Chemical Processing Department, Hanford Atomic Products Operation. See Fig. IV-1 for general location of 234-5 Building within the 200-W Area. The Recuplex waste recovery process is for the purpose of recovery and purification of plutonium from waste streams originating in the Plutonium Processing Plant and miscellaneous wastes from other facilities both offsite and onsite.

The Recuplex complex contains dissolvers, feed preparation tanks, solvent extraction contactor, and miscellaneous auxiliary equipment. See Fig. IV-2 for arrangement of Recuplex hoods (Room 221). A process flow diagram covering the portion of the process of immediate interest is shown in Fig. IV-3. The solvent extraction process is performed in the H-1 and H-2 columns. The feed solution is continuously fed to the intermediate feed point of the H-1 column. This feed contains plutonium, which is contaminated primarily by ionic impurities rather than by uranium or fission products , and a nitric acid and aluminum nitrate salting agent. A counter-current flow of aqueous phase rises through the 20 per cent tributyl phosphate (TBP) in carbon tetrachloride (CCl_4) in the column and extracts the plutonium essentially quantitatively into the organic phase, but leaves the ionic impurities essentially quantitatively in the aqueous phase. An aqueous scrub stream (CAS) introduced at the bottom of the column further purifies the plutonium by washing ionic impurities back from the solvent phase to the aqueous phase. An intermediate scrub (CAIS) or product reflux introduced three feet above the CAS feed point, further purifies the plutonium as well as concentrates the plutonium in the columns to about 100 grams per liter.

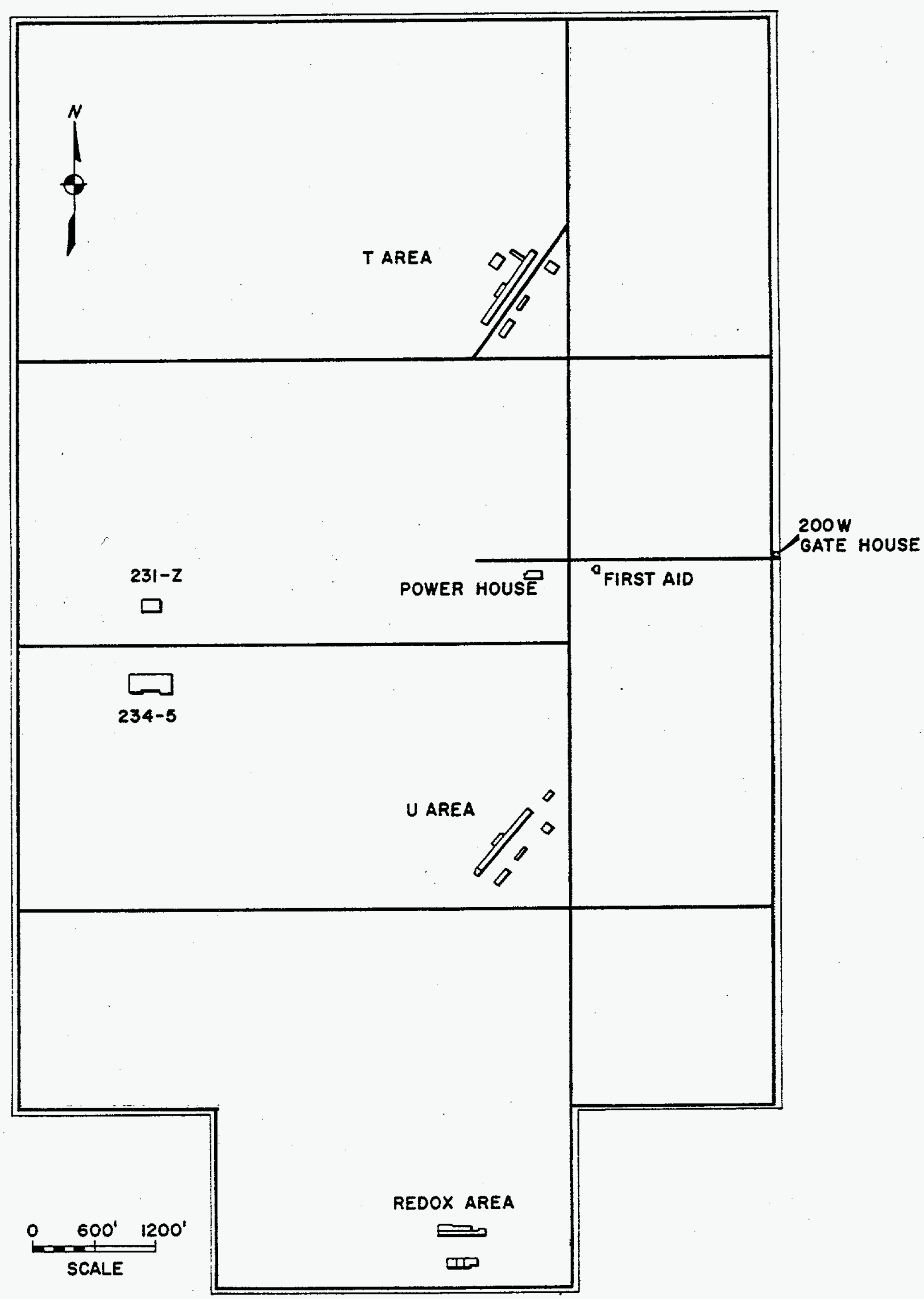
The organic stream containing the plutonium is pumped to the top of the H-3 column, where a counterflow of aqueous strip solution (a small amount of reductant in a 0.15 M nitric solution) transfers the plutonium back into an aqueous phase. This stripping column product (CAIS) is used as the intermediate scrub in the extraction column (H-1 and H-2). This recycling of product into the system is continued until the concentration is about 100 grams per liter, at which point product is removed from the top of the stripping column (H-3) and received in the product receiver tank (J-1).

The organic solvent, essentially free of plutonium, leaves the bottom of the H-3 column and enters the solvent treatment tanks (K-1 and K-2) . Essentially all of the plutonium in the effluent organic forms a strongly organic-favoring plutonium complex with dibutylphosphate (DBP), a primary decomposition product of tributylphosphate. This "unstrippable" plutonium is removed from the organic phase in the solvent treatment tanks (K-1 or K-2) as the organic phase falls through (and is periodically agitated with) an aqueous cap (FS) of ferrous ammonium sulfate, sulfamic acid, and nitric acid. After the plutonium concentration in this cap reaches about three grams/liter, as determined by sampling in the K-1 or K-2 tanks, it is transferred to the organic wash receiver tank (G-58) via the transfer tank (K-9). Periodically, the DBP is removed from the organic phase with a carbonate wash.

Fig. IV-4 is a photograph of a model of the SE hood. This illustration more clearly shows the physical locations of the equipment in the hood, including the K-9 tank in which the nuclear excursion took place and the J-1 tank overflow point.

[redacted]

Fig. IV-5 is a pictorial flow diagram of the SE process. This figure concerns itself mainly with the route by which product solution entered the K-9 tank, viz., from the J-1 tank via the J-1 overflow to the sump, and from the sump via the 1" temporary plastic line to the K-9 tank.



SIMPLIFIED PLAN OF 200W AREA

FIGURE IV-1

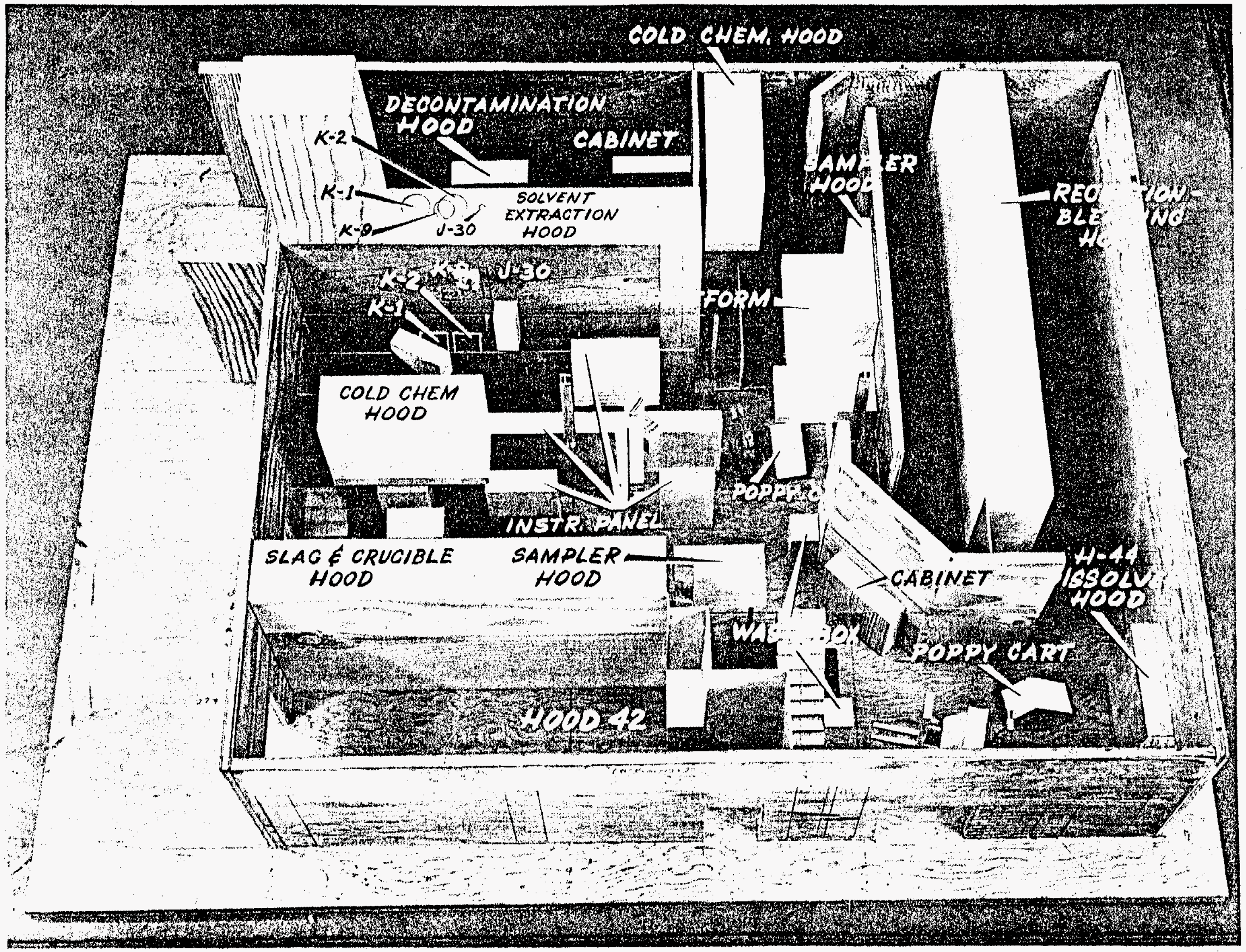


FIGURE IV-2
Model of Hood Arrangement in Room 221

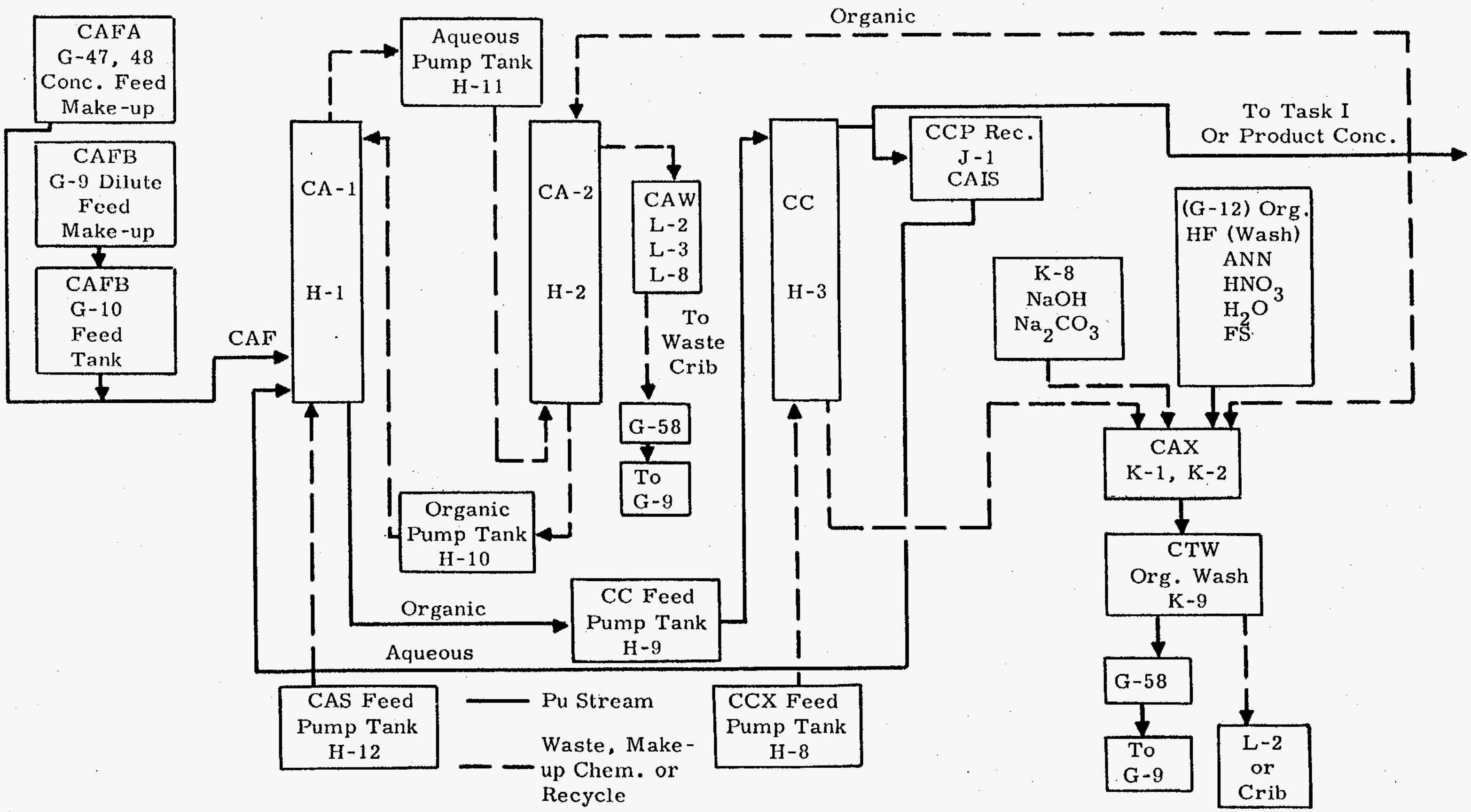


FIGURE IV-3

Solvent Extraction Process - Recuplex

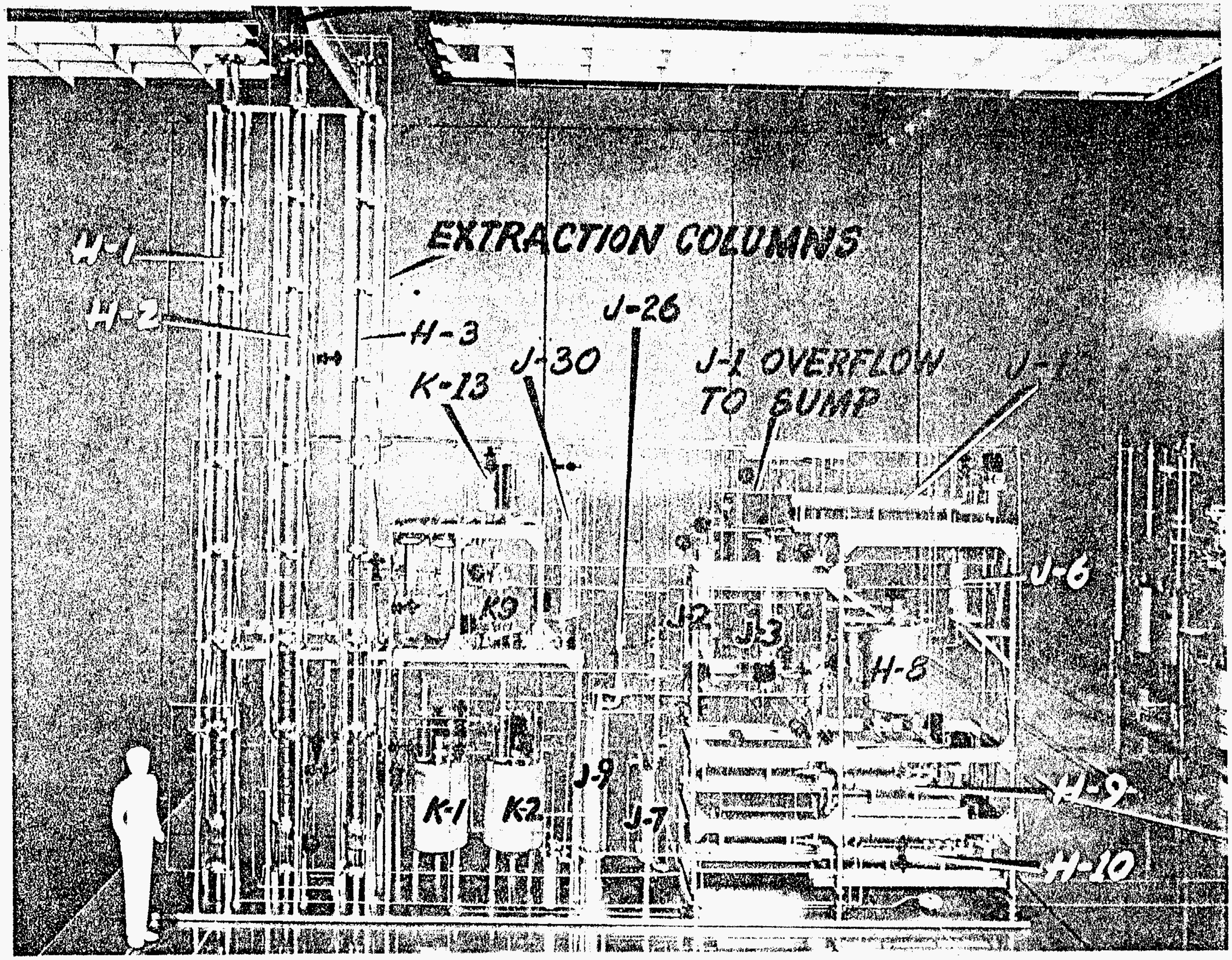


FIGURE IV-4
Model of SE Hood

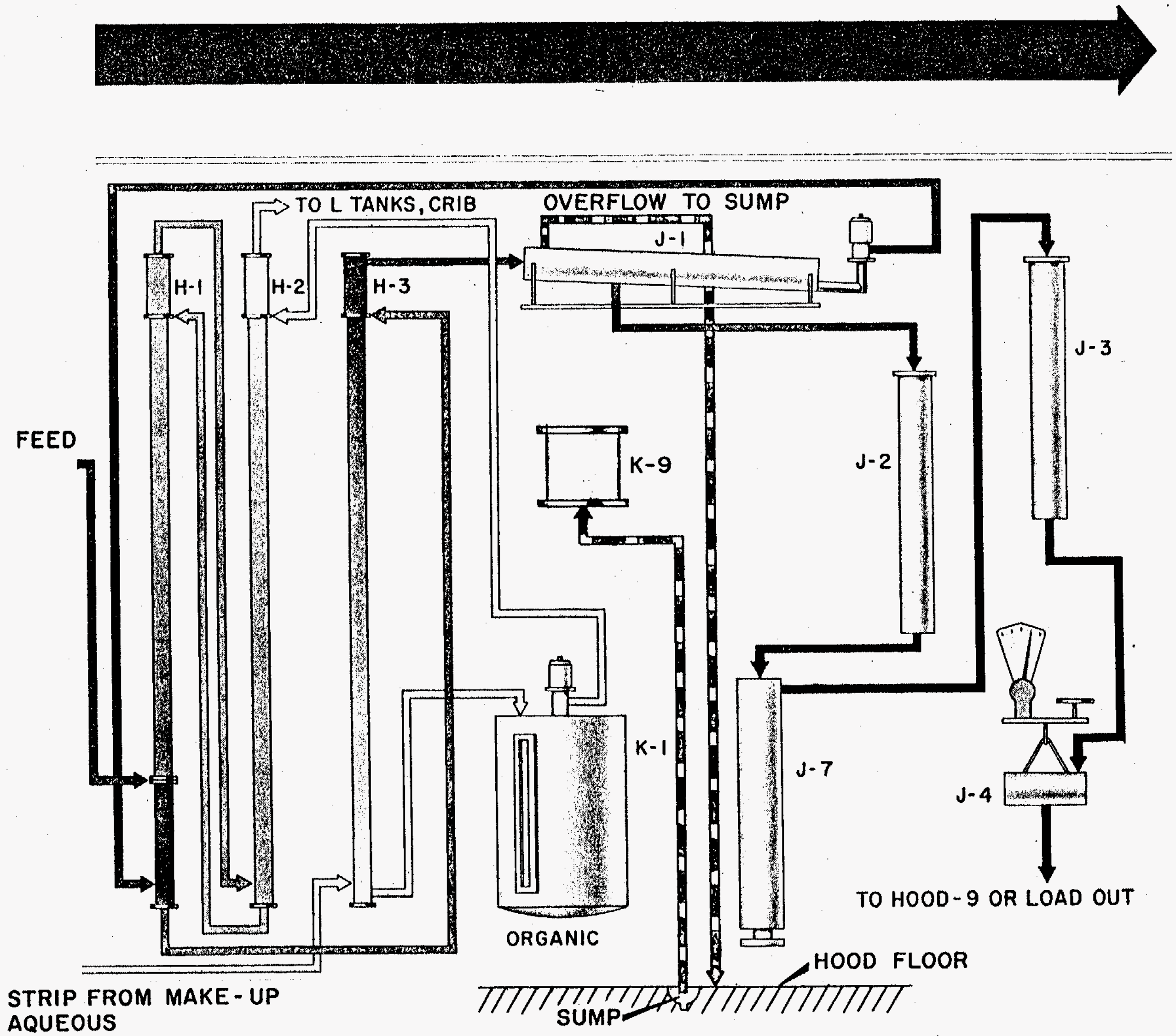


FIGURE IV-5
Pictorial Flow Diagram of SE Process

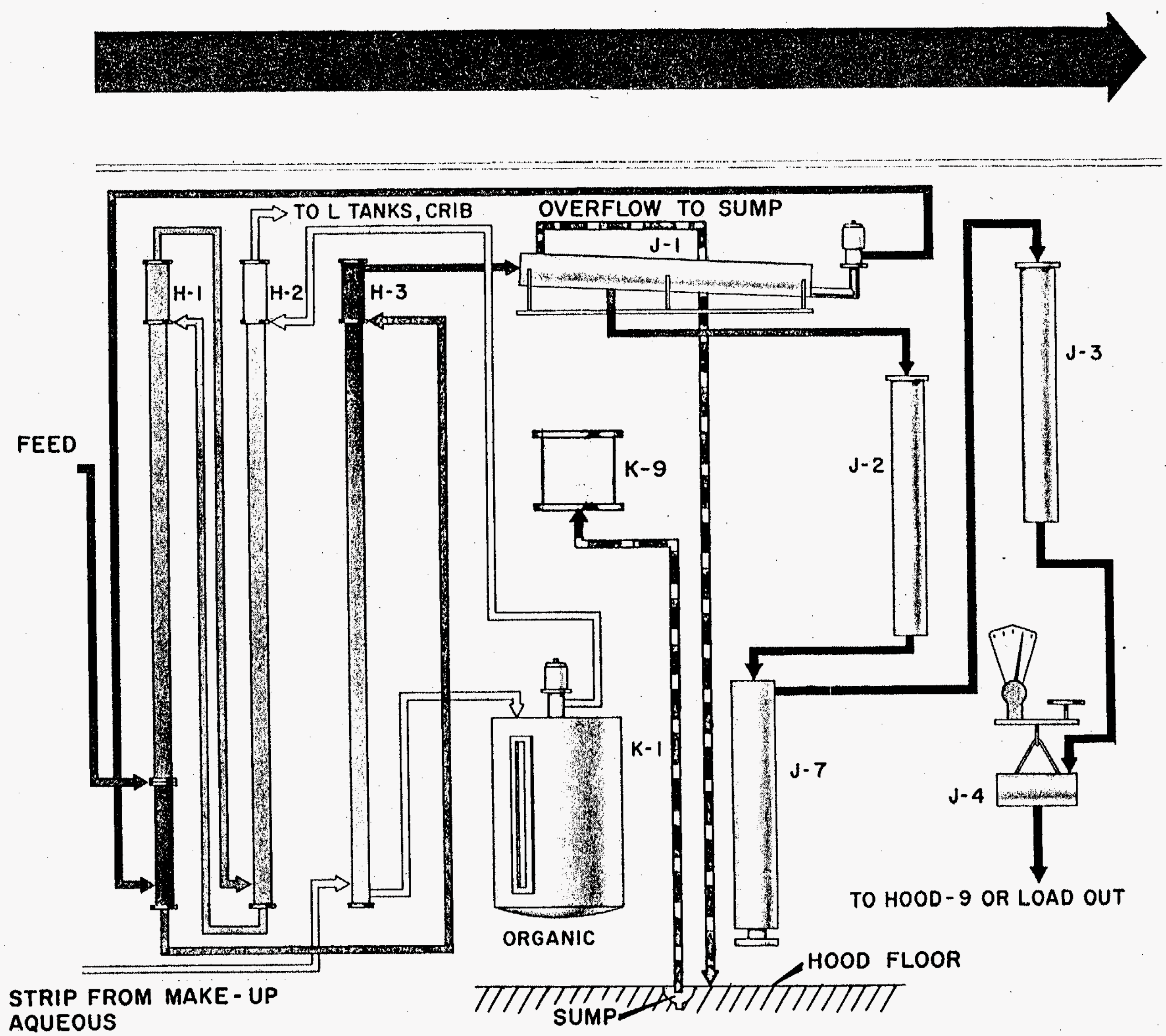


FIGURE IV-5
Pictorial Flow Diagram of SE Process

V. ORGANIZATION

The places of the Recuplex operation and of related nuclear safety functions in the Hanford Atomic Products Operation (HAPO) are shown in Fig. V-1. The Recuplex plant is an operating responsibility of the Plutonium Recovery Operation (PRO). A supervisor heads the Plutonium Recovery Operation. The Recuplex plant operates continuously, and the actual operations are performed by four shifts (A, B, C, and D), each of which is led by a Specialist, and each of which has seven operators.

Operation of the plant is carried out as specified by the engineers of the Finished Products Chemical Technology Operation (FPCTO). The duties of these engineers include the evaluation of all operations in Recuplex for nuclear safety (as well as for process adequacy, etc.). The Supervisor, Plutonium Recovery Operation is responsible for seeing that the operations are executed as specified by the engineers. Many of the nuclear safety precautions require the observance of special procedures on the part of the operators. The specification of these procedures is the duty of the engineers of FPCTO. The shift specialist has the responsibility of interpreting the engineering specifications to the operators, and seeing that they are enforced.

The critical mass control specifications for a new process, new equipment, or new method of operation are drafted by FPCTO. They then are reviewed by the Senior Engineer (Nuclear Safety) CPD, who reports through the Manager - Advanced Process Development to the Manager - Research and Engineering, CPD, who then approves the critical mass control specifications. The approved specifications are transmitted both to FPCTO and to the Plutonium Recovery Operation (PRO). When PRO desires to make a change in equipment or method of operation, it may do so on its own responsibility provided it believes the change to be clearly within the approved critical mass control specification. If it believes the change not to be clearly within the approved specification, or if it is in doubt, it must refer the change to FPCTO, who may approve the change if it believes the change to be clearly within the approved specification. However, if FPCTO is in doubt or believes the change outside the specification, the change must be referred to the Senior Engineer (Nuclear Safety) CPD, who will either approve it or require that a new critical mass control specification be prepared and put through the approval routine.

Training of operators is primarily by means of on-the-job instruction. However, numerous safety meetings also are held, and the importance of adherence to specifications is emphasized. The consequences of a criticality accident were well known to the operators, since they had viewed films showing the condition of individuals who were exposed in criticality accidents elsewhere.

FPCTO has audit responsibility to see that specifications are being properly interpreted. The FPCTO engineers make visual observations daily and notify operating supervisors immediately if corrections are needed.

The Hanford Laboratories Operation, through its Physics and Instrument Research and Development Operation, provides to the Senior Engineer (Nuclear Safety) CPD improvements in the technological bases for nuclear safety and consultation services for this and other matters. Such consultation includes the making of inspections and audits upon request.

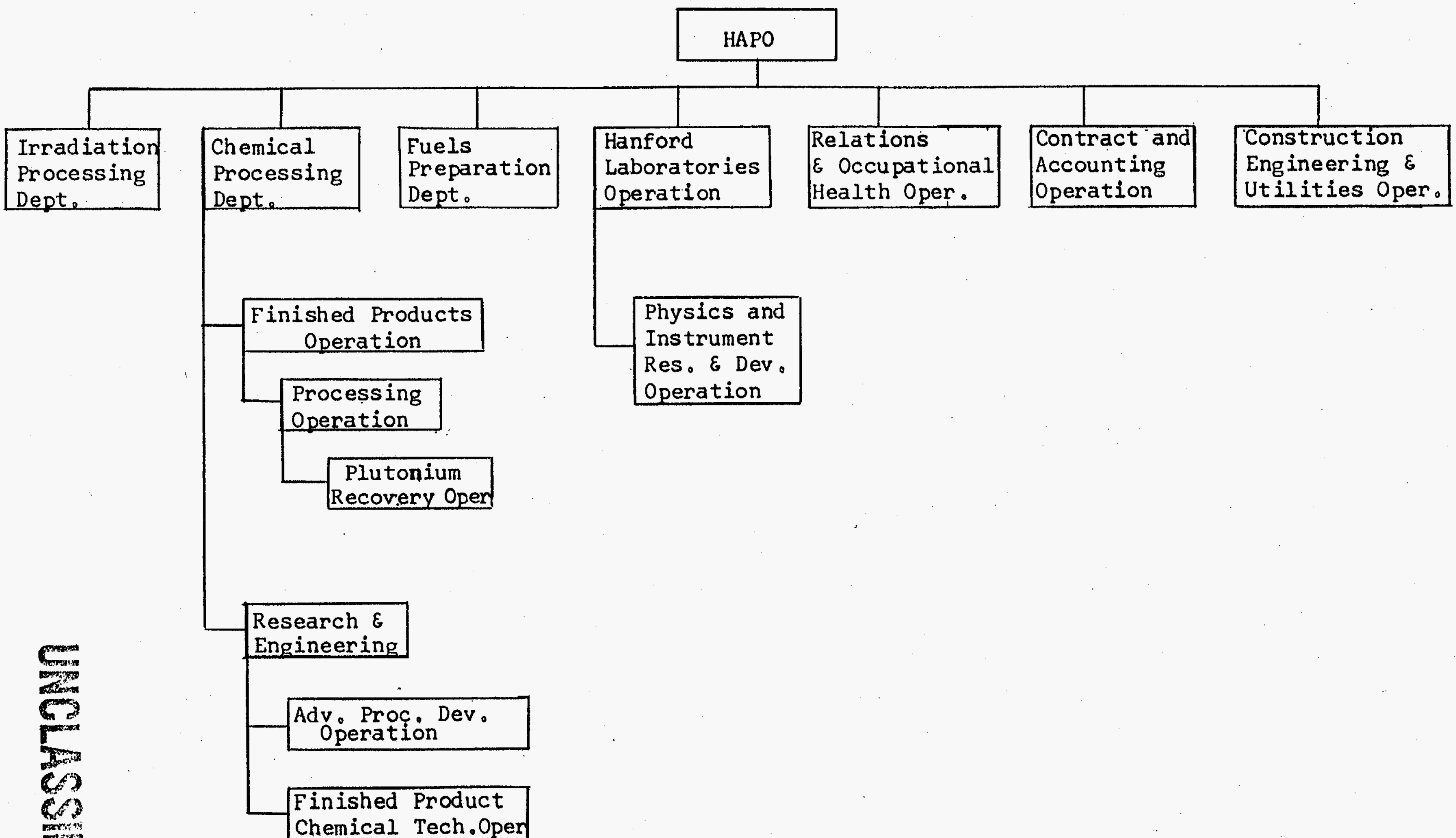


Fig. V-1

HAPO ORGANIZATION PERTINENT TO APRIL 7, 1962 CRITICALITY ACCIDENT

VI. DESCRIPTION OF OPERATIONS PRIOR TO INCIDENT

On February 22, 1962 the process engineer for the Recuplex Operation recommended that the operation be shut down to remove material which had accumulated on the floor of the solvent extraction hood. Management concurred in this recommendation and the decision was made to shut off all rich feed to the system until the solvent extraction floor could be cleaned up and certain piping and structural members could be replaced. The material on the floor had accumulated over a period of months due to deterioration of the equipment with resultant leakage of liquids to the hood floors. These liquids, composed of both process organic and aqueous solutions, had attacked the plastic bags and neoprene gloves which had accumulated on the floor, resulting in a mass of sludge resembling black tar containing varying concentrations of plutonium over the area involved.

Detailed procedures were prepared to cover this clean-up program and issued on February 26, 1962 and March 8, 1962 (see Exhibit 3-C).

Operations according to the clean-out procedures proceeded during the month of March and the solvent extraction hood floor was reported as clean on March 30, 1962.

In summary, the floor clean-up procedures required that successive volumes of aluminum nitrate and nitric acid be added to the floors, sampled and analyzed and, depending upon analysis, specific volumes transferred by vacuum through a temporary 1" plastic line (which had been installed on March 14, 1962 for this specific purpose) to the K-9 tank to which cadmium nitrate had previously been added as a safety precaution. This material from K-9 was then transferred to L-2, a waste tank, into a solution of water, nitric acid, aluminum nitrate, sodium nitrate and mistron. This operation was continued until four batches from K-9 had been accumulated in the L-2 tank, at which time 200 liters of contact organic containing 8 liters of dibutyl butyl phosphonate was added to the L-2 tank and agitated for two hours to extract the Pu from the aqueous phase and then it was sampled and analyzed. The aqueous phase, when stripped of plutonium, was discarded to cribs and the organic phase was washed with an extractant composed of water, nitric acid, ferrous sulfamate and hydrofluoric acid. This extractant was then run through the solvent extraction system for plutonium recovery and the organic phase was saved for subsequent contacts. This procedure was repeated during the month until such time as the floor was cleaned.

Following this clean-up the recovery system was loaded with the undissolved tarry material which required that the system be cleaned thoroughly before it could be put back into normal operation.

This clean-out was initiated on March 31, 1962 and was composed of a series of hydrofluoric acid flushes, followed by aluminum nitrate to complex the fluoride ion, starting at the waste tanks and working through the system with basic emphasis on recovering the plutonium and discarding the sludge-contaminated organic and aqueous solutions.

During the above operations considerable difficulty was experienced with plugging of lines, flooding of the organic extraction columns and system leaks. This caused considerable rework of both the organic and aqueous streams. This clean-out had proceeded up to the point that the auxiliary systems, i.e., organic receiver tanks (K-1, K-2), organic transfer-decant tank (K-9), and waste tanks

(L-2, L-3, L-8) were in the final stages of the flush, and steps were being taken to commence clean-out of the extraction columns when the excursion took place.

Specific operations leading up to the incident were as follows:

On the 12-8 shift on April 7, 1962, 550 liters of contact organic, used several times for contacting aqueous solutions which contained plutonium above the cribbing limits, was moved from its storage tank (G-36) to waste receiver tank (L-2) and sampled. The analysis which was reported on the same shift showed 2.11 grams Pu/liter (later corrected to 2.19 grams/liter), or that approximately 1200 total grams of plutonium was in the tank. The shift specialist decided to wash part of this organic to reduce the Pu content. Approximately 130 liters were moved from L-2 back to G-36 and 200 liters were to be drawn in four batches from L-2 via K-9 tank by vacuum and dropped by gravity to the K-2 tank for washing with an aqueous phase containing ferrous sulfamate and hydrofluoric acid to extract the plutonium from the organic phase. This aqueous phase, after sufficient contact time, was to be decanted back into the K-9 tank and then pumped to the G-58 tank to be used as feed for the solvent extraction columns.

On the 12-8 shift, the first transfer of 55 liters was made from the L-2 tank to K-9 and dropped by gravity to the K-2 tank. This transfer was made by drawing the material back through the 431 valve into the bottom of K-9 because it was reported to be a faster means of transfer than through the normal routing through the 506 valve into the top of K-9. It was reported by the operator on the 12-8 shift that there was essentially no aqueous layer on the organic in K-9, although this could have been in error due to the poor visibility in the hood and the difficulty of seeing in the tank from the operating floor level.

The 8-4 shift continued the transfer of contact organic from L-2 through K-9 to K-2 by opening valve 506, which is the normal route from L-2 to K-9. The operator who continued these transfers (Employee No. 1) does not remember closing the 543 and 431 valves (found open subsequently) which were used on the previous shift and were reportedly left open by the 12-8 shift operator, which allowed the material to be moved into K-9 from L-2 by two routes simultaneously. This transfer continued intermittently during the morning of April 7, 1962 until a total of 3 or 4 batches of approximately 50-55 liters each had been transferred into K-2 tank. (Operator recollection is hazy as to whether 3 or 4 batches were transferred.) The intermittent operation occurred due to interruptions caused by a flooding condition in the solvent extraction columns which required the operator's attention.

At approximately 10:30 Employee No. 18 relieved the regular operator, Employee No. 1, for personal relief and finished transferring the last 25 liters from L-2 to K-9. He dropped a total of 50 liters into K-2 from K-9 and notified the regular operator, when he returned, that the transfer had been completed and all valves were closed. The regular operator then took over and reported subsequent to the incident that there was an aqueous cap of 10-30 liters on the top of the organic phase in K-2 with a total of 210 liters of organic in K-2.

The operator proceeded to decant the cap from K-2 back up to K-9 and was in the process of getting ready to add wash chemicals (ferrous sulfamate and water) from K-8 (chemical addition tank) to K-2 when the incident occurred in K-9 tank.

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In adding these chemicals to K-2, standard practice had developed whereby the vacuum in K-9 was used to break the air lock in the interconnect line from the K-8 tank to the K-2 tank by cracking the valve (433) to K-9 momentarily to start the chemical flow. Following the incident the chemicals were not found in the K-8 tank and the valve from K-8 to the sewer was found partially open. The 433 valve to K-9 was found closed.

Investigation subsequent to the incident has developed the following information:

1. At the time of the incident the columns were operating on a fabrication oil wash feed from G-10, CAFB (dilute feed) solvent extraction feed tank. The feed from the concentrated feed system was the button line supernates or spilled liquid from the reception and blending hood floor.

2. The sump in the floor of the hood contained liquid up to the top of the sump (2-4 liters) on 4-25-62. This liquid contained both aqueous and organic phase which analyzed 1-2 grams Pu/liter in the aqueous phase and 60-130 grams/liter in the organic phase, depending upon sample location in the sump. On the day of the incident it was estimated that 20-30 liters of solution of unknown concentration was on the floor. However, visibility in the SE hood is so poor little credence can be placed in such estimates.

3. An analysis of charts (Fig. VIII-1) showing the H-3 column (stripping column) product concentration, the J-1 vessel (column reflux intermediate tank) weight factor, and strip solution flow rate to H-3 column, and the J-1 flow rate to the H-1 column (extraction column), revealed the source of a major plutonium overflow to the floor of the hood between 0600 and 0800 on April 17, 1962.

4. The process vacuum (line vacuum possibly as high as 26" mercury) was apparently on the K-9 tank at the time of the incident.

5. The temporary plastic line from the bottom of K-9 tank was in place with one end lying in the bottom of the sump. The temporary ball valve installed in this line was found to be in the closed position and the permanent valve (431) in the line to the bottom of K-9 tank, to which this line is attached, was found open.

6. The valve (433) between K-9 and the chemical addition line from K-8 to K-2 was found closed.

7. The material which went critical in K-9 vessel was analyzed subsequent to the incident and found to have the following analysis:

<u>K-9 Receiver</u>

<u>One phase, aqueous solution</u> (Laboratory Sample #1420 R - 4-20-62)

Pu	=	34.8 grams/liter

[redacted]

[redacted]

SpG	=	1.118
Fe	=	0.052 M
H^+	=	1.23 M
Na	=	0.018 M
NO_3^-	=	1.96 M
SO_4^{--}	=	0.11 M
NH_4^+	=	0.24 grams/liter (0.013 M)
Al	=	1.4 grams/liter (0.05 M)
F	=	0.45 grams/liter (0.024 M)
Cl	=	0.14 grams/liter (0.004 M)
Pu valence	=	+4
Am^{241}	=	2.53×10^6 d/m/ml
Volume	=	39 liters
Total Pu	=	1357 grams

Fission products (back calc. to 4-7-62 - 11:00)

Ru^{103}	=	2.20×10^{16} fissions/liter
$ZrNb^{95}$	=	2.0×10^{16} fissions/liter
Ba^{140}	=	1.6×10^{16} fissions/liter

Also found Mo^{99}, Ce^{143}, TeI^{132}, I^{131}, Nd^{147}

Spectrographic analysis, ppm

Ag	=	< 20	Mg	=	100
Al	=	> 20,000	Mn	=	400
As	=	-	Mo	=	-
B	=	40	Na	=	4,000
Be	=	-	Ni	=	100
Bi	=	-	P	=	-
Ca	=	40	Pb	=	1,000

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Cd	=	20	Sb	=	-
Cr	=	100	Si	=	100
Cu	=	2,000	Sn	=	< 20
Fe	=	70,000*	T	=	-
Ge	=	-	V	=	-
K	=	400	Zn	=	2,000
Li	=	-			

Distribution coefficients

K-9 solution vs. 15 percent TBP in CCl_4 (equal volume) $E_a^o = 0.22$

K-9 solution vs. 25 percent DBBP in CCl_4 (equal volume) $E_a^o = 5.0$

Material from K-9 was transferred into PR cans S-124 and S-134 after the incident.

S-124 (962-S, 963-S, 5-4-62)

Top	Pu	=	35.6 grams/liter
Bottom	Pu	=	36.2 grams/liter

S-134 (964-S, 965-S, 5-4-62)

Top	Pu	=	36.2 grams/liter
Bottom	Pu	=	36.2 grams/liter

(*) Estimated

(-) Not detected

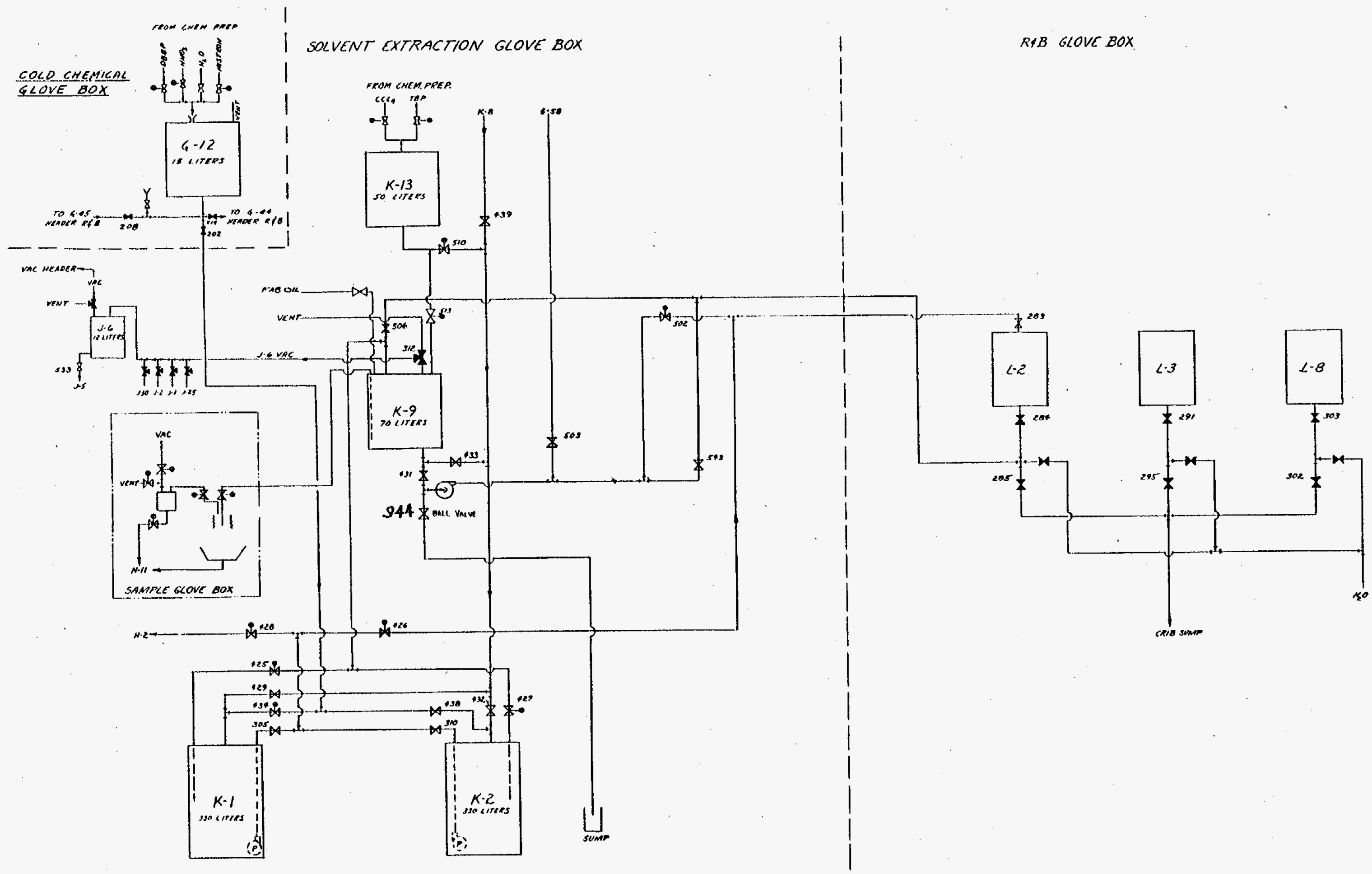

FIGURE VI-1
Solvent Extraction Partial Flow Diagram

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VII. DESCRIPTION OF ACCIDENT AND POSTACCIDENT EVENTS

The period from just before the accident up to the time of this report is conveniently divided as follows:

A. The period of the accident proper - from a few seconds prior to the accident up to the first notification of persons other than those present in the 200-W Area.

B. The subsequent period prior to the assumption of control by the Emergency Control Center (ECC) in Richland.

C. The subsequent period prior to the cessation of the chain reaction.

D. The subsequent period prior to the preparation of this report.

This section of the report will also contain a summary of reports and announcements made and a brief record of the handling of the four employees directly involved, and an account of the resumption of certain operations in 200-W.

A. The Period of the Accident Proper

At the time of the accident the 234-5 Building and immediate environs contained 24 persons, disposed as indicated on the attached diagram (Fig. VII-1). Fig. IV-1 shows the 234-5 Building in relation to other parts of the 200-W Area. The duties of these 24 employees are briefly indicated in the following table. Since the accident occurred on a Saturday, most of the people normally assigned to day work in the building were absent.

TABLE VII-1 EMPLOYEE NUMBERS AND DESCRIPTIVE TITLES

Employee No.	Job	Employee No.	Job
1	Recuplex operator	13	Process operator
2	Patrolman	14	Chemical process operator
3	Engineer	15	Process operator
4	Engineer	16	Engineer
5	Power operator	17	*Specialist in Recuplex
6	Accounting clerk	18	Process operator
7	Power operator	19	Patrolman (in 2701-Z)
8	Chemical analyst	20	Patrolman (in 2701-Z)
9	Technologist	21	Pipefitter
10	Laboratory Leader	22	Chemical analyst
11	Radiation monitor	23	Utility operator
12	Utility operator	24	Process chemist

* The position of Specialist carries responsibility for technical aspects of the work of the Operators, and is hence a semisupervisory position. The Specialist, however, is not a professionally trained person.

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The status of operations and of the processing equipment at the time of the accident, as it has been reported to or reconstructed by the Investigation Committee is given in Section VI of this report.

The operator (employee #1) stated that, "I had started to open my K-8 to K-2 chemical addition valve," when he saw a blue flash and heard a sound like that made by the drawing of an electric arc. He was standing directly in front of and somewhat below K-9 (his head is estimated to have been three feet south and four feet below the center of K-9). He reported that the flash was above him, and in K-9 or possibly to the right of K-9 by a foot or two. Employee #17, the shift specialist, was standing a few feet to the rear and left of employee #1. His view was somewhat obstructed both by employee #1 and by the lead shields which stand in front of the hood. However, he also saw the flash and heard the sound reported by employee #1, and generally agreed with employee #1 as to the location of the flash. Employee #1 described the flash as having a "jagged" appearance, "somewhat like lightning." (Employee #1 has an apparent muscular imbalance between his eyes, which might make his visual observations somewhat unreliable under some conditions. This imbalance is a condition of long standing and antedates the accident by some years.)

Employee #1 heard the building poppies first, followed by the criticality alarm siren in a very short time. He turned one of the emergency switches which shuts off power to certain process operations and left the area immediately. Employee #17 also left instantly by a different route. Employee #23, who was on the mezzanine in the 221 Area also left promptly, as did a pipefitter, employee #21, in an area which was essentially a part of but somewhat shielded from the operating area. All but two of the other employees in the building also evacuated quickly. One of the two was employee #7, a power operator who was at work in the attic of the building at the end away from the 221 Area. This employee was discovered to be missing when an informal accounting of those remembered to be in the building was made by other employees at the 234-5 badge house. Employee #7 was called on the telephone from the badge house and immediately left Building 234-5. He had heard the alarm but thought it was an alarm attached to some of the equipment for which he was responsible, and accordingly was investigating this possibility when telephoned. The other employee whose exit was slightly delayed was employee #6, an accountability clerk, who paused to lock up her safe. These two employees took about four and two minutes, respectively, to reach the gate house. All the others were at the gate house in a much shorter time. All employees in 234-5 but one left by the most direct route. All but one of the employees in the building at the time of the accident were wearing their film dosimeters. The exception had his film dosimeter on his coat which was hanging a few feet from him. A few supplementary dosimeters (finger rings, neutron badges) were being worn at the time of the accident.

After leaving the building, all employees congregated either in the 2701-Z Gate House or in the area northeast of the 2704-Z Building, using it as a shield from the 234-5 Building. A radiation monitor who had been present in the 234-5 Building left by a back exit, got into a pickup truck, and drove around to the Gate House before all the other employees had evacuated the building. He was able, therefore, to make radiation measurements almost immediately in the Gate House and warn all personnel to evacuate further since dose rates up to 200 mr/hour were registered. Most of the 234-5 personnel boarded the evacuation bus and were driven to the 200-W Area First Aid Building. Some others had private cars which were used and patrol vehicles evacuated the rest. Approximately five to ten minutes elapsed between the time of the incident and evacuation of the Gate House - 2704-Z Building Area.

The evacuation proceeded smoothly; there was little confusion. Nearly all the employees responded to the alarm promptly and properly. There was some criticism of the fact that the evacuation bus appeared to be on the verge of failing to run. The First Aid area was too small for the number of people involved; if the accident had occurred during a regular work day, this might well have led to considerable confusion.

The exact time of the accident was widely quoted by those on the scene or notified of it at an early hour to be 1059. This is the time at which an electric clock, on the circuit cut off by the emergency switch, was stopped. This time is approximately verified by the neutron count rate recorder at the 234-5 incinerator (about 100 yds from tank K-9) and from a neutron count rate recorder located in room 221. This time is also consistent with the other times variously noted and recorded, as indicated in the next portion of this narrative.

Notification to the emergency patrol officer in Richland proceeded as follows:

A patrolman who had been in 234-5 at the time of the alarm went at once to the 234-5 badge house where at 1102 he notified the 200 West radio operator (by telephone) that the 234-5 alarm had sounded. Immediately following, a second patrolman also at the 234-5 badge house telephoned the 200 West radio operator that the alarm appeared genuine. The radio operator contacted the patrol lieutenant in the 200 Area and dispatched two patrol cars to the 234-5 badge house. At 1107 the radio operator notified the Emergency Patrol Officer in Richland of the incident although the radio operator did not yet know the nature of the emergency.

Employee #17, who was the senior supervisory employee in the building, telephoned his Section Manager in Richland with the news of the accident at about 1103. This was probably the first external notification of the accident.

B. Subsequent Period up to Assumption of Control by Emergency Control Center

1. Events in the Field

The transportation of the evacuees from 234-5 to the First Aid Building (2719-WA) took place at about the time of notification to the Emergency Officer (1107).

Upon arrival at First Aid, all employees were given a "Quick Sort" check, i.e., a Geiger-Mueller tube was placed on the abdomen, the employee bent his body over the tube, and the count rate due to any neutron-induced activity in the body was measured. Several, but not all, were also given immediate contamination surveys. In addition to the Quick Sort procedure, bioassay samples were taken and dosimeters were exchanged.

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All personnel who were working in the radiation zone portions of the 234-5 Building were given complete contamination surveys prior to release from the 2717-WA (First Aid) Building. There was unanimous praise of the Radiation Specialists in general and the selflessness of employee #24 (who performed the initial Quick Sort at First Aid) and employee #17. The practice evacuation drills paid off handsomely and the evacuation procedures seemed to work very well. No one present in the 234-5 Building had any difficulty in hearing the criticality sirens.

The Quick Sort procedure identified three employees (#1, #17, and #23) as having sufficient induced radioactivity to warrant their being put under immediate medical observation.

The three employees who were to be sent to the hospital were sent to Richland in a radio patrol car, leaving the 200-W Area at 1132 and arriving at the hospital in Richland a few minutes before 12 noon. Upon arrival the three employees were first given an examination for radioactive contamination, which required a few minutes. During this examination, a Company physician arrived and took charge of the three patients.

In the 200-W Area, meanwhile, the following events were transpiring:

Employees #10 and #11 (a Laboratory Leader and a Radiation Specialist) immediately following the evacuation to the First Aid Building started a survey of the 234-5 Building perimeter fence and roadways, finding no contamination and radiation levels of about 50 mr/hr at the badge house. They alerted Redox personnel and obtained spare instruments from the UO_3 Plant. They also checked the laundry building for contamination since all of its beta-gamma detector instruments responded at the time of the excursion.

Employee #24 had arranged for barricade of Z Plant roadway upon evacuation.

The Manager, Control Operation, Finished Products, who had been notified in Sunnyside of the emergency by phone by employee #24, arrived a few moments before noon. Employee #6 (Accounting Clerk) was found at the area gate and instructed to return to First Aid.

Arrangements were made at First Aid to obtain bioassay specimens from all personnel, including the patrolmen in the area, to send all health badges in for processing, and also to perform the Quick Sort procedure for the patrolmen and employee #6. Employee #21 was sent to the hospital because he had been moderately near the source. Employees #10 and #11 returned from their tour about 1220 and reported everything under control. They were requested to stay out of all radiation zones.

The Control Operation Manager arranged for an AEC Security man and an AEC Safety Engineer to drive him to the 234-5 Building for the purpose of retrieving the three radiation monitoring personnel from that building.

These three radiation monitoring personnel had re-entered the 234-5 Building at about 1215 for about 15 minutes. One man kept time while the other two made surveys with gamma-beta sensitive instruments and recovered a Hurst dosimeter from Room 221 and one near the south door to 234-5. Dose rates as high as 5 r/hr were measured by this team in Room 221. Readings outside the building were also made by this team and ranged from 10-50 mr/hr from the door on the northeast side of the building to the main entrance on the north side of the building. Inside the building dose rates up to 350 mr/hr were measured on the top of the stairs inside the main entrance, and in Corridor No. 2. No alpha contamination could be found. On emerging from the 234-5 Building, Room 169 exit, the three monitors were met by the Control Operation Manager, AEC Safety Engineer and the Processing Operation Manager who had just arrived. They were ordered to leave the area immediately.

It was decided to be desirable to make neutron measurements. The nearest BF_3 instrument available outside the 234-5 Building was in the 231-Z Building, about 100 yards away. The Radiation Analyst from Z Plant who had just arrived with other monitors was dispatched with a patrolman to get it. It was observed and reported at this time that the nuclear reaction was continuing. At about 1240 the Manager, Production of the Chemical Processing Department arrived at the 234-5 Badge House from his headquarters at the 200-W Patrol Building, and, subject to the direction of the ECC, took firm charge of field operations. All personnel were withdrawn to the Patrol Building, and First Aid and Laundry operations were shut down. By this time a considerable number of radiation monitoring personnel and some technically trained supervisory personnel had arrived from other areas in the plant and from Richland.

2. Events in Richland

In Richland, mobilization of the ECC was proceeding. At about 1110 the AEC duty officer in Richland was notified of the accident by the Patrol Duty Captain in the ECC. A call was placed to the home of the General Manager, HAPO, but no one answered. (His wife had already been notified and had left to contact her husband who was a few miles away.) The 703 Building desk and North Badge House were instructed to start calling persons on their notification list, giving them the following message: "A criticality problem has occurred in a hood in the Recuplex Line in the 234-5 Building and the 234-5 Building is being evacuated." By 1120 the General Electric Security Officer had been notified, as had the manager of the Patrol Operation, and several others. About 1125, persons who had received these telephone communications began to arrive at the ECC, among them the Manager - CPD. With his concurrence, the Hanford Laboratories Crash Alarm was activated at 1127. Within about ten minutes, three members of the HLO emergency team arrived at the ECC, closely followed by several additional members, including the Manager - Hanford Laboratories Operation. Within the first hour after activation of the ECC:

a. Barricades were requested to control traffic approaching the 200 West Area.

b. Environmental survey teams were dispatched to evaluate any resultant ground contamination.

c. Radiation monitoring assistance was sent to the 200-W Area.

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d. Kadlec Hospital was notified that three men who were involved in a radiation accident were being brought to Kadlec. Radiation Specialists were sent to Kadlec to await arrival of the men.

e. The 3705 Building was activated to provide personnel dosimeter evaluation.

f. The 329 Building was activated to provide counting of the criticality dosimeters, blood samples, and other activated materials which could help in the dosimetry evaluations.

g. Periodic reports from Meteorology - particularly wind directions and speed - were requested and utilized in directing the environmental survey teams.

h. Technical assistance was dispatched to the 200-W Area. As noted above, the Manager - Production, CPD, was dispatched from the ECC to be Field Operations Manager during this period also, arriving and setting up his command post in the 200-W Patrol Headquarters at about 1234. There was constant communication between the ECC, 200-W Area, various patrol posts, and cars. The chain of notification of AEC and GE personnel was also at work. The General Manager - HAPO arrived at the ECC about 1130, having been reached by telephone and messenger. The Manager - HOO arrived at the ECC at 1200.

By 1240, April 7, about one hour and 40 minutes after the accident, the ECC had been activated, a Field Operations Manager had been established and had gone into action. The situation thus entered a new phase, in which it continued until it was established that the chain reaction had ceased.

C. Subsequent Period Prior to Cessation of Chain Reaction

Realization that the chain reaction was actually continuing appears to have crystallized about 1235, although the possiblility had been recognized from the first. When this fact became evident, the principal aim of operations became the avoidance of any act which would cause an intensification of the reaction, and the development of means of safely stopping the reaction. It was quickly decided that no further entry of personnel to the 234-5 Building would be permitted except for the correction of conditions which might otherwise cause further serious damage. Accordingly, only the following additional entries were carried out:

1. Two men entered to shut off a dissolver left running in one of the laboratories (about 1350, April 7).

2. Four men entered to shut off five electric appliances known to have been left on. While in the building, they also recovered the remaining dosimeters, and radiation levels in the building were noted and mapped. Both neutron and gamma-beta sensitive badges and instruments were used. Dose rates up to 2.5 r/hr and above 250 mrem/hr neutrons were encountered. A laboratory gas burner was shut off from outside the building at the gas bottle manifold.

Radiation levels at various points in the vicinity of the 234-5 Building were taken. Within about eight hours, it began to appear that after the first two or three hours (before fully systematic observations had started) the chain reaction rate had been decreasing. For this reason, although a number of proposals for stopping the reaction had been made and seriously considered, it was concluded that the best course of action consisted of allowing the reaction to die by itself if it would do so, as seemed likely. Fig. VII-2 shows the measured neutron counting rates at a point about 110 feet from the K-9 tank, and somewhat shielded from it by concrete walls. As shown on the chart, the neutron flux dropped to background about 37 hours after the accident. Gamma measurements taken during this period are in agreement with the cessation of the chain reaction at about midnight, April 8.

During this period a number of additional actions were taken to minimize risk of exposure of additional employees. At about 1300, April 7, it was decided that the 200-W Area should be evacuated except for certain necessary services which could be carried out by employees at some distance from the 234-5 Building (e.g., power plant operation, some 4000 feet distant). At 1304 the evacuation signal was sounded and all persons except those noted were removed to the main gate of the 200-W Area. Various road blocks and traffic controls were set up. Affected subcontractors were notified that their employees should not report for work on Monday, April 9. Additional monitoring points were established, and aerial surveys were made.

At about 1300 on April 7, the Whole Body Counter in Richland was activated. Film dosimeters from the involved personnel were received in the 300 Area at 1320, April 7, and the preliminary gamma dose estimates were available by about 1430, April 7. Blood samples and urine samples were collected from each of the three men who were in unshielded positions at the time of the accident; preliminary estimates of neutron dose from blood sodium activation were completed prior to 1510, April 7. Between 1800 and 2030 on April 7, all four of the hospitalized men were put through the Hanford Whole Body Counter. (All the other 18 employees in the building at the time of the accident were subsequently put through the Whole Body Counter.)

At about 1500, April 7, the General Manager - HAPO created three distinct groups:

1. A Working Group, to investigate all the approaches that might be taken with ultimate objective of safely quenching the reaction. This group was to create plans, but could not put them into effect without approval of the Advisory Council. The Working Group was made up of employees having detailed technical and operational familiarity with the Recuplex facility.

2. An Advisory Council, to review and approve the plans of the Working Group. The Advisory Council was made up of senior technical management individuals, one of whom was the Manager - CPD.

3. An Investigation Committee, made up of senior technical staff or management individuals, charged with determining the cause of the accident if possible, with evaluating the way in which it was handled, and making recommendations to prevent a recurrence. The Investigation Committee was forbidden to take an active role in the work of the other two groups, in order not to compromise its objectivity. Although the Investigation Committee was set up initially to consist of five General Electric

employees and one AEC representative, AEC-Washington later stipulated that the chairman of the Investigation Committee must be an AEC employee. Accordingly, the final composition of the committee was five GE employees and two AEC employees, one of whom was the chairman. An additional GE employee having considerable technical background in the field of interest served as secretary of the committee.

D. Subsequent Period Prior to This Report

Termination of the chain reaction meant that the objective of operations became primarily to assure that no chain reaction could recur, and secondarily, to acquire information which would enable a valid explanation of how the accident had been brought about.

1. Steps to Render Facility Safe

It was determined that the first step would be entry by a small remotely-controlled robot which had been constructed for use in the event of a reactor accident requiring the remote handling of irradiated fuel slugs (Fig. VII-3). This device was rigged up to carry a television camera and other equipment. The TV camera enabled the remotely-situated operator to steer the robot clear of obstructions, and also to perform a variety of manipulations. The TV camera also made it possible to obtain readings of gages and dials remotely, without having to send a man into the process room itself. The TVRM (Television Robot Monitor) made numerous entries, controlled by an operator situated in Corridor No. 3 about 100 feet from the suspect tank K-9 and enjoying some protection from intervening walls. It was estimated that in the event of an excursion in K-9 of 5×10^{17} fissions, the TVRM operator would receive a dose less than one rem. (The original excursion plus the subsequent periods of fluctuating or sustained chain reaction was then estimated to have involved about 4×10^{17} fissions.) Thus, operations with the TVRM could be conducted in relative safety insofar as personnel exposure was concerned. Early entries were for the purpose of reconnoitering the status of Room 221, reading dials and gages, placing lights in strategic locations, moving furniture, equipment, etc., out of obstructive positions, and placing instruments where needed. These entries confirmed that there was no mechanical damage outside the hood, that all external gages read as they should have at the point in the process where the accident occurred, and that there was no alpha contamination above normal background in the room. The most significant result was obtained when on April 12 the TVRM was equipped with a highly directional gamma probe, and the hood was surveyed for gamma activity with it. This survey disclosed unmistakably that tank K-9 was the only strong source of gamma radiation in the room, thus confirming that the excursion had occurred in K-9 and that the resulting fission products were still confined to K-9 and not outside it, e.g., in the sump.

Attention turned next to the problem of restoration of K-9 to atmospheric pressure. At the time of the accident, the vapor space in K-9 was connected to a vacuum manifold (it is by this means that liquids are moved into K-9 from lower tanks). The pressure in the vacuum manifold was possibly as low as about 26" Hg subatmospheric. It seemed possible that there might be boiling of the liquid in K-9 or air in-leakage

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through connections to the bottom of K-9. In either case, the average density of the liquid layer in K-9 would be reduced by the boiling or sparging, and it seemed possible that the condition of subcriticality might be being maintained by this means. In that case, restoration of atmospheric pressure might cause another nuclear excursion. (For this reason, an important concern during this period was to assure the maintenance of the vacuum. Fortunately, the vacuum pumps were located outside the building proper and so were accessible with little risk.) A valve located on top of K-9 controlled its communication with the vacuum header; actuation of this valve would shut off vacuum and vent the tank to the hood atmosphere. The valve is an air-actuated type, and is in turn controlled by a control-panel-mounted air valve. Turning the panel-mounted valve 90° should actuate the vacuum-vent valve on K-9.

It was decided, in view of the risk of criticality, to use the TVRM to turn the panel-mounted valve. However, on the first attempt (April 13), due probably to the awkward angle at which the TVRM had to work, the valve handle was broken off, leaving only a short stub. It was then necessary to make a special tool for the TVRM by which, on April 14, the handle was successfully turned. The crucial parameter under observation at this time was the neutron flux as recorded by instruments previously placed in the vicinity of K-9. No significant change in flux whatever was observed, thus indicating no change in multiplication in K-9. However, it was impossible to be sure whether this meant that vacuum had been removed from K-9 without causing criticality, or whether the K-9 vacuum-vent valve had simply not been actuated. This possibility had been foreseen, and could have been obviated by simply shutting off the vacuum pump, so that the entire vacuum header would come quickly to atmospheric pressure. However, this procedure had been rejected because it might result in suck-back of liquid from the vacuum header into K-9, and a resulting renewal of criticality. The next step, therefore, was to close the valve connecting the vacuum trap (J-6) to the vacuum header. This trap, located between K-9 and the vacuum header, was indicated to be empty by the gage reading as seen with the TVRM camera. Prior to closing the J-6 valve, however, the TVRM was again used to survey the SE hood floor and tanks. The survey showed all the fission activity still to be in K-9. Had there been a sizable leak below liquid level in K-9, some fission activity would have been expected to show up on the floor upon shutting off the vacuum. The survey, therefore, showed that either no such leak existed, or that the vacuum had not been shut off of K-9, or both.

The J-6 valve was shut off on April 16 after spending considerable effort in evaluating the risks involved if it should develop that, contrary to indications, J-6 contained liquid and the K-9 vacuum-vent valve were still open to the vacuum system. The closing of the J-6 vacuum valve was uneventful.

During the above described operations, plans had been under intensive study for the removal of at least a large part of the contents of K-9 to a geometrically favorable vessel. The plan adopted involved sucking the contents of K-9 out through its sampling tube, which was to be connected to a long plastic tube terminating in a geometrically favorable tank located in a room in the laboratory wing of the building about 130 feet from K-9. However, before this or any other plan of similar purpose could be adopted, it was judged necessary to send a human observer into the 221 area. Since this represented a distinct departure from previous operations, new procedures had to be devised and evaluated. Initially, the observation team (two were always sent) was permitted only to observe conditions, and to take instrumental readings. They were forbidden to touch any valves or to operate any controls. They were required to stop at stated points and wait for determination that their presence was not affecting the neutron multiplication, although indications and calculations were that K-9 was safely subcritical. This observation procedure was carried out on April 18. The K-9 drainage procedure above mentioned was adopted and executed successfully on April 20. The turning of the valve which allowed the contents of K-9 to be removed through its sample tube was accomplished by an electrically driven, remotely-operated actuator, built for the occasion. The connection of the plastic tube to the sample line, and the connection of the electric drive to the sample valve handle had to be performed manually. Of the approximately 39 liters of liquid in K-9 at the start of the removal, about 25 were removed to the external tank. The operation proceeded smoothly. A sample of the extracted liquid was analyzed and found to contain about 34.8 grams/liter of Pu and fission product activity equivalent to 2×10^{16} fissions/liter. It is thus implied that the solution in K-9 contained about 1360 grams of Pu, and that the fissions in the incident came to about 8×10^{17}.

Although the most obvious criticality hazard had been removed by the actions just described, there was some uncertainty as to the quantity, type (organic or aqueous), Pu concentration, and other chemical composition of the contents of the other tanks in the 221 Area (including several in the R&B hood). It was clearly necessary that these vessels be sampled, but that significant residual criticality risk must be assumed still to remain. Although K-9 had been identified as the vessel in which the excursion had occurred, the manner in which the Pu concentration had arrived at K-9 had not been determined. The next step, therefore, was to add cadmium nitrate solution to those vessels in Recuplex which were not geometrically favorable and in which there was any significant probability of plutonium in critical quantities. In planning this step, it was necessary to take a very conservative view of what might be contained in any given tank since data available permitted only rough estimates in some cases, and the fact of the accident itself indicated anomalous conditions in the equipment. Cadmium nitrate solution addition could conceivably have caused another criticality under the right conditions. Addition of the cadmium nitrate solution was accomplished on April 24 and 25. A line through which one of the additions was to be made was found to be plugged, and a new procedure had to be devised for introducing the solution into that tank, K-2. It was necessary to agitate the contents of each tank to which cadmium nitrate was added to assure that it would be effectively distributed. This was done using the regular process agitators, but wired so that they could be turned on or off from a remote location. This obviated the necessity for a man to be present in the room during agitation, when, conceivably, a temporarily critical condition could have been caused. The agitation was completed and a number of samples were taken for chemical analysis on April 25.

Procedures for systematically taking and analyzing samples from all tanks were then carried out over a period of several weeks. At the time of preparation of this report only one vessel in the SE hood (J-26A) had not been sampled. This vessel is geometrically safe, and usually contains some plutonium salts in solid form since its function is to remove solvent from plutonium solutions by trickling them over a steam coil. It is thought that this vessel (not in use at the time of the accident) had no part in the accident or the events leading up to it. Subsequent operations were for the purpose of determining the cause of the accident and are accordingly reported in the immediately following section.

2. Steps to Determine the Cause of the Accident

The Investigation Committee had held its first formal session on April 9, although its members had been almost constantly present in the ECC from about 1530, April 7, and were hence aware in great detail of the status of the accident and measures taken to deal with it.

The Investigation Committee conducted 35 formal interviewing sessions, of some 25 different people who had information about the accident. Twenty-three persons, mostly different from the 25 just mentioned, were asked for or volunteered written reports of their actions at the time of the accident, or regarding their interpretation of the events of the accident. Numerous informal conversations have been held with persons possibly able to contribute to an understanding of the accident.

The Investigation Committee made a number of requests for information which involved considerable work on the part of the Chemical Processing Department. These requests were met wherever possible within the bounds of safety. In fact, several of the safetying procedures finally used were appreciably longer and more expensive than they would have been had the only objective been to render the facility safe, regardless of the loss or destruction of evidence regarding the cause of the accident.

Information requested about the Recuplex facility, its operation near the time of the accident by the Investigation Committee, includes the following:

a. A description of the Recuplex system including equipment numbers or designations, function, and volume of each component.

b. Standard and special operating procedures.

c. The rationale behind any special operating procedures.

d. Supervisor's log books.

e. Recuplex shift log book, status and transfer sheets, and sample log.

f. Analytical sample records.

g. Analytical Laboratory data of recent samples.

h. Reanalysis of existing samples still in the laboratory.

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i. The volume, type, and Pu concentrations in the liquids in every tank, column, or vessel in the SE hood and in the L-2, L-3, L-8, G-36, and G-58 tanks of the R&B hood. Where both organic and aqueous phases were present, the volume and Pu concentration were desired on each phase.

j. Analyses for acid, fluoride, and ferrous sulfamate on any aqueous solution in tanks K-9, K-2, L-2, L-3, L-8, G-36, G-58, and the SE hood sump.

k. Plutonium distribution data after equal volume contacts of the following solutions: SE sump and K-2 organic; L-3 aqueous and L-2 organic (or K-2 organic).

l. The positions (open, partially open, or closed) of all valves in the SE hood and those between the SE hood and L-2, L-3, and L-8.

m. The position of the plastic line from the bottom of K-9 to the SE sump, the position of a reported 1/2" plastic line from the top of K-9 to the sump, and the positions of the ends of these two lines relative to the sump and the J-30 line.

n. The chemical analysis of anything resembling precipitated solids in vessels L-2, L-3, and L-8 in the SE hood.

o. The amount, type, and Pu content of any materials in vent or vacuum traps and in stack filter.

p. The identity of the vessel in which criticality occurred.

q. A radiochemical estimate of the number of fissions which took place.

r. Photographs at each stage of the entry and reconnaissance operations.

s. An up to date organization chart which includes all positions having responsibilities associated with incidents of this type.

t. Recuplex experience records of all process operators, utility operators, and shift specialists who were assigned to the Recuplex Operation as of April 7, 1962; and in addition, the ages and seniority dates of the men, if nonexempt, or their years of service in CPD operations if exempt.

u. Standards, guides, and criteria.

v. Records of safety reviews.

w. Records of safety training and drills.

x. Records of external (safety) audits.

y. The HOO files relating to Project CAC-880.

z. Applicable information regarding Washington State's labor compensation laws relative to nuclear incidents, conditions, if any, under which sections of this report and partly reserved to a later report. At this point in the report will be given an outline of the way in which the potentially injured employees were handled.

As previously noted, four employees in all were hospitalized. All were in or closely adjacent to the room housing the SE hood in which the accident occurred. All were put through the Quick Sort procedure at the First Aid Building (2719-WA), and three employees, #1, #17, and #23, were quickly identified as being sufficiently radioactive to warrant observation in the hospital. They were accordingly sent to Richland in a patrol car at 1132. Employee #21 was sent in to the hospital somewhat later, about 1315, April 7, since he also had been moderately close to the source.

Radiation Specialists were awaiting the three employees at the hospital on arrival, and before they had finished examining the employees for external radioactive contamination, a GE physician arrived to take charge of the cases. Employee #1, who had been closest to the source at the time of the accident and who was found to have received the largest dose of radiation was seriously apprehensive and appeared to be sure that his exposure would prove fatal. The others were calm; all were highly cooperative throughout. By 1510, both gamma and neutron doses had been estimated and were immediately communicated to the four hospitalized employees. All appeared much relieved, particularly #1. Families of the four men were notified of the accident at about 1315 and told that they could see the men at once. All the patients were asked if they wished to be seen by their own personal physicians; only employee #1 requested this, and was seen by his physician within about ten minutes after his request. The men were placed in the hospital in private rooms as bed patients.

During the late afternoon and early evening of April 7, three of the men were interviewed separately by their supervision in an effort to get any information about the accident which would be useful in making the facility safe or explaining what had happened. It was considered that employee #21, because of his location at the time of the accident and the nature of his duties, would be unable to shed light on the cause of the accident. The interviews with the other three were recorded on tape. One of the men asked to be interviewed again on the morning of April 8, and this interview was also recorded, but due to faulty recording much of the interview was lost. (This employee has since been reinterviewed several times so the information which he imparted is available.)

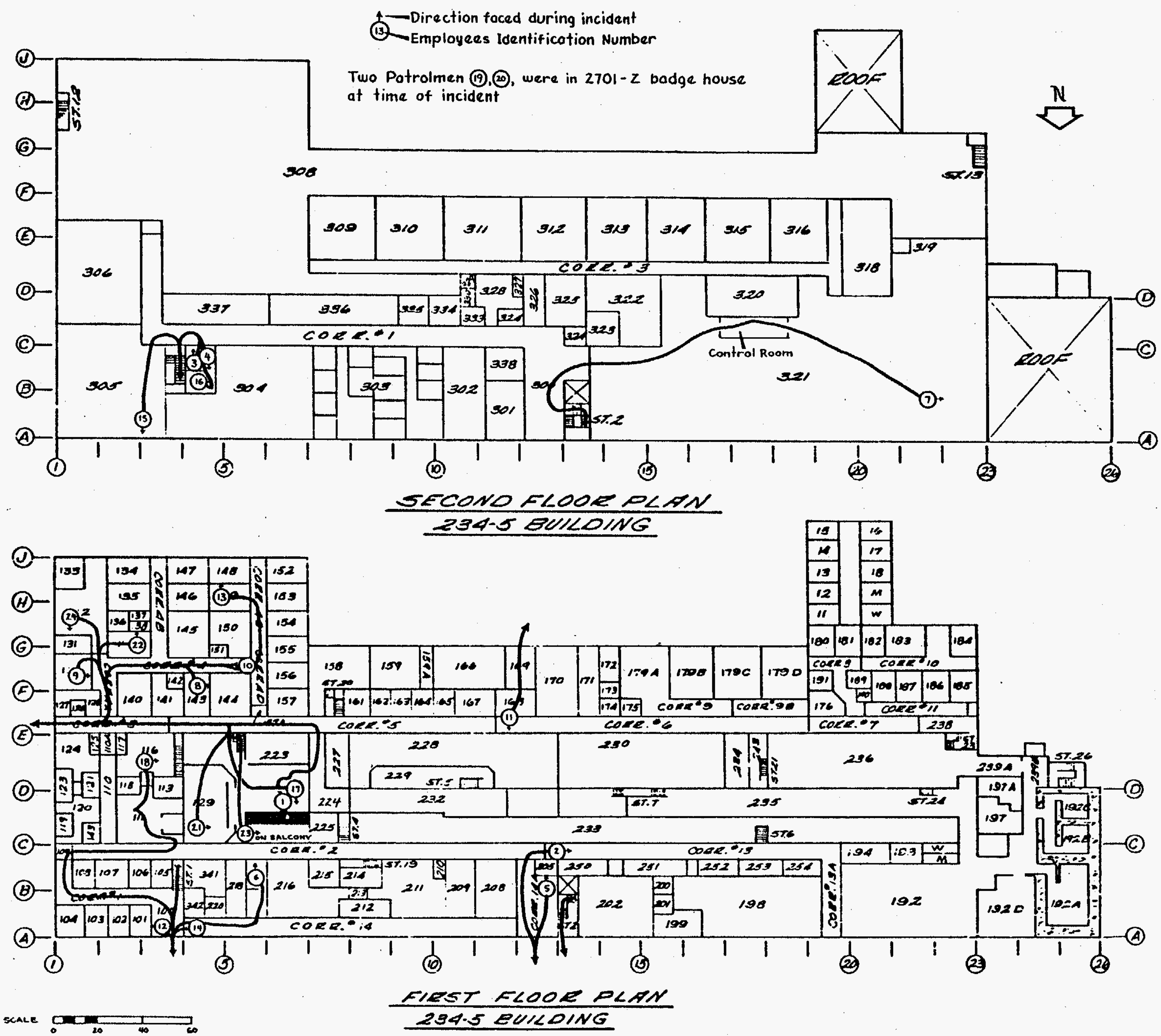
Employee #21 was the first to be discharged from the hospital, on April 8. The others were released for eight hours each on April 11, 14, and 15, and were discharged from the hospital on April 16. Since discharge, tests and observations of various types have been made on the three men initially hospitalized, in order to acquire scientific information. They have participated willingly in this program. Periodic observation to determine what, if any, long range effects their exposure may have had, also have continued and will continue.

G. Re-establishment of Operations

Evacuation of the 200-W Area on April 7 stopped normal production activities there. By April 13, it was apparent that resumption of operations at some distance from 234-5 would be safe. Accordingly, a 1500 feet exclusion radius (with minor exceptions later granted) around 234-5 was established, and on April 16 operation of Redox resumed. By April 26, it was clear that operations in 234-5 other than those in Recuplex could be safely resumed. Accordingly, steps were taken on April 30 to reactivate the button-line and fabrication operations. Getting back into operation required several weeks from this date, however, since it was necessary to establish a different method of handling the button-line filtrates which were formerly sent to Recuplex. The ECC was closed on April 27 and the Advisory Council went into a deactivated state. CPD set up special internal organizational machinery to carry through the remaining activities in Recuplex and to supply the Investigation Committee with needed information.

The Recuplex facility is at present shut down. No firm decision regarding putting it back into operation has been made known. However, construction of the replacement facility, authorized by the AEC just before the accident, has started. As an interim measure, temporarily acceptable ways of handling the materials formerly sent to Recuplex have been worked out. Since some portions of the equipment in the SE hood have been removed, it thus appears progressively less likely that Recuplex will be put back into operation.

LOCATION OF PERSONNEL AND EVACUATION ROUTES DURING CRITICALITY INCIDENT, 4-7-62



[redacted]

Fig. VII-1
Rev. 4-24-62

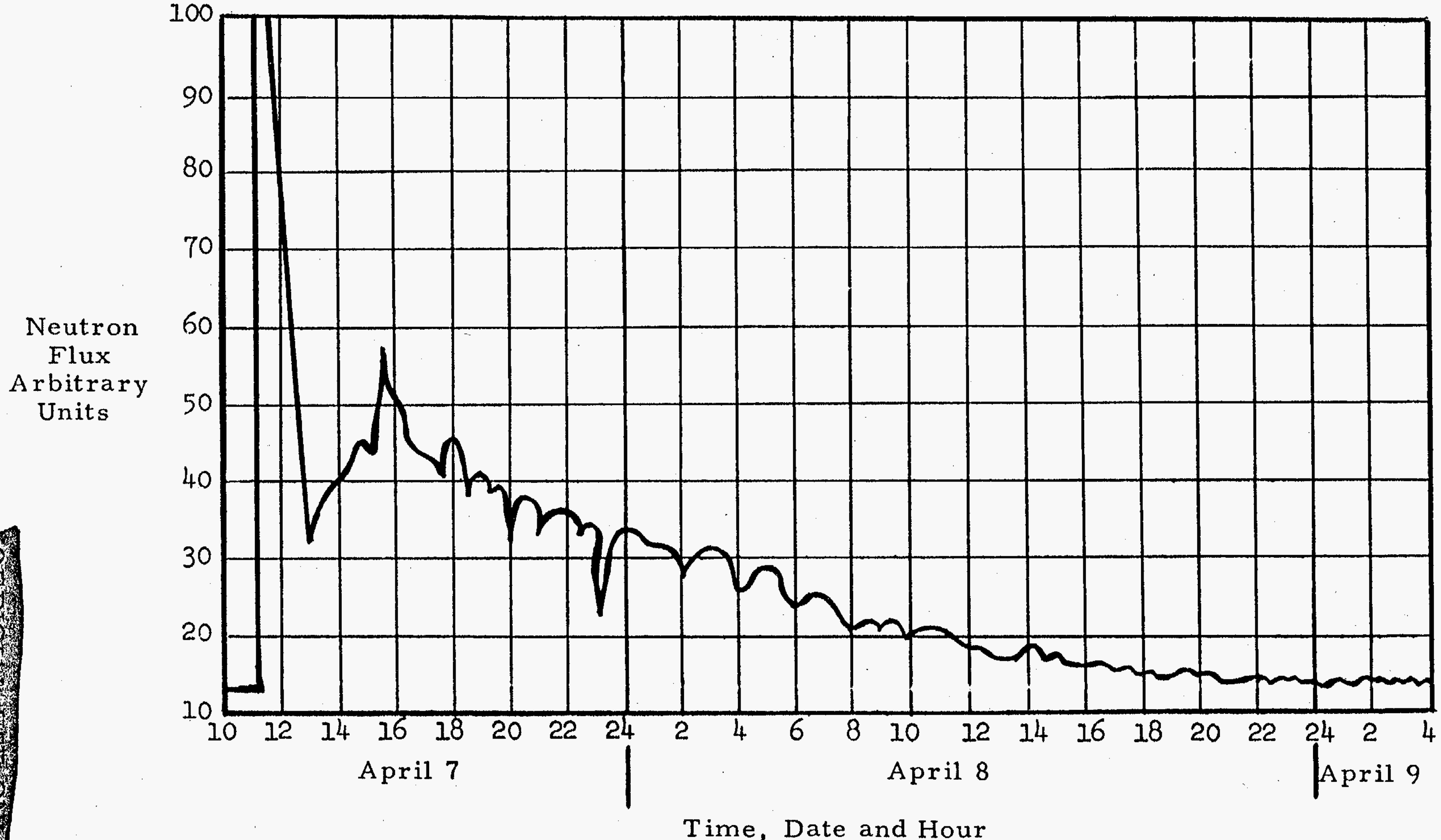


FIGURE VII-2
Measured Neutron Flux at Point Outside 234-5

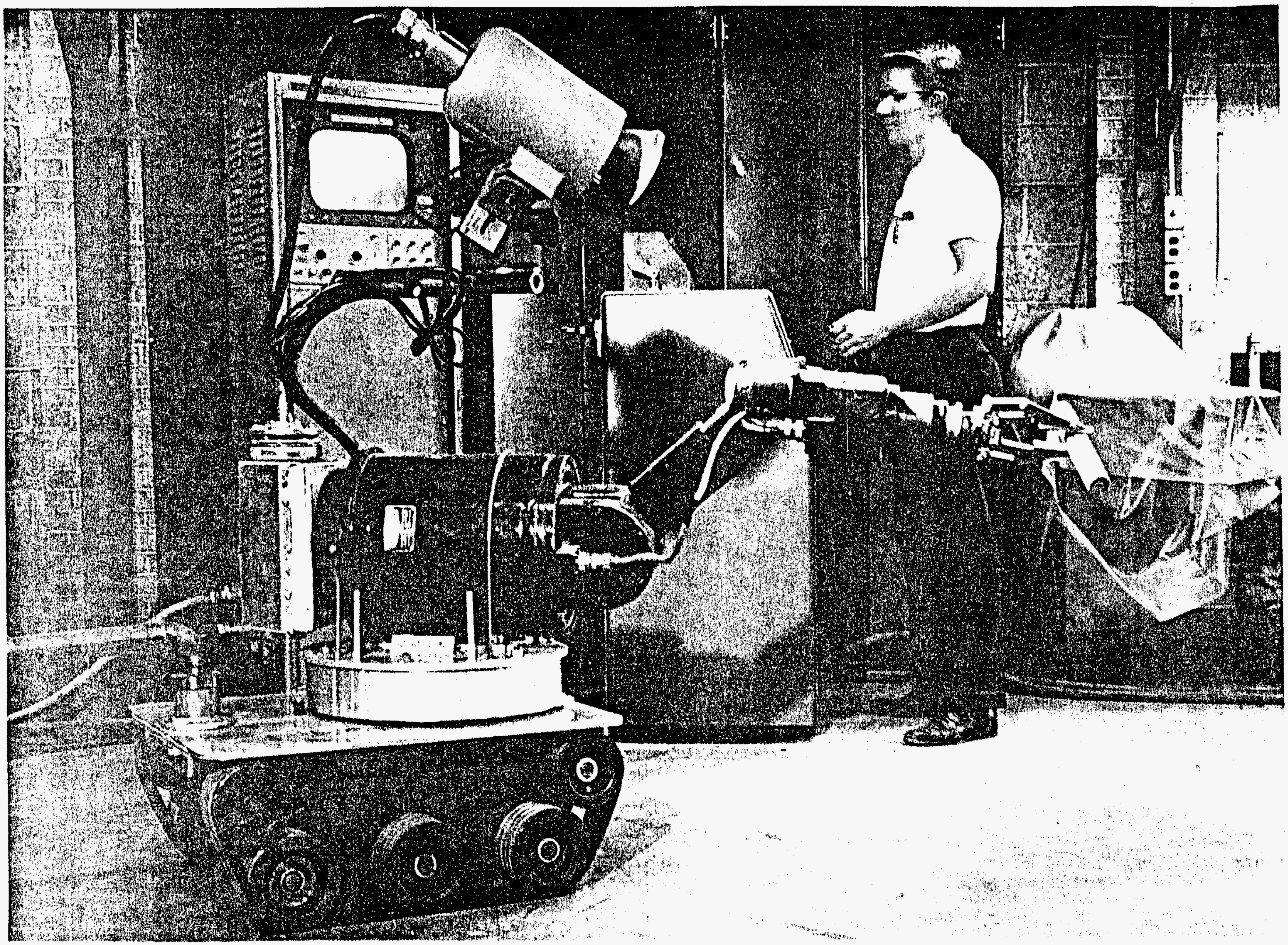


FIGURE VII-3
Remotely Controlled Robot, TV Camera and Console

[redacted]

VIII. DISCUSSION

This section of the report contains the significant facts regarding the accident and a discussion of them.

The discussion falls naturally into three parts:

A. The operation of the system set up for dealing with the accident.

B. The explanation of the accident itself.

C. Measures which would have prevented the accident.

A. The Operation of the System Set up for Dealing with the Accident

The system set up for dealing with possible accidents such as this involved the taking of certain actions by both the GE and HOO organizations. Although there were later found to have been minor deviations from the plan, these were insignificant and, in general, the plan functioned smoothly. The employees in Building 234-5 evacuated the building promptly, in the main, and the one or two who delayed slightly were renotified by fellow employees of the seriousness of the situation so that their delay was minimal. Radiation monitoring personnel went to work promptly and efficiently; the potentially injured employees were quickly identified and placed under medical care within an hour of their exposure. All employees involved in the evacuation behaved in a calm, orderly way. The systems of notification to the Emergency Control Center, to line supervision, and to AEC officials worked well. Details are recorded in Section VII of this report. Of particular note are the facts that the Hanford Laboratories Crash Alarm System resulted in manning the ERC within about ten minutes of the giving of the crash alarm, that the HAPO General Manager was at the ECC within about 30 minutes and the Manager HOO-AEC was notified within 30 minutes of the accident, despite the fact that the accident occurred on a Saturday, when many people are normally not easily accessible.

In Section VII are recorded the steps taken to set up organizations for planning the moves to deal with the facility, for review of those plans, and for investigation of the accident.

The Investigation Committee had an excellent opportunity to observe in detail the planning and handling of the postaccident measures to neutralize the facility and to learn the cause of the accident. These measures were planned, reviewed, and executed with meticulous regard for the safety of the individuals involved. This approach was appropriate, in view of the fact that it was not known whether conditions were such that another nuclear excursion might start up upon minor disturbance. This necessarily cautious approach resulted in using the first thirteen days after the accident to neutralize tank K-9, and an additional three days to poison the significant geometrically unfavorable tanks. The personnel who planned, reviewed, and executed the "quenching" operations exhibited a high order of ingenuity and resourcefulness.

The releases of information to the public and to project employees appear to have been timely and adequate. Within a few hours, a press release had been prepared and cleared with local AEC authorities and with Washington-AEC. Some terminology in that portion of the release which concerned the extent of the injuries sustained by the four employees involved, later was questioned by Washington-AEC as possibly being liable to misinterpretation by persons not familiar with the precise meaning of the terms used. This was the only significantly adverse comment noted on any of the releases.

B. Explanation of the Accident Itself

In spite of careful review of a large mass of evidence and testimony, it has not been possible for the Committee to develop an explanation of the accident which completely agrees with all the technical data or all the personal testimony. An acceptable explanation has, however, been developed. To the extent that it does not agree with technical data or personal testimony, the acceptance of this explanation implies that the technical data are in some degree unreliable, and that the personal testimony also is partly unreliable. The Committee has seen several examples of both these types of unreliability in the information supplied it in this investigation (this does not imply any intent to mislead the Committee), and is, therefore, willing to accept an explanation which does not fit all the data and testimony, provided it does agree with the better-established parts of the evidence.

The most plausible explanation of the accident comprises the following statements:

1. During the latter part of the 12-8 shift on April 7, product solution flowed intermittently from the top of column H-3 (solvent extraction stripping column - see Fig. IV-5 for flow diagram) to vessel J-1 (a product receiver tank) and was intermittently removed from J-1 during this period. However, during part of the period, input sufficiently exceeded output to cause J-1 to fill and then to overflow. The overflow went via a line provided for the purpose to the floor of the SE hood.

   The evidence for this statement is summarized on Fig. VIII-1, which is a record of inflow to J-1, outflow from J-1, and weight factor (i.e., depth x density) in J-1. This figure is drawn from charts taken from recorders after the accident. The traces on the original charts were not as sharp as these drawings might imply, because of instrument noise and sticking of the tracing stylus in places. However, the uncertainties thus introduced are not enough to invalidate the conclusion above-stated. It will be observed that for considerable periods between 0600 and 0800, the weight factor indicated J-1 to be full while input was occurring at rates greater than output. During these periods, J-1 must have been overflowing.

   Statement 1 is not controverted by any of the physical evidence. Consistent with statement 1 is the observation by all the operators that there was liquid on the floor of the hood before the accident (although they differ somewhat on the extent of the pool of liquid). The 12-8 operator, on whose shift the presumed overflow occurred, does not recall having seen any overflow occurring, but did not specifically look for one. Visibility through the plastic hood walls is extremely poor (for example, several minutes of study was required on the part of a Committee member before he could be convinced that he was seeing the sump location) and it is judged unlikely that an operator would have noticed the overflow by direct observation unless he had been looking for it. The operator did not specifically recall checking the J-1 weight factor instrument (his only means of determining liquid level in J-1). The shift Specialist who came on duty at 0800 made a careful visual check of the SE hood for leaks, and found none active. (The evidences of old leaks were clear and plentiful in the hood after the accident.) However, by this time the overflow would have stopped, and even if continuing, might have gone unnoticed in a leak search, since the overflow line extended clear to the hood floor. Thus, the personal belief of the 12-8 operator that the overflow did not occur is not conclusive.

The Committee regards statement 1 as essentially established.

2. At some time within several minutes before 1059 and while suction was on tank K-9, valve #944 was opened, allowed to remain open for a few minutes, and then closed. This resulted in sucking some of the strong product solution from the sump (where it was in a thin slab geometry and therefore, necessarily subcritical) into K-9 where its geometry became such as to make it almost critical.

To establish plausibility of statement 2, the following arguments are adduced:

a. The quantity and Pu concentration of the overflow from J-1 were at at least sufficient to account for the quantity and concentration of the Pu solution found in K-9 after the accident.

b. The composition of the solution found in K-9 after the accident, as regards its constituents other than Pu, is consistent with the hypothecated origin of this solution.

c. A physically feasible path existed from the sump to K-9 via valve #944, and only this valve needed to be opened to draw liquid from the sump into K-9.

d. Opportunity for opening and closing of valve #944 existed.

e. The manner in which the power probably varied during the excursion is consistent with triggering mechanisms which could have been operative.

Various other explanations have been examined and found less plausible, or actually impossible. These arguments may be elaborated as follows:

a. The quantity and Pu concentration of the overflow from J-1 were at least sufficient to account for the quantity and concentration of the Pu solution found in K-9 after the accident.

After the accident, K-9 contained about 39 liters of aqueous solution of 34.8 grams/liter Pu concentration plus a crudely estimated 68 grams (max.) of Pu in solids, and a few hundred milliliters of strong organic Pu solution in the inferior connected piping for a total quantity of 1400-1500 grams of Pu. From Fig. VIII-2 it has been estimated that a total volume of about 48 liters overflowed from J-1. (The H-8 flow through the column and into J-1 was at the rate of 0.66 liters/minute for 90 minutes (~59 liters total) in the 0600-0800 interval. The rate of outflow from J-1 was 0.36 liter/minute for 30 minutes (~11 liters total). The weight factor indicator showed J-1 full throughout the entire two-hour interval, so all of the difference (59 - 11 = 48 liters) must have overflowed onto the floor.) The Pu concentration found in the J-1 tank after the accident was 34.4 grams/liter, but the Pu concentration in the J-1 liquid during the interval 0600-0800 is estimated from Fig. VIII-2 (H-3 column product concentration) to have been about 45 grams/liter average. Hence, the Pu overflowing onto the floor was about 48 x 45 = 2160 grams.

The brown rings left on the glass walls of K-9 suggest that the volume of the solution at the time of the accident was about 45 liters,* which decreased by evaporation and radiolysis to the 39 liters found afterward. The concentration of Pu in the original K-9 solution would then have been about 30 grams/liter. The difference between the 45 grams/liter concentration in the overflow to the floor and the 30 grams/liter in K-9 is accounted for by assuming dilution of the floor solution with aqueous phase drawn from L-2, through K-9 and thence into K-2, where it formed the 10-30 liter aqueous cap reported by both the 8-4 shift operators. This solution would presumably be of the same concentration as that later found in L-2, i.e., 0.118 gram/liter. Mixing of the two liquids in the ratio two parts J-1 overflow to one part L-2 aqueous phase would give 45 liters of 30 grams/liter solution in K-9. Such a calculation is obviously not very accurate, since it does not take into account possible dilution of the J-1 overflow while on the floor; however, the impression given by all the operators was that there was only a little liquid (of the order of several liters) on the floor during the day or two before the accident.

In any event, it is evident that the J-1 overflow provided more than the requisite amount of Pu for K-9.

The residue remaining in the sump after the accident was sampled on April 25 and was analyzed for Pu also. Both aqueous and organic phases were present. The aqueous phase, at various depths in the sump, contained 1.4 to 2.5 grams/liter Pu, while the organic phase (black, tarry, and lighter than the aqueous phase) contained 61 to 132 grams/liter Pu. The low density of the organic phase suggests loss of CCl_4 by evaporation over the several week-long interval between the accident and the sampling. Loss of CCl_4 would make the remaining TBP a more powerful solvent for Pu. The low Pu content of the aqueous phase thus does not necessarily indicate that 45 grams/liter aqueous Pu solution could not have been on the floor, but is consistent with the supposition that the Pu was extracted into the organic phase on the floor and in the sump after the accident.

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*As noted elsewhere, criticality calculations suggest that the initial volume was about 50 liters. The apparent discrepancy between 45 liters and 50 liters does not affect the argument or conclusions.

b. The composition of the solution found in K-9 after the accident, as regards its constituents other than Pu, is consistent with the hypothecated origin of this solution.

The solutions found after the accident in H-7, J-1, K-9, and L-2 were all analyzed chemically for acidity, sulfate, ammonium, and iron. If the solution in K-9 was the result of mixing J-1 overflow with L-2 aqueous phase, the composition of the K-9 solution should be calculable from those of H-7, J-1, and L-2. H-7 is included here because it is the cold chemical feed tank from which the aqueous stripping solution is pumped into the bottom of column H-3.

On emerging from the top of H-3, this solution, now carrying Pu as well as its original constituents, passes to J-1. Thus, the non-plutonium analysis of H-7 should be the same as that of J-1 and may be used in place of the J-1 analysis in calculating the composition of K-9. The accompanying Table VIII-1 shows the results of calculating the K-9 composition in both ways. In both cases, it was assumed that the K-9 solution resulted from mixing 15 liters of L-2 solution with 30 liters of J-1 overflow as would be necessary to make the Pu content of K-9 come out right. It is apparent that there is a rough correspondence between the calculated and found compositions of K-9. The H-7 analyses are probably more reliable than those of J-1, since the H-8 solution corresponds closely to what was supposed to be fed into the column at the time, whereas the J-1 analysis does not and is more difficult to perform. Allowances must be made for possible floor contamination of the J-1 overflow, and for the known tendency for samples from J-1 to be high in sulfate, due presumably to sulfate solids being picked up out of the tank with the sample. Although agreement leaves something to be desired, the general pattern of agreement among the Pu, H^+, SO_4^{--}, and NH_4^+ constituents (using the H-7 analysis for the latter) can hardly be coincidental and is regarded as supporting the conclusion that J-1 overflow liquid found its way into K-9.

The possible sources of aqueous Pu solution of concentration greater than 30 grams/liter are shown in Table VIII-2, according to post-accident analyses of the contents of all vessels in the SE and R&B hoods.

It will be observed that three of the tanks (G-66, J-2, and J-3) contained solutions of such high acidity as probably to preclude their being the origin of the solution in K-9, and two of the three are also excluded by their sulfate contents. Of the remaining tanks, G-59 is located in the R&B hood and could transfer into the SE hood only via tanks G-65 and G-66 (also in R&B hood), of which one (G-65) was found empty and the other (G-66) has already been excluded. J-7, if diluted to 30 grams/liter, would be 1.85 M acid, which is well above the acidity of K-9 (1.07 M) but perhaps not high enough to rule out J-7 as a source in view of analytical uncertainties. Tracing out of the lines leaving J-7 discloses no open path to K-9. While it is theoretically possible for the

TABLE VIII-1 CALCULATED AND FOUND COMPOSITION OF K-9 SOLUTION (MOLALITIES)*

Constituent	H-7	J-1	L-2	K-9: At time of accident**	K-9: From L-2 and H-7	K-9: From L-2 and J-1
H^+	0.558	2.10	3.30	1.07	1.47	2.50
SO_4^{--}	0.16	0.28	0.036	0.095	.12	.20
NH_4^+	0.03	0.42	0.10	0.011	.054	.31
Fe	0.0019	0.003	0.01	0.04	.004	.005

*Assuming ratio of floor solution to L-2 solution is 2:1.

**Assuming volume of 45 liter in K-9 at time of accident.

[redacted]

TABLE VIII-2 AQUEOUS SOLUTIONS OF MORE THAN 30 GRAMS/LITER PU CONTENT

Vessel No.	Pu g/l	H^+ M	SO_4^{--} M	NH_4^+ M	Fe M	Remarks
G-59	71.4	4.01				In R&B hood. Volume solution 17 liters, 214 grams Pu.
G-66	32.4	6.68#				45.5 liter vessel, contained 34 liters solution
J-1	34.4	2.10	0.28	0.023	0.003	
J-2*	22.4	7.98#	2.1#	0.0056	0.0057	40.6 liter vessel, 2.5 liters solution contained
J-3	86.4	9.60#	3.16#	0.01	0.007	40.6 liter vessel, 2 liters solution contained
J-7	111.2	6.87				37.2 liter vessel, 16 liters solution contained
K-9	30.0	1.07	0.095	0.011	0.04	Calculated composition at time of accident

*Included here because of uncertainties about accuracy of analyses.

#Indicates an analysis so high as to preclude this solution as the origin of the Pu in K-9.

contents of J-7 to find their way to the floor, this would require a series of manipulations of valves or pumps. No such series is suggested by any evidence or testimony.

c. A physically feasible path existed from the sump to K-9 via valve #944, and only this valve needed to be opened to draw liquid from the sump into K-9.

As shown in Fig. IV-5, a plastic line had been installed for temporary use during the floor cleaning operations between valve #944 and the sump. While the floor cleaning operations were going on, floor flushes were drawn by suction into K-9 from the sump. To guard against criticality in geometrically unfavorable K-9, a procedure of first putting cadmium nitrate solution in K-9 was followed. Suction was applied to K-9 from the vacuum header; valves #431 and #944 were open, and other valves to K-9 were closed.

The floor cleaning operations had been finished but the temporary plastic line had not yet been removed (an order for its removal had been issued a few days before the accident). After the accident, valve #431 was found open as shown on Fig. VIII-2. Valve #944 was found closed. This valve is of the quarter-turn-to-open type, with a ball type plug. Rotating the valve handle (a simple bar) from 3 o'clock to 12 o'clock opens the valve completely.

Examination of the vacuum-vent valve (#312) after the accident showed it to be open to the vent, as it should be as a result of the procedure used to render K-9 harmless. Whether this valve was actually open to the vacuum header at the time of the accident cannot be confirmed after the fact, but since several suction transfers into K-9 had been made during the morning of April 7, and since the operator states that #312 was open to vacuum at the time of the accident, and since there is no controverting evidence or testimony, it may safely be assumed that suction was available in K-9 so that if valve #944 were opened, liquid from the sump could enter K-9.

d. Opportunity for opening and closing the valve existed.

The handle of valve #944 is located inside the hood, approximately as shown in Fig. VIII-3. The valve works easily, but in order to operate it, the operator must put his hand into glove B and reach inside the hood, a distance of 1 - 1 1/2 feet. Both the regular operator (employee#1) and his relief operator (employee #18) were familiar with the valve and its function. Both operators had the opportunity to open and later to close the valve, as required by the explanation considered most plausible. Both operators state that they do not recall doing so. Both state that accidental opening of #944 while reaching for one of the other valves in the vicinity is possible, but unlikely.

e. The manner in which the power probably varied during the excursion is consistent with triggering mechanisms which could have been operative.

In Appendix 8 will be found a discussion of a physical anlysis of the excursion. This analysis shows, among other things, that if criticality occurred as a result of a continuing steady addition of uniform plutonium solution, the rate of addition probably had to be less than (very roughly) 0.1 - 1 ml/sec. Had it been much larger than this, the size of the initial pulse would have substantially exceeded the $\sim 10^{16}$ fissions which it is believed to have contained. Since putting $\sim$50 liters of solution into the tank would have required 14 hours at 1 ml/sec, and since the time available for filling the tank was apparently 15 minutes or less, this does not seem to have been the triggering mechanism. However, other mechanisms, capable of adding the last increment of reactivity at a slow rate once the tank was almost critical, exist. For example:

1) Addition of 1400-1500 grams Pu at a concentration greater than 30 grams/liter followed by dilution with a small stream of dilute nitric acid. Such dilution could occur as a result of sucking the aqueous cap off K-2 into K-9, as was actually done.

2) Addition of final increment of reactivity as result of deaeration of contents of K-9 following the dumping of the aqueous cap off K-2 on top of the more concentrated solution in K-9. Such deaeration would be stretched out over a longer period than normal by the effect of the suction applied to K-9.

3) Addition of final increment of reactivity as result of settling out of organic phase (a neutron absorber and hence reactivity depressant) drawn into K-9 as an incidental part of the decanting of the aqueous cap off K-2. The finding, after the accident, of a few hundred milliliters of organic phase in the piping at the bottom of K-9 is consistent with this possibility.

Although it has not been possible to establish the exact triggering mechanism, it is apparent that any one or any combination of the three indicated above would be consistent with the evidence and testimony available.

f. Various other explanations have been examined and found less plausible or actually impossible.

At the time of the Committee's preliminary report, it had been found that there was an accumulation of dried solids on a valve between the top of the stripping column H-3 and J-2, a product receiver and acid addition tank. The dried solids were found to contain 37% Pu, corresponding approximately to plutonium nitrate. Leakage of product solution onto the floor was at once suggested. The valve and its connected piping were removed and tested in the laboratory for leakage. The leakages through the closed valve and through the fitting were less than 0.1 ml/min and 1 ml/min, respectively, under pressures much higher than could have existed in the process. It is obvious that neither leak could account for the quantity of Pu which got into K-9.

The possibility that an accumulation of solids in K-9 might have played a significant role was ruled out by examining the bottom of K-9 and finding on it at most less than 68 grams of solids.

The possibility that valve #944 might have been leaking sufficiently to admit the sump liquid under suction, and then to somehow retain the liquid above it for several weeks was suggested. Valve #944 was removed, with its associated piping, having first immobilized the valve handle in its as-found position by application of a self-setting resin. Hydraulic tests were then made, which proved the valve to be nonleaking. The internal parts of the valve appeared clean and bright; there was no indication that any solid or semi-solid material was present to act as a sealant against downward flow. It was also hypothesized that there might be some position of the handle of valve #944 which would permit upward flow at the necessary rate of several liters per minute in response to the suction ($\sim$20-25 inches Hg subatmospheric) on K-9, but would not permit downward flow when the suction was removed or would limit downward flow to a slow rate. Experiments to find such a setting of the handle did not disclose the existence of any setting at which the flow rate relationships even approximately satisfied the hypothesis.

It was found that although the valve handle worked easily, it stayed in any position in which it was put. Creeping from a slightly open to a tightly closed position under the action of gravity hence seems excluded.

The possibility of entry of strong Pu solution into K-9 through openings other than K-9 also was considered. Reference to Fig. VIII-2 shows that all exits from and entrances to K-9 were blocked by closed valves or by a capped line. Moreover, the lines beyond these closed valves were found in every case to lead proximately to other closed valves or to vessels containing either no plutonium in aqueous solution, or aqueous plutonium solutions of concentration much less than the 30 grams/liter minimum which must have existed in K-9 at the time of the accident. Thus, leakage of one of these valves would not have admitted sufficiently concentrated Pu solution to account for what was found in K-9.

As implied earlier in this section, there was also a systematic survey of the possible sources of Pu solution of 30 grams/liter or stronger, with a view to determining whether they could contribute 30 grams/liter or stronger solution to K-9, either by transmission through pipes, or by leakage to the floor, and thence into K-9 via valve #944. This survey disclosed no plausible source of Pu solution except J-1.

The foregoing most plausible explanation of the accident considers only that evidence which is directly pertinent to this explanation. In the course of searching for an explanation of the accident, much additional evidence was developed. Some bits of this additional evidence are at variance with what was expected to be found. For example:

1) The chemical operator said that he had put certain chemicals into tank K-8 in preparation for washing the organic phase in K-2. After the accident, K-8 was empty, and its drain line valve was partly open to the waste collection system. Why this valve was partly open is not known.

2) The aqueous solution in G-36, a waste storage vessel, was 7 M acid instead of about 3 M as expected. No explanation is available.

3) The product solution in J-1 was 2.1 M in acid, whereas it was expected to be about 0.6 M. No explanation is available.

4) The solution in tank L-2 was found to consist of about 175 liters of aqueous solution of 0.118 gram/liter Pu content. It had been expected that the tank would contain about this same volume of organic solution of about 2.1 grams/liter Pu concentration. This condition, while unexpected, was not considered abnormal since this tank contained dilute wastes, of both phases, collected from several sources over a period of a few shifts.

These conditions are not of a type which would be expected to create a nuclear safety problem but, being anomalous, they might be suspected of some connection with the accident. No such connection has been found, and these points remain minor and probably disconnected anomalies.

C. <u>Measures Which Would Have Prevented the Accident</u>

Certain conditions existed in the Recuplex facility on April 7 which were necessary to the accident, and which were not necessary to operation of the equipment. Correction of these specific conditions would probably have prevented the accident. The conditions referred to are:

1. K-9 was geometrically unfavorable, and although the introduction into it of fixed poison had been considered, no such poison was present.

   On at least three previous occasions there had been "over-batch" incidents in K-9, i.e., the specified maximum quantity of Pu allowed in the tank at any one time had been exceeded. Because these mass limite are set quite conservatively, there was no criticality in any of these cases. Partly as a result of these incidents, the installation of Pyrex glass raschig rings in K-9 had been considered. The boron contained in the Pyrex would have been a powerful suppressant of neutron multiplication. However, there were some objections to the installation of the rings (mixing of the contents of the tank would be more difficult, hold-up of liquid on the surface of the rings would be increased, sampling would be less reliable), and it was concluded that the right answer to this and other recognized problems of the Recuplex facility was the construction of a new facility - Project CAC-880. Approval of this project had been requested, but its final authorization involved considerable delay, as elsewhere noted.

2. K-9 was not equipped with an alarm-sounding neutron counter which would signal the presence of too-large quantities of Pu.

   The installation of a neutron counter (which would sense the spontaneous fission neutrons from Pu^{240}) for detection of too-large quantities of Pu in K-9 had also been discussed. However, no decisive action had

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[redacted]

been taken, it being indicated that a counter of the type desired would be quite expensive and further study seemed desirable. Counters are available on various of the process vessels, but in order to get a reading from them, one must first set a selector switch to the counter of interest, since several counters feed into the same meter through a selector switch. No counter was installed on K-9. There was here also some feeling that the proper course of action was to replace K-9 with a geometrically favorable vessel, as planned in Project CAC-880, and that the real answer was to get approval on CAC-880.

3. The directly associated operating organization did not realize that a J-1 overflow would bypass J-5.

Until about three years ago the overflow from J-1 was directed to J-5, a tank which serves also as an overflow catch tank for various other vessels. J-5 itself overflows to the sump, but is provided with a high level alarm which notifies the operator to pump out J-5 into another tank from which appropriate final disposition of the overflow can be made. About three years ago, it was found that occasionally there would be contamination of J-1 with less pure overflow solutions from another vessel. The contamination was traced to a form of backing-up through the overflow line. To make sure of curing this trouble, a new overflow line was installed directly from J-1 to the floor. This change did not introduce a direct nuclear hazard, since the floor of the hood is geometrically favorable. However, after the accident it was found that relatively few people in the operating organization were aware of the existence of the direct overflow line from J-1 to the floor, and the operators relied upon the J-5 alarm signal to notify them of an impending overflow to the floor. The installation of the line was reviewed and approved by the Critical Mass Engineer at the time of installation, but the operating procedures do not mention the line or its effect on operations.

The drawings of the equipment in the SE hood, available at the time of the accident, do not show the direct overflow line from J-1 to the floor. The line was discovered during the course of the postaccident activities requested by the Investigation Committee and aimed at acquiring an up to date set of "as-built" drawings.

4. The operators did not observe or did not properly interpret the weight factor indication on J-1.

That an overflow might be occurring could have been inferred from the fact that the weight factor chart indicated the vessel to be full. However, this, in turn, would have required knowledge of the specific gravity of the solution in J-1. The input-output flow charts would also have given some hint of overflow had they been studied continuously. However, even in normal circumstances, the operator and the shift specialist are too busy to be expected to do such work. On April 7, they were doubly busy since there had been difficulty in keeping the H-1 and H-2 columns from flooding and this had taken much of the operator's attention on both the 12-8 and 8-4 shifts. Thus, while it would have been possible for the operator to have detected the overflow from J-1, it is not reasonable to expect him to have done so.

5. Valve #431 was open.

The Committee learned that when suction is applied to K-9 there are two routes by which liquid may be drawn from the same opening at the bottom of L-2 (a tank used for collection of contact organic, located in the R&B hood) into K-9. One of these routes admits the liquid to the top of K-9, through valve #506 (see Fig. VIII-2). The other admits liquid to K-9 through its bottom, via valve #431, the pump, and valve #543. The "normal" path was through valve #506, into the top of K-9. However, some of the operators felt that the transfer went faster if the other route (via valve #431) was used. Operating instructions did not forbid the use of the route through valve #431, and this route had been used on the 12-8 shift in making transfers from L-2 to K-9 and thence to K-2. Valve #431 was left open as a result of these transfers. The 8-4 operator did not make a complete valve status check when he came on duty, and was, hence, unaware that #431 was open. Had it been closed, the accident would not have happened.

6. The temporary line from the sump to valve #944 had been allowed to stay in place after its usefulness was past.

During the planned use of this line, the procedure called for first determining the Pu content of the sump contents, then placing in K-9 a specified quantity of $Cd (NO_3)_2$ solution before sucking the sump liquid into K-9. These precautions were carefully detailed in a special instruction which had Critical Mass Engineering approval. This instruction was silent on the subject of removal of the temporary plastic line after the floor clean-up had been concluded. However, the supervisor's instructions to the operating crew after the floor clean-up had been completed included directions to cease using the temporary plastic line. A work order for removal of the line had been written four days after need of the line ceased. After another three days, the work itself had not been performed. The work order was being handled as a routine scheduling item at the time of the incident. Thus, a full week had passed without correction of this primary hazard to critical mass safety.

7. Valve #944 was operated, contrary to oral instructions. As previously pointed out, no one admits to having operated valve #944, but no other plausible explanation is available.

[redacted]

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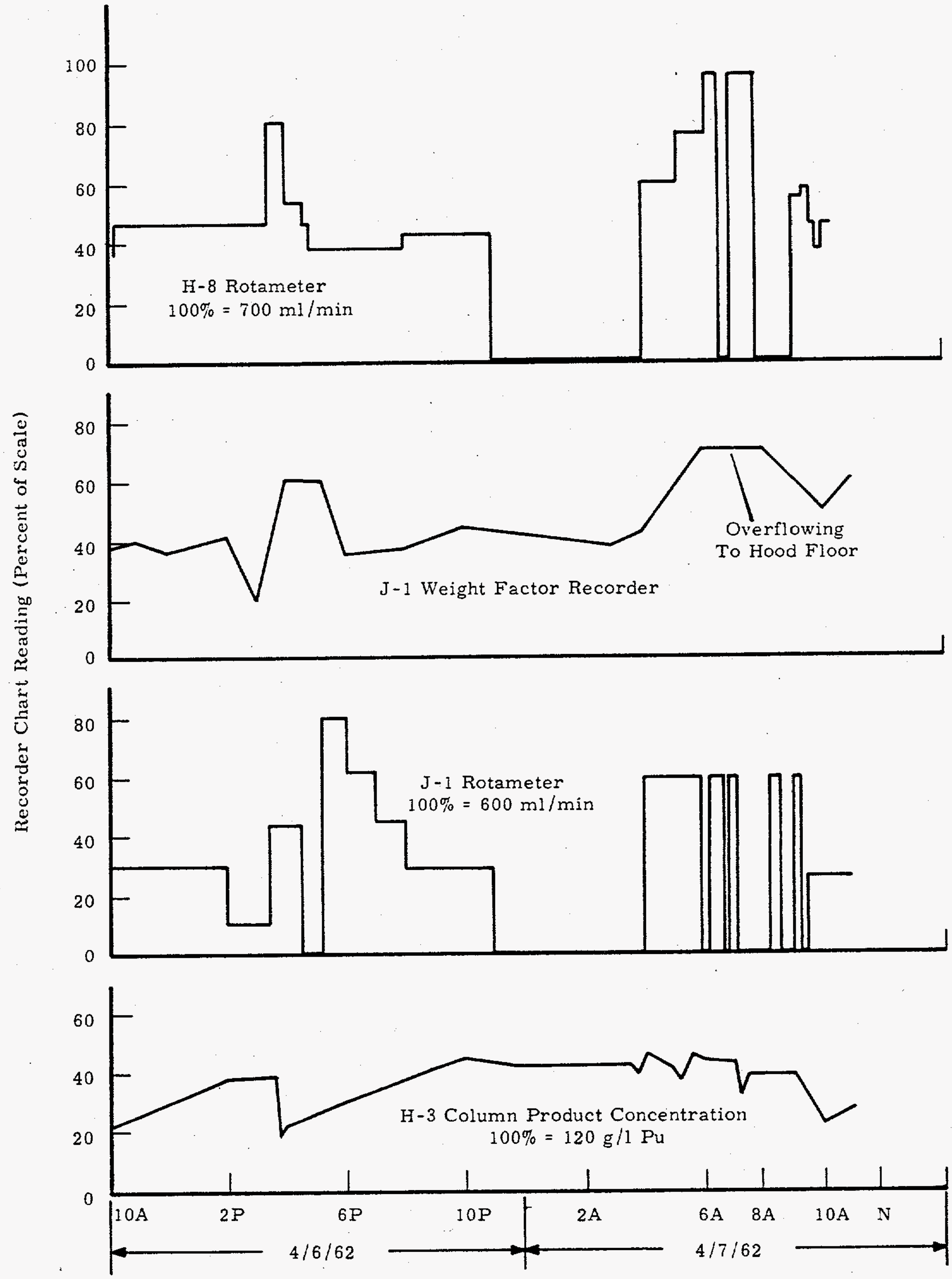

FIGURE VIII-1

J-1 Flow and CCP Record

AEC-GE RICHLAND, WASH.

[redacted]

[redacted]

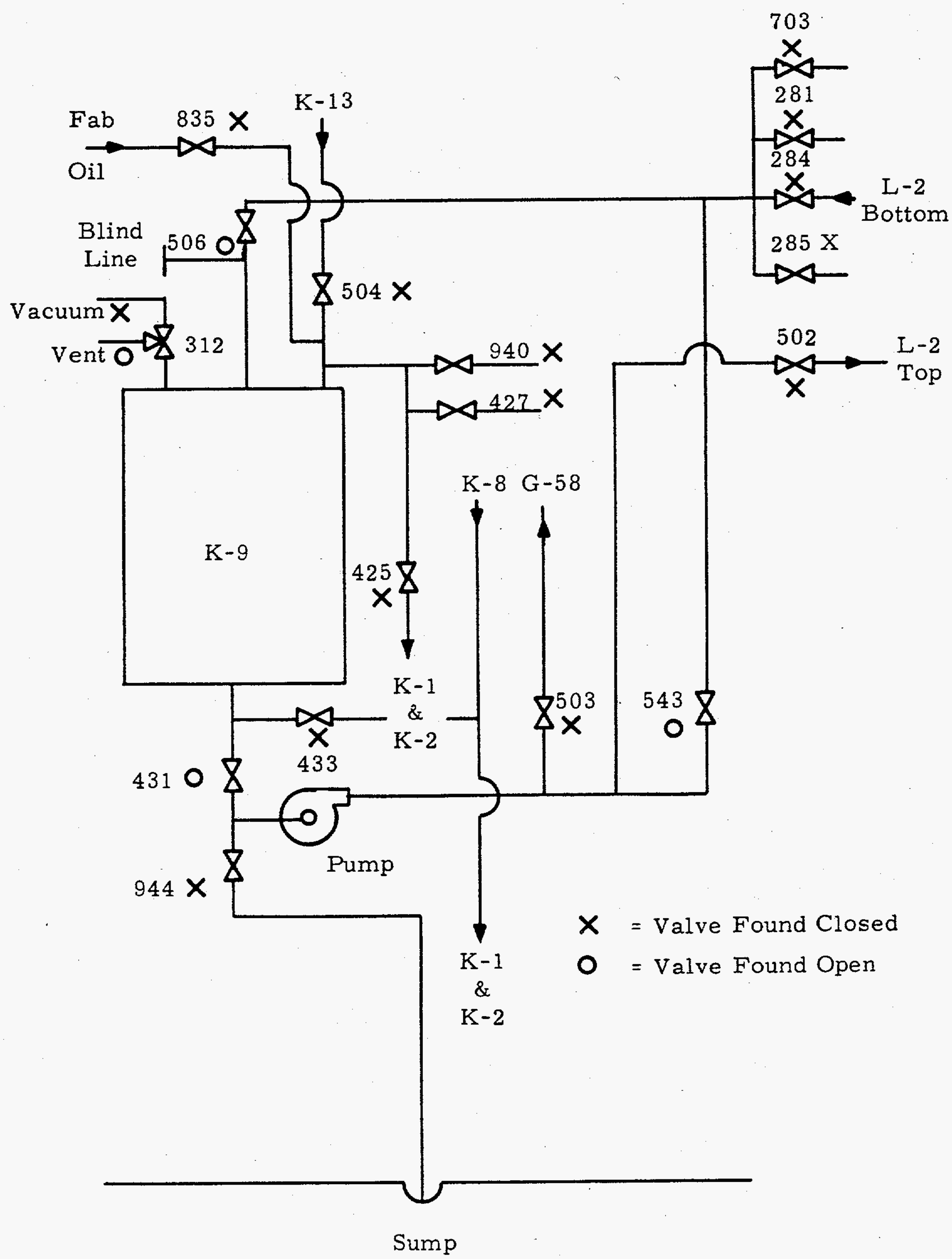

FIGURE VIII-2

K-9 Piping and Post-Accident Valve Status

[redacted]

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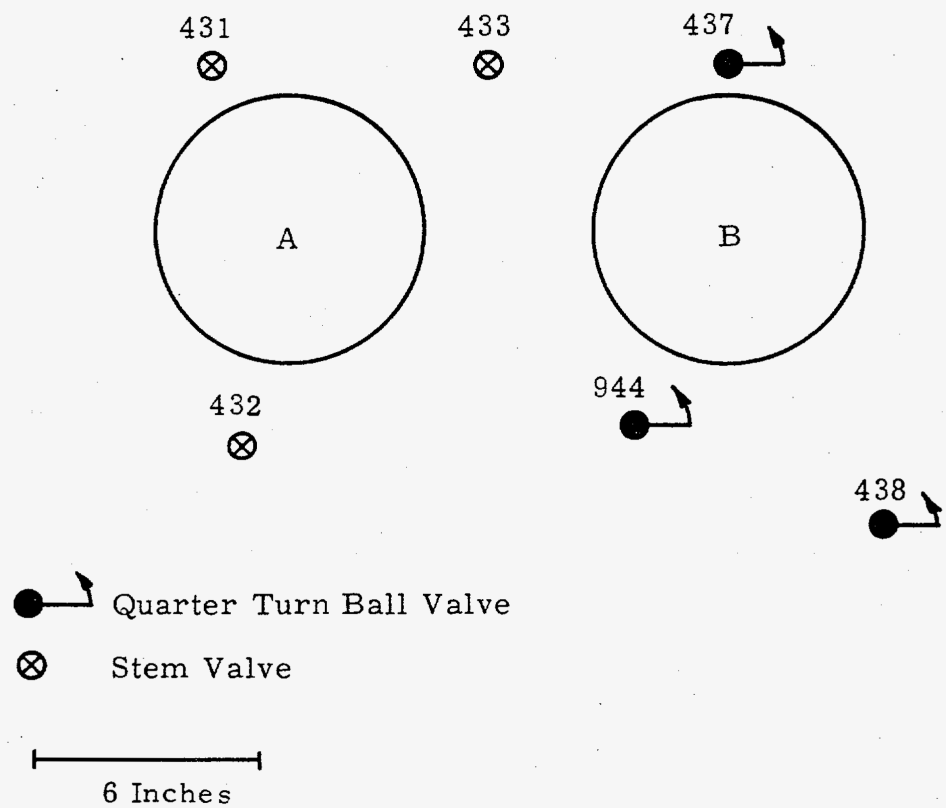

A & B are Glove Ports, Dia. Approx. 9"

431	K-9 to Pump
432	K-8 to K-2
433	K-9 to K-8 Header
437	K-8 to K-8 Header
438	G-12 to K-2
944	Sump to K-9

FIGURE VIII-3

Approximate Locations of Glove Ports and Valve Handles in Vicinity of Valve 944. Note: All the Valves Shown are Operated Manually Through the Glove Ports

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IX. ACKNOWLEDGEMENTS

The Committee acknowledges the valuable assistance given so generously by many individuals of the HOO and HAPO organizations, especially the members of the Finished Products Operation. The technical assistance of H. H. Hopkins and H. W. Crocker of the 234-5 Development Operation is gratefully acknowledged. The cooperation of the General Electric and Atomic Energy Commission organizations has made a difficult task considerably more plesant.

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X. SIGNATURES

INVESTIGATION COMMITTEE

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Hanford Laboratories Operation, HAPO

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Physics and Instrument Research and Development, HLO, HAPO

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Mobley, W. N., Manager
Manufacturing
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Nuclear Chemist
Production Division, HOO

Zangar, Carl N., Chairman
Director, Health and Safety Division
Hanford Operations Office

[redacted]

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APPENDIX 1

EMERGENCY and DISASTER PLAN

The HOO "Procedures for Emergencies" are contained in AEC Manual - HA Supplement HA 06H1-01. Pertinent portions of the Manual are quoted below:

06H1-01 Purpose

The purpose of this chapter is to establish procedures for providing assistance in protection of health and safety of the general public against (a) radioactive materials under license, (b) government-owned radioactive or toxic materials involved in accidents off-site, and (c) on-site accidents involving possible spread of contamination off-site. It also provides for safeguarding of radioactive, sensitive or critical government-owned materials so involved. The portions of this Chapter which relate to contractor personnel are not intended to alter the contractor's internal emergency plans or to alter civil defense plans in effect to cope with enemy action.

06H1-03 Emergency Plans

Plans for notification and action are shown in the Appendixes for the categories of emergencies described below:

031 On-site Contractor Incidents. The plan shown in Appendix 06H1-031 outlines the procedure to be followed in the event of an accident originating at HOO which may result in the spreading of radioactive contamination (gas, liquid, or particulate) or any other toxic material outside the Hanford Restricted Area.

The HOO Emergency Committee is to be notified in accordance with Appendix 06H1-031 given below:

Appendix 06H1

Emergency Committee

Name	Office Ext.No.	Home Phone	Home Address
F. J. McHale - Chairman	6-5441	WH 4-5193	1317 Tunis Richland
Alternate: O. R. Simpson	6-5441	WH 7-7475	1210 Gowen Richland
V. R. Holmquist	6-4011	WH 8-3195	1602 Johnston Richland
Alternate: D. J. Keigher	6-4011	WH 5-7537	642 Chestnut Richland

[redacted]

[redacted]

Emergency Committee (Continued)

Name	Office Ext.No.	Home Phone	Home Address
A. T. Gifford	6-5291	WH 3-3257	1935 Harris Richland
Alternate: H. E. Parker	6-5291	WH 6-6820	1706 Gaillard Pl. Richland
J. L. Dickson	6-4646	WH 3-1676	2126 Harris Richland
Alternate: C. F. Goodner	6-4731	WH 3-1961	509 Basswood Richland
INFORMATION DIVISION, DIRECTOR			
M. R. Cydell	6-4933	WH 6-6215	1918 Harris Richland
Alternate: L. D. Weir	6-4822	WH 7-2815	1713 Hunt Richland

Notification Call List for Emergency
Resulting from Radiation Accidents in Alaska,
Oregon and Washington and Other Off-Site Requests for Aid

In the event of an emergency of the types described in Manual Chapter 06H1, Subsections 032 and 034, the following individuals will be alerted:

1. Atomic Energy Commission:

Name	Office Ext.No.	Home Phone	Home Address
H. G. Hicks	6-5496	JU 2-8940	1216 W. 27th Ave. Kennewick
K. L. Englund	6-5496	WH 7-5665	1409 Jadwin Richland

2. General Electric Company (HAPO Radiation Protection Operation):

Name	Office Ext.No.	Home Phone	Home Address
K. R. Heid	3589	WH 5-1447	1513 Sanford Richland
A. J. Stevens	3376	WH 3-3783	1920 Howell Richland
A. R. Keene	3740	WH 4-0820	519 Catskill Richland

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2. General Electric Company (HAPO Radiation Protection Operation) continued:

Name	Office Ext.No.	Home Phone	Home Address
Alternates:			
G. E. Backman	3153	WH 6-6443	1606 Davison Richland
L. A. Carter	3598	WH 7-2358	1028 Birch Avenue Richland
E. C. Watson	3135	WH 4-9512	2104 Pullen Richland
3. The Emergency Medical Team			
Dr. W. D. Norwood	6-4010	WH 4-5155	1937 Harris Richland
Alternates:			
Dr. Philip A. Fuqua	6-4414	WH 4-5180	1217 Gowen Richland
Dr. Bradford C. Scudder	6-4948	WH 7-7565	1816 Hunt Richland

06H1-04 Emergency Action Organizations

041 An Emergency Committee is hereby established which will be responsible for initiating such measures, safeguards, and actions as deemed necessary to properly fulfill the AEC-HOO responsibilities in the event of emergencies.

The following officials will function as the permanent Committee:

(See call list Appendix 06H1-031).

Chairman - Director, Security Division (or alternate)
Director, Safety Division (or alternate)
Director, Production Division (or alternate)
Chief, Transportation & Traffic Branch, Construction Engineering and Supply Division (or alternate)

06H1-05 Notification

051 All published plans contemplate that the HOO Security Duty Officer will be notified at once of any emergency condition which falls within the scope of this chapter.

052 The HOO Security Duty Officer will obtain from the individual notifying him of the accident (or from such other sources as deemed necessary) the location, time, access, weather conditions, personnel involved, agency,

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individual reporting and phone number, habitation in the vicinity, and any other information pertaining to the incident. In all cases, he shall instruct the person notifying him to keep all persons away (a minimum of 500 feet from weapons, otherwise 50 feet) from the material and the site involved until specific instructions are issued by the Emergency Committee.

If the notification is received by another HOO Division or Office, the minimum instructions contained above will be given to the person reporting the incident.

053 The HOO Security Duty Officer will immediately report the above information to the Chairman, Emergency Committee, listed in Appendix 06H1-031 and request further instructions to be given the person reporting the incident.

054 The HOO Security Duty Officer will immediately notify other members of the Emergency Committee listed in Appendix 06H1-031 and request them to report to the AEC Airport.

055 If medical advice or action is required, the Emergency Medical Team will be alerted by the HOO Security Duty Officer by use of the call list in Appendix 06H1-042.

The GE-HAPO incident notification follows the order shown below:

*GE Patrol Emergency Officer notifies GE personnel only except for the AEC Security Duty Officer who is responsible for notifying HOO personnel identified in Appendix 06H1-031.

HANFORD ATOMIC PRODUCTS OPERATION
Master Primary Emergency Call List
For
Plant Disaster and Evacuation

Source of Alarm

Supervisors - Manufacturing Areas
Level III Managers

*GE Patrol Emergency Officer
(Located in ERC - 703 Bldg.)

Business Phone	Home Phone	
		Area Patrol Notification Crash Alarm
6-4122	WH 4-5197	W. E. Johnson
6-5441		AEC Security Duty Offier (Notifies individuals identified in Appendix 06H1-031)
6-4387 or 6-4069		703 Reception Desk

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Business Phone		Home Phone	
6-4740		WH 6-6715	A. B. Greninger or
2-5156		YO 7-3774	O. C. Schroeder or
2-5484		WH 7-3295	C. A. Priode
6-4733		WH 6-6777	G. R. MacArthur
3626		WH 5-2128	R. L. Dickeman or
3562		WH 5-1702	W. N. Mobley or
3874		WH 5-0772	H. E. Berg
3642	(8:00 AM to 4:30 PM Mon. thru Fri. -	H. M. Parker or	
3740	other Hrs. use H.L.O. Crash Alarm)	A. R. Keene or	
3738		R. F. Foster	
6-4055		WH 4-4770	R. J. Schier
6-4524		WH 4-6275	L. L. German or
6-4022		JU 2-7693	C. W. Weeks
6-4002			North Gate House
2-7699		WH 4-0452	P. H. Reinker or
2-7706		WH 3-9507	J. H. Warren or
2-7807		WH 7-0253	P. R. McMurray
6-5486		JU 6-4386	C. E. Crandall
6-4010		WH 4-5155	W. D. Norwood, M.D. or
6-4414		WH 4-5180	P. A. Fuqua, M. D.
6-4755		WH 7-7675	M. F. Rice or
6-4754		WH 7-7725	E. G. Jones
2-7321			Electrical Dispatcher
2-7716			Meteorology Tower
6-4935	(8:00 AM to 4:00 PM)		Train Dispatcher
Direct Line			Telephone Operator

[redacted]

[redacted]

The General Electric Company has in existence plant-wide emergency and disaster plans. For the past few months the Company has been reviewing these plans and recently presented to HOO for review and comment a new version of these plans. They are contained in documents HW-70700, HW-72200, and HAN-81167. Since the new plans have not been approved and issued in final form, the Committee has reviewed the existing plans contained in the "Manual of Standards Practices - Finished Products Operation - 234-5 Building", dated June 1, 1961.

The entire Manual consists of nine sections as follows:

Subject	Section
Emergency Procedures	I
Safety	II
Radiation Hazard	III
Property Accounting	IV
Essential Material and Supply Procedure	V
Process Control	VI
Standard Operating Procedure	VII
Job Description and Responsibilities	VIII
234-5 Building Security Rules and Regulations	IX

Section I pertains to emergency plans. Part 101 pertains to the Z Plant evacuation plan, and Part 102 deals directly with the Nuclear Excursion Evacuation Plan, while Part 104 deals with emergency Procedures. Pertinent portions of these parts are extracted below:

Part 101 - Finished Products Operation Evacuation Plan
Z-Plant Evacuation Plan
Purpose

It is established that an organized withdrawal of personnel from the Plants in FPO is considered necessary to minimize the possible loss of life in case of an actual enemy action. Following an alert, a distance greater than ten miles from any target area is desired. In case of a Take Cover signal, which indicates an immediate attack or bombing, the 234-5 Building tunnel is regarded as the Z-Plant underground shelter and the Electrical Gallery in 224-U is regarded as the U Plant underground shelter. In case of an Alert signal, all personnel in FPO will evacuate to its staging area which is already pre-arranged by Security Patrol personnel. Prior to an evacuation, each unit in FPO areas will be expected to perform those functions that are required to shut down a facility.

Alarm Systems
234-5 Building

The 234-5 Building is equipped with a klaxon that can be heard throughout the building. The activation switch is located in the Button Line Specialist's office, Room 251-Z. The Processing Operation Supervisor is responsible for seeing that the alarm switch is activated. Areas unable to be reached by the Alarm System such as outside ground, 291-Z, 2704-Z, and 241 Sump Area, will be covered by dispatched personnel using a "shutdown card" system.

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Types of Evacuations
Evacuation Class I

Local emergencies arising from radiation or industrial hazards which warrant evacuation of a building, facility, or the area, are known as Class I evacuations. The ranking Processing Supervisor, the Recovery Specialist in his absence, or principal occupant of a non-processing operation is responsible for making the decision to evacuate, notifying Security Patrol Radio Operation, and initiating the All Clear signal.

Evacuation Class II

An emergency which is of sufficient scope to involve another area is known as a Class II evacuation. The decision to evacuate the area in which the emergency occurs is the responsibility of the Evacuation Director of that area. The decision to evacuate other facilities or areas will be made by the Emergency Relocation Center or the Evacuation Director of the area in question. The persons making the decision will notify the Security Patrol Radio Operator and initiate the All Clear Signal.

Practice Evacuations

In order that the evacuation plan may function smoothly in time of emergency, it is desirable that the practice evacuation be held periodically. General Electric Chemical Processing Department's Organization and Policy Guide states:

"The Manager, Processing Operation, in each plant is responsible for scheduling practice evacuations such that each shift will participate at least once each calendar year. The element of surprise should be maintained insofar as is practical to effectively evaluate the practice. A report of the practice, including participation, pertinent times, and other appropriate comments should be sent to the Specialist, Health, Safety and Radiation within 24 hours."

Signals

Evacuation

5 minute steady blast from the Power House and/or building klaxons. The 224-U, 234-5, and 231 Buildings are equipped with klaxon systems. The 2704-Z and 2705-Z Buildings and 222-U Building must be notified by telephone or dispatched personnel.

In a facility evacuation the only signals will be those located within the buildings of the facilities.

Alarm Tests

Once per quarter the evacuation alarms in the 224-U, 234-5, and 231 Buildings will be tested for thirty seconds to insure their workability. All persons in these two buildings must be alerted in advance that this is a "test" in order to avoid the possibility of a panic.

Evacuation Responsibility

The signal for an alert will be communicated by the Control Center to Area Security Patrol who will initiate the evacuation by means of the Crash Alarm System.

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When the signal "Civil Defense Alert" is received by an area, normal operations will be discontinued. After facilities have been prepared for evacuation, the area will be evacuated.

The decision to evacuate either of the 200 Areas for causes rising within it is the responsibility of the ranking Operations Supervisor who shall be the evacuation director. Line of command is as follows:

1. Ranking Processing Supervisor of the Special Separations Processing and Auxiliary Operation.

2. Ranking Processing Supervisor in 234-5 Building (alternate).

Z-Plant Processing Supervisor will be directly responsible for originating the signal to evacuate the Z-Plant facility. In his absence the Recovery Specialist will assume the responsibility.

The U-Plant Specialist will be directly responsible for originating the signal to evacuate the U-Plant facility.

The line of command in FPO is as follows:

1. Operation Supervisor, Processing Operation.
2. Specialist, Product Recovery (alternate).
3. Plutonium Metallurgy Operation Supervisor.

<u>Facility Evacuation</u>

The ranking Processing Supervisor in the 234-5 Building and the Specialist in the 224-U Building are responsible for initiating all evacuations for causes arising within the facility. In order to initiate the alarm, he will notify Area Security Patrol on 7775 (200-West). The message will be as follows:

1. Evacuation for ____________________(give facility name).
2. Evacuating for ____________________(give reason).

The supervisor or specialist will prepare his facility for evacuation and complete the exit.

In case of an Area Evacuation, the announcement over the Crash Alarm System will be applicable of the following:

1. "This is an (Evacuation - Class I; Evacuation - Class II; A Civil Defense Alert). Evacuate!"

2. "This is a Civil Defense Take Cover Signal. Seek Shelter!"

3. "This is a Practice Evacuation. Proceed according to plan."

Each Crash Alarm station must not hang up until the message is clearly understood and acknowledged by repeating the telephone number to the radio operator. No station that has left the conference can be re-connected to the conference except by re-establishment of the entire conference to all parties. If unable to deliver the message, the fact will be reported to the Shift Lieutenant who will investigate and take appropriate action to insure notification.

When a "Crash Alarm" is received, the following must be done by the ranking Operations Supervisor or alternate:

234-5 Building

1. Activate the Evacuation Klaxon (switch located in room 251).

2. Dispatch personnel with shut-down cards to follow prescribed shut-down duties.

3. Should audio alarm fail, notification of personnel at these locations will be made by telephone or runners.

4. If an Evacuation Alarm is received during shift work, a runner must be dispatched to inspect the 231 Building, 272-Z, 2705-Z, 2704-Z, and clear the area.

Evacuation Procedure Weekends

When a "Crash Alarm" is received on weekends and no Z plant supervisor is present, the A, B, C, and D shift operator who is on duty will activate the evacuation klaxon in the 234-5 Building.

He will assume the 231 Building is cleared of personnel unless he knows differently from inspections made of the building prior to evacuating Z-Plant. If personnel are known to be in the 231 Building, he will activate the evacuation alarm in Room 26B of the 231 Building.

He will then leave the building through the duct level and out the No. 7 Power Room door to clear personnel from these areas which are unable to be reached by the building klaxon.

The A, B, C, and D operators will then check the 272-Z, 2704-Z, and 2705-Z Buildings for personnel and proceed to the evacuation bus.

In U-Plant, the shift operator will activate the klaxon, inspect the premises for other personnel and proceed to the evacuation bus.

The A, B, C, and D operators are approved evacuation drivers.

102 FINISHED PRODUCTS OPERATION NUCLEAR EXCURSION EVACUATION PLAN

102.1 EVACUATION PLAN - NUCLEAR EXCURSION, FINISHED PRODUCTS OPERATION

Introduction

Since the potential for a nuclear excursion exists wherever nuclear materials are handled, it becomes necessary to provide a procedure for evacuating personnel from the premises. This procedure is separate and distinct from the Plant Defense Plan Emergency Evacuation Procedure.

Discussion

Ten radiation detection devices for nuclear excursions are located throughout the 234-5 Building. There are two in the UO_3 Plant. The warning signal is a continuous siren. At the sound of the siren everyone should immediately evacuate the building by the nearest exit. Arrows pointing to the nearest exit are painted throughout the building. Once outside, a distance of 100 feet from the building should be attained and maintained and everyone should gather at the evacuation buses. The Section Manager and all Sub-section Managers should be notified as soon as practical.

It is important to note that in the event of a nuclear excursion, time is of the essence! Extremely high gamma ray fields will exist even though the nuclear reaction may subside. Lethal doses of radiation may be avoided if not a second is lost in evacuation. Do not bother to lock files, change clothes, or shut down the process, unless you can hit the "shut-down button" on the way out.

Practice evacuations will be held at least four times a year. Everyone will be notified in advance of a practice evacuation so that they may leave immediately when the alarm sounds without affecting the process or violating security.

Visitors

Visitors will evacuate by the routes described above along with the building residents. All visitors should be made aware of an evacuation plan by the hosts when they enter the area.

Re-Entry Procedure

Ranking management in the Processing, Fabrication, Control and Maintenance Operations shall set up headquarters with the Manager of the Processing Operation in charge. The Control Operation Manager will be responsible for evaluating radiological hazards and personnel dose rates. The Maintenance Operation Manager shall be responsible for determining the safe condition of the affected structure and the electrical and power equipment. No re-entry to the plant exclusion area shall be allowed without the concurrence of the Control Operation Manager and after radiation levels have been defined. Immediate steps shall be taken by this group to effect the following:

1. Completely define radiation levels throughout plant area, posting them conspicuously at general approaches. (Obtain gamma and neutron measuring instruments from neighboring facilities.)

2. Consult with experts on critical mass prior to re-entry of zones where the excursion took place. (Suggested contacts are: R. L. Stevenson, E. D. Clayton, P. F. Gast.) The cause of the excursion and the status of the equipment must be determined, and the procedural steps must be planned before any action is taken to kill the reaction.

3. Eliminate all potential fire hazards (e.g. Pu in moist air, electrical hazards). Adjust ventilation to minimize spread of contamination. Secure all classified material and products. Place non-affected areas in safe standby.

4. Set up a central office of communications, records of all subsequent activities (including first-hand reports, radiation levels, equipment loss, etc.) and supplies (SWP clothing, masks, decontaminating agents, radiation survey instruments, replacement film badges, etc.).

5. Arrange for the emergency processing of all personnel exposure badges and pencils, the analyses of blood samples as required to determine exposures of those most affected and the emergency treatment of personnel.

6. Organize clean-up squads, waste hauling and repair service.

7. Assess the extent of the damage and recommend need for revision to production schedules, emergency procurement of replacement equipment or any other steps necessary to resume continuity of production.

104 EMERGENCY PROCEDURES

104.2 CHEMICAL PROCESSING DEPARTMENT EMERGENCY RESCUE PROCEDURE

Purpose

Voluntary CPD personnel will be trained and organized to function as rescue squads in the event of a disaster from natural, internal, or external causes.

Responsibility

Relations Practices is responsible for personnel training arrangements, procurement of equipment, maintenance of the rescue procedure and integration of the rescue program.

Personnel

One squad of trained personnel will be established on each of the A, B, C, D, and day shifts. A shift squad will consist of eight men and the day squad will consist of six men, for a total of 38 CPD rescue personnel.

A personnel roster will be posted on bulletin boards in Redox, Purex, Power and General Maintenance, Finished Products Operation, and other appropriate locations.

Rescue personnel will carry special identification cards. In an actual emergency rescue personnel will be admitted to all exclusion areas.

Equipment

One bus will be equipped with rescue equipment as recommended by the Office of Civil and Defense Mobilization. Deviations from these recommendations may be made considering Department conditions and the availability of similar equipment. The bus will be identified by blue and white Civil Defense colors and the letters "200 Areas Emergency Rescue". It will be parked near the 200-West Area Fire Station. Mechanical maintenance of the rescue bus will be performed by 200-West Area Light Equipment Maintenance Operation, CE & UO.

Rescue squad leaders will inventory equipment monthly and drive the bus for a test run within the area. The Patrol Radio Operator should be notified prior to making the test run.

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Procedure

A. Non-Evacuation Emergenices

Incidents such as fire, explosion, collision, structural or equipment failure may endanger life, but not involve radiation or contamination. Similar incidents may occur within exclusion areas, but may not cause the facility to be evacuated.

Notification

The ranking Processing Supervisor or principal occupant of a non-processing facility will call the Area Patrol Radio Operator, 7702 West Area, 7302 East Area, and request assistance of the rescue crew. The notification will be made on the Crash Alarm System: "A non-evacuation emergency exists in the ________ ________ Operation. Instruct all rescue personnel to report to __________ Building, 200 _____ Area immediately."

Supervision will immediately notify rescue personnel and dispatch them to the site.

Mobilization

Rescue personnel will immediately assemble at the main entrance of their respective work locations and depart for the disaster site using any available transportation.

Upon arrival at the site, rescue personnel will assemble at the rescue bus and receive instructions from the ranking Processing Supervisor of the facility requesting aid.

Practice

Practice non-evacuation emergencies will be scheduled as needed to evaluate the effectiveness of the procedure.

B. Evacuation Emergencies

Conditions which require evacuation of facilities or areas are defined in the 200 Areas Master Evacuation Plan.

Notification

Unless otherwise instructed, rescue personnel will board the evacuation buses or report to designated shelters with other personnel.

Mobilization

Upon arrival at the point of area exit or the designated staging area, rescue personnel will assemble at the rescue bus and await instructions of the Evacuation Director. This information may be relayed to the Rescue Squad Leader by a Security Patrol radio car.

Duties of Rescue Personnel

Participate fully in training program; respond to emergency and practice alarms; drive rescue bus; inventory rescue equipment; request replacement when shift is changed.

[redacted]

Obtain dose rates and oral radiation work instruction before entering a Radiation Zone.

Training Program

CE & UO Fire Protection Operation will conduct the training program. New rescue personnel will receive 60 hours of instruction and field work; refresher programs of 16 hours will be scheduled annually.

Additional Help

Depending upon the need, other special services may be requested of the Patrol Radio Operator by the Supervisor initiating the notification.

A. Industrial Medical - Field First Aid, transport injured.

B. Security Patrol - Roadblock, control of personnel, radio communication.

C. CE & UO Line Maintenance - De-energize, restore electrical lines.

D. Disaster Crews from IPD and FPD - Additional rescue personnel and equipment.

APPENDIX 2

PRIOR AUDITS OF SAFETY

The committee has investigated the organizational requirement for providing reviews and audits of criticality control procedures and finds that all formal requirements have been met and that the requirements themselves appear to be reasonable.

The Chemical Processing Department Organization and Policy Guide No. 11.9 defines policy, general practices and responsibility for control of critical mass hazards. This OPG was issued 4-15-60.

Paragraph 7 of Section III, Procedures states:

> "7. Internal audits will be performed at the direction of the Operation Manager (Purex, Finished Products, or Special Separation Processing Auxiliaries) on a continuing basis to assure that administrative controls are adequate and adhered to. Independent audits will be performed in accordance with paragraphs 8 and 9, Responsibility."

Paragraphs 8, 9 and 11 of Section IV, Responsibility are:

> "8. The Manager, Production Operation, is responsible for providing independent annual audits of critical mass control performance in CPD production facilities and laboratories."

> "9. The Department General Manager, at his discretion, will provide audits of Department critical mass control specifications and procedures by recognized experts not associated with the operation of Hanford Atomic Products Operation."

> "11. The Senior Engineer (Nuclear Safety), Advance Process Operation, Research and Engineering Operation, is responsible for producing an annual review and technical appraisal of Department Critical Mass Control Activities."

During the period from October 1960 through September 1961, a total of 42 visual audits were conducted in the 234-5 Building by a supervisor in the Radiation Monitoring Operation. In the period from October 1961 to February 1962 the frequency of audits dropped slightly with a total of 12. These visual audits are valuable for controlling criticality hazards in most areas within the 234-5 Bldg. but are incapable of determining the status in the Recuplex Area.

A review of criticality procedures in the Chemical Processing Department was conducted on May 19 and 20, 1960, by A. D. Callihan of ORNL, H. C. Paxton of LASL and P. F. Gast of HLO. The report of this review in its entirety is reproduced and appended as Exhibit 2-A.

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Another review of criticality procedures was conducted on September 8 and 12, 1961, by a group of experts internal to Hanford but external to the Chemical Processing Department. The members of the review committee were C. L. Brown, W. S. Nechodom, C. R. Richey and P. F. Gast. The report of this committee is appended as Exhibit 2-B.

The Senior Engineer (Nuclear Safety) has written a "Nuclear Safety Review" in the fall of each year since 1958. These reviews all written by R. L. Stevenson and listed as Confidential-Undocumented have the following numbers and issue dates:

HW-58077, issued November 4, 1958
HW-62632, issued November 12, 1959
HW-67643, issued November 21, 1960
HW-71588, issued November 9, 1961

In general, these reviews, both internal and external, reflect some concern for the difficulties of maintaining adequate control of nuclear safety in the Recuplex Facility because of the presence of non-critically safe tanks, the difficulties of direct observation in the hoods, and the deteriorated condition of the facility itself. Actions taken as the result of recommendations of the external review committees are included in Appendix 4.

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C O P Y

cc: AD Callihan (ORNL)
HC Paxton (LASL)
FW Albaugh
VR Cooper-RL Stevenson
PF Gast (2)
JH Warren

May 24, 1960

W. K. MacCready, Manager
CHEMICAL PROCESSING DEPARTMENT
2704-E Bldg.
200-East Area

CRITICALITY REVIEW

At your request, the procedures and practices of the Chemical Processing Department with respect to criticality safety were reviewed on May 19 and 20 by A. D. Callihan of ORNL, H. C. Paxton of LASL, and P. F. Gast of HLO. The Hanford Laboratories operations in Building 231-Z were included in the review because of its location in the 200-W Area. The review concentrated upon 234-5 Bldg. and 231-Z Bldg., but Redox and Purex buildings were also briefly considered.

The Redox and Purex processes were described to us and the bases for criticality control in the various process vessels were reviewed. A similar review was made of 234-5 operations followed by a tour of the building. Operations in 231-Z were discussed with HLO personnel and that building was also toured.

We found the criticality safety situation to be generally satisfactory but believe that there are some possibilities for improvement in certain respects which we mention specifically below. We found an awareness of the importance of criticality control in all those to whom we talked and a general appreciation of the factors which enter into such control. Those having specific responsibilities in this area were well-informed and generously cooperative in assisting us in carrying out this review.

Commendatory efforts have been made in the instruction and training of operating supervisors and operators in the criticality area and it is recommended that this training be repeated as turnover of personnel warrants and that periodic refreshers be given as appropriate.

The Research and Engineering Operation carries heavy responsibility in providing criticality specifications, and it is recommended that consideration be given to increasing the number of people in the operation whose primary field of activity is criticality. The discussion of each criticality problem, no matter how straightforward it appears to be, by two or more people, each of whom is competent in the field, gives added assurance that nothing will be overlooked. We make this recommendation as a matter of principle and not from any lack of confidence in the present specialist.

Foremost, perhaps, in the impressions formed by the members of this panel in the course of their survey of the operational areas noted above is an awareness of a striking need for improvement in what might be succinctly described as "house-

EXHIBIT 2-A(1)

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keeping." It is our opinion that greater-than-normal care must be exercised in processes with fissionable materials to minimize the accumulation of unknown and perhaps indeterminable quantities of these materials in areas adjacent to operations through spillage, leakage, etc. It is strongly emphasized that nuclear accidents in chemical and metallurgical operations will no doubt continue to occur in areas where fissionable materials are not expected to be by design, rather than in well-developed equipment and processes. In the design of new equipment or modernization of existing equipment, it is recommended that particular attention be given to incorporating features which minimize spillage and leakage.

Freedom of observation of existing process trains has been materially lessened by damage to plastic enclosures and by obscurant materials. We were informed that as, at least, a partial result of this loss of visibility, a quantity of plutonium collected adjacent to a vacuum drum filter in Building 234-5. The entire Recuplex Process is even more hidden from inspection.

In further comment on the Recuplex Process, it is recognized that all salvage operations are difficult, that the need of a new and larger train is recognized and is being planned, and that the situation at the time of this review was aggravated by a recent break in an extraction column. Nevertheless, it is recommended that reasonable attempts be made to clean the area enclosing the Process and that careful consideration be given to convenient operation and maintenance in the design of the replacement.

It is also believed that storage of fissionable and other materials in the same area should be discouraged, a condition observed particularly in one of the storage vaults. If the use of a secured area is necessary for the various materials, some segregation should be effected by, say, the rearrangement of existing shelving to serve as partitions. By further comment, it is recommended that consideration be given more generally to equipping storage shelving with barriers to aid in enforcing loading regulations and to conspicuously posting current regulations in the storage areas.

The technical bases for criticality control appear to be sound, and are well interpreted both in examples of operating specifications that we have seen and in actual plant practice. Backup instrumentation where there is reliance upon concentration control, and the attention given to effective isolation of unsafe tanks in cold lines are considered of primary importance. Discussions touched upon a couple of questions of policy that might influence the economies of future plant construction--whether strict adherence to the "two-contingency" rule is essential for shielded processes, and whether "safe" dimensions need be defined in terms of complete water reflection regardless of surroundings. In each case, we favor realism rather than any artificial restriction.

/s/ P. F. Gast

For the Criticality Review Group

PF Gast:mcs

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HANFORD LABORATORIES OPERATION
GENERAL ELECTRIC
RICHLAND, WASHINGTON

October 20, 1961

P. H. Reinker, General Manager
CHEMICAL PROCESSING DEPARTMENT
2704-E Building, 200-East Area

CPD CRITICALITY REVIEW

At the request of the Research and Engineering Operation, a nuclear safety review has been made of the plutonium processing plants in CPD. The review committee consisted of C. L. Brown, W. S. Nechodom, C. R. Richey, and P. F. Gast. Visits were made to the Purex and Redox Plants on August 31, 1961, and to Z Plant on September 8 and 12, 1961.

Special attention was given to Z Plant at the request of W. J. Gartin. In his letter to V. R. Cooper, June 12, 1961, Mr. Gartin pointed out that not only have many operational changes been made and inventories increased since the last audit in May 1960, but accountability records for the latter part of FY-1961 showed a significant negative increase in the B-PID for Recuplex and Fabrication. The ngative shift in B-PID could be due to imprecision in some waste stream measurements, or to actual plutonium hold-up in the equipment. The committee was asked to look into the possibility of an undetected plutonium buildup in Recuplex or Fabrication and appraise the potential of a criticality hazard.

The comments and conclusions of the review committee are given in this letter. A brief summary of the recommendations are as follows:

Redox - No suggestions for improvement.

Purex - a) Revise the method of handling off-standard plutonium nitrate solution to eliminate transferring 60 g Pu/l solution to the HAF makeup tank at the head end of the building. (Transfers of similar material at Redox are made at < 6 g Pu/l).

b) Install an audible criticality alarm in the canyon area to warn the crane operator or personnel that might be working on the canyon deck in the event of an excursion.

Z-Plant-a) Concerning the Z-Plant B-PID, have a detailed accountability study made to be certain that all or part of the -27 Kg B-PID for Recuplex is not due to unaccounted for plutonium in some part of the process. The review committee is reasonably certain that the -23 Kg B-PID in Fabrication is not a criticality problem but the committee does not have the same assurance about Recuplex, mainly because criticality control in Recuplex depends on the accountability of plutonium transfers, vessel cleanouts, etc., and not on visual inspection.

[redacted]

[redacted]

b) In Task I, install additional devices on the calciner hopper to warn of a plutonium oxalate buildup.

c) In Recuplex, improve the neutron monitoring system used for criticality control.

d) Review the Recuplex process periodically to assure that PuO_2 particles in significant amounts are not working their way through the Recuplex process and settling out in geometrically unsafe vessels.

e) Check the D-6 sump to be certain plutonium solids are not building up.

f) Review the plutonium nitrate handling procedure in Room 149.

g) Formalize the personnel training program by specifying the amount of training each person is to receive yearly, both cumulatively and as review. Institute a system of records to insure that training is received. Expand the program to include training on the criticality hazards associated with each job description or operation. Attempt to devise a more formal method of personnel selection to fill those positions where criticality hazards exist.

h) Include in OPG's and vigorously pursue a program of developing instrumentation to replace, where feasible, administrative procedures in the monitoring of equipment to prevent the development of critically unsafe conditions.

i) Clearly post nuclear safety limits at all work locations and storage areas. (There were posted limits at most, but not all locations.)

We would like to point out that many of these items are recognized by Plant personnel, and it is evident that there is a continuing effort to improve safety margins. The reason for including them here is to make the review comprehensive in noting the potential danger areas recognized by the committee.

A. REDOX PLANT

Criticality control measures in the Redox Plant appear adequate and the committee has no recommendations for improvement. Comments concerning the Redox review are given below:

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1. In the partitioning operation, plutonium buildups have been recurring in some of the columns for several years; however, this problem has been under constant surveillance and several control measures are used to assure nuclear safety.

2. In the 233 Building, where the higher concentrations of plutonium are encountered, all of the vessels and sumps are now safe by geometry. There appear to be no criticality hazards remaining in this area that are not recognized by Plant personnel.

3. The method used for recycling high concentration, off-standard $Pu(NO_3)_4$ solution back to the feed makeup vessels is to dilute the solution to < 6 g/l in a geometrically safe tank, and then jet the dilute solution to the feed makeup tank, which is not safe by geometry. Nuclear safety in this operation is based on assuring that the dilution has been completed before the transfer is made. The criticality controls used on this operation appeared adequate to the committee.

B. PUREX PLANT

Over all, the control measures in Purex are adequate; however, there are two recommendations the committee would like to make.

1. Revise the method of transferring off-standard plutonium nitrate solution to the head end of the process. The method used at Purex is not the same as used at Redox. At Purex, the solution transferred to the head end enters the HAF makeup tank at about 60 g Pu/l. The HAF tank is quite large and not safe by geometry; also, the sump below this tank is not safe by geometry. Nuclear safety is assured by guaranteeing (a) a large water volume in the makeup tank, and (b) constant agitation. Either an undetected agitation failure in the HAF tank or a break in the transfer line permitting 60 g Pu/l solution to accumulate in the "E Cell" sump, could possibly result in an excursion. It was pointed out to the committee by Purex personnel that the potential hazard of this process is recognized and modifications are planned that will reduce the frequency or eliminate such transfers. The committee favors eliminating transfers at 60 g Pu/l and using a procedure similar to the one used at Redox.

2. Install an audible criticality alarm somewhere in the canyon to warn the crane operator or other personnel in the event of an excursion. It was indicated that personnel sometimes work on the canyon deck and the only device for indicating that an excursion has taken place is the high gamma indicator in the crane cab.

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RICHLAND, WASHINGTON

October 20, 1961

P. H. Reinker

C. Z PLANT

Z Plant was reviewed in four parts: Processing, Fabrication, Recuplex, and the Development Laboratory. The B-PID was also considered in the review. In general, criticality control in all areas appeared adequate. Comments and suggestions that may help improve control are given below:

1. B-PID

The magnitude of the recent shift in Z Plant B-PID is indicated in the four-year summary given below. The values are reasonably steady until 1961.

	Z Plant B-PID, Kg 1958	1959	1960	1961
PPO	+ 78	+ 9	- 21	- 8
Fabrication	- 9	- 10	- 7	- 23
Dissolving	- 72	- 31	+ 31	+ 2
Extraction	- 16	- 12	+ 3	- 27
Metal Recovery	- 17	- 9	+ 2	- 14
PRO Feed Storage	- 9	- 3	- 33	- 7
Vac. Trap	-	+ 11	+ 4	+ 1
Net for Year	- 45	- 45	- 21	- 76

In reviewing the figures for 1961, the trend in all Z Plant operations is steady until about March. Between March and June 1961, the B-PID for Fabrication went from - 5 to - 23 and for Product Recovery, from - 15 to - 45. In the other operations, the shift was much less significant.

The -23 Kg B-PID for Fabrication would represent about 3+ critical masses. For dry metal in the form of chips, turnings, oxide, etc., it would take 7+ Kg to reach critical. In reviewing the Fabrication line, the committee could see no areas where uncontrolled plutonium buildups might be occurring. Visibility into the processing hoods is good and significant accumulations should be readily spotted.

The B-PID in Recuplex is of much higher significance, because the plutonium is water moderated. About 600 g of plutonium could be critical under optimum conditions, which means that the -27 Kg B-PID represents 40+ critical masses. Nevertheless, in reviewing Recuplex, the criticality controls and operational procedures appear adequate. Under these controls, the vessels, sumps, etc., in the Recuplex Facility are safe. The committee could see no areas where uncontrolled buildups might be occurring, or areas where a criticality hazard might

EXHIBIT 2-I(4)

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exist that is not already recognized by plant personnel. However, since the equipment cannot be visually inspected, and the primary criticality control is on the accountability of solution transfers and the thoroughness of equipment cleanouts, it is recommended that a more detailed review be made of the B-PID to be certain that part of the 23 Kg is definitely not in some remote part of the equipment. Further suggestions for improving control in Recuplex are given in (3).

2. Fabrication

Controls appear adequate and the committee has no recommendations for improvement. Although there are very large quantities of plutonium in the fabrication line, no areas were noted where a buildup might be occurring.

3. Plutonium Reprocessing

It is recognized that the old Recuplex Facility is in poor condition and that a new facility is to be built. In the review, therefore, the committee looked for areas that might require immediate attention to improve safety in the interim period. The recommendations of the committee are as follows:

a) In Recuplex, improve the criticality controls on the feed and receiver tanks of the H-1 and H-2 columns, particularly on G-10, K-1, and K-2. One feature that could be improved is the neutron monitoring system. One of the safety devices on many of the geometrically unsafe vessels in Recuplex is a neutron monitor to indicate higher-than-normal quantities or concentrations of plutonium. Most of these monitors are connected to a single point recorder and are not on alarm. To make readings on the vessels, the operator must switch the recorder from channel to channel; such readings are taken routinely each shift. It is recommended that each of these monitors have its own channel and that an alarm point be set on each to call attention to larger-than-normal amounts of plutonium. It may also be possible to connect the alarm points to the interlock systems on G-10, K-1, and K-2, to shut off the feed valve to these tanks in the event of an alarm. It is also suggested that the possibility be reviewed of adding "poisoned" Raschig rings to vessels G-10, K-1, and K-2, as an added safety feature.

b) Determine if plutonium is reaching and building up in the D-6 sump tank. Since this is a very large tank and not routinely agitated, and the inlet is some distance from the sampling point, plutonium solids might be building up near the inlet.

c) In the plutonium oxide dissolution hood of the analytical laboratory, the nuclear safety procedure for handling plutonium nitrate solution should be reviewed to be certain of the margin of safety. It was noted that the posted limits permitted three bottles (12 liters total), each containing 400 g Pu (1.2 Kg total), to be in the hood at one time at a 14-inch spacing. It was not readily apparent that the three bottles would be safe if they were side by side. If this were the case, safety would be based on only one contingency--the 14-inch spacing--rather than on the recommended minimum of two contingencies.

d) The committee would like to make one other observation concerning Recuplex. Since one of the methods of preparing feed for Recuplex is now to burn the plutonium metal to PuO_2 before dissolving rather than dissolving the metal directly, the slow movement of the PuO_2 particles in the form of dust and undissolved PuO_2 over a period of weeks or months into unsafe vessels and remote areas should be carefully watched. More specifically, there should be assurance that the cleanouts of geometrically unsafe vessels are complete, that large amounts of PuO_2 do not accumulate in some local part of the E-4 system, and that the PuO_2 does not work its way into unsafe tanks (such as D-6), where it is not expected to be found.

4. <u>Personnel Training</u>

The primary protection against criticality incidents in the 234-5 process must necessarily be personnel training. The importance of personnel training has been recognized in previous criticality hazards reviews, in the annual CPD Nuclear Safety Review, and in CPD OPG 11.9, "Critical Mass Control".

Specifications implementing the technical requirements of OPG 11.9 exist. Formal procedures have been established to control changes or relaxations in the specifications to insure continued safe operation. Since administrative procedures which require personnel training are recognized as equally important in insuring safet operation, formal specifications, a planned schedule, and formal goals should be established which encompass the subject of personnel training. It is recommended that personnel training be formalized at least to the point of establishing a system for measuring and recording the training level of all personnel, and specific goals established for improving training levels. A specific suggestion is to generate by a set date written descriptions of the criticality hazards and hazards control techniques associated with each phase of plant operation, preferably by job description. A further goal, of course, is to guarantee familiarity of each operator with these hazards and techniques.

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5. Posting of Limits

It was noted that in some areas, criticality control limits are very clearly posted. It is recommended that the posting of these limits be uniform throughout the building and leave no room for doubt as to what may and may not be done in handling the plutonium in each particular area.

6. Criticality Control Instrumentation

As pointed out in the section on Personnel Training, administrative control appears to be, necessarily, the primary protection against criticality incidents. Nevertheless, it appears highly desirable that, whenever possible, automatic fail-safe protective devices be provided to replace administrative procedures.

No formal requirements exist for a program of expanding safety instrumentation. The OPG 11.9, for example, emphasizes critically safe design, administrative procedures, analytical methods, and critical incident detection alarms, but does not mention monitoring instrumentation for the purpose of preventing the development of critically unsafe conditions.

In some cases it should be possible to convert normal process instruments to automatic protective use. For example, several instances have been noted where periodic manual recording of process flows is relied on to detect the buildup of excessive concentrations of plutonium in extraction columns. The addition of fail-safe alarms to this instrumentation would eliminate reliance on administrative procedures. In other cases, neutron monitors have already been installed to detect excessive plutonium concentrations in tanks and dissolvers such as the G-10 tank in Recuplex. This instrumentation is not continuously on-line, nor does it contain automatic warning systems; these revisions are recommended above. The GE-312 digital computer which is being tested for process control on the fabrication line appears to hold promise as a long-range solution to automatic criticality hazards control, provided that its function is expanded to cover all of the critically-sensitive portions of the process and direct (not administrative) connections are made from the process to the computer. This long range plan should not, however, preclude the earlier development and installation of other types of instrumentation which could later be used to provide input to a monitoring computer.

Paul F. Gast
Manager
PHYSICS AND INSTRUMENT RESEARCH
AND DEVELOPMENT

PF Gast:mcs [redacted]

EXHIBIT 2-B(7)

[redacted]

cc: RG Barnes
CL Brown
ED Clayton
RW Doerr
JE Faulkner
WJ Gartin
PF Gast
PF Gast (l.b.)
MK Harmon
BF Judson
PR McMurray
LM Meeker
WS Nechodom
CR Richey
AE Smith
RL Stevenson
RE Tomlinson
JH Warren
CT Groswith

EXHIBIT 2-B(8)

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APPENDIX 3

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OPERATING PROCEDURES AND STANDARDS

The Committee has investigated the basis for operation of the Recuplex facility, and finds that there are established operating procedures and standards for carrying on these operations. A basic document is the "Manual of Standard Practices" of the Finished Products Operation of CPD. This manual contains, in addition to sections on such matters as emergency procedures, radiation hazards and property accounting, rather complete sections on Process Control and Standard Operating Procedure for the 234-5 Building. The Recuplex Operating Procedures total 190 pages; the type of detail in these procedures is illustrated in "Solvent Addition to K-1 and K-2", attached as Exhibit 3-A. The original process standards for various operations of 234-5 Building are contained in HW-40517, "Process Standards for Plutonium Isolation, Purification and Fabrication."

Preparation of the Operating Procedures for Recuplex is a responsibility of the Research and Engineering Section of CPD, and this component also provides supplementary "Operating Aids" containing specific process information for current application. An example is attached as Exhibit 3-B. Other process suggestions and run plan information items are provided in memorandum form to the operating group by supporting technical personnel from Research and Engineering - A February 26, 1962 memorandum, "Recuplex Hood Floor Clean-Up," and a March 8, 1962 memorandum, "SE Floor Processing Via K-9 and L-2," are attached as Exhibit 3-C.

Plant tests of new process features are carried out under provisions of a "Process Test," which must be approved by the responsible operating and technical managers, i.e., the Manager, Finished Products Operation, and the Manager, Finished Products Chemical Technology. An example is attached as Exhibit 3-D. Flowsheet revisions are issued periodically by Finished Products Chemical Technology; the most recent changes are covered by L. E. Bruns' letter of January 11, 1962, to L. A. Berry, "Recuplex Flowsheets" - see Exhibit 3-E.

In the important area of criticality control, procedures and practices are governed by CPD Organization and Policy Guide No. 11.9 on Critical Mass Control, with provisions regarding operational controls, process and equipment reviews and evaluations, internal and external audits, and related matters including the requirement for written critical mass control specifications. OPG 11.9 is reproduced here as Exhibit 3-F, and the current status of critical mass control specifications and waivers for 234-5 Building is attached as Exhibit 3-G. Two further safeguards against criticality incidents are to be noted. Neutron counters are used on a number of vessels in the Recuplex system to assist in product accounting and to protect against overbatching. Also, there is an interlock system designed to prevent crossmixing between the critically safe vessels carrying high concentration plutonium solutions and the non-critically safe vessels which are expected to handle only low concentrations of product. A complete description of the interlock safeguards is given in secret document HW-64491, "Critical Mass Control Specification - Recuplex," R. E. Smith, April 4, 1960.

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11.00 SOLVENT ADDITION TO K-1 AND K-2

TBP and CCL_4 are added directly to the SE hood from tanks G-23 and K-3, respectively. These tanks are located in the chemical make-up room, 337. Tank K-13 in the SE hood is used as a measuring tank for these reagents.

Periodically, addition of CCL_4 to the organic is necessitated by its evaporation and relative solubility in the aqueous phase.

Due to the formation of TBP hydrolysis products and other degradation impurities, the complete solvent inventory is renewed periodically.

Specific gravity range for the on-line organic is 1.465 to 1.495. If the specific gravity is above 1.495, it is rich in CCL_4 and must be butted with TBP. If the specific gravity is below 1.465, it is rich in TBP and must be butted with CCL_4.

11.01 Butting of TBP-rich Solvent with 100% CCL_4

a. From the specific gravity of the CAX analysis, compute the volume of CCL_4 to adjust the specific gravity to 1.49.

Calculation:

$$V\ ccl_4 = \frac{V_s\ (1.49 - SpGr)}{0.105}$$

Where: $V\ ccl_4$ = liters of CCL_4 addition.
V_s = liters of CAX solution
SpGr. = Specific Gravity of CAX

b. Make the addition in accordance with Step 11.05.

11.02 Butting of CCL_4-rich Solvent with TBP

a. From the specific gravity of the CAX analysis, calculate the volume of TBP to adjust the specific gravity to 1.49.

Calculation:

$$V_{tbp} = \frac{V_s\ (SpGr. - 1.49)}{0.514}$$

Where: V_{tbp} = liters of TBP addition
V_s = liters of CAX solution
SpGr. = specific gravity of CAX

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b. Make the addition in accordance with Step 11.05.

c. Treat the solvent with one-20 liter, 5% sodium carbonate wash in accordance with Procedure 12.00, Step 12.02.

11.03 <u>New solvent Make-Up</u>

a. Normal organic solution volume is 200 liters of 15% TBP. Make-up is 30 liters of 100% TBP and 170 liters of 100% CCL_4.

b. Other total volume can be adding one liter of 100% TBP to 5.7 liters of 100% CCL_4.

c. Make additions to the K-tank in accordance with Step 11.05.

d. Treat the organic with one-20 liter, 5% sodium carbonate wash in accordance with Procedure 12.00, Step 12.05.

11.04 <u>New Solvent Make-Up on Used Organic</u>

a. Treat the used organic with two-15 liter FS washes in accordance with Procedure 12.00, Step 12.03.

b. Butt the used organic to 200 liters.

<u>Calculation</u>:

$$V_{ccl_4} = 166 - (1.61)(V_s)(SpGr. - 0.976)$$

$$V_{tbp} = 200 - (V_s + V_{ccl_4})$$

Where:

V_{ccl_4} = liters of carbon tetrachloride to be added

V_s = volume of used organic in the K-1 or K-2 tank before butting

SpGr. = Specific gravity of the K-1 or K-2 solvent before butting. (Use last CAX analysis.)

V_{tbp} = liters of TBP to be added.

c. Make the additions in accordance with step 11.05.

d. Treat the butted solvent with two 20 liter caustic-carbonate washes. (19 liters of 5% sodium carbonate, Na_2CO_3, and one liter of sodium hydroxide, NaOH.) See Procedure 12.00, Step 12.05.

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11.05 Addition to K-1 and K-2

a. Obtain from the above calculations the proper volume of TBP and/or CCL_4 to be added to K-13.

b. Valve Check:

Tank G-23 (TBP) to K-13		Tank K-3 (CCL_4) to K-13	
Valve No.	Position	Valve No.	Position
504	Closed	501	Closed
510	Closed	504	Closed
537	Closed	510	Closed

c. Open valve 537 and receive the proper volume of TBP or open valve 501 and receive the proper volume of CCL_4 into K-13.

CAUTION: If the addition of TBP or CCL_4 exceeds 45 L, be careful not to overflow K-13.

d. Transfer the CCL_4 or TBP from K-13 to K-1 or K-2 by gravity.

e. Valve Check:

Transfer to K-1		Transfer to K-2	
Valve No.	Position	Valve No.	Position
301	Closed	308	Closed
305	Closed	310	Closed
425	Closed	427	Closed
429	Closed	429	Closed
432	Closed	432	Closed
433	Closed	433	Closed
434	Closed	437	Closed
437	Closed	438	Closed
504	Closed	504	Closed
510	Closed	510	Closed

f. Check the liquid level in K-1 or K-2.

g. Open valves 510 and 429 (for K-1) or 432 (for K-2) and transfer the organic solution by gravity.

h. Close valves 510 and 429 or 432.

i. Turn on switch SW-32 (for K-1) or SW-35 (for K-2) and agitate the organic for at least 5 minutes.

j. Turn off switch SW-34 or SW-35.

k. Record the final liquid level in K-1 or K-2.

l. TBP additions must receive Na_2CO_3 - NaOH wash in accordance with Procedure 12.00, Step 12.05 prior to use in the columns.

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[redacted]

LF Brown

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September 13, 1960

Mr. J. J. Courtney
Manager, Processing
Finished Products
234-5 Building, 200-W Area

OPERATING AIDS FOR RECENT SOLVENT EXTRACTION CHANGES

Recent SE changes were (a) moving all lower half H-1 inlets and outlets up one section, (b) changing the H-1 plates to the original type 1/8" hole nozzle plates, with no plates in the glass section above the bottom disengaging section (loss of 30 inches of extraction section), (c) adding sodium nitrite continuously to J-1, (d) putting a J-2 (product feed tank) pump into service. Items (a) and (b) should reduce H-1 bellows failures and improve extraction column capacity. Item (c) should pre-oxidize recycle product from Pu(III) to Pu(IV), hence benefitting waste losses and compensating for the loss of 30 inches of extraction section. Having a separate product feed tank, J-2, to the continuous concentrator, J-26 A, should minimize formation of polymer in the product system.

These changes have been under trial for the past week. Since the changes have been working satisfactorily, certain operating aids are presented in conjunction with the changes.

1. Sodium Nitrite Additions

   a. Rotameter for continuous addition should be kept above 12 on the gage.

   b. No $NaNO_2$ should be added to SC G-9 batches.

   c. Normal CTH-1 $NaNO_2$ should be added to CTH-1 only G-9 batches (add $NaNO_2$ at G-9).

   d. Normal $NaNO_2$ should be added to contact organic washes.

2. Organic Washing

   a. FG cap should be removed at least once per day.

   b. Organic should be carbonate washed if CCW Pu exceeds 0.2 g/l.

   c. If rapid breakdown of TBP persists (noted by constant Pu build-up in organic), check $NaNO_2$ additions and carbonate wash organic or discard to C-36 (or crib) 3 consecutive batches of Pu-washed organic.

Exhibit 3-B-(1)

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OPERATING AIDS FOR RECENT SOLVENT EXTRACTION CHANGES (Continued)

3. Column Rates and Frequencies

a. High H-1, H-2 frequencies and/or rates (within 90% of flooding) should be maintained, since 30 inches of extraction height has been eliminated.

b. If H-3 color line is hard to maintain, the following should help:

(1) Reduce the nitric in the CAS to 2 liters per batch.

(2) Reduce continuous $NaNO_2$ rate to 10 on the gage for 8 hours.

(3) Reduce organic rate 10% for 8 hours.

(4) Add ½ gallon/400 liters extra sulfuric acid to H-7 for one batch.

c. If H-2 color line is high:

(1) Reduce J-1 CAIS rate if possible.

(2) Increase organic rate 10% for 8 hours.

(3) Reduce Pu input (by diluting CAFA feed) from CAFA for 4 hours.

4. CAFD Make-Ups

a. S & C

(1) Add 30 liters HNO_3 per batch only if organic is contaminated (e.g., processing SE sump material).

(2) Add 10 liters Mistron.

(3) Dilute with CTW's to less than a sp. gr. of 1.35. (If CTW's available, all S & C's above 1.30 can be diluted with up to 70 liters, all above 1.25 with up to 30 liters.)

(4) If G-9 is too full to make the above dilutions, transfer sufficient G-9 solution to G-10 so the additions can be made.

(5) Agitate by air sparging for 15 minutes (maximum).

Exhibit 3-B-(2)

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OPERATING AIDS FOR RECENT SOLVENT EXTRACTION CHANGES (Continued)

4. b. CTW

(1) 270 liters CTW
(2) 150 liters ANN
(3) 50 liters HNO_3
(4) 10 liters Mistron
(5) 10 liters $NaNO_2$

c. L-Tank Organic Washes (made up in L-tanks for direct processing. See specific procedures.)

d. CAW Rework (all batches above 0.3 g/l should be reworked)

(1) 300 liters CAW
(2) 50 liters ANN
(3) 20 liters HNO_3
(4) 5 liters Mistron
(5) 20 liters $NaNO_2$

5. CAFA Make-Up

a. Hood 42 and Hood 43: dilute to less than 40 g/l with Mistron and ANN.

b. RF, IFF, HF: 2 liters Mistron

c. SE Floor: 5 liters HNO_3
5 liters Mistron 2 L $NaNO_2$

d. RS Floor: 2 liters Mistron

e. RCR

(1) Dilute to 40 g/l with ANN and Mistron.

(2) If below 40 g/l, process directly to columns.

f. Purex or Redox PR Solutions

(1) Dilute to less than 100 g/l with Mistron and ANN.

(2) Cut rates to one-half normal rates.

Exhibit 3-B-(3)

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OPERATING AIDS FOR RECENT SOLVENT EXTRACTION CHANGES (Continued)

5. g. J-9: Process as is.

h. J-2 Rework: Dilute to 40 g/1 with Mistron and ANN.

i. J-5

(1) If H-10 or H-11 overflow, send to H-10.

(2) If aqueous, blend to G-47, G-48, and add:

5 liters ANN

2 liters Mistron

6. Organic Contacting

a. Contact L-batches above 0.013 g/1 with G-36 organic.

b. L-batches above 0.3 g/1 should be reworked via the CAFB system.

c. Before contacting, add 15 liters $NaNO_2$ to L-batch.

d. Add 100 to 200 liters contact organic from G-36 and agitate for 30 minutes.

e. Decant organic plus 20 liters CAW back to G-36.

f. If the Pu concentration in the L-batch does not reduce as expected, add 4 liters DBBP and 30 liters HNO_3 to next contact.

g. G-36 contact organic should be sampled once per month, or, if a series of high L-batches are contacted, it should be sampled once per week.

h. When organic exceeds 0.8 g/1, the organic should be decanted from the CAW and given an 80 liter FS plus 50 liters HF (one bottle HF/20 liters water) 30 minute contact (see procedure).

Exhibit 3-B-(4)

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OPERATING AIDS FOR RECENT SOLVENT EXTRACTION CHANGES (Continued)

7. Product Concentration

   a. Add 18 liters J-1 to pump safety heel (WF=15) in J-2, WF approximately 65.

   b. Add 4 liters nitric and 100 ml anti-foam and agitate 10 minutes.

   c. Process to J-26 A (with full jacket steam on J-26 A if possible) in 1½ hours (drop in WF of 4.5 divisions/10 minutes). There should be a WF of about 25 to 30 in J-7 (9 to 10 liters) after processing one batch.

Finished Products Technology
Research and Engineering

LE Bruns:cmb

cc: RE Smith
LM Knights
JA Low
PRO Specialists
Recaplex
LE Bruns

54-6000-102 (1-58)

Recuplex Solvent Extraction

CHEMICAL PROCESSING DEPARTMENT
GENERAL ELECTRIC
RICHLAND, WASHINGTON

[redacted]

February 26, 1962

Mr. L. A. Berry
Processing (Recovery)
Finished Products Operation
234-5 Building, 200-W Area

RECUPLEX HOOD FLOOR CLEAN-UP

Increased equipment failures have led to a floor sump condition that the solvent extraction process cannot handle efficiently. It has been decided that the Recuplex RB and SE hood floors should be cleaned, processing only floor solutions, floor flushes, supernates, and other virgin feed necessary to maintain continuous primary plant operation. A procedure outline for cleaning the floor and other process recommendations are given below.

Procedure Outline

The best approach may be: 1) remove the existing floor solutions; 2) flush the floors as much as possible with solutions that can dissolve some of the sludge (reference: memo from G. V. Becker, dated February 8, 1962); and 3) actually scraping and removing the final sludge that cannot be dissolved. The recommended procedure outline is (detailed procedures will be written where necessary):

1. Remove the solutions that have filled all process tanks (floor material plus virgin feed led to excessive rework).

2. SE Hood

   a. Convert CO column from HF to FS.

   b. Add vacuum removal line from CO column organic effluent to K-9.

   c. Increase CO column outlet jack-leg from 1/2-inch to 1-inch line or plastic tubing.

   d. Process floor solutions to columns by one of the three alternatives:

      (1) Floor solution and CCW through the CO column.

      (2) Floor solution organic to H-10, aqueous to CO column, and H-3 organic through CO column.

Exhibit 3-C-(1)

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RECUPLEX HOOD FLOOR CLEAN-UP (Continued)

(3) Floor solution organic to H-10, aqueous through CO column, and H-3 organic directly to the K-tanks.

e. Flush SE floor with 30% nitric via J-2, J-2 pump, and spray nozzle to floor.

f. Follow nitric with CCl_4-TBP flushes and CCl_4 alone flushes.

3. RB Hood

a. Process floor solution via G-47, G-48 using normal flowsheet make-up.

b. Flush with a mixture of 2:1:1/ANN:HNO_3:water by mixing solution in L-tank and spraying onto the hood floor via the CAW pump.

c. It may be necessary to also flush the RB hood with CCl_4-TBP.

4. CAFB: Use Y flowsheet or specially prescribed flowsheets.

NOTE: Other procedures and systems are being studied which may replace or add to the above.

5. Remove final sludge manually.

Process Recommendations

1. Check all L-2 organic wash solutions (final make-up) for E o/a. E o/a with 15% TBP in CCl_4 (new organic) should exceed 7.

2. Waste streams should be sampled every 8 hours, or when color conditions indicate high wastes.

3. All HF additions should immediately be followed by a 1-liter ANN plus 5-liter water flush (FS may be required to offset ANN salting strength).

4. Chemical additions should comply with recommended procedure. Excessive additions of nitric, nitrite, FS, HF, antifoam, and mistron can lead to poor column operation.

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RECUPLEX HOOD FLOOR CLEAN-UP (Continued)

5. For efficient L-tank washing with organic contact solutions, the plutonium concentration of the organic should be kept below 1.5 g/l.

6. Contact organic should be given a single wash and then returned to G-36 for future contact use. An organic of 0.2 g/l or less is good for contacting high CAW's.

7. High CAW's lead to excessive rework. CAW's should be kept below 0.05 g/l if possible. If wastes are continually high, sample CAW stream for E o/a and notify Research and Engineering Operation.

Finished Products Chemical Technology
Research and Engineering Operation

LE Bruns:cmb

cc: WJ Cartin
JJ Courtney
LM Meeker
LM Knights
PRO Specialists
FPCT File

[redacted]

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RICHLAND, WASHINGTON

[redacted]

March 8, 1962

Mr. L. A. Berry
Processing (Recovery)
Finished Products Operation
234-5 Building, 200-W Area

SE FLOOR PROCESSING VIA K-9 AND L-2

As demonstrated in CAW contacts, DBBP-CCl_4 will remove almost all the plutonium from the SE floor solids. Hence, it has been recommended that the floor solids be sent directly to K-9 (organic wash receiver tank) to L-2 (waste tank), and there contacted with TBP-DBBP-CCl_4.

Criticality dangers can be eliminated by careful analyses of the floor material and by addition of cadmium to the K-9 tank.

A salt system is necessary, hence, an ANN-HNO_3 flush should be flushed onto the floor via J-5 overflow or via J-2 pump and spray nozzle.

It will be necessary to attach a saran line from K-9 to the floor. It should be a 3/4-inch line with a vacuum nozzle at the floor end. A 1/2-inch by 4-inch nozzle may suffice. The saran can be connected to the valve used to empty the CO column.

Plugging of lines, especially K-9 to L-2, may be a problem. Flushing the lines with CCl_4-TBP, or 60% HNO_3 frequently may alleviate this potential trouble.

If floor analyses are so high that handling via K-9 and L-2 is impractical, a glass tank (3 feet high) with perforated polythene cartridge insert has been designed for handling floor material. Floor sludge is vacuumed into the cartridge and liquid free of solids is sent through solvent extraction. When the cartridge is full of solids, the solids are TBP-CCl_4-washed, the cartridge removed and buried, and then replaced with a new cartridge.

The recommended procedure is as follows:

1. Add about 200 liters of the following mixture to the hood floors:

   100 liters ANN

   100 liters HNO_3

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Exhibit 3-C-(1)

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SE FLOOR PROCESSING VIA K-9 AND L-2 (Continued)

2. Sample 500 ml of sludge and check for plutonium in neutron counter.

_______________ grams.

(NOTE: As check, send 25 ml sludge to the laboratory. The laboratory should contact 5 ml sludge with 5 ml column organic and analyze organic for plutonium.)

3. Add ~~4 liters~~ 4100 grams ±25 of cadmium nitrate to K-9.

4. If 500 ml sample indicates less than 2 grams, can add 60 liters. See table:

Neutron Count	Liters to K-9
0 - 2 grams	60
2 — 4 grams	40
4 - 8 grams	20
8 - 16 grams	10
16 - 32 grams	5

5. Use vacuum line (3/4-inch saran) from floor to K-9 to transfer sludge and liquid to K-9.

6. To L-2 add:
   - 50 liters water
   - 100 liters ANN
   - 30 liters HNO_3
   - 30 liters $NaNO_2$
   - 20 liters mistron

7. Vacuum sparge K-9 two minutes and transfer to L-2. Follow each K-9 transfer with 10 liters column organic. or 10 L. nitric 60%.

54-6000-102 (1-50)

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[redacted]

SE FLOOR PROCESSING VIA K-9 AND L-2 (Continued)

8. Transfer 3 more batches, 4 in all, as in item 4 above, to L-2. E.g., if 500 ml bottle has 10 grams by neutron count, one K-9 batch will contain 10 liters of floor material.

   Record NF of L-2. ____________________

9. To aqueous in L-2 add 200 liters of spent column organic ~~and 6 liters of~~ SP.

10. Agitate for two hours and sample both phases.

    Aqueous ______________ g/l

    Organic ______________ g/l

11. If aqueous below 0.05 g/l, aqueous can be cribbed.

12. If organic above 3 g/l, return 100 liters to K-tank and wash with 100 liters of column organic. When first hundred washed, transfer second hundred to K-tank and wash in similar manner.

    Wash: 30 liters water

    10 liters HNO_3

    1 liter FS

    4 bottles NF

13. If organic less than 3 g/l, transfer to C-36 for later washing. Transfer to aqueous NF noted in item 8.

14. Wash C-36 organic according to procedure book.

15. Continue removing floor material until SE floor free of almost all solids.

L C Brun[signature]

Finished Products Chemical Technology
Research and Engineering Operation

LC Brunstad

Exhibit 3-C-(6)

cc: [illegible] PFO Specialists
[illegible] Ramaley
[illegible] LC Bruns
[illegible]

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[redacted]

cc: JJ Courtney
LM Meeker
AJ Low
LA Berry
HH Hopkins
MJ Szulinski
HW Crocker
VR Cooper
CW Nilsen - LE Bruns
Recuplex
PRO Specialists
File

PROCESS TEST

TEST NO. 61-3-T

Building 234-5

Area or Task Recuplex (Ammonium Bifluoride)

Description of Test:

A new process* has been developed for the recovery of high temperature (1000°C) plutonium dioxide (PuO_2). The process converts PuO_2 to $PuF_4 \cdot NH_4F$ in a molten salt of ammonium bifluoride (NH_4FHF) in one hour. The fusion mass is then cooled and dissolved in a solution of aluminum nitrate ($Al(NO_3)_3$) with the conversion of the $PuF_4 \cdot NH_4F$ to plutonium nitrate ($Pu(NO_3)_4$).

It is recommended that the new process be tried in the existing dissolvers in Hood 42. All equipment changes that are necessary for testing the process have been completed by the previous addition of a water off-gas scrubber. Additional equipment changes may be necessary for a production flowsheet.

The recommended procedure will be to approach the plutonium batch limit in the dissolver by 100 gram increments.

* HW-68655, "Ammonium Bifluoride Fusion of Ignited Plutonium Dioxide", H. W. Crocker, February 24, 1961 (Confidential).

Objective: To reduce the run time cycle, and to reduce the number of clean-out runs by increasing percent recovery.

Duration of Test: 10 Runs

Sponsor: C. W. Nilsen

Date Issued: April 3, 1961

APPROVALS: [signature] Date 4-3-61
Acting Manager, Finished Products

[signature] Date 4/3/61
Manager, Finished Products Chemical Tech.

[redacted]

Exhibit 3-D-(1)

[redacted]

JAN 18 1962

January 11, 1962

Mr. L. A. Berry
Recovery
Finished Products Operation
234-5 Building, 200-W Area

RECUPLEX FLOWSHEETS

Experience since the last flowsheet issuance, July 28, 1961, has led to various additions and changes. The new X and Y flowsheets appear at the end of this memorandum. The Z flowsheet, floor feed flowsheet, has been eliminated in preference to processing the material through the HF column.

At present, the HF column is used for separating the phases when processing SE floor material. Instead of HF being added, nitric acid and ANN are being added as make-up for floor material and for extra salting strength. When the HF outlet and inlet systems are repiped, the new plastic column can then be used for its prime purpose, organic clean-up (RB and SE floor material secondary), with HF as the organic washing additive. When this occurs, new flowsheets will be issued.

Only the Y flowsheet shows the presence of the HF column (dotted lines show routing as an HF column), since the normal X flowsheet should be able to handle the sump material in the "A" feed system.

The principal changes to the Y flowsheet are:

1. Reduction of sulphuric acid addition in the CCX to a minimum and substitution of HN (hydroxylamine nitrate) in the FS (ferrous sulfamate) solution (CTW) for sulphuric acid. This reduced the overall sulphate in the system and should reduce the extraction waste losses. It will reduce stripping efficiency and may reduce organic batch waste efficiency.

2. Addition of S & C material to the Y flowsheet blended with CTW's, SN condensate, and synthetic feed.

3. Addition of various combinations of "B" feed whose ratio may be used as a quick guide for blends not shown in the flowsheet.

4. Entry of aqueous floor material, nitric, and ANN between the H-1 and H-2 columns.

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Exhibit 3-E(1)

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RECUPLEX FLOWSHEETS (Continued)

5. Addition of HF column (though not yet used for its prime purpose).

6. Increase of "B" feed rates based on the past four months experience with recycle.

7. Various changes in additions and rates. Notes are changed to meet the new conditions.

The normal X flowsheet was changed only in reduction of sulfate in the CCX and FS, and minor rate and addition changes.

Lester E. Bruns

Finished Products Chemical Technology
Research and Engineering Operation

LE Bruns:cmb

cc: WJ Gartin
JJ Courtney
LM Meeker
CJ Berglund
LE Bruns
HW Crocker
HH Hopkins
LM Knights
MJ Szulinski
Extra - 6

[redacted]

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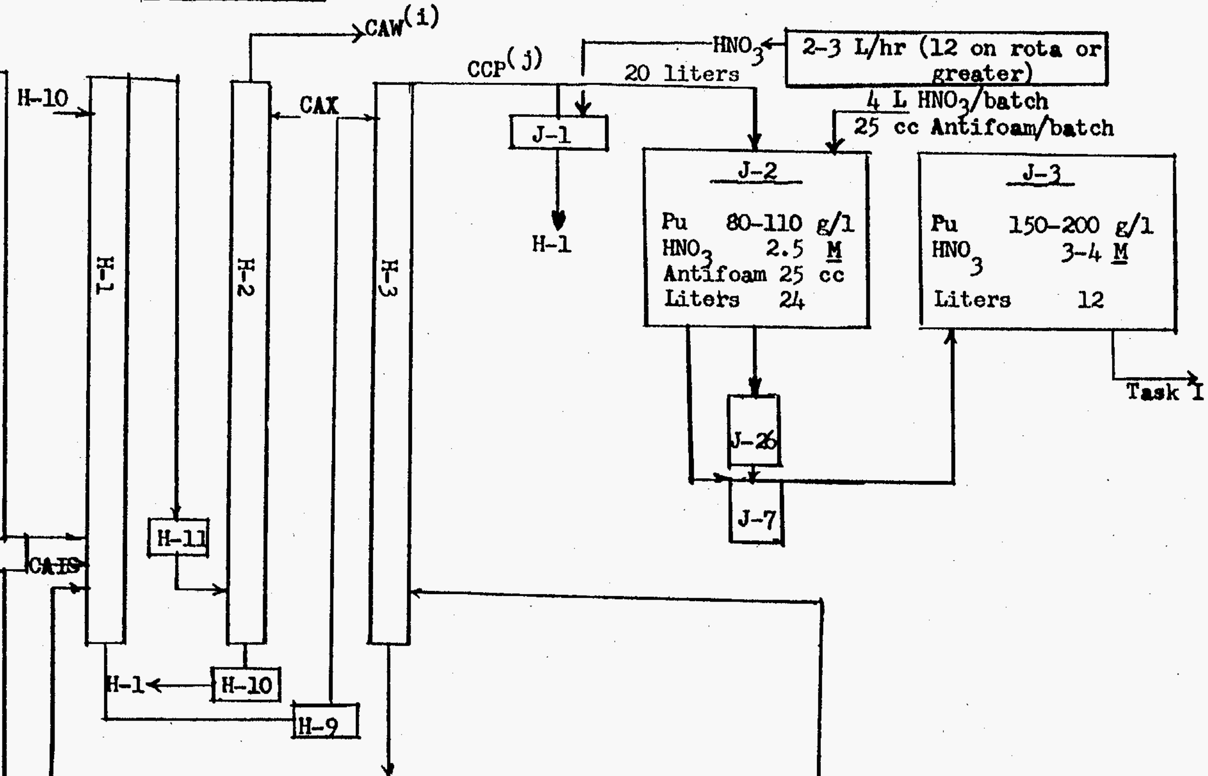
NORMAL FLOWSHEET (a)



CAFA (b)

Feed	ANN	$NaNO_2$	HNO_3	Mistron	Feed	Rate
MR	2 L	-	-	3 L	10 L	30%
CDMR	2 L	-	-	3 L	10 L	30%
J-5	-	-	5 L	2 L	20 L	30%
G-54	-	5 L	5 L	2 L	20 L	40%
J-9	-	-	-	-	20 L	60%
J-2	-	-	5 L	2 L	20 L	40%
SN's	-	5 L	-	2 L	20 L	50%
Flushes (c)	-	5 L	5 L	2 L	15 L	30%
RB Floor	-	5 L	-	5 L	15 L	30%
SE Floor	-	-	5 L	5 L	15 L	30%

CAFB (d)

Feed	ANN	HNO_3	$NaNO_2$	Mist.	Feed	Dil (e)	Rate
S & C	-	-	5 L	10 L	300-400 L	(f)	50%+
Powders	-	-	5 L	10 L	200-400 L	-	50%+
SCFP	-	-	5 L	10 L	200-400 L	(f)	50%+
PuOxide	-	-	10 L	10 L	200-400 L	-	50%+
CTW's	150 L	50 L	30 L	10 L	150 L	- (g)	50%+
Synthetic	150 L	50 L	10 L	10 L	-	150 L	50%+
CAW's (h)	50 L	50 L	10 L	5 L	300 L	-	50%+
Sch	100 L	20 L	5 L	10 L	200 L	-	50%+

CAS

HNO_3	0.5 L
Water	17 L
Flow	10-20%

CAX (k)

% TBP	18 - 23
Sp. Gr.	1.47 - 1.43

Flow: Sp.Gr.	Ml/Min
1.47	1100
1.43	900

CCX (l)

HN	0.06 M
HNO_3	0.15 M
H_2SO_4	0.09 M
FAS	0.0008 M
Sulfamic Acid	0.0016 M
Flow	40 - 60%

(See Notes on following page.)

FLOWSHEET X

Exhibit 3-E(3)

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FLOWSHEET X (Continued)

NOTES:

(a) Flowsheet Highlights:

1. CAFA about 20% CAFB flow.

2. CCP concentrated to about 200 g/l.

3. CAX semicontinuously washed with FS.

4. If H-3 color line difficult to maintain, carbonate wash or crib organic.

5. If H-2 color line high, draw off product and/or increase salting strength.

6. Maintain highest frequencies possible without flooding.

(b) CAFA rates can be increased if flooding is not a problem and if CCP concentration system can handle high Pu input.

(c) Flushes include IFF's, hood floor flushes, rag flushes, etc.

(d) Can either dilute high sp. gr. CAFB's or increase CAS rate to 50% chart.

(e) Dilution in preferred order: CTW's, G-63 and 64, CAW's, water.

(f) Dilute to specific gravity less than 1.35. If excess CTW's or G-63 and 64 available, all S & C's or SCFP's above 1.30 can be diluted with up to 70 liters, all above 1.25 with up to 30 liters.

(g) G-63, 64, or water.

(h) Filter CAW's before reworking (or drop 50 L bottoms to crib).

(i) High CAW's (above 0.013 g/l) should be contacted with:

20 liters $NaNO_2$
15 liters HNO_3 + 10 L mistron
100 - 200 liters organic
30 minutes contact
15 minutes settling

(j) CCP's can be concentrated by going directly to J-2 from H-3 and pumping J-2 to J-26 (if J-2 pump is available). If no J-2 pump, J-2 can be dropped to J-7 directly. Try to concentrate as much as possible in J-26 (less impurities) and a minimum in J-7.

(k) The CAX should be semicontinuously washed by adding 40 liters FS as a cap to each K-tank and agitating organic contents with FS before sending organic to columns. The organic should be carbonate washed (3 consecutive batches) if the H-3 color line cannot be maintained at specified rates.

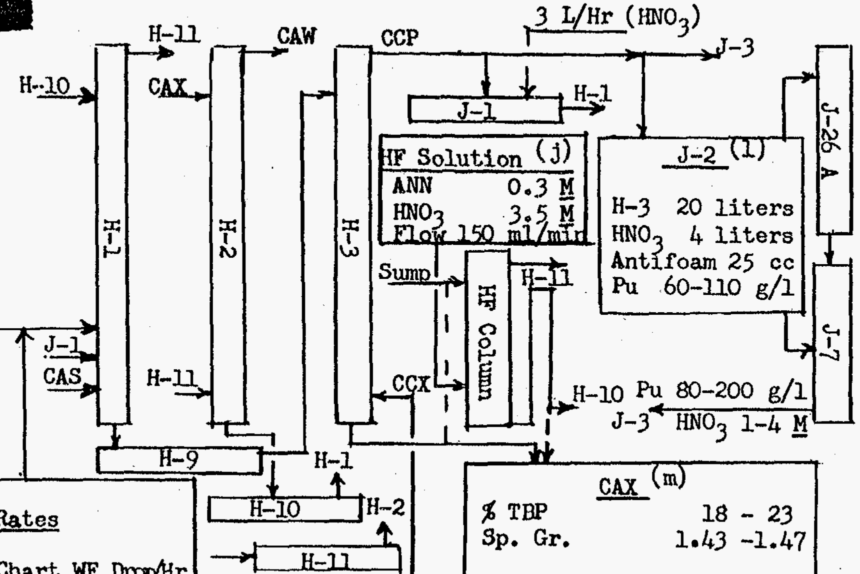
(l) CCX rates should be kept as low as possible. If unable to maintain low rates, carbonate wash organic (see k).

[redacted]

[redacted]

"A" FEED MAKE-UP IN G-47, 48 (a)

Type Feed	Liters Addition (b): Feed	ANN	HNO_3	$NaNO_2$	Mistron	Rates: Ml/Min	% Chart	WF Drop/30 Min.
MR	10	–	–	–	–	300	50	12
CDMR	10	–	–	–	–	250	40	10
J-5	25	–	–	–	–	300	50	12
J-9	25	–	–	–	–	600	100	24
J-2	25	–	–	–	–	300	50	12
RCR (c)	20	–	–	5	–	300	50	12
Flushes	15	–	–	5	5	300	50	12
Floors	10	–	5	5	5	250	40	10



"B" FEED MAKE UP IN G-9 (d)

Type Feed	Feed	ANN	HNO_3	Dilution	$NaNO_2$	Mistron	Dilution (e) Material
CTW	150	150	70	–	30	10	–
Synthetic	–	150	80	150	10	10	G-63,64, H_2O
SCP or SCCO	200 to 400	–	–	(f)	10	20	
SCF or SCFP (g)	200	50	50	100	10 or 20(CTW)	20	CTW's, G-63, 64, or H_2O
CAW (h)	300	50	40	–	20	10	
SC & CAW (i)	100SC 200CAW	40	40	–	15	20	
Fab. Oil	400	–	–	–	–	–	
SCH	200	100	30	70	10	20	

G-10 Rates

	Ml/Min	% Chart	WF Drop/Hr.
Min.	1170	50	12
Max.	1800	70	19

H-1

CAS

HNO_3	0.5 liters
Water	20.0 liters
Flow	10 - 20%
	(6 - 12 Div. WF/hr)

CCX (k)

HN	0.06 M
HNO_3	0.16 M
FAS	0.0008 M
Sulfamic	0.0016 M
H_2SO_4	0.09 M
Flow	40 - 60%

CAX (m)

% TBP	18 - 23
Sp. Gr.	1.43 -1.47

Flow

Sp.Gr.	Ml/Min	% Chart
1.47	>900	32
1.43	>700	27

Organic Pu Wash

FS:	FAS	0.1 M
	Sulfamic	0.05 M
	HNO_3	1.0 M
	HN	0.2 M
	Volume	40 liter
HF:	HF	1.0 M
	HNO	1.0 M
	Volume	20 liter

FLOWSHEET Y

Exhibit 3-E(5)

[redacted]

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FLOWSHEET Y (Continued)

NOTES:

(a) Use mostly MR's and CDMR's, others when necessary. G-48 should be used for rich "A" feed and G-47 for flushes, sumps, etc. G-48 should always contain rich "A" feed.

(b) Use ANN if system is low in salt, 5 liters ANN/20 liters other. Use extra HNO_3 if organic is bad and frequent floods are occurring, 5 liters HNO_3/20 liters other. Use extra mistron if S & C feed is giving flooding trouble, 5 liters/20 liters other. Various blends are also possible, especially RCR with floor or flush materials. RCR's contain high acid, hence a blend might be as follows:

10 liters RB floor
10 liters RCR
5 liters $NaNO_2$
2 liters mistron

(c) If SN's become a rate problem, draw off SN's at a lower Sp. Gr. to prevent line from slowing down.

(d) Strongly salted "B" feed, yet low in Sp. Gr., should give sufficient salt and capacity to system. If salting is weak (color line rise), increase "B" feed rate.

(e) Dilution material could be CAW, though it is not as effective as water, G-63, or CTW's, e.g., synthetic plus CAW:

75 liters ANN
80 liters HNO_3
50 liters water
200 liters CAW
10 liters $NaNO_2$
10 liters mistron

(f) Can mix SCP or SCCO with CTW, synthetic, or CAW, but it must be mixed in the ratio of chemicals specified, e.g., SCP plus CTW's: 200 liters SCP plus 75 liters CTW, 75 liters ANN, 35 liters HNO_3, 15 liters $NaNO_2$ (no extra mistron required).

(g) CAW's should not be used as diluent for Sp. Gr. will be too high in rich feed flowsheet.

(h) CAW's should be reworked only 1/3 of the time to avoid sulfate build-up and other impurity build-ups (one out of every third batch could be reworked).

(i) Fab. oil is made up in L-tanks.

(j) Presently using salt solution, since only floor material is being added to the HF column. This will be changed to an HF solution when organic from H-3 routinely goes through HF column. Dotted lines indicate eventual path of organic in and out of HF column.

(k) CCX rate must be kept as low as possible to realize 80 - 100 g/l CCP.

(l) Control CCP concentration above 80 g/l by:
a. Increasing or decreasing "A" feed input, maintaining organic at saturation; and
b. By increasing or decreasing constant CCP removal to J-2 or J-3.
c. Anything over 100 g/l can be sent directly to Task I (if Task I can accept).

(m) CAX should be decreased in rate with decreasing Sp. Gr. If color rises in H-1 due to over-saturation, increase product draw-off despite CCP concentration rather than increasing organic.

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Exhibit 3-E(6)

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CHEMICAL PROCESSING DEPARTMENT

C-953-M AEC-GE RICHLAND, WASH.

ORGANIZATION AND POLICY GUIDE

SUBJECT	CLASSIFICATION	NO.
CHEMICAL PROCESSING DEPARTMENT CRITICAL MASS CONTROL	General	11.9

I. PURPOSE

The purpose of this guide is to establish Chemical Processing Department policy, general practices and responsibility for control of critical mass hazards associated with the materials handled in the chemical processing plants.

II. POLICY

It is the policy of the Chemical Processing Department that, where practicable, facilities and equipment will be designed to exclude critical mass hazards. For those instances where this cannot be done there will be in effect a critical mass control system based on written specifications, implemented by written administrative procedures. Appropriate personnel training and enforcement will characterize the use of the administrative procedures.

The Management of each facility handling fissionable materials will be responsible for establishing training programs to fully acquaint all building personnel, (and other employees who work from time to time within or near the facility), with the control program including the incident detection-alarm system, and building evacuation and re-entrance procedures.

III. PROCEDURES

1. Potential for critical mass incident will be examined at the time designs are being developed for new facilities, or for revisions to existing facilities, and this potential will be minimized by appropriate design. Critically safe geometry will be the preferred design criterion.

2. In situations where safety cannot be assured by geometry, administrative procedures for control of the process operation within safe limits will be established and enforced. Critical mass control under these procedures will be based on operational controls such as dilution, neutron poisons, and batch size limits. These procedures shall be in the form of written specifications for the particular facility under consideration. Adherence to the written specifications will be implemented by incorporation of specific instructions in operating procedures, by posting of critical mass control limits in appropriate locations, and through training of personnel.

3. When process equipment is altered or is replaced by equipment not identical with the original in design, the effects of the changes on critical mass control safety margins must be evaluated. If the changes reduce the margins of safety provided by existing control procedures, these procedures shall be revised to re-establish the required margins of safety prior to introducing fissionable materials into the equipment. On the other hand, when the changes increase the margins of safety, it may be desirable to revise procedures in order to recognize the improved situation.

Exhibit 3-F(1)

ISSUED BY THE	DATE ISSUED	SUPERSEDES ISSUE DATED	PAGE
General Manager	4-15-60	NEW	

2. The Operation Manager (Purex, Finished Products, or Special Separation Processing and Auxiliaries), is responsible for implementation of critical mass control.

3. The Operation Manager (Purex, Finished Products, or Special Separation Processing and Auxiliaries), is responsible for the maintenance of a critical mass incident alarm system, building-personnel evacuation procedures and post-incident, building re-entry procedures. The safety of building visitors will be factored into the procedures. It is, also, the responsibility of the Manager to test these procedures at sufficient intervals to assure himself that all building personnel are trained to respond satisfactorily to the critical mass alarm.

4. The Operation Manager (Purex, Finished Products, or Special Separation Processing and Auxiliaries), with assistance from the Manager, Technology (Purex, Finished Products, Redox), is responsible for providing critical mass control training programs for employees associated with the facility.

5. The Manager, Research and Engineering Operation, or his delegated representative, must approve, in writing prior to use, all alterations of process or process equipment which affect critical mass control.

6. It is the responsibility of the Operation Manager (Purex, Finished Products, or Special Separation Processing and Auxiliaries), to have all known incidents involving compromise of critical mass control specifications investigated and corrective action taken. Documentation of findings and recommendations is required. Infractions of critical mass control specifications which result in a critical mass incident, or would have except for fortuitous circumstances, will be investigated by a group of individuals appointed by the Department General Manager.

7. The Operation Manager (Purex, Finished Products, or Special Separation Processing and Auxiliaries), with the cooperation of the Manager, Technology (Purex, Finished Products, Redox), is responsible for continued, day-to-day follow-up on quality of specifications, adequacy of control and level of performance under the regulations established.

8. The Manager, Production Operation, is responsible for providing independent, annual audits of critical mass control performance in CPD production facilities and laboratories.

9. The Department General Manager, at his discretion, will provide audits of Department critical mass control specifications and procedures by recognized experts not associated with the operation of Hanford Atomic Products Operation.

10. The Manager, Research and Engineering Operation, is responsible for providing the liaison with the Hanford Laboratories Operation, and off-site, required to keep appropriate Department personnel abreast with the latest technical knowledge having bearing on critical mass control. He is responsible for recommending specific critical mass problems, which in his judgment deserve attention, to the Hanford Laboratories Operation for experimental investigation.

11. The Senior Engineer (Nuclear Safety), Advance Process Development Operation, Research and Engineering Operation, is responsible for producing an annual review and technical appraisal of Department Critical Mass Control activities.

12. The Manager, Facilities Engineering Operation, is responsible for implementing the policy with reference to engineering design.

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STATUS OF CRITICAL MASS CONTROL SPECIFICATIONS AND WAIVERS

I. BUTTON LINE

SPECIFICATIONS

Document Number	Title	Date Issued	Remarks
HW-69731	Critical Mass Control Specification for the Plutonium Feed Storage Facility (HC-6)	6-1-61	
HW-66936	Critical Mass Control Specification Hoods 7C and 9B	1-23-61	
HW-63432	Critical Mass Control Specification for Task III - RMA Line	1-8-60	
HW-40581	Transportation and Storage Limits for Loaded Purex PR Cans	12-30-55	Other references: HW-40517 HW-31967

WAIVERS

Number	Title	Date Issued	Expiration Date	Remarks
B-2	Interim Critical Mass Specification for the RMC Button Line	11-2-60	Open until superseded by CMCS	

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II. FABRICATION LINE

SPECIFICATIONS

Document Number	Title	Date Issued	Remarks
HW-65513	Critical Mass Control Specification for RMC Fabrication Line	6-15-60	
HW-63651	Critical Mass Control Specification for Storage of Cutting Oil Waste in the Hydraulic Oil Disposal Hood - RMC Line	2-1-60	
HW-54888	Nuclear Safety - Shipment of Pit 65 Model	2-7-58	

WAIVERS

Number	Title	Date Issued	Expiration Date	Remarks
F-16	Machining Hoods 41-M-1 and 41-M-2	9-6-61	10-23-61	
F-15	For Test Casting, Machining, and Handling up to 3.5 kgs Model MC-1251 Shells, RMC Line	8-21-61	10-15-61	
F-14	For Hot and Cold Treating Shells in the Dry Atmosphere Hood, RMA Line	7-24-61	10-24-61	Supersedes F-13
F-8	For Triple Nest Storage of Plutonium Shell Castings in Storage Hoods 22-SR and 44-SR	5-12-61	Open until revised CMCS is written	
F-3	For Operating the New Casting and Break-Out Hood (HC-27C and B) on RMC Line	4-12-61	Open until superseded by revision of RMC Line CMCS	

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III. FINAL INSPECTION AND ANALYTICAL LABORATORY

SPECIFICATIONS

Document Number	Title	Date Issued	Remarks
HW-67479 Revised	Critical Mass Control Specification for Product Inspection	6-21-61	
HW-66570	Critical Mass Control Specification for 234-5 Analytical Lab.	12-7-60	

WAIVERS

Number	Title	Date Issued	Expiration Date	Remarks
I-10	For Storing Plutonium Metal Samples in Rooms 138 and 139, 234-5 Analytical Laboratory	9-20-61	1-15-62	
I-9	For Storing 50 Bird Cages, Each Containing Up to 4.5 kgs of Plutonium Metal, in Room 172	9-20-61	1-8-61	Supersedes I-6.
I-8	For Making Neutron Emissivity Checks on Buttons for Assessing Pu^{240} Content	8-28-61	11-30-61	
I-7	For Storing 150 Loaded Bird Cages in Room 194 Storage Vault	8-25-61	12-31-61 (or until superseded by a revision of HW-67479 Rev.)	

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IV. RECOVERY LINE

SPECIFICATIONS

Document Number	Title	Date Issued	Remarks
HW-66456	Critical Mass Control Specification for Room 161, 234-5 Bldg.	8-22-60	
HW-65204	Critical Mass Control Specification for Hood 42 (Recuplex)	5-8-60	Waivers R-11 and R-13
HW-64491	Critical Mass Control Specification-Recuplex	4-4-60	
HW-63364	Critical Mass Control Specification for Storage and Handling of Cutting Oil Waste in Hood 41 and Room 227	11-1-60	

WAIVERS

Number	Title	Date Issued	Expiration Date	Remarks
R-18	For Dissolving Plutonium Oxide in Room 149 of 234-5 Analytical Laboratory	9-13-61	12-31-61	Supersedes R-10
R-17	For Storing Z Plant Waste in T-103 Igloo	8-21-61	12-31-61	
R-16	For Storing Plutonium-Aluminum Alloy Fuel Elements in the Empty Gas Cylinder Storage Area, 234-5 Building	8-11-61	7-31-62	
R-15	For Flushing the 26-Inch Vacuum Vent Line in 234-5 Bldg.	8-11-61	7-31-62	See "General"
R-14	For Storing ANL Pu Waste (SMD-1452-C Groups 7, 8, 9) in the Army Storage Igloos	7-15-61	12-31-61	See "General"
R-13	For Dissolving Pu Oxide in Hood 42 (Recuplex)	6-22-61	Open until replaced by CMCS	Supersedes R-12

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WAIVERS (Con't.)

Number	Title	Date Issued	Expiration Date	Remarks
R-11	For Loading PR Cans from Hoods 42 - 43 (Recuplex)	6-13-61	Open until replaced by CMCS	
R-9	For Oxidizing Pu Skulls in Hood 227	5-29-61	Open until replaced by CMCS	Supersedes R-8
R-6	For Storing Pu Dry Recovery Products in the Army Storage Igloos	5-5-61	Superseded by HW-69809 except for "Shipment by Truck" (see limitation number 6 in R-6).	
R-3	For Storing Pu Skulls and Oxides in Vaults 173 and 175	3-31-61	Until HW-59437 is revised	

V. GENERAL

SPECIFICATIONS

Document Number	Title	Issued	Remarks
HW-69809	Critical Mass Control Specification for Storing Plutonium-Bearing Materials in the Army Ammunition Storage Igloos	7-6-61	Limitation No. 6 of Waiver R-6 still valid.
HW-69730	Critical Mass Control Specification for Storing Plutonium Metal in Room 172, 234-5 Building	6-1-61	
HW-60772 Revised	Critical Mass Control Specification for Vault 174	5-8-61	
HW-68452	Nuclear Safety Specification - Redwood Car	2-10-61	
HW-65616	Critical Mass Control Specification for Waste Hutment	6-20-60	Waiver dated 10-12-60 (PV Lid Storage)

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SPECIFICATIONS (Con't.)

Document Number	Title	Date Issued	Remarks
HW-64293	Critical Mass Control Specification for Transferring Pu Metal from Task III to Vault 175	3-16-60	
HW-63742	Critical Mass Control Specification - Vault 225	2-12-60	
HW-62196	Critical Mass Control Specification for Storage of Cutting Oil Waste in Room 3 of Tunnel 4	10-12-59	
HW-61626	Critical Mass Control Specification for Storage of Cutting Oil Waste in Room 221 (Recuplex)	9-1-59	
HW-61033	Critical Mass Control Specification - Z Plant Waste Storage in 213 Area (Gable Mountain) and 221-B Building	7-13-59	Waiver dated 10-12-60 (PV Lid Storage)
HW-59437	Revised Critical Mass Control Specification - Vault 173 and 175	3-23-59	See Waiver R-3

WAIVERS

Number	Title	Date Issued	Expiration Date	Remarks
G-6	For Temporary Storage of Plutonium Metal and Dry Recovery Products in the 234-5 Bldg., Room 166	9-20-61	1-22-62	Supersedes G-5
R-15	For Flushing the 26-Inch Vacuum Vent Line in 234-5 Bldg.	8-11-61	7-31-62	See "Recovery Line"
R-14	For Storing ANL Pu Waste (SMD-1452-C Groups 7, 8, 9) in the Army Storage Igloos	7-5-61	12-31-61	See "Recovery Line"
----	Temporary Waiver to Permit Storage of Boxes Containing PV Lids in Areas Covered by Document No. HW-61033	10-12-60	Open	
---	Temporary Waiver for Storing Plutonium-Bearing CWS Filters in the Waste Hutment, 231 Area or 221-B Bldg.	8-18-60	Open	

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[redacted]

Distribution:

CL Brown	WJ Gartin	IM Meeker	Extra (20)
LE Bruns	PF Gast	HM Parker (2)	Investigation Committee (7)
JJ Courtney	RL Junkins	PH Reinker	
RL Dickeman	AR Keene (2)	HP Shaw	
WS Frank	WW Kinney (3)	JH Warren	

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APPENDIX 4

PRIOR ACTIONS TO INCREASE SAFETY

Criticality audits and safety reviews frequently initiated the studies and actions which increased the safety of the operation. The annual CPD reviews (see Appendix 2) provided a summary of all actions taken during each year. The audits by experts outside the CPD organization also led to direct action. For example, the recommendation of the external committee in May 1960 (see Exhibit 2-A) resulted in the assignment of a second CPD engineer to critical mass safety.

The external audit of October 20, 1961 is given under Appendix 2, Exhibit 2-B. The response to this audit is appended in Exhibit 4-A.

In lieu of extensive exhibits on actions taken to increase nuclear safety, the actions are summarized in four categories which follow:

I. Studies and Procedures

Engineering studies related to Recuplex have been continuous from the beginning. Examples of those having critical mass significance are as follows:

- A. Removal of DBP from TBP-CCl_4
- B. Precipitation and polymer formation in plutonium nitrate solutions.
- C. Designing a Recuplex vacuum trap.
- D. Pu concentrations permissible in transferring to critically unsafe tanks.
- E. Validity of neutron counting as a plutonium measurement.
- F. HF flushing of Recuplex equipment.
- G. Operating aids for solvent extraction changes.

The results of such studies were applied by means of the Recuplex engineers writing procedures for the operation. Thus, standard procedures, special procedures, etc., were proposed to the operating supervision and revised as necessary to achieve mutual objectives.

A policy was adopted to submit equipment plans and important process changes to an engineer specializing in critical mass safety. His evaluation (aided as necessary by consultants) and approval were necessary prior to effecting any change. In the course of time all phases of critical mass safety were reviewed. It is appropriate to quote five cardinal rules which were evolved.

- A. No process changes or equipment changes will be made or put into operation without (a) a nuclear safety review by Research and Engineering personnel, (b) proper batch limits being posted as necessary, (c) properly approved procedures being issued for the guidance of supervision and operators, and (d) all personnel involved being properly trained and made aware of batch limits.

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B. All procedures will be written to contain built-in safety factors which would require a minimum of three errors (equipment or human) before criticality would be reached under ideal conditions.

C. No violations of batch size control procedures will be tolerated on the part of anyone, exempt or nonexempt. Prompt disciplinary action will be taken for any violation.

D. In any questionable situation, the process or equipment will immediately be shut down and the situation will be reviewed with proper authority before proceeding.

E. Accountability of plutonium will be made across each segment of the process, and complete system clean-outs will be made at frequent intervals as apparent shortages indicate the possibility of plutonium build-up. All segments of the process system will be flushed and inspected at least twice per year.

The results of engineering studies and procedure changes became apparent in subsequent annual nuclear safety reviews (Appendix 2) and in the equipment changes and plans for changes which are described later.

II. Training of Personnel

The training and retraining of 234-5 Building personnel was pursued with renewed vigor starting in 1958. There were two phases to the training. One was concerned with emergency procedures in event of a criticality incident; the other phase was concerned with preventive measures. The following comments apply to Recuplex specifically and generally to the entire building.

A. Emergency Training

Following installation of the criticality alarms, all personnel were trained in recognizing the audible signal, in evacuating promptly, in the route to be followed, and where to assemble after exiting. Written instructions were posted and evacuation directional arrows painted on the walls with appropriate wording.

Practice alarms were scheduled twice a year for each shift work schedule. For example, there were four tests made on January 5 and 6, 1962, to cover all shifts. Prior to this, on June 16 and 17, 1961, there were four criticality alarm tests and all shifts practiced the evacuation.

A false alarm from one of the detectors during a maintenance check caused an additional practice evacuation in early February. It occurred at lunch time in the area of the lunch room. Everyone departed immediately. The three flights of stairs were crowded momentarily but no complications were experienced.

The people on duty April 7th when the criticality incident occurred demonstrated their training by their prompt and correct response, particularly in use of the "panic button" or emergency shutdown switch. Not all Recuplex operators were trained in use of this switch.

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B. Preventive Training

The experience records of the chemical operators and shift specialists in Recuplex imply a high degree of skill generally. The new men among the utility operators did not have responsibilities exceeding the extent of their training.

The records show nuclear safety training sessions were scheduled for Recuplex and other personnel in June and July of 1961. These training classes were conducted by the engineers who had responsibility for critical mass safety and were conversant with both the process and with safety requirements.

Safety meetings were held monthly for all employees. Organizational policy required that part of each meeting be devoted to nuclear safety.

Many of the personnel had viewed a British film on nuclear safety and some had seen colored pictures of the unpleasant consequences resulting from nuclear incidents occurring elsewhere.

Recent actions include additional safety meetings for supervisors (including shift specialists) held by the Manager, FPO, and the scheduling of similar meetings on emergency procedures to begin in April. In addition, the log book of the Recuplex supervisor contains numerous instructions to shift personnel which show active interest and concern with nuclear safety.

In general terms, the training of all concerned had imparted an understanding of "safe" and "unsafe" vessels, batch size importance, package spacing and labeling, and of the requirement to sample and anlayze before moving anything to an "unsafe" vessel.

III. New Facility

The replacement of Recuplex had received extensive attention. Early in 1959, there was an exchange of letters between the AEC and GE which referenced a detailed study, "New Recuplex Facility - Z Plant."

The budget study of June 1959, lists a request for $5,300,000 for Recuplex replacement. The schedule called for $1,000,000 in 1961, $3,500,000 in 1962, and $800,000 in 1963. These are fiscal years. Construction was to end in the second quarter of FY-63.

This cost was unacceptable to the AEC, therefore the requirements were minimized in subsequent actions.

The preliminary project proposal (Project CAC-880) asking for $150,000 for Title I services was delivered to HOO on November 17, 1959. This was approved for $100,000 on January 25, 1960, and Title I activity was authorized following inquiries about sending scrap off-site. Revision I, an increase from $100,000 to $250,000 for interim design funds was requested in August 1960. Approval by AEC dated September 20 1960, authorized a total of $150,000.

Project Proposal Rev. 2 was sent to HOO on October 31, 1960, followed by "Design Scope of Z Plant - Plutonium Reclamation Facility" on November 7, 1960. These requested (a) total project authorization of $2,900,000 and (b) authority for General Electric to perform Title I, II, and III services; related management services in the amount of $1,706,000 were also requested.

A letter to the Division of Production, AEC Headquarters, from the HOO Manager on November 28, 1960, gives the following pertinent description:

> "The present Recuplex facility is inadequate for (1) contemplated loads, (2) shielding of operations to the extent that operators must be rotated to stay within exposure tolerances, (3) critical mass considerations to the extent that administrative controls must be applied.
>
> The crowded conditions, resulting inaccessibility and significant deterioration have doubled the required maintenance in the past three years which results in a corresponding decrease in operating efficiency.
>
> The proposed facility will: (1) provide capacity to handle forecasted loads, (2) reduce personnel exposure to radiation under current and future Pu processing conditions, (3) allow process work to be done in nuclearly safe equipment, (4) reduce loss of Pu to the ground, and (5) allow future campaigned segregation of Pu of different exposure levels."

A letter of December 28, 1960, advised AEC that GE would be compelled to discontinue design unless additional funds were authorized within one week.

On January 5, 1961, GE was directed to discontinue design activity. AEC expected additional information from which to reach a decision which would permit resumption of project activity in February 1961.

After further communication the funds were increased to $200,000 on January 27, 1961, and Project CAC-880 was authorized for $2,900,000 on March 21, 1961.

During July 1961, and thereafter, there were letters on the possible commercial processing and on possible off-site centralized processing of plutonium scrap for the AEC complex. The communications include recovery costs, Recuplex maintenance costs, storage and shipping problems, design problems, and means of preventing preferential treatment of an AEC contractor over a non-AEC contractor. The records show concern by both GE and AEC over the progressive deterioration of Recuplex. No date could be given when permanent shutdown would be forced by equipment failures or for plant safety.

On August 30, 1961, Phase I contract bidders on Project CAC-880 were notified by wire that bid opening had been postponed. Active procurement was also stopped.

In the months that followed, GE developed means to deal with mounting plutonium recovery problems. Some of the measures developed were not wholly dependent upon Recuplex operability. Meanwhile, the AEC complex wrestled with Commission- ide aspects of the plutonium recovery problem.

Finally, by letter of March 29, 1962, seven months after the bid delay, GE was advised to proceed immediately on all phases of Project CAC-880. The file shows clearly that both HOO and HAPO recognized safety as one of the important justifications for CAC-880, although not the only justification.

IV. Recuplex Alterations

Recuplex was originally built under Project CG-496 as a semiworks. The purpose of Project CGC-723, proposed late in 1956 and completed in 1959, was to convert Recuplex from a semiworks to a manufacturing facility. Several improvements were made at that time to increase nuclear safety. These included replacement of the bottom disengaging section of the H-3 column, provision of a critically safe filtrate receiver and concentrator, and the replacement of surge tanks H-9 and H-10 and feed receiver tank G-50 with critically safe vessels.

In addition to the changes made under the conversion project, there are other alterations completed or contemplated which have a bearing on nuclear safety.

A. Changes Completed

Among those things accomplished which had improved the nuclear safety of the Recuplex operation, we list the following:

Replacement of the building vacuum header which was 6-inch diameter with one which is 4-inch diameter.

Installation of criticality incident alarms (gamma activated) throughout the building with additional audible signals added later as necessary.

Posting of instructions and directional arrows for evacuation.

Installation of additional neutron probes at vessels D-8, D-9, G-10, G-58, L-2, D-1, and bottom of H-3 column.

Addition of an organic wash column.

In April 1959, the J-1 tank overflow pipe was disconnected from the common overflow header which leads to the J-5 overflow tank. A plastic overflow line directly from J-1 to the hood floor was installed, thus by-passing J-5 and its liquid-level alarm. This change assured that overflows of other tanks could not contaminate the product solution in J-1.

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B. Changes Incomplete

Changes in Recuplex equipment which have been contemplated but have not been accomplished are as follows:

Conversion K-9 tank to a safe status by filling it with Pyrex glass Raschig rings. These would occupy only about 15% of the volume while the boron of the glass would serve as an effective poison.

Operation of an additional safe vessel between the organic effluent of the H-3 column and tanks K-1 and 2. For this purpose the CO column was already in place but routine operation had not been achieved.

Replacement of some Recuplex piping for which Teflon tubing had been purchased.

Addition of new hoods 44 and 45. Hood 44 installation is about 80% complete and fabrication of Hood 45 and equipment is about 90% complete. These additions were to provide dissolvers, feed tanks, and storage tanks which are all critically safe. With use of these, some unsafe tanks could be retired from use.

There was another small but very significant item. A maintenance work request (number 12169) was issued April 4, 1962, by a shift specialist to "Remove the polythene line from the SE floor to K-9 header and plug the valve." Date required "A.S.A.P." This removal had not been accomplished by April 7, the date of the incident.

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RECEIVED
NOV 30 1961
P. H. REINKER

November 30, 1961

Mr. P. H. Reinker, General Manager
Chemical Processing Department

NUCLEAR SAFETY REVIEW

Reference: (1) Letter, P. H. Reinker to W. J. Gartin, P. R. McMurray and R. E. Tomlinson, "Nuclear Safety Review", dated November 1, 1961.

(2) Letter, P. F. Gast to P. H. Reinker, "CPD Criticality Review", dated October 20, 1961.

In your letter of November 1 (Reference 1), you requested our comments on the recommendations made by P. F. Gast, et al, in the recent CPD Criticality Review (Reference 2). For convenience, each recommendation is copied as summarized in the Criticality Review, and is followed by our comments and/or proposed action.

Redox - "No suggestions for improvement."

No comment.

Purex - "a) Revise the method of handling off-standard plutonium nitrate solution to eliminate transferring 60 g Pu/l solution to the HAF makeup tank at the head end of the building. (Transfers of similar material at Redox are made at <6 g Pu/l)."

Comment: A second system of agitating the contents of the HAF make-up tank will be installed. It will be independently interlocked so that receipt of solution via this route without agitation would require the simultaneous failure of two automatic safety systems plus an operating error. In addition, a fixed poison grid is to be installed in the E-cell sump; under these conditions, criticality would not result even though 60 g/l plutonium were to leak into the sump. These installations should be complete by March, 1962.

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CHEMICAL PROCESSING DEPARTMENT [redacted]

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The second mixing system is planned as a supplemental control measure because of the following considerations:

(1) The dilution of plutonium solution from 60 to 6 grams per liter would have to be done in a geometrically favorable vessel. No space is available for such a vessel within existing confinement areas.

(2) Automatic dilution of such transfers, such as by jets motivated by dilute nitric acid, might be acceptable for transfer of product solution for rework, although process control would be adversely affected by such a procedure. The transfer of dilute materials, such as plant flushes and non-routine recycle solutions during plant shutdown and brandy recovery operations, is process controlled at present, and the additional dilution resulting from such a jet would be almost prohibitive.

"b) Install an audible criticality alarm in the canyon area to warn the crane operator or personnel that might be working on the canyon deck in the event of an excursion."

Comment: Although we believe the present communication system is adequate, a siren will be installed in the canyon to advise personnel there of an incident anywhere in the building. This siren will be activated by any of the criticality detectors. This installation should be complete by February, 1962.

Z Plant - "a) Concerning the Z-Plant B-PID, have a detailed accountability study made to be certain that all or part of the -27 Kg B-PID for Recuplex is not due to unaccounted for plutonium in some part of the process. The review committee is reasonably certain that the -23 Kg B-PID in Fabrication is not a criticality problem, but the committee does not have the same assurance about Recuplex, mainly because criticality control in Recuplex depends on the accountability of plutonium transfers, vessel cleanouts, etc., and not on visual inspection."

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Comment: This recommendation is essentially a restatement of the basic question posed by W. J. Gartin in his letter of June 12, 1961 to V. R. Cooper requesting a criticality audit. The basic request for assurance that no nuclear hazard is extant because of the B-PID in Recuplex was answered in a letter from R. E. Tomlinson to W. J. Gartin, dated November 6, 1961 in which he pointed out that independent measurements of neutron flux confirm the absence of hazardous accumulations of plutonium in the equipment. A broad program to improve the B-PID situation is in progress as outlined below.

A program was initiated October 4, 1961, to investigate Recuplex waste, to determine if undetected amounts of plutonium may be in the waste stream, and to estimate the plutonium content in the waste crib. Finished Products Operation is taking the samples; laboratory groups, Redox and Finished Products Operation, will analyze the samples; and Finished Products Chemical Technology will evaluate the results.

Routine neutron monitoring surveys are being taken in Recuplex to detect plutonium accumulation in the hoods. Research and Engineering personnel have taken three surveys; Finished Products Operation will assume responsibility for these routine surveys. This type of survey does not give a quantitative result, but does indicate when and where clean-outs should be made. Routine equipment clean-outs, plus additional clean-outs as indicated by survey, should be helpful in maintaining control of the in-line inventory. It is known that some plutonium is deposited outside the equipment as a result of process leaks (continuously occurring as the old equipment is badly deteriorated, fails frequently, and requires continual maintenance to maintain operations). Finished Products Operation has attempted clean-up programs to remove "sludge-like" material from hood floors. The large number of leaks makes this a continuous job. The recently installed HF column may prove very helpful to speed up processing of floor material and "sludge". However it is expected that the same general conditions will persist until the new recovery facility is completed.

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[redacted]

Action yet to be initiated includes investigation of samples to determine the validity of sampling and analysis.

The use of "poison" Raschig rings to D-1, K-9 and K-10 tanks is also being considered as an added safety factor. At the present it appears that it may be easier to install new tanks than to modify present tanks to accommodate rings.

<u>Z Plant</u> - "b) In Task I, install additional devices on the calciner hopper to warn of a plutonium oxalate buildup."

Comment: This recommendation is being investigated. It appears that it may be feasible to devise a count rate meter such that the gamma from the plutonium oxalate in the hopper could be read. Such a system could possibly be alarmed.

The hopper in use is believed to incorporate the most nearly foolproof design that is practical. The hopper and chute are geometrically favorable. Of course, if the calciner plugs, the hopper fills and the oxalate spills onto the floor. Currently, we are relying on the button line operators to shut the process down if this ever happens.

"c) In Recuplex, improve the neutron monitoring system used for criticality control."

Comment: A continuous neutron monitoring recording system is being obtained to monitor the geometrically unsafe D-1 (batch S & C dissolver), G-10 ("B" feed), and K-4 (organic receiver) tanks, and the CAW (waste) overflow line. This system should be ready for installation by February, 1962.

Alarms are to be installed on the continuously monitored systems by May, 1962. This may be earlier, depending on what equipment changes are necessary and what items need to be purchased.

Plans have been made to connect the alarm points to the interlock systems such that any alarm will automatically shut off the feed to G-10, K-1, and K-2 tanks. Target date is August, 1962.

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CHEMICAL PROCESSING DEPARTMENT

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RICHLAND, WASHINGTON

Z Plant - "d) Review the Recuplex process periodically to assure that PuO_2 particles in significant amounts are not working their way through the Recuplex process and settling out in geometrically unsafe vessels."

Comment: Neutron monitoring and routine flushes (HF - HNO_3) are being performed periodically to clean out geometrically unsafe vessels. Reduced neutron counts after flushing are indications that plutonium build-ups have been removed.

The hood exhaust filters are the primary barrier for preventing PuO_2 from entering the E-4 system. Surveys of the system should indicate if plutonium materials were entering and accumulating in the system. These surveys are conducted by Finished Products Operation. The burning hood is cleaned frequently to prevent oxide accumulation.

"e) Check the D-6 sump to be certain plutonium solids are not building up."

Comment: This tank is surveyed periodically by neutron counter. No solids were noted in this tank on a visual inspection made about a year ago, and recent neutron surveys indicate no accumulation. In August, 1961, this tank was cleaned out completely with a total of 2.2 grams of plutonium being measured in the total clean-out solution. Clean-outs will continue to be made annually, or oftener if indicated by analysis or neutron counting.

"f) Review the plutonium nitrate handling procedure in Room 149."

Comment; A review of the limits and procedures indicated that the critical mass controls met the recommendations of OPG 11.9. The procedure was improved however after the visit by the audit team.

"g) Formalize the personnel training program by specifying the amount of training each person is to receive yearly, both cumulatively and as review. Institute a system of records to insure that training is received. Expand the program

[redacted]

to include training on the criticality hazards associated with each job description or operation. Attempt to devise a more formal method of personnel selection to fill those positions where criticality hazards exist."

Comment: We have a program calling for some specialized educational training in the field of criticality and its control, as well as a walk-through excursion drill at least every six months. New employees are orientated with a program to make them aware of safety rules, special work permits, and job hazard breakdowns, all of which are prepared with criticality control in mind. All personnel are required to attend safety meetings at least once a month and one phase of this meeting is directed toward radiation (and criticality) safety. It is our opinion that criticality training for operators should include thorough instruction of the rules and the consequences that would result if the rules were not observed. We do not propose to give operators the kind of training required to determine critical mass limits. Operators are not allowed to modify rules and limits.

Although we exercise some selectivity in the assignment of personnel to the Z Plant, the existing union contract does not allow complete freedom in the choice of operators. The company would have to establish that a man was not competent to perform the job before he could be denied an opportunity to work in the Z Plant. New operator candidates are tested by employment before being hired.

"h) Include in OPG's and vigorously pursue a program of developing instrumentation to replace, where feasible, administrative procedures in the monitoring of equipment to prevent the development of critically unsafe conditions."

Comment: Instrumentation required for immediate use has been covered in previous sections. Whether included in the OPG's or not, our long range plans include developing "fail safe" devices to replace administrative procedures wherever practical. Some of these devices may be developed in time for testing and use on the Recuplex line, but more likely will not be ready until Project 880 is complete. Included in our current thoughts is the possibility of computer controlled processes and criticality warning systems.

[redacted]

"1) Clearly post nuclear safety limits at all work locations and storage areas. (There were posted limits at most, but not all locations.)"

Comment: All locations are now clearly posted.

R. E. Tomlinson

Acting Manager
Research and Engineering

/jap

cc: WJ Gartin
PF Gast
CT Groswith
MC Leverett
PR McMurray
RE Tomlinson (2)

W J Gartin
Manager
Finished Products

P R McMurray
Manager - Purex

C B Foster
Manager -
Special Separation Processing
and Auxiliaries

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APPENDIX 5

CLAIMS

The Investigation Committee, through the AEC and General Electric Counsels, has explored Washington State's labor compensation laws relative to radiation incidents, the conditions under which an individual may initiate a claim, and conditions, if any, under which a claimant may initiate a suit. Answers to these questions are contained in some detail in the attached Exhibits 5-A and 5-B.

Briefly, it can be stated that the sole remedy for a workman suffering a disability through a traumatic injury is under the Workmen's Compensation statutes, regardless of fault. However, if the workman's injury was caused by the negligence of another not in the same employ, he has the right to sue the negligent party or to receive only Workmen's Compensation. If he elects Workmen's Compensation, the suit for negligence is assigned to the state. If he elects to sue for negligence, he still receives various Workmen's Compensation benefits but the state recovers the cost of furnishing the benefits from the recovery in the suit for negligence.

On April 24, 1962, three employees, No. 1, No. 17, and No. 23, filed a Report of Accident with the Washington State Department of Labor and Industries. The Reports constitute applications for compensation. They were accompanied by a supplemental letter from the HAPO attending physician which pointed out that although extensive tests had been made, they revealed no evidence of harmful effects. The physician's letter also recommended that the matter be kept open as the long-range possibility of harmful effects cannot now be ruled out.

The Committee has no evidence that the three employees will institute a claim for injuries sustained.

[redacted]

GENERAL ELECTRIC
COMPANY

RICHLAND, WASHINGTON . . . TELEPHONE WHitehall 2-1111
Ext. 6-5486

HANFORD
ATOMIC
PRODUCTS
OPERATION
703 Bldg., 700 Area

April 30, 1962

U. S. Atomic Energy Commission
Hanford Operations Office
Richland, Washington

Attention: Mr. Carl N. Zangar, Chairman
Investigation Committee

Gentlemen:

INVESTIGATION OF RECUPLEX CRITICALITY INCIDENT

This is in response to your request of April 18, 1962, for information regarding workmen's compensation laws and claims for use in connection with your investigation of the Recuplex Criticality Incident. The questions are covered in the order presented:

1. Washington State's labor compensation laws relative to radiation incidents.

   In general under Washington law compensation is available to workmen who are ". . . injured in the course of . . . employment . . ." (51.32.010*). Injury is defined by statute as a ". . . sudden and tangible happening, of a traumatic nature, producing an immediate or prompt result, and occurring from without, and such physical conditions as result therefrom" (51.08.100). An occupational disease is defined as ". . . such disease or infection as arises naturally and proximately out of employment . . ." (51.08.140). The Washington Workmen's Compensation Act under which workmen's compensation benefits are paid applies to all

* References are to sections of The Revised Code of Washington

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Hanford Atomic Products Operation employees under the provisions of Contract W-7412-Eng-25, between the Department of Labor and Industries, State of Washington, the Atomic Energy Commission and General Electric Company.

A claim based upon an "injury" must be filed within one year after the injury occurred or the rights of dependents or beneficiaries have accrued (51.28.050). A claim for an "occupational disease" must be filed within one year after a physician's notice to the workman of the existence of his "occupational disease" (51.28.055). The Act does not describe specific types of injuries or name specific diseases which are covered. Instead, the terms "injury" and "occupational disease", as defined, are applied to the pertinent facts in each case. The statutory definitions by virtue of their broadness clearly cover radiation hazards. The line between traumatic injury and occupational disease may not always be clear. Claims for radiation injury are easier to establish because of the element of a sudden traumatic happening. Whether a particular disease is an "occupational disease" and covered under the Act depends upon whether it is found to have arisen "naturally and proximately" out of the employment. It is clearly the intent of the Act to cover any disease which is in fact caused by radiation in the course of employment.

Once a claim is established on the basis of "injury" or "occupational disease" allowable benefits are identical. The workman, in case of "injury" or "occupational disease", or, in the event of his death, the workman's family or dependents are entitled to compensation under the Act. The amounts payable in the event of death or permanent total disability are based upon marital status and the number of dependents. Compensation for permanent partial disability is based upon impairment of bodily function or amputation of the member involved. Washington is one of the states with no limitation on the cost or duration of treatment or compensation for loss of time from work. Eligible workmen are free to choose any physician qualified to treat their condition.

2. <u>Conditions, if any, under which an individual may initiate a claim.</u>

Where a workman is entitled to compensation he must file his application together with the certificate of the physician who attended him. It is the duty of the attending physician to inform the workman of his rights and to lend all necessary assistance in making application for compensation without charge to the workman (51.28.020). While the physician must inform the workman of his rights and assist in making application for compensation, the burden is on the workman to file his claims for benefits (Pate v. General Electric, 43 Washington 2nd, 185).

Where death results from injury the parties entitled to compensation or someone on their behalf must apply to the Department for such compensation (51.28.030).

3. Organizations or individuals that may be sued, if any, by claimant.

Unless injury or death results from the deliberate intention of the employer to produce such injury or death, claimant's recovery is limited to that provided under the Act. If injury or death results from such deliberate and intentional act of the employer, the workman or his dependents may receive the workmen's compensation and also have a cause of action against the employer for any additional damages over the amount received or receivable under the Act (51.24.020).

If injury or death is due to the negligence or other wrongful act of a third party not in the same employ, claimant may elect to proceed under the compensation law or to seek a remedy against such a third party. If he makes the former election, such right of action as he may have against a third party is assigned to the state. If he makes the latter election he receives the compensation to which he is entitled under the compensation law and the state is entitled by way of subrogation to reimbursment out of his ultimate recovery, if any, from such third party.

Report of Accident forms have been completed and forwarded to the Department of Labor and Industries on behalf of Messrs. Aardal, Lohdefinck, and Williamson. The report constitutes application for compensation. They were accompanied by a supplemental letter from the attending physician which pointed out that although extensive tests

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had been made, they revealed no evidence of harmful effects. It was recommended that the matter be kept open as the long-range possibility of harmful effects could not now be ruled out.

Sincerely,

Counsel

Clayton H. Crandall:beh

[redacted]

STANDARD FORM NO. 64

[redacted]

Office Memorandum • UNITED STATES GOVERNMENT

TO : C. N. Zangar, Chairman
Investigation Committee

DATE: May 2, 1962

FROM : C. G. Brinck
Chief Counel

SUBJECT: LEGAL INFORMATION RELATIVE TO RECUPLEX CRITICALITY INCIDENT

GC:RCF

In your request for information dated April 18, 1962, relative to subject criticality incident you requested three types of information. We answer your request as follows:

1. Washington State's Labor Compensation Laws Relative to Radiation Incidents.

We have described the Washington State statutes by paraphrasing the applicable sections and grouping them in the following order: definitions, description of workmen's rights, and reporting.

a. Definitions.

1. RCW 51.08.100

"Injury" means a sudden and tangible happening, of a traumatic nature, producing an immediate or prompt result, and occurring from without, and such physical conditions as result therefrom.

2. RCW 51.08.140

"Occupational disease" means such disease or infection as arise naturally and proximately out of employment under the mandatory or elective adoption provisions of this title.

b. Description of Workmen's Rights.

1. RCW 51.04.010

A workman's sole remedy is under the Workmen's Compensation statutes, regardless of fault, when injured in extra hazardous work.

2. RCW 51.24.010

If the workman's injury was caused by the negligence of another not in the same employ, he has the right to receive only Workmen's Compensation or sue the negligent party, whichever he

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Exhibit 5-B (1)

elects. If he elects Workmen's Compensation, the suit for negligence is assigned to the state. If he elects to sue for negligence, he still receives various Workmen's Compensation benefits but the state recovers the cost of furnishing the benefits from the recovery in the suit for negligence.

3. RCW 51.32.010

Gives the workman the right to receive compensation for a disability caused by traumatic injury.

4. RCW 51.36.010

Gives the workman the right to receive medical care for a disability caused by traumatic injury.

5. RCW 51.32.180

Gives the workman the right to receive medical care and compensation for an occupational disease.

6. RCW 51.32.050-060-070-080-090

Sets forth standards for determining amount of compensation due. The standards provide for varying amounts of compensation depending on whether the disability is permanent or temporary, partial or total, and various other factors such as number of dependents.

7. RCW 51.12.060

Provides that Workmen's Compensation applies to all United States lands or premises to extent permitted by 40 USCA § 290. 40 USCA § 290 allows states to apply their workmen's compensation laws to workmen, other than federal employees, working on federal property.

8. RCW 51.04.040

Superior Court has power to enforce attendance of witnesses and production of books and records before the department.

9. RCW 51.04.050

Physicians having examined or treated claimants may be required to testify and are not exempt from testifying by reason of physician-patient relation.

c. Reporting.

1. RCW 51.28.010

When accident occurs workman must notify employer and employer

[redacted]

at once reports accident and injury resulting therefrom to department and also to any local representative of department.

2. RCW 51.48.060

Physician is guilty of misdemeanor if fails to report, within 10 days of treatment, a description of treatment and an estimate of probable duration of injury.

3. RCW 51.28.050

No application valid unless filed within one year after day upon which injury occurred or rights of dependents accrued.

4. RCW 51.28.055

Occupational disease claims must be filed within one year of date workman had notice from physician of existence of occupational disease without reference to date of origin.

5. RCW 51.32.160

If aggravation of disability takes place or be discovered after rate of compensation established, in any case director may, upon application of beneficiary, made within five years of establishment of compensation, or upon his own motion, readjust rate of compensation. No act done by director or department prior to a written order for readjustment shall be ground for such readjustment.

Wash. Sess. Laws 1951, ch. 144. Allows department to enter into a contract with AEC or GE regarding workmen's compensation and both GE and the AEC have entered into such contracts.

2. Conditions, if Any, Under Which an Individual May Initiate a Claim.

The conditions which must occur before an individual may initiate a claim are as follows:

a. The workman must be employed in an extra hazardous occupation as defined by the Workmen's Compensation laws. The three GE employees' occupations were so considered.

b. The workman must suffer a disability either through a traumatic injury or because of an occupational disease or infection in the course of his employment. The three GE employees involved herein were within the course of their employment.

c. The workman must be able to show a disability. In this regard

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a workman who is unable to work for more than three days is entitled to temporary disability compensation.

d. The workman must make a timely filing of his claim.

1. In the case of a traumatic injury, the workman must initiate a claim within one year of the accident.

2. In the case of an occupational disease or infection, the workman must initiate his claim within one year of notice from a physician that he is suffering from an occupational disease. In this regard the court, in the case of Simpson Logging Co. v. Dept. Labor & Industries (1949), 32 Wn.(2d) 472, 202 P.(2d) 448 said: "No disease can be held not to be an occupational disease as a matter of law, where it is proven that the condition of an extra hazardous employment naturally and proximately produced the disease, and but for the exposure to such conditions the disease would not have been contracted."

3. Organization or Individuals That May be Sued (If Any) by the Claimant.

The only information we can give relating to this question is set forth in RCW 51.24.010 which we have paraphrased and set forth as paragraph 1.b.2., supra. If the incident was proximately caused by the negligence of a party other than GE or its employees, the three GE employees can sue the negligent parties under the aforementioned RCW 51.24.010. If the incident was proximately caused by the negligence of GE or its employees, the three GE employees' only remedy is under the Workmen's Compensation laws of the State of Washington.

[redacted]

APPENDIX 6

DOSIMETRY*

INTRODUCTION

At 10:59 AM (PST), Saturday, April 7, 1962, a criticality accident occurred in a plutonium waste chemical recovery facility at the Hanford Atomic Products Operation, operated for the Atomic Energy Commission by the General Electric Company. Four men were hospitalized but were released after medical observation and after estimates of the radiation doses received were available. This report describes the dosimetry investigation that was made following the accident. This investigation was facilitated by the fact that all employees affected had personnel dosimeters in their possession when the incident occurred. The interpretation of the data supplied by these dosimeters was supplemented by information gathered by techniques that were developed in connection with other accidents. Below, the available information is first presented and then applied in a discussion of the dosimetry of the people involved in the accident.

DESCRIPTION OF THE ACCIDENT

The accident occurred in a facility known as Recuplex within a building known as the 234-5 Building. When the accident occurred, there were twenty-two persons in the 234-5 Building. The criticality alarm siren started almost at once (several people reported that air-proportional alpha contamination monitors broke down slightly before the siren sounded). All persons

* This report was prepared by a committee consisting of C. C. Gamertsfelder, H. V. Larson, J. M. Nielsen, W. C. Roesch (Chairman), and E. C. Watson. It reports the work of a number of people at Hanford.

in the 234-5 Building evacuated to a gate house (2701-Z) about a hundred yards from 234-5 and then took shelter behind another building (2704-Z) when the former area was found to have an exposure rate of about 200 mr/hour. Within five to ten minutes they had evacuated these areas in the evacuation bus or by private car. Two patrolmen, stationed in the gate house at the time of the excursion, increased the total number of evacuees to twenty-four.

The evacuees went to the first aid building for the area (except for one who went to the area badge house and was directed to first aid). By this time the employees who had been in the Recuplex area and had seen the Cerenkov radiation flash were known; however, all employees were given a "Quick Sort" examination to determine who had been exposed to significant fast neutron doses[1)]. The counting rate of a Geiger counter held at their abdomen was observed while the person bent over around the counter. Only those employees who had been in the Recuplex area gave significant readings.

Contamination surveys of the evacuees were also made while they were at the first aid building. No contamination was found. Their personnel dosimeters were collected for examination. Personal effects were examined for radioactivity and then sent in for laboratory study. The first blood and hair samples and excreta collections were made.

After examination and treatment at Kadlec Hospital, four persons, including the three most highly exposed, were sent to the Hanford Whole Body Counter for examination. The next day all but one of the remaining evacuees were also examined at the Counter; the last man was examined the following day. Whole body counts and blood and excreta collection were repeated on the most highly exposed persons until no radioactivity of interest was detectable.

Information was obtained immediately from each employee to establish where he had been when the criticality alarm sounded and how he left the building. Detailed personal interviews were made during the following week. All but five people in the 234-5 Building evacuated immediately upon hearing the siren; all but one had left within about two minutes; the last man was out within four minutes. The routes each one followed in leaving the building are shown in Figures 1 and 2.

Information for the three most highly exposed persons was made as detailed as their recollections would allow. Figure 3 shows where these people were standing at the time they saw the Cerenkov radiation flash. Employee #1 was standing immediately below the critical vessel, the K-9 Tank, manipulating a valve at the face of the hood containing the tank. His body was very close to the hood wall. His eyes were about 5 feet from the center of the K-9 Tank; the parts of the trunk of his body were between 6 and 8 feet away. Employee #17 was standing about 2 feet to the side and about 5 feet behind Employee #1. There was a movable lead shield behind #1, but #17 was in full view of #1 and of the K-9 Tank. #17's eyes were about 10 feet from the center of K-9 and the trunk of his body was 10 to 11 feet away. The K-9 Tank is cylindrical with a capacity of 69 liters; it contained about 45 liters when the excursion occurred. The tank has a Pyrex wall about 3/8 inch thick and a steel bottom plate about one inch thick. #1 and #17 were exposed to radiations coming through both the wall and the bottom. The only other materials between them and the tank were the half inch thick lucite hood walls and some plumbing inside the hood. Employee #23 was standing in front of another hood about 26 feet from the center of K-9. Most of the radiation reaching him probably came through the sides of the tank. The only materials between him and K-9 were the lucite walls of

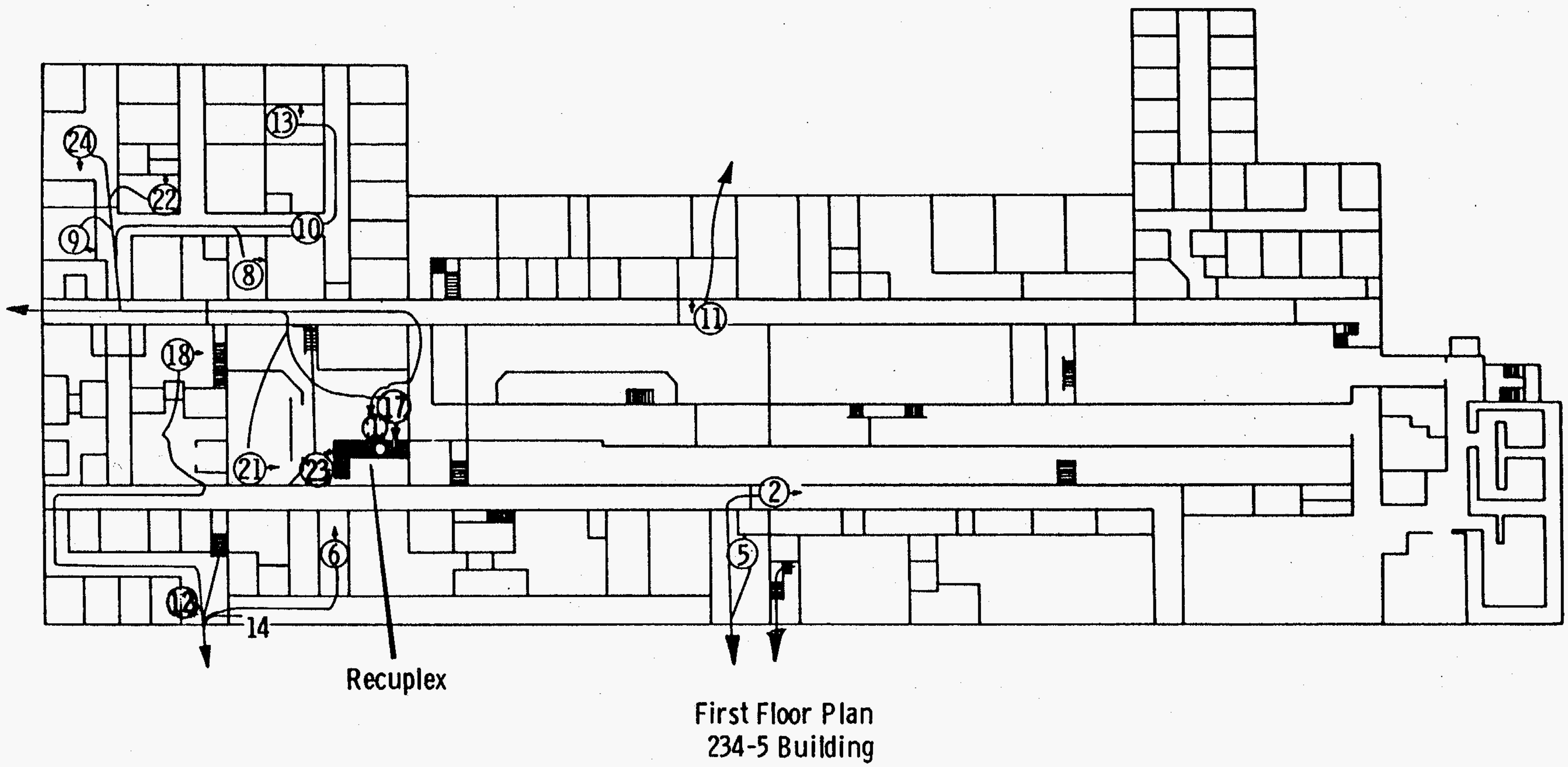

FIGURE 1

Routes Followed by Employees Evacuating the 234-5 Building
(First floor)

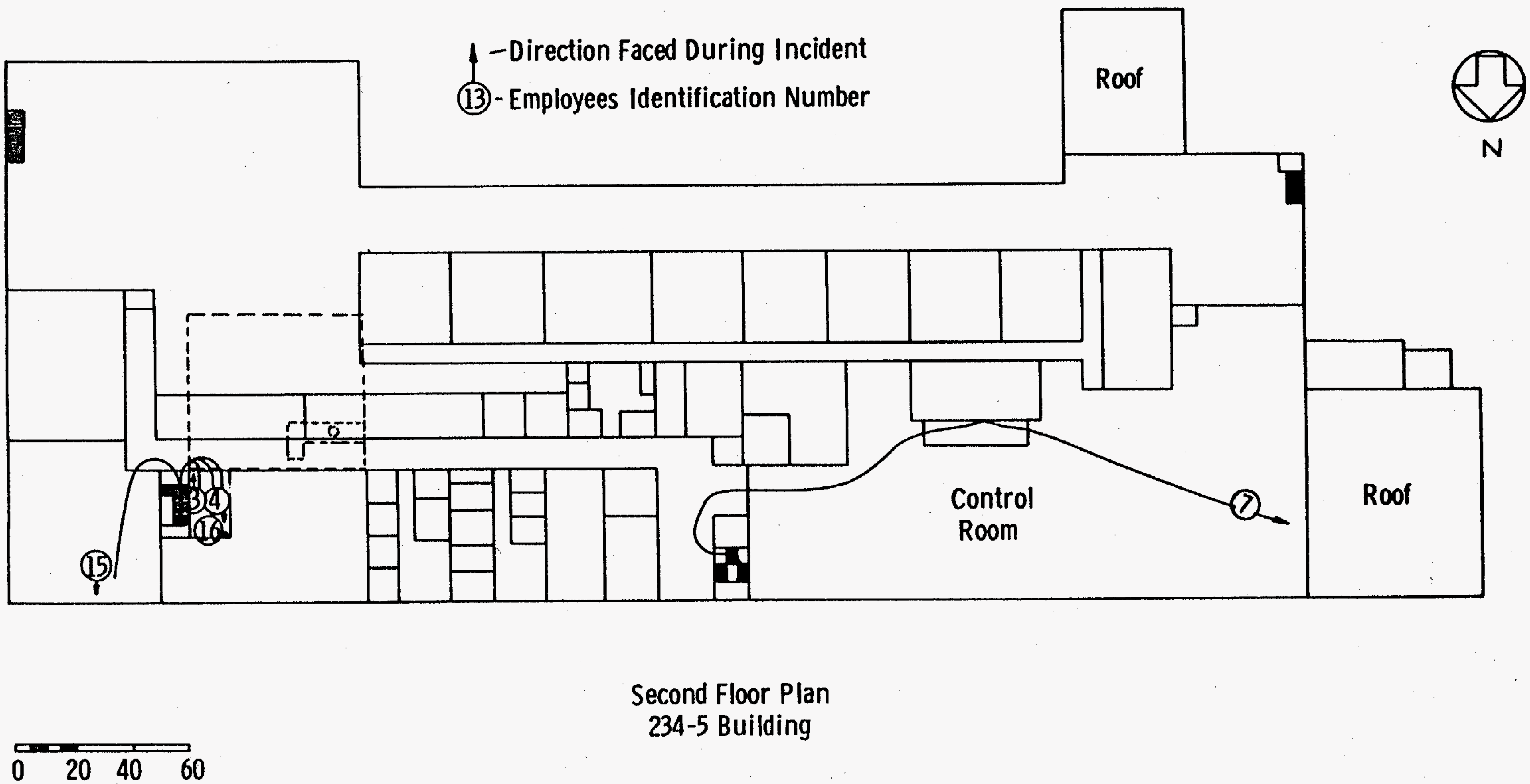

FIGURE 2

Routes Followed by Employees Evacuating the 234-5 Building (Second floor)

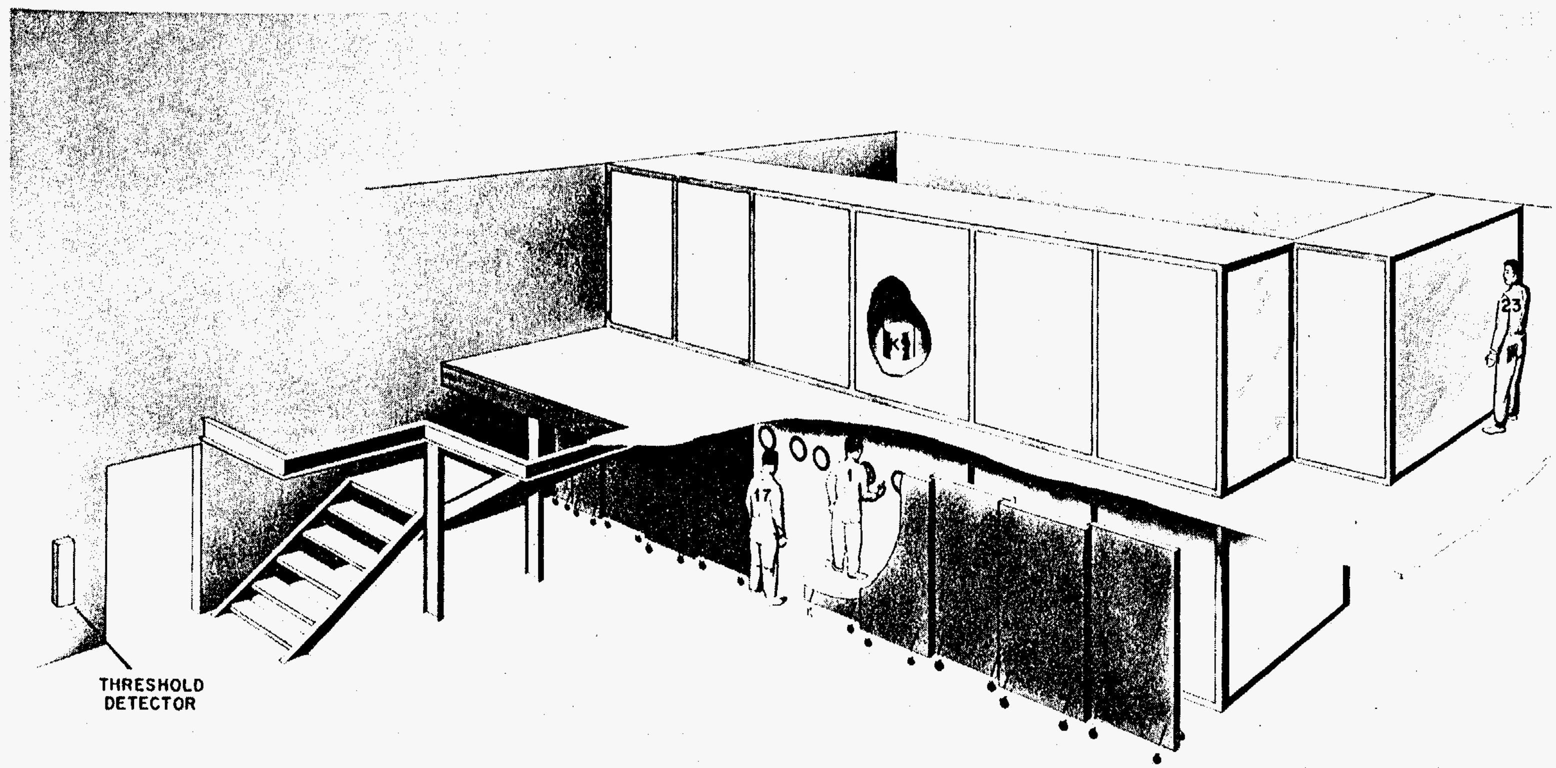

FIGURE 3

Positions of Employees in the Recuplex Area at the Time of the Accident. The Position of the Threshold Dosimeter is Also Shown.

the hood containing K-9 and the hood he was facing and the thin metal back of the latter.

Of the next two most highly exposed people, Employee #6 was about 30 feet from K-9 with one concrete wall about 4 inches thick and one metal partition wall in between. This employee delayed to lock up some classified documents but was outside the building in about 25 seconds. Employee #21 was about 40 feet away and was shielded by an 8 inch thick concrete wall.

Before considering the measurements made for each individual, information of general interest can be obtained from instruments that were near the scene of the accident. Two recording BF_3 counters (one for high levels, one for low) were operating at the time of the accident in an incinerator room in the 234-5 Building. The data from the chart recorders are plotted in Figure 4. They indicate an initial excursion the exact magnitude of which cannot be determined because the flux level is recorded only every 30 seconds and it may be expected to vary by orders of magnitude within such a time period. Following this initial pulse which presumably activated the criticality alarm there was a continuing nuclear reaction of a magnitude sufficient to keep the recorder off-scale for a period of about 30 minutes. After the recorder returned to on-scale readings the fissioning continued at a generally reduced rate till 36 hours after the incident began. It appears that those in a position to be most seriously exposed to the critical vessel evacuated in time to limit their exposure to only a part of the initial excursion.

A threshold detector[2)] was located about 26 feet from the critical vessel. Its position is shown in Figure 3. At least one of the steel beams of the stairway shown in the figure was on the line-of-sight between the

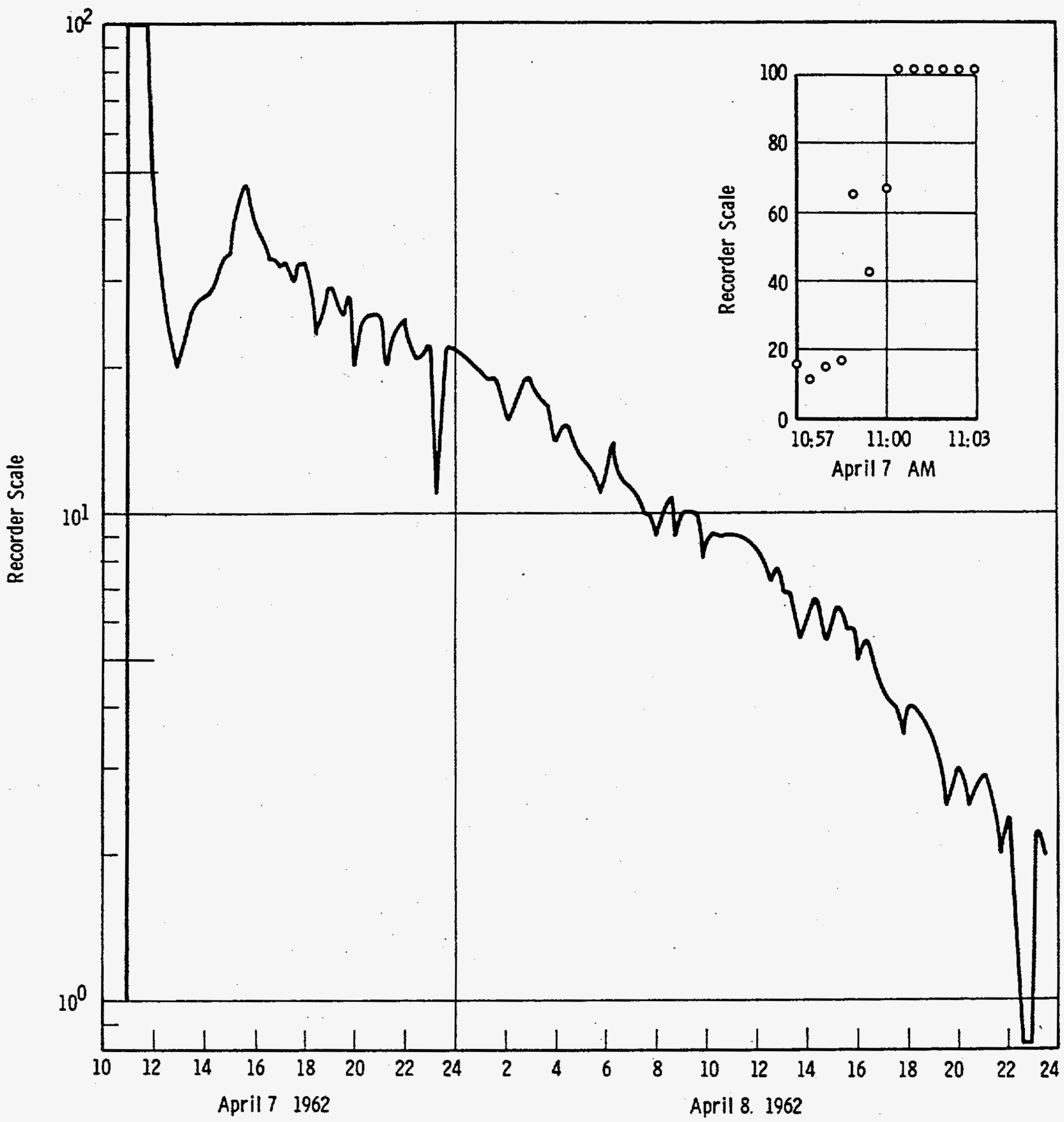

FIGURE 4

Data from a Recording BF_3 Counter Operating in the 234-5 Building at the Time of the Accident.

vessel and the dosimeter. The metal grid floor of the mezzanine level, the stairway, and another hood at the head of the stairs provided masses of material in which radiation from K-9 could scatter and then reach the detector. These certainly influenced the relative spectra of the neutrons reaching the detector as compared to those reaching the men. For lack of other information, however, the spectrum received by the detector was used in analyzing other pertinent data. The detector was removed about 96 minutes after the accidental excursions started so it was present during the large excursion shown in Figure 4 as well as during the time the people were present.

The results obtained from analysis of the threshold detector are given in Table I. The results relative to the neutrons/cm^2 measured with the plutonium foil are also given. The latter is assumed to include all the neutrons above 1 Kev.

TABLE I

Threshold Detector Results

Neutron Energy Band	n/cm^2	Relative* n/cm^2	Relative* Dose
Thermal	1.17×10^{10}	0.39	0.005
1--750 Kev	1.26×10^{10}	0.42	0.25
0.75--1.5 Mev	1.05×10^{10}	0.35	0.40
1.5--2.5 Mev	0.34×10^{10}	0.11	0.15
>2.5 Mev	0.35×10^{10}	0.12	0.20

*Relative to n/cm^2 or to dose for neutrons above 1 Kev.

The number spectrum is presented in Figure 5. For comparison several other spectra obtained with threshold detectors[3][4][5] and normalized in the same way are shown in Figure 6. Figure 7 shows histograms prepared from calculated spectra[6]; since information is lost in going from the calculated spectra to

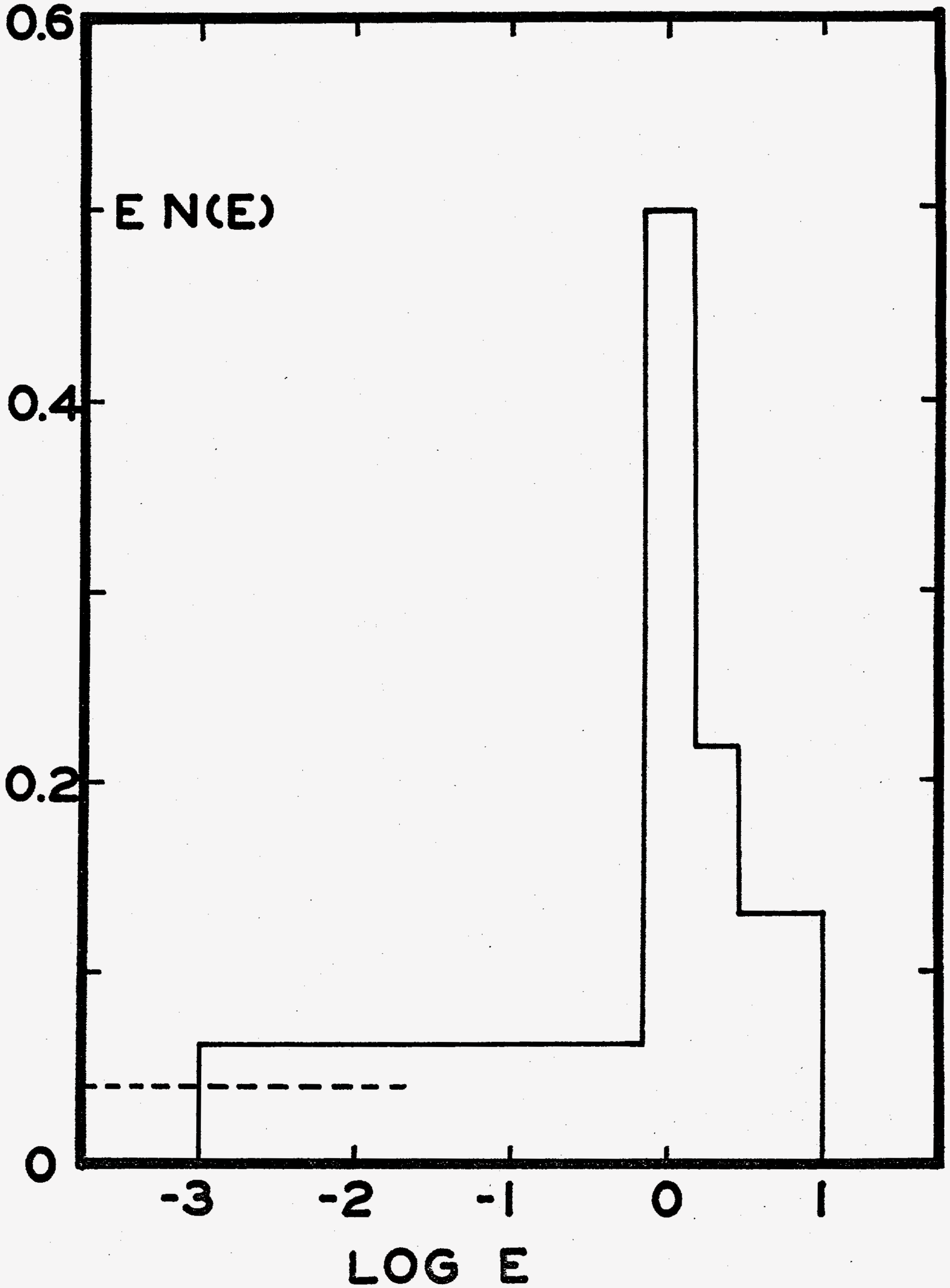

FIGURE 5

Spectrum Measured with Threshold Detector During Recuplex Accident.

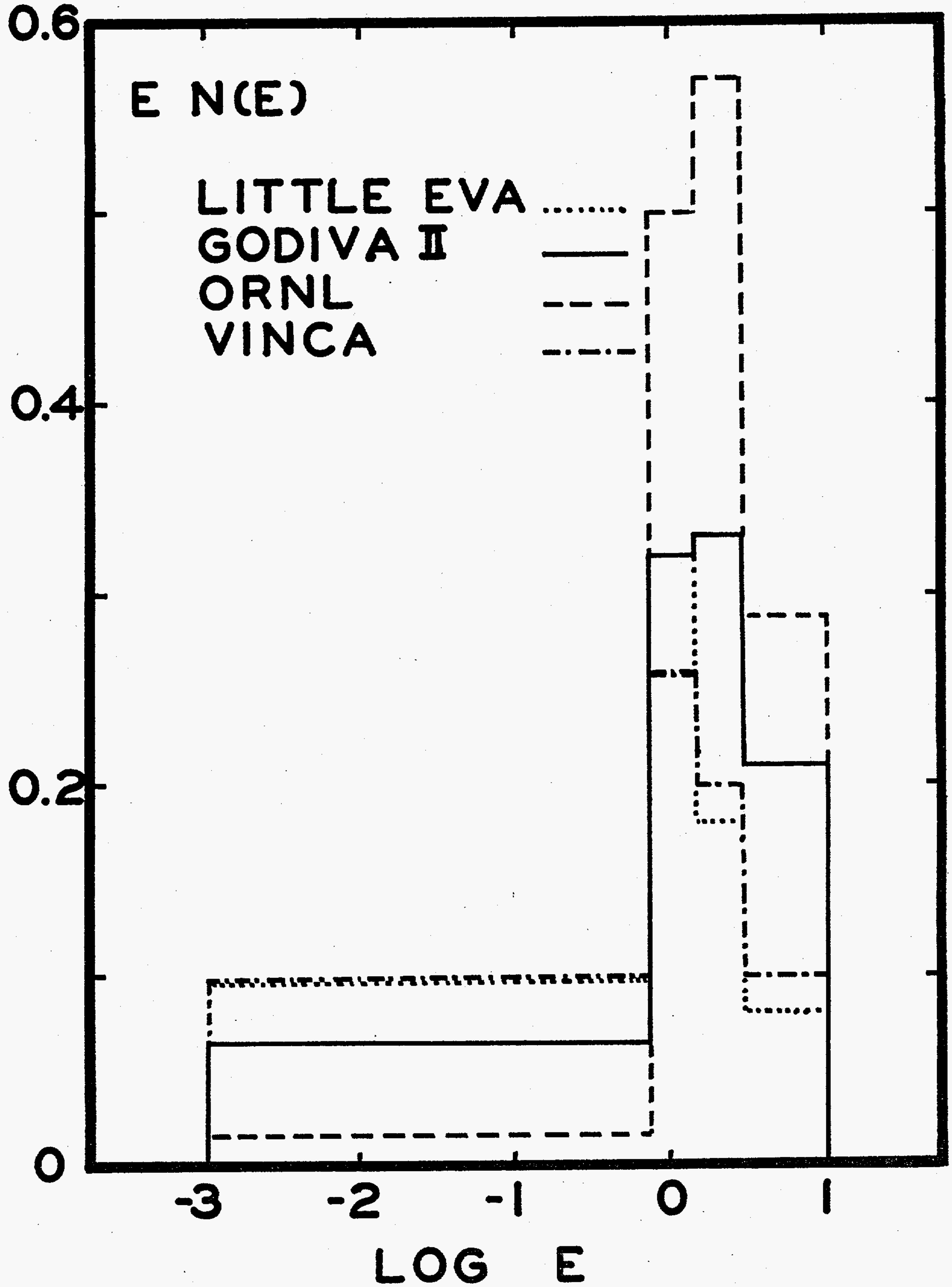

FIGURE 6

Experimental Spectra Measured with Threshold Detectors.

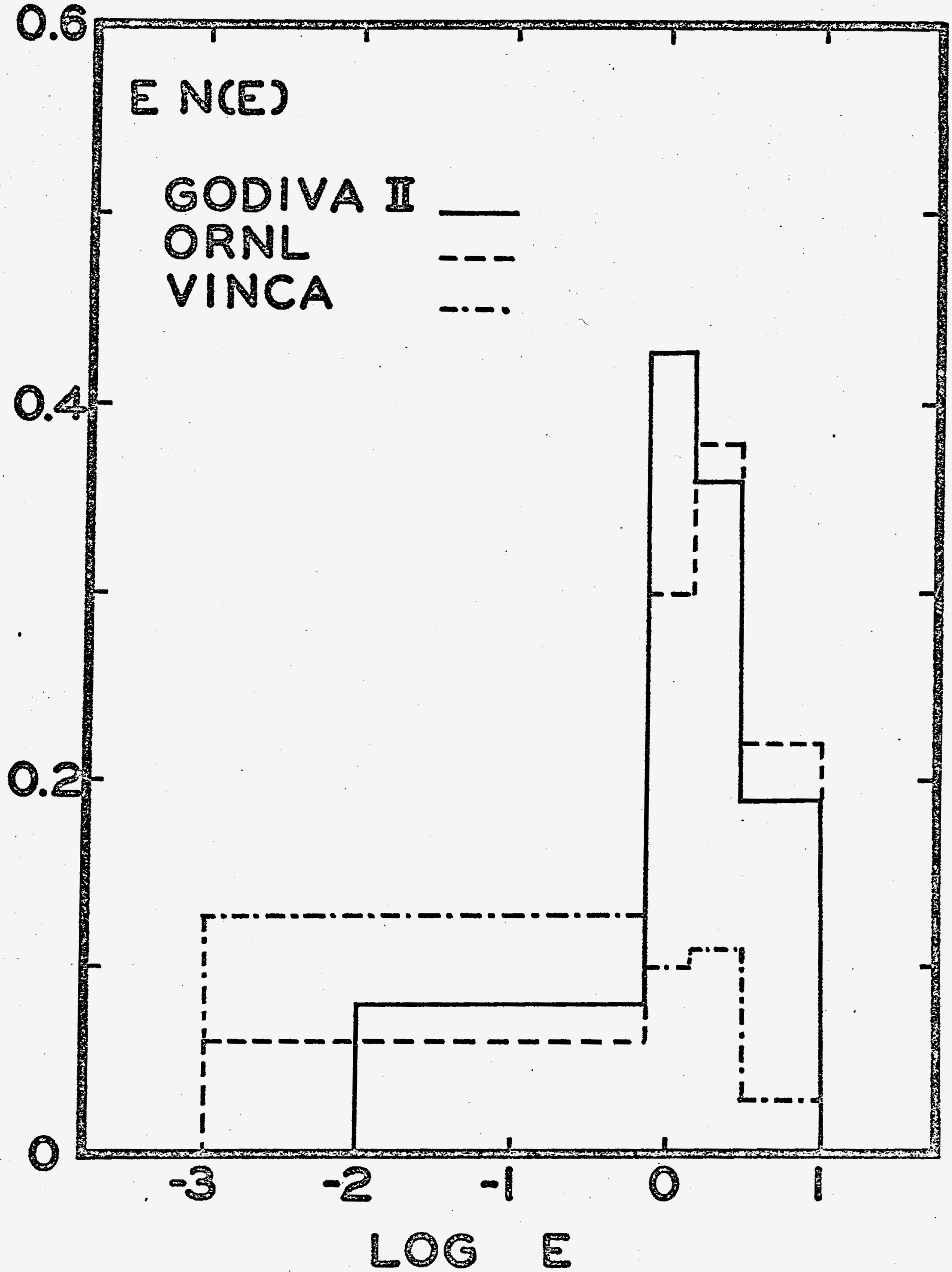

FIGURE 7

Theoretical Spectra (histograms) Calculated for Threshold Detectors.

the histograms, the original normalized spectra are given in Figure 8. There is not close agreement between the present spectrum and any of the others, but the general features are the same and the differences are of the sort to be expected if the present results include the effects of a significant number of scattered, and hence lower energy, neutrons. Table I also contains the dose spectrum normalized to unit dose for the neutrons above 1 Kev.

The threshold detector was calibrated and interpreted in a slightly different manner[7)] from that described in the original reference[2)]. The calibration constant provided for the sulfur disk in reference 7 was increased by a factor 1.5 = 0.34/0.23. The 0.34 is the cross section in barns of the S(n,p) reaction at 4.2 Mev, the energy used in the calibration. The 0.23 is the effective cross section in barns for neutrons above 2.5 Mev for spectra similar in shape to fission spectra above this energy. The intermediate neutron energy spectrum was estimated from the activation in the gold and cadmium-covered gold foils in the detector. If ϕ_{th} was the thermal neutrons/cm^2 and if σ_{2200} is the activation cross section of gold for neutrons whose velocity is 2200 m/sec, then the difference in activity of the two foils is proportional to $\frac{1}{2}\sqrt{\pi}\sigma_{2200}\,\phi_{th}$. If the intermediate neutron flux is assumed to be given by $k\phi_{Pu}/E$, where E is the neutron energy, k is a constant, and ϕ_{Pu} the flux measured by the shielded plutonium foil, then the activation of the cadmium covered foil is proportional to

$$k\,\phi_{Pu}\int\sigma_{act}\ (dE/E)$$

where the integral is over the activation cross section of gold. Measured foil activities of 1.6 and 1.0 x 10^6 disintegrations/min, Hughes'[8)] values of the cross sections, and flux ratios from Table I give k = 0.042. This is shown as a dashed line in Figure 5 and is in good agreement with the spectrum determined with the threshold foils.

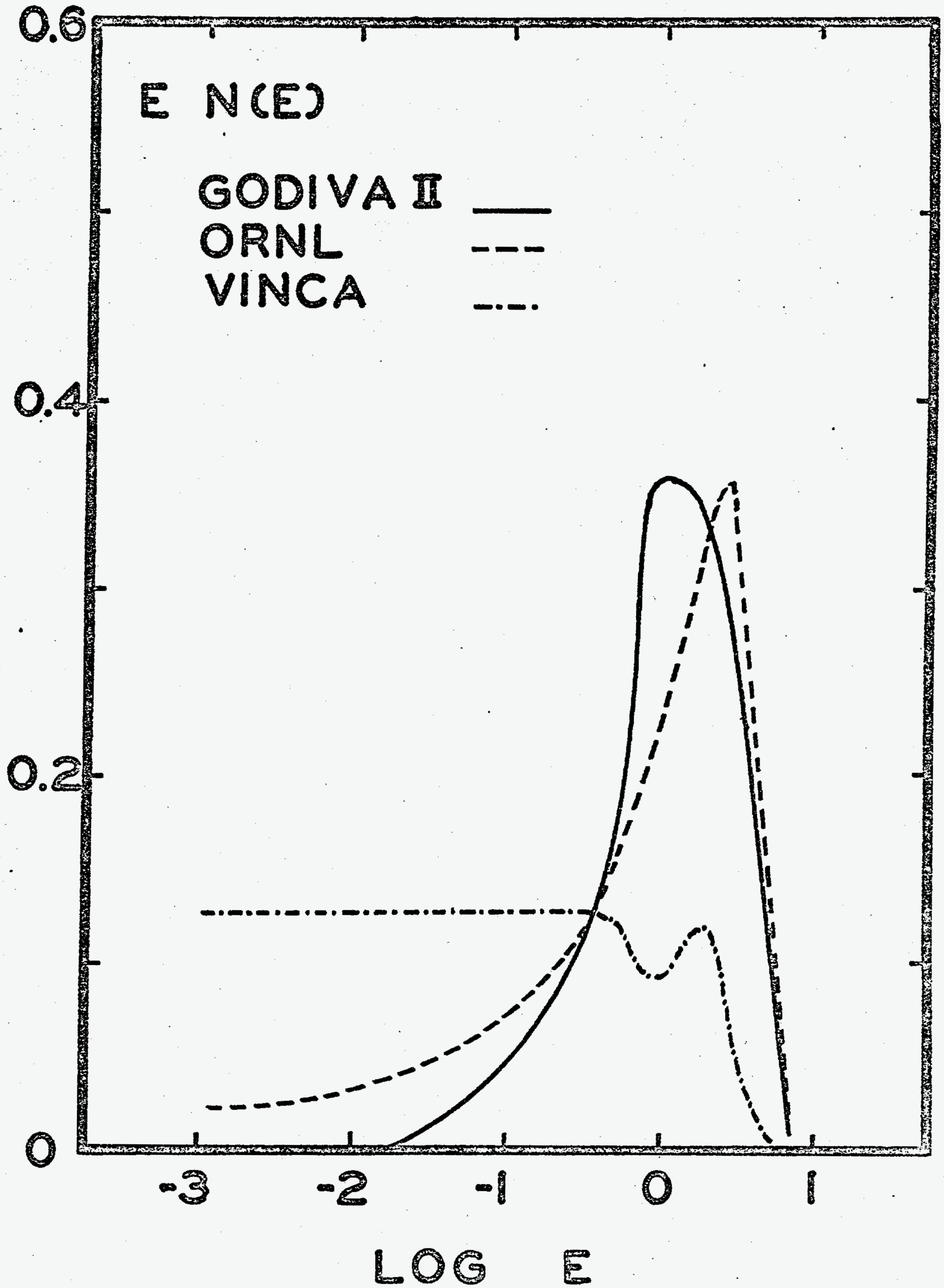

FIGURE 8

Theoretical Spectra from Which the Histograms of Figure 7 Were Prepared.

PERSONNEL DOSIMETERS

Each of the persons near the critical vessel* at the time of the accident was wearing his Hanford Film Badge Dosimeter[9]. The dosimeters had last been exchanged 15 days before the accident; therefore, particularly for the smaller doses, a significant part of the darkening of the film may have been produced during employment prior to the accident.

The exposures of Employees #1, #17, and #23 were so great that the developed sensitive (508) film from their dosimeters was too dark to permit optical density measurements. The insensitive (1290) film from their dosimeters was used to obtain their doses. Because of slow neutron activation of the aluminum and silver absorbers in the dosimeters, there was additional darkening of the areas of the dosimeter covered by them so the usual interpretation methods could not be used. The doses were determined from the densities of the unshielded portion of the dosimeter (the open window). There is an uncertainty in doing this[10] because during both exposure and calibration the film is affected by secondary electrons produced by the photons in the environment of the dosimeter as well as in the material of the dosimeter itself. In the present case the dose determined from the open window could have been as much as 15 percent too low because of this effect. The dosimeter contains a lead strip in which the payroll number and other information is punched. For the films in question there was enough unused area under the lead tape to take a densitometer reading. These readings were compared with similar readings on the calibration films; they gave dose estimates that confirmed those from the open window readings. In making this comparison it is assumed that there is no appreciable slow neutron

*Two patrolmen stationed in the gate house received negligible doses and are not considered further in this report.

activation of the lead tapes and no effect due to different photon spectra.

Some of the darkening of these films must have been due to neutron activation of the materials in the emulsion. It has been reported[11)] that 0.13 rad of thermal neutrons or about 40 rads of fast neutrons (first collision dose) would produce the same darkening of 1290 film as 1 r of Co-60 gamma rays. For example, if the exposure of Employee #1 was 25 rads of fast neutrons plus 0.5 rad of thermal neutrons, the darkening predicted would be equivalent to 4.5 r of gamma radiation. This is 7 per cent of the dose measured as described above.

The dosimeters of the other people in the 234-5 Building were, where necessary, read by these same methods but with the 508 film. The results of all the film badge dosimeter measurements are given in Table II. No corrections have been made for the neutron darkening just mentioned.

TABLE II

Personnel Dosimeter Results
(All Exposures in Roentgens)

Employee	508 Film	1290 Film	Neutron Film	Finger Ring
# 1		63		80
2	0.03			
3	0.12			
4	0.15			
5	0.02			
6	0.98			
7	0.04			
8	0.10			
9	0.05			
10	0.06			
11	0.07			
12	0.20			
13	0.13			
14	0.70			
15	0.20			
16	0.1			
17		23		
18	0.40			
21	1.0			
22	0.05			
23		13	10	5.7
24	0.02			

Employees #21 and #23 were wearing neutron film badge dosimeters[12]. In each case the nuclear track plate was so darkened by the photon exposure that recoil tracks could not be identified. In the case of #23, approximate readings of the 508 film in the dosimeter could be made. They indicate a gamma ray dose of about 10 r, in agreement with his regular dosimeter, and about 3.5×10^9 neutrons/cm^2 of thermal neutrons.

Employees #1 and #23 were wearing film ring dosimeters. These indicated doses of 80 and 5.7 r, respectively.

Two additional studies were made with the personnel dosimeters of Employees #1, #17, and #23. The very dark 508 films were exposed to slow neutrons and measurements of the activation of the developed silver used as a measurement of the gamma ray dose received[13][14]. The activation of the films was done in the large moderator used for producing slow neutron fluxes with the Van de Graaff accelerator[15]. The radioactivity was easily measurable [16], but it was found that the three films were at or very near the first maximum of the curve of activity versus dose for the calibration film[17]. It was not possible to get accurate dose estimates. The same slow neutron facility was used to estimate the neutron flux that had produced the excess darkening on the 1290 film behind the silver shields. Fresh films were exposed to gamma ray doses in the range of those to which the people were exposed and then exposed to slow neutrons until the total flux producing the same density pattern as on the personnel film was found. The neutron fluxes found in this way were decreased by a factor 0.79 to allow for the fact that part of the activation during the accident was due to intermediate energy neutrons. The factor was calculated from the gold foil activities in the threshold detector and the thermal neutron cross sections and resonance integrals of gold and silver[8]. The thermal neutron fields estimated by this method are given in Table III.

TABLE III

Thermal Neutron Estimates From Film Badges

Employee	Thermal Neutrons/cm^2	Estimated Uncertainty
# 1	2.3×10^{10}	10%
#17	6.5×10^{9}	50%
#23	3.1×10^{9}	200%

WHOLE BODY COUNTING

The occupants of the 234-5 Building at the time of the accident were counted in the Hanford Whole Body Counter[18]. The measured values of Na-24 activity, corrected for decay since the time of the accident, and the individual's weights are given in Table IV. No correction was made for Na-24 that might have been eliminated before the counting took place; it is estimated that only a few percent was missed in this way for those counted immediately. The quotient of the number of microcuries by the body weight in kilograms was multiplied by 215 rad-kg/μc to obtain the first collision dose to the person.

The factor 215 rad-kg/μc was obtained by averaging the following two experimental values. Measurements[19] with a burro at the mock-up of the Oak Ridge criticality accident gave 204 rad-kg/μc. An experiment with solutions of sodium salts in bottles at the Godiva II reactor gave 226 rad-kg/μc[20].

Recently the dosimetry investigation of the Vinca critical accident was reported[5)] for which an average factor of 81 rad-kg/μc was used (neglecting corrections for the weights of the individual persons). The difference between this figure and those above is due to the presence of a very large proportion of thermal neutrons near the Vinca reactor. If the threshold detector measurements reported for that reactor and those reported above for the present criticality accident are used to estimate the neutron first collision dose per unit Na-24 activation[21)], the rad-kg/μc factor for the Hanford accident is about 2.3 times that for the Vinca, i.e., about 190 rad-kg/μc. This is satisfactorily close to the value used above. Although, as remarked above, the threshold detector measurements for the Hanford accident probably represent a different spectrum than that to which the employees were exposed because of attenuation and scattering, the comparison of the Vinca and Hanford spectra to estimate the above factor is not much affected by the difference.

It is estimated that the Na-24 burdens were determined to an accuracy of about 5 percent where counting data were not limited by statistics. Counting statistics became important for burdens of about 0.001 μc (before correction for decay). Those employees in whom less than 0.001 μc was detected were assigned a dose of less than 0.01 rad.

TABLE IV

Whole Body Counting Results

Employee	μc Na-24	Weight kg	Neutron First Collision Dose--rads
# 1	7.55	70.4	23
2	0.001	85.3	< 0.01
3	0.014	71.8	0.04
4	0.022	95.4	0.05
5	0.001	93.4	<0.01
6	0.088	55.3	0.34
7	0.002	68.5	<0.01
8	0.004	71.2	0.01
9	0.001	61.2	<0.01
10	0.006	71.7	0.02
11	0.001	73.5	<0.01
12	0.008	75.9	0.02
13	0.001	70.8	<0.01
14	0.034	70.3	0.10
15	0.003	67.1	<0.01
16	0.010	84.8	0.02
17	4.20	98.1	9.2
18	0.019	85	0.05
21	0.055	72.7	0.16
22	0.001	56.7	<0.01
23	1.12	82.4	2.9
24	0.001	78.9	<0.01

The presence of K-42 was noticed in those people who had large Na-24 burdens. The amounts present were consistent with estimates from abundance and cross-section data which indicate that there should be about one seventh as many microcuries of K-42 as of Na-24. Employees #1, #17, and #23 were counted several more times at the whole body counter. The Na-24 was observed to disappear with the expected 15 hour half-life. Each of these three men was found to have had some Au-198 produced in fillings in his teeth. In the case of #17 the gold was in bridge-work that could be removed. This made it possible to count him with the P-32 counter[22]. After the original report on the counter, the detector was moved to a counting position over the head rather than over the chest in order to reduce interference by other isotopes;

the presence of radioactive gold fillings would have prevented such measurements. The first count for P-32 was made on #17 ten days after the accident. The P-32 was easily detected. The counting rate due to the P-32 decreased exponentially with a 14.5 day half-life (i.e., the radioactive decay half-life) rather than the 8 to 10 day half-life observed for subjects who receive P-32 intravenously. This indicated that most of the P-32 being observed was formed in the relatively tightly bound phosphorous, probably that in the skull, rather than that more mobile portion in which the intravenously injected P-32 appears. Thus the calibration of the counter, which was done with intravenously injected subjects, was not applicable; if applied anyway, the calibration would have indicated two to three times as much P-32 as predicted from the activity of the Na-24 present.

Na-24 IN BLOOD

Two 2 cm^3 blood samples each for Employees #1, #17, and #23 were counted for Na-24. The first samples were counted on a three inch well crystal scintillation counter. They had coagulated before they could be counted. The second set of samples was treated with heparin to prevent coagulation. They were counted for 30 minutes on a total absorption gamma-ray spectrometer[23)]. The results of the two counts, corrected for decay from the time of the accident, are given in Table V. The agreement is considered reasonably good.

The activity density of the Na-24 in the whole blood was converted to neutron first collision dose by multiplying by the factor 1.65×10^5 rad-$cm^3/\mu c$. This is the ratio of first collision dose to blood activity found in the Oak Ridge burro experiment[19)].

If the sodium in the whole body and in the blood are equally irradiated by slow neutrons or if there is rapid equilibration of the sodium throughout all compartments in the body, then this factor should be related to the factor used above with the whole body counter data. The ratio of μc/kg of Na-24 in the body to μc/cm^3 in the blood should equal the ratio of the density of sodium in the body (105 g/70 kg for the standard man[24]) to that in the blood (1.91×10^{-3} g/cm^3 [25]): ($1.91 \times 10^{-3} \times 70$)/105 = 1.27×10^{-3}. $1.65 \times 10^{5} \times 1.27 \times 10^{-3}$ = 210 rad-kg/μc, in good agreement with the figure chosen above for the whole body counting. This comparison is significant because the blood and whole body activities of the burro were determined in different ways. A similar comparison can be made using the data obtained after the critical accident at Los Alamos. The fatally exposed employee was found to have 0.00531 μc/cm^3 of Na-24 in whole blood and 293 μc in his whole body, which weighed 71.5 kg[26]. (0.00531×71.5)/293 = 1.30×10^{-3} in good agreement with the above value. This latter value is particularly significant because the neutron dose distribution in the man's body was very non-uniform. The agreement between the two results indicates that the sodium had been able to effectively equilibrate throughout the body.

TABLE V

Na-24 in Blood
(Two Samples From Each Employee)

Employee	Na-24 μc/cm^3 blood	Neutron First Collision Dose rads
# 1	1.5×10^{-4}	25 ± 2.5
	1.8×10^{-4}	30 ± 3.0
# 17	8.8×10^{-5}	15 ± 2.2
	7.3×10^{-5}	12 ± 1.2
# 23	2.0×10^{-5}	4.0 ± 1.2
	2.1×10^{-5}	3.4 ± 0.8

Na-24 IN EXCRETA

The first urine samples from Employees #1, #17, and #23 were counted on a three inch well crystal scintillation counter. These measurements were repeated and all later samples were measured on a five inch well crystal scintillation counter[27]. Sample size varied from 2 to 500 cm^3 and counting time from 5 to 30 minutes depending on the activity of the sample. The results, corrected for decay from the time of the accident, are given in Table VI. The Na-24 activity found in feces was negligible.

TABLE VI

Na-24 in Urine

Employee	Date	Average Dis./min-ml	Total ml	Total Dis./min
# 1	4/7/62	174.1	1685	2.93×10^5
	4/8/62	210.9	3800	8.01×10^5
	4/9/62	229.7	4340	9.97×10^5
	4/10/62	142.0	2500	3.55×10^5
	4/11-12/62	77.8	4900	3.81×10^5
	4/12-13/62	135.0	4280	5.78×10^5
# 17	4/7/62	339.5	580	1.97×10^5
	4/8/62	310.7	3020	9.38×10^5
	4/9/62	185.5	3200	5.94×10^5
	4/10/62	120.0	3300	3.96×10^5
	4/11-12/62	136.8	3225	4.41×10^5
	4/12-13/62	135.0	1950	2.63×10^5
# 23	4/7/62	66.7	1415	0.94×10^5
	4/8/62	44.3	3935	1.74×10^5
	4/9/62	27.8	3850	1.07×10^5
	4/12-13/62	40.5	3050	1.24×10^5

P-32 IN HAIR

Samples of hair were taken from Employees #1, #17, and #23 from several locations on their bodies. The P-32 was separated from the hair[28] and counted in a low background proportional counter. The sulfur content was determined for several samples by a spectrometric method and found to agree with the results of Peterson, et.al.[29)] so their value, 47.7 mg sulfur per gram of hair, was then assumed for all calculations. The results are listed in Table VII. The time integral of the flux density of neutrons having energies greater than 2.5 Mev and the first collision dose due to these neutrons were calculated using the formula given by Peterson, et. al. Their formula gives factors of 6.44×10^6 neutrons/cm^2 per dis./min-g sulfur and 0.0246 rads per dis./min-g sulfur.

TABLE VII

P-32 in Hair

	Hair Sample			Neutrons Above 2.5 Mev	
Employee	Type	cm from Top of Head	dis/min-g	Neutrons/cm^2	First Collision Dose
# 1	Head, Posterior	0		2.4×10^9	9.3
	Chest	33-77		2.9×10^9	11
	Pubic	87		1.8×10^9	6.9
	Leg	135-161		1.5×10^9	5.6
	(Fingernail				
	Left		24		
	Right)		37		
	(Toenails)		11		
# 17	Chest	43-73		1.4×10^9	5.2
	Pubic	94		7.7×10^8	2.9
	Back	34		9.1×10^8	3.5
# 23	Head	0		4.3×10^8	1.6
	Pubic	93		3.8×10^8	1.4

RADIOACTIVITY OF OTHER OBJECTS

A variety of other objects was collected from the three principals and measured for radioactivity in a five inch well crystal scintillation counter[27]. Later these same objects were activated with slow neutrons in the large moderator in the same way as in the study of the film badges described above[16]. The neutron fluxes in the large moderator that produced the same activity as in the accident were corrected to allow for the intermediate energy neutron activation during the accident. The effective resonance integral for the gold in the eye frames of Employee #17's glasses was found to be 581 barns (compared to 1300 for thin foils[8]) by the cadmium ratio. Otherwise, the thin foil values were used. The thermal neutron fluxes estimated in this way are listed in Table VIII.

RBE DOSE

RBE dose (in rem) is the product of the absorbed dose in rads by an agreed RBE multiplier. Its function is to provide a common, additive measurement of all radiations that expresses the radiation protection hazard involved in exposures to the radiations. NBS Handbook 59[30] recommends RBE values which are dependent upon the linear energy transfer to tissue by the charged particles generated by the radiation. These values of RBE are to be used in assessing hazards due to long continued low level irradiation. The value usually accepted for neutron irradiation is 10, but this is not applicable for the acute exposures described in this report. Indeed, one of the reasons for the careful analysis of the data provided by such accidents is to provide RBE's that might be suitable. For this reason none of the doses given in this report has been converted to an RBE dose. For purposes of administrative recording of whole body radiation exposures

TABLE VIII

Radioactivity of Other Objects

Employee	Item	Location cm from Top of Head	Radioisotope Measured	Large Moderator Neutrons/cm^2	Thermal Neutrons/cm^2
# 1	Silver shield from film badge	~ 40	Cu-64	1.49×10^{10}	1.34×10^{10}
	Ball point pen, minus tip	45	Cu-64	1.37×10^{10}	1.23×10^{10}
	Tip of ball point pen	45	Cu-64	0.99×10^{10}	0.89×10^{10}
# 17	Silver shield from film badge	~ 40	Cu-64	0.73×10^{10}	0.66×10^{10}
	Nickel	100	Mn-56	0.48×10^{10}	0.42×10^{10}
	Belt buckle	73	Cu-64	0.42×10^{10}	0.38×10^{10}
	Lens of eye glasses	12	Na-24	0.63×10^{10}	
	Frame of eye glasses	12	Au-198	1.07×10^{10}	0.59×10^{10}
# 23	Silver shield from film badge	~ 47	Cu-64	0.22×10^{10}	0.22×10^{10}
	Pencil clip	47	Mn-56	0.18×10^{10}	0.16×10^{10}
	Button	34	Cu-64	0.19×10^{10}	0.17×10^{10}
	Watch band	(86)	Mn-56	0.16×10^{10}	0.14×10^{10}

of the employees involved an RBE factor of 2 for acute neutron exposure was assumed. This is largely based on extrapolation from experimental animal exposures and data from previous accidental exposures of humans[19]. The doses to the eyes were recorded with an assumed RBE of 10[31].

CONCLUSIONS AND SUMMARY

Our primary sources of information concerning the exposure of individuals during the accident are their personnel dosimeters for the gamma rays and the whole body counts and blood activation for the neutrons. The dosimeters constitute practically point detectors. The backscattering for gamma rays is small so the dosimeters indicate the first collision photon dose where they were worn. The activation of Na-23 takes place throughout the body. The experiments performed to relate Na-23 activation to neutron dose, however, have related the activation to the first collision dose. Consequently, these primary sources give us information on the first collision dose. It has been customary to report first collision doses in accidents such as the present one in the belief that greater complexity would hinder rather than help correlation of observed biological effects with physical dose measurements.

Employees #1 and #17 were close enough to the critical vessel that the actual absorbed dose must have been fairly non-uniform within their bodies. The relation of Na-23 activation to first collision dose may not, therefore, be quite the same as in the calibration experiments. The relationship is even more complicated by the fact that we do not know the exact course of events following the first critical excursion. During this period the men were moving rapidly and their position and orientation relative to the critical vessel were constantly changing. We do not know if there were any other critical excursions during this period or whether they received practically all their dose during the first one. The only indication we have that these subsequent motions were not very important is the value of the ratio of the gamma ray to the neutron dose. This ratio was between 2 and 3 for the two men close to the critical vessel. This is in good agreement with values observed in similar circumstances[6]. Their motions and the possible later excursions would affect their personnel dosimeter readings even more than the Na-23 activation because of the changing shielding of the dosimeters by the body. The fact that they do not appear to have had a substantial effect on the ratio suggests that most of the dose came during one critical excursion while they were nearly stationary.

The doses determined from sulfur activation in hair were about one half those obtained from Na-23 activation. They should, of course, be lower because they are the doses for only those neutrons above 2.5 Mev. The threshold detector, Table I, would indicate that only 20 percent of the dose should come from such neutrons. The application of the latter data are suspect because, as already discussed, the detector may not have been exposed to exactly the same spectrum as the people. On the other hand, some of the difference may be due to a difference in the relation between first collision dose and Na-23 activation in the calibration experiments and in the present accident because of greater non-uniformity of the dose distribution during the accident. The neutrons/cm^2 detected by sulfur activation can also be compared with the number of thermal neutrons. There are several measurements of the two on exposed people that are for nearly the same parts of the body. A ratio of neutrons/cm^2 above the sulfur threshold to thermal neutrons/cm^2 of about 0.2 was obtained where such measurements were made. The threshold detector gave 0.3. Probably this is as close agreement as we can expect. The scattering and absorbing materials in a human body are enough different from those near the detector to produce this much difference in the thermal flux density. (It will be noted that these ratios differ by just the factor of 1.5 by which the calibration of the threshold detector was changed to allow for the energy at which the calibration was made. Some of the difference may be due to error in this factor. The calibration was performed at 4.2 Mev. The S(n,p) cross section has a sharp maximum at this energy. A small error in energy would have resulted in decreasing the factor.)

It appears that there may be some uncertainty in the doses determined from Na-23 activation, but that it is probably not very great. Employee #1 received the highest exposure. The first collision doses were 23-30 rads from fast neutrons and 63 roentgens in the central region of his body. The dose due to thermal neutrons was negligible in comparison. The P-32 measurements in hair suggest a variation by a factor of at least two for the doses in different parts of the body. This is compatible with variation as the inverse square of the distance from the center of the critical vessel. The neutron dose to the eyes is considered to be of importance in an exposure such as this because of the possibility of cataract formation. Inverse square variation suggests a dose of 42-54 rads of neutrons for his eyes.

Employee #17 received the next highest exposure. They were 9-12 rads from neutrons and 23 roentgens in the central region of the body. These doses are related to those received by #1 by the inverse square of the distance from the center of the critical vessel. By the inverse square law the neutron dose to his eyes must have been 11-14 rads.

Employee #23 received about 3 rads from neutrons and 13 roentgens and these must have been pretty uniform over his body. Employees #6 and #21 each received about 1 roentgen and 0.34 and 0.16 rads from neutrons, respectively. The rest of the people in the 234-5 Building at the time of the accident received considerably less exposure. The doses they did receive can be taken to be those given by their personnel dosimeters, Table II, and their whole body counts, Table IV.

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29. Peterson, D. F., F. E. Mitchell, and W. H. Langham, "Estimation of Fast Neutron Doses in Man by S^{32} $(n,p)P^{32}$ Reaction in Body Hair", Health Physics 6 1-5 (1961).

30. Permissible Dose from External Sources of Ionizing Radiation, NBS Handbook 59, Superintendent of Documents, Washington, D.C., 1954.

31. Personal Communication, V. P. Bond to A. R. Keene, May 9, 1962.

[redacted]

APPENDIX 7 **UNCLASSIFIED**

MEDICAL REPORT

As a result of the criticality incident at the Recuplex Operation of 234-5 on April 7, 1962, four men involved in the operation were hospitalized at approximately noon. Case summaries are given below:

EMPLOYEE NO. 1 (Age 40)

1. Estimated acute whole body radiation exposure gamma 63r, neutron 24 rads, total (RBE=2) 110 rem.

2. He believed he had received a fatal exposure.

3. He described feeling an instant sensation of heat over his upper body and a dry sensation of his mouth which persisted for several hours.

4. His fluid intake was above normal for several days.

5. He was able to eat his evening meal at about 6:00 PM, or approximately 7 hours after the incident.

6. He had a temperature in the vicinity of 100°F developing the next morning after the incident and persisting for about 24 hours.

7. He experienced great relief following notification of his dosage estimate. This was approximately 5 hours after the incident.

8. There was no nausea or erythema at any time.

9. Daily blood counts were done. Blood and urine samples were collected for detailed chemical studies and bone marrow aspiration biopsies were made on the first and seventh days.

10. The fluctuation in the absolute lymphocyte have not been below or above the usual normal range but are interpreted as minor variations resulting from the exposure.

11. The maximum estimated dose to the eye crystaline lens could be as high as 790 rem.

12. A slit-lamp examination of both eyes was done and will be repeated at appropriate intervals.

13. The gonad dose is presently estimated at 60r gamma, and 30 rads neutron. On the 5th day a testicular biopsy was performed and follow-up studies are planned at three-week intervals into July, and at appropriate intervals thereafter as indicated.

14. He was discharged from the hospital on the ninth day which was April 16, 1962.

15. He vomited once after breakfast on the seventh day.

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EMPLOYEE NO. 17 (Age 50)

1. Estimated acute whole body radiation exposure gamma 23r, neutron 10 rads, total (RBE=2) 43 rem.

2. There was no nausea or vomiting at any time.

3. On the second day just before lunch he experienced a very mild shock-like reaction which he described as a sudden feeling of weakness. There was no pain and he recovered rather quickly.

4. Daily blood counts were done. Blood and urine samples for detailed studies were collected, and on the first and seventh days bone marrow aspirations were made. The clinical and laboratory findings to date have been compatible with the estimated dosage and essentially within normal ranges.

5. The maximum dose to the lens of the eye is estimated at 230 rem.

6. He was discharged from the hospital on the 9th day, April 16, 1962.

7. On the 5th day an attempt was made to obtain a testicular biopsy, however, due to a hypotensive reaction, no biopsy was obtained.

8. The clinical and laboratory findings to date have been compatible with the estimated dose and essentially within normal ranges.

EMPLOYEE NO. 23 (Age 27)

1. Estimated acute whole body radiation exposure gamma 13r, neutron 3 rads, total (RBE=2) 19 rem.

2. He experienced no nausea or vomiting.

3. Daily blood counts were done. Blood and urine samples were collected for detailed chemical studies and on the first and seventh days bone marrow aspirations were made.

4. On the fifth day a testicular biopsy was performed.

5. There has been no physical or laboratory findings to date which might be attributable to radiation exposure.

6. He was released from the hospital on the ninth day.

EMPLOYEE NO. 21 (Age 43)

1. Estimated dose 1.4 rem.

2. He was admitted to the hospital because of uncertainty of exposure.

3. He had no complaints and there were no significant findings.

4. Upon confirmation of his estimated dosage, he was discharged from the hospital at about 5:00 PM on April 8, 1962, one day following his admission.

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Two consultants were employed by the contractor to evaluate his procedures and methods of treating the patients and to assist in examining the patients. The two consultants were: G. A. Andrews, M.D., and C. C. Lushbaugh, M.D. Both consultants thought that the General Electric Medical Staff was doing an excellent job and were impressed by their thoroughness and scope.

A medical report containing clinical and laboratory data is attached as Exhibit 7-A.

A complete, comprehensive, medical report is being prepared by the Industrial Medical Staff of the contractor. This report cannot be completed until certain tests (such as sperm count) have been repeated for several more months. The final medical report will be issued separately as soon as it becomes available.

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HANFORD ATOMIC PRODUCTS OPERATION

RELATIONS OPERATION

April 20, 1962

U. S. Atomic Energy Commission
Hanford Operations Office
Richland, Washington

Attention: Mr. Carl N. Zangar, Chairman
Investigation Committee

Gentlemen:

RECORD OF MEDICAL HISTORY AND TREATMENT
OF HAPO CRITICALITY CASES, 4-7-62,
INTERIM REPORT UP TO DATE OF 4-18-62

The following information is submitted as per request letter C. N. Zangar to P. A. Fuqua, M. D., dated April 11, 1962 relating to the radiation incident at Recuplex on April 7, 1962.

I CASE SUMMARIES

Employee No. 1 - Estimated acute whole body radiation exposure gamma 63r, neutron 24 rads, total (RBE = 2) 110 rem

Admitted to Kadlec Methodist Hospital 4-7-62.

Employee No. 1, a white male, age 40, who stated that he had always been well, was obviously apprehensive when first seen. He believed that he had received a fatal exposure. His apprehensiveness, however, was very well controlled. After seeing the flash, he has described feeling an instant sensation of heat over his upper body and a dry sensation of his mouth which persisted for several hours. One high blood pressure reading was recorded prior to receiving dosage information. His fluid intake was above normal for several days. He described a heavy or tense feeling in his stomach for several hours. He was, however, able to eat his evening meal well, at about 6:00 P.M., or seven hours after the accident. He had a temperature in the vicinity of 100°F developing the next morning after the accident and persisting for about 24 hours. He experienced great relief following notification of dosage estimate about 5 hours after the accident. There was no nausea or erythema at any time. He vomited once after breakfast on the 7th day.

On the third day he experienced an activation of a chronic eczema on the dorsum of his fingers on the right hand. There was a palpable tender epitrochlear node. This subsided in about 36 hours with local treatment.

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GENERAL ELECTRIC

He had some nasal allergy prior to the accident. He had been receiving a vaccine.

Daily blood counts were done. Blood and urine samples were collected for detailed chemical studies. On the 1st and 7th day bone marrow aspiration biopsies were made. On the 5th day a testicular biopsy was performed. The clinical and laboratory findings to date have been grossly compatible with the estimated dose and essentially within normal ranges. The fluctuations in the absolute lymphocyte counts have not been below or above the usual normal range but could be interpreted as minor variations resulting from the exposure.

The maximum estimated dose to the eye crystaline lens could be as high as 790 rem based on an exposure of 90r gamma and 70 rads neutron and an RBE of 10 for lenticular injury. A slit-lamp examination of both eyes was done and will be repeated at appropriate intervals. The gonad dose is presently estimated at 60r gamma and 30 rads neutron. Follow-up sperm studies are planned at three week intervals into July and at appropriate intervals thereafter as indicated.

Employee No. 1 has been an extremely cooperative patient and has participated most willingly in studies being carried out.

On the 4th, 7th and 8th days, Emp. No. 1 was released from the hospital to his home between the hours of 1:00 and 9:00 P.M. He was discharged from the hospital on the 9th day, 4-16-62.

Employee No. 17 - Estimated acute whole body radiation exposure gamma 23r, neutron 10 rads, total (RBE = 2) 43 rem

Admitted to Kadlec Methodist Hospital 4-7-62.

Employee No. 17, a white male, age 50, stated that he had always been well. He saw the flash but because of the promptness of the warning signal, admitted to no apprehension, nor did he show any when first seen. There was no nausea or vomiting at any time. There was a streak of redness on his abdomen on the second day but this appeared to be due to the abrasion of his clothing.

On the second day just before lunch he experienced a very mild shock like reaction which he described as a sudden feeling of weakness. There was no pain and he recovered rather quickly.

Daily blood counts were done. Blood and urine samples for detailed studies were collected. On the 1st and 7th day, bone marrow aspirations were made. On the 5th day, due to a hypotensive reaction, a testicular biopsy procedure had to be discontinued. No biopsy was obtained. The clinical and laboratory findings to date have been compatible with the estimated dose and essentially within normal ranges. The maximum dose to the lens of the eyes is now estimated at 230 rem using 30r gamma and

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20 rads neutron and an RBE factor of 10 for neutrons with respect to lenticular changes.

Employee No. 17 has been a very cooperative patient and has participated most willingly in studies being carried out, although he admits to some concern and some apprehensiveness about hospital procedures.

On the 4th, 7th and 8th day, Employee No. 17 was released from the hospital to his home between the hours of 1:00 and 9:00 P.M. He was discharged from the hospital on the 9th day, 4-16-62.

<u>Employee No. 23</u> - Estimated acute whole body radiation exposure gamma 13r, neutron 3 rads, total (RBE = 2) 19 rem

Admitted to Kadlec Methodist Hospital 4-7-62

Employee No. 23, a white, dark complexioned, male, age 27, stated that he had always been well. He experienced no nausea or vomiting. On the evening of the 4th day he developed an erythema on his face believed to have resulted from being in the sun and wind for about 45 minutes during the preceding afternoon.

Daily blood counts were done. Blood and urine samples were collected for detailed chemistry studies. On the 1st and 7th day, bone marrow aspirations were made. On the 5th day, a testicular biopsy was performed. There has been no physical or laboratory findings to date which might be attributable to radiation exposure.

Employee No. 23 has been a very cooperative patient and participated willingly in all studies being carried out.

On the 4th, 7th and 8th day, patient was released from the hospital to his home between the hours of 1:00 and 9:00 P.M. He was discharged from the hospital on the 9th day, 4-16-62.

<u>Employee No. 21</u> - 1.4 rem

Admitted to Kadlec Methodist Hospital 4-7-62.

Employee No. 21, a white male, age 43, was examined by Dr. Rehm and transferred to Dr. Rutherford after admission. He had no complaints and there were no significant findings. He was admitted because of uncertainty of exposure dosage. Hiw work location, however, was behind a concrete wall. On confirming his dosage estimate of 2 rem, he was discharged from the hospital the day following admission, 4-8-62, at about 5:00 P.M.

He was cooperative and very happy that his exposure was small and that he could be released.

[redacted]

II OVERALL CASE MANAGEMENT DETAIL FIRST 72 HOURS

Physician Notification of Criticality Accident

The physician on emergency call, Dr. Rutherford, was called 10 - 15 minutes after the accident at 11:00 A.M. on April 7, 1962 by Mrs. Botker the nurse on duty, 200-W Area. He reported to the 200-W Area about 45 minutes later.

At approximately 11:45 A.M., Mr. Schier called Dr. Rehm at his home who reported to Kadlec Hospital 10 - 15 minutes later. At this time, approximately 12:00 Noon, Emp. 1, Employee 17 and Emp. #23 were at the hospital undergoing surveys by radiation monitors. There was no immediate medical demand except to obtain venous blood samples for assay. The hospital laboratory technician, Miss Ritter, immediately began to carry out this procedure on all three patients. Mr. Schier requested Dr. Rehm to call Dr. Fuqua at approximately 12:05 P.M. and Dr. Fuqua arrived at the hospital about 10 minutes later. Immediately prior to Dr. Rehm's call to Dr. Fuqua, Dr. Fuqua had received a patrol call reporting a criticality accident in 234-5 Building along with the information that Dr. Scudder had requested that Dr. Fuqua be notified. Dr. Fuqua asked the patrol officer if he knew where Dr. Scudder was. He did not know. Dr. Fuqua called Dr. Scudder's home to determine if he, Dr. Fuqua, should report to the Emergency Control Center, the hospital, or to the 200-W Area. From Dr. Scudder at his home Dr. Fuqua learned that Dr. Scudder had no additional information. While Dr. Fuqua and Dr. Scudder were on the telephone, a patrolman came to Dr. Scudder's house, reporting the criticality accident and also that some people were being taken to the hospital. Dr. Fuqua requested Dr. Scudder to stand by.

On Dr. Fuqua's arrival at the hospital at approximately 12:15 P.M., the patients were being surveyed and blood samples were being taken. Dr. Fuqua obtained available information from Dr. Rehm, Mr. Schier and Mr. German and from radiation monitoring personnel concerning the accident and the survey results. Dr. Fuqua called Dr. Scudder and asked him to report to the hospital which he did within 10 - 15 minutes.

On release of the patients by radiation monitors, the patients were taken to separate rooms in the emergency out-patient department of the hospital and examined: Emp. 1 by Dr. Fuqua, Employee 17 by Dr. Scudder and Emp. #23 by Dr. Rehm. On completion of these examinations and further monitoring and sample collecting, they were all admitted to the hospital as bed patients in separate private rooms before 2:00 P.M. Shortly following this, Emp. #21 was brought to the out-patient department of the hospital, was surveyed by radiation monitors, examined by Dr. Rehm, and admitted to hospital, also as a bed patient, in a private room.

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Case Management Detail First 72 Hours

4-7-62 Patients closely watched for signs of nausea and vomiting. Patients asked if wished to be seen by their own personal physicians. Mrs. Emp. 1 requested that Employee 1 be seen by Dr. Corrado and this was effected in about 10 minutes after the request. Employee 17 Employee 23 and Emp. #21 did not wish to be seen by personal physician. Drs. Fuqua, Scudder, Rehm and Dr. Marks, hospital pathologist, planned laboratory procedures to be carried out. Estimated dosages in rem, Emp. 1, 110, Employee 17, 43, Employee 23, 19 and Emp. #21, under 2, were received from H. M. Parker at approximately 4:00 P.M. and each patient was immediately so advised by the physician assigned to his care. The clinical course of all patients thus far had confirmed the estimated dosages by the absence of any clinically significant events. The patients all ate good evening meals. They were sedated with nembutal at about 9:00 P.M. They all rested well and there were no significant developments during the night.

4-8-62 General examinations were repeated. Emp. 1 had developed a temperature in the vicinity of 100°F. His fluid intake was high. He had had a nasal allergy and a low grade chronic eczema on dorsum of fingers of the right hand. Examinations of Employee 17, Employee 23 and Emp. #21 were essentially negative. Dr. Krammer took a bone marrow aspiration biopsy from each patient's sternum in the early afternoon. Dr. Bender of the Oak Ridge National Laboratory was contacted and it was agreed that he would come to Richland to obtain blood samples for tissue culture and chromosome aberration studies. During the course of the evening patients were sent individually to the whole body counter for Na^{24} evaluation, and then to the office of Dr. Davis, opthalmologist, for slit-lamp examination for free floating red cells in the anterior chamber of the eye. None were seen. Additional hair samples for P^{32} evaluation were taken. The clinical course continued to be excellent. Dr. Norwood who was at the IMA meeting in Chicago, was called by Dr. Fuqua to inform him of the condition of the patients. It was agreed that their condition did not warrant his return.

4-9-62 Dr. Bender obtained tissue cultures for chromosome studies between 7:00 and 8:00 A.M. and returned to Oak Ridge. General examinations were repeated. Emp. 1 requested nose drops and his fluid intake remained high. His temperature had returned to normal. Telephone consultation was carried out by Dr. Fuqua with Dr. Joe Howland of the University of Rochester Medical School and Dr. Norwood in Chicago. Dr. Howland requested concurrence in sending out Dr. Ingram, a University of Rochester Medical School hematologist, for the purpose of definitive blood and bone marrow examination. Concurrence was given. Urine and blood chemistry studies were planned. The clinical course and daily blood counts continued to confirm estimated dosages. Dr. Norwood's discussion of these cases with Dr. Finkel of Argonne and Dr. Shipman of Los Alamos confirmed adequacy of management of cases.

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4-10-62 General examinations were repeated. Emp. 1's chronic eczema on dorsum of fingers of right hand was activated and there was a palpable tender epitrachlear node. Hot soaks and cortisone ointment was ordered. Emp. 1 was sent to the whole body counter to better evaluate dosage being received from induced activity of a fixed gold inlaid dental bridge of upper central incisors. At Mr. Schier's request to procure two consultants to look over the overall case management, Dr. Fuqua had telephone consultations with Dr. Andrews of the Oak Ridge National Institute of Nuclear Studies, with Dr. Lushbaugh of Los Alamos, and with Dr. Norwood in Chicago. Dr. Andrews and Dr. Lushbaugh were asked to see patients in consultation and accepted. Details of laboratory studies were arranged. Dr. Fuqua also made arrangements with Dr. Paulsen, a University of Washington School of Medicine endrocrinologist, to come to Richland for sperm studies.

Very truly yours,

P. A. Fuqua, M. D., Manager
Occupational Medical Operation

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Attachment
Consultant Reports

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[redacted]

It appears to me that an excellent job is being done of managing this accident. The patients should all recover from the immediate radiation effects without significant incident. They could safely be out of the hospital if clinical and hematologic observations can be continued at least three times weekly. It is worth while to save 24 hour urine collections for another week for amino acid determinations. If X-rays of the chest have not been made within the last year, these should probably be done. I am thinking of inter current disease not directly related to the accident. (I suppose that anything that happens to the health of these men in the next few months will be attributed by some to the exposure.) Similarly, Employee No. 17 cardiovascular status needs watching.

In the Y-12 accident in Oak Ridge we found it difficult to keep all clinical and laboratory data organized -- especially special research findings which were not always reported promptly, if at all. We found it best to try to keep all available data on the charts of the individual patients.

I note that care has been taken to record permission of patients for release of data. This should be continued and it would be worth while to have this in written form, for either newspaper or scientific news releases.

G. A. Andrews, M. D.
Acting Medical Director
Oak Ridge Institute of Nuclear Studies
Oak Ridge, Tennessee

* * * * * *

I appreciate very much the opportunity of examining Employee No. 1, Employee No. 17 and Employee No. 23 and the laboratory records in these cases. In my opinion there is at present no gross evidence of physical injury from the radiation exposure. The laboratory findings are compatible with a dose of ionizing radiation far below what could be considered serious to these men. The dosage estimates seem to me to fit the minor changes observable in the total lymphoid count, the early slight leukocytosis, the chromosomal and nuclear cytologic changes in the bone marrow and the absence of other laboratory and clinical signs. I would not anticipate any true morbidity in these cases. I believe, however, that because of the present inadequacy of our basic knowledge of the damage caused by such radiation exposure that these men should continue to be followed closely clinically and by objective laboratory observations on blood morphology, blood chemistry, bone marrow, and testicular biopsy and sperm counts if possible. These observations would help correct any unforeseen abnormality that might develop.

I have talked at length with Dr. P. A. Fuqua and his staff concerning their plans for these continuing studies and am quite impressed by their thoroughness and scope. Thank you again for asking me to see these cases.

C. C. Lushbaugh, M. D.
Pathologist
Los Alamos Scientific Laboratory &
University of California
Los Alamos, New Mexico

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RICHLAND, WASHINGTON . . . TELEPHONE WHitehall 2-1111

HANFORD ATOMIC PRODUCTS OPERATION

RELATIONS OPERATION

April 30, 1962

U. S. Atomic Energy Commission
Hanford Operations Office
Richland, Washington

Attention: Mr. Carl N. Zangar

Gentlemen:

The following supplemental information is submitted at your request concerning clinical and laboratory data on HAPO criticality cases April 7, 1962:

Blood Counts

	Hgb	PCV	RBC	WBC	Platelets R-E	Platelets Phase	Abs. Lymph	Abs. Neut.	Retic.
Employee No. 1									
4-7 (3 P.M.)	14.1	42	4.46	16,100	352		1,770	14,200	
4-7 (9 P.M.)				13,200			3,550	9,050	
4-8	13.7	41	3.67	8,620	328	332	1,980	6,200	0.7
4-9	13.6	41	4.18	9,480	265	280	2,560	6,540	1.1
4-10	14.2	43	5.36	17,670	290	210	2,830	14,100	1.1
4-11	13.5	43	4.58	8,100	245	215	2,270	5,510	0.4
4-13	13.0	41	4.41	8,450	217	205	1,940	6,080	0.5
4-15	13.7	44	4.38	8,900	216	219	2,400	6,140	0.8
4-17	13.4	41	4.41	12,800	210	205	4,610	7,810	
4-20	13.5	41	4.10	9,780	251	251	2,840	7,340	1.1
4-23	13.8	43	4.45	9,360	220	224	2,620	6,460	1.0
4-25	14.1	45	4.50	11,450	218	214	3,090	8,020	1.4
Employee No. 17									
4-7 (3 P.M.)	14.3	43	5.03	10,300	198		2,790	7,100	
4-7 (9 P.M.)				6,800			1,740	4,400	
4-8	14.7	49		6,830			2,190	3,960	0.8
4-9	15.9	48	5.68	5,620	203	187	1,570	3,650	1.4
4-10	16.4	50	6.97	5,940	237	200	1,840	3,500	0.9
4-11	16	49	5.60	7,570	200	217	1,890	5,000	1.0
4-13	15.9	50	5.10	8,700	198	200	2,700	5,220	0.9
4-15	15.9	49	5.29	10,270	220	219	2,460	7,090	0.8
4-17	15.0	48	5.21	8,750	194	202	2,190	5,950	
4-20	15.7	47	5.08	8,530	202	202	2,130	5,460	1.0
4-23	15.3	47	4.97	6,550	196	197	1,640	4,320	0.9
4-25	15.2	46	5.18	7,190	210	200	1,440	5,250	1.2

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U. S. Atomic Energy Commission -2- April 30, 1962

Blood Counts

Employee No. 23	Hgb	PCV	RBC	WBC	Platelets R-E	Platelets Phase	Abs. Lymph	Abs. Neut.	Retic.
4-7 (3 P.M.)	15.4	47	4.98	10,800	207		1,620	8,320	
4-7 (9 P.M.)				12,040			2,680	8,520	
4-8	15.3	49	5.08	7,950	291	224	3,260	3,290	0.8
4-9	16.0	50	4.74	7,730	300	248	2,470	5,020	0.8
4-10	17.5	50	7.2	12,950	230	188	4,400	7,900	1.8
4-11	16	49	5.04	10,300	211	198	1,960	8,140	1.4
4-13	15.9	50	5.1	9,190	197	205	2,300	6,430	1.0
4-15	15.7	50	5.54	7,800	232	224	2,650	4,680	0.9
4-17	15.4	49	4.99	9,790	197	192	3,620	5,480	
4-20	16.6	53	5.64	9,910	192	199	3,570	5,550	1.0
4-23	16.7	51	5.21	9,060	211	218	3,170	5,530	1.1
4-25	16.8	52	5.53	9,060	220	208	2,810	5,800	2.7

Laboratory Data

	Normal	Employee No. 1	Employee No. 17	Employee No. 23
Chloride	98-106	102	101	105
Na	136-145	138	140	140
K	3.5-5.0	4.5	4.2	4.6
BUN	10-20	14	17	10
Protein	6-8	7.3	7.0	8.1
Glucose (4-11)	65-90	89	100	89
(4-10)		88	94	110
Calcium	8.5-10.5	12	11	8
Phosphorus	2.4-4.5	3.8	4.0	3.3
Alkaline Phosphates	1.5-4.0 Bodansky units	4	1.6	2.4
SGOT	8-40	20	20	18
SGPT	5-35	21	18	12
Ceph. floc. 24 hrs.	0-2+	trace	trace	2+
. 48 hrs.	0-2+	trace	trace	3+
Prothrombin time		100%	100%	100%
Amylase	60-160	56	61	56
Uric acid	3.0-6.0	3.8	4.6	4.5
Thymol turbidity	Below 4 units	1.8	3.0	3.2
Bilirubin, direct	0-0.4	0.2	0.1	0.2
, total	0.25-1.0	0.4	0.4	0.4
Creatinine	0.5-1.0	0.55	0.85	0.9
Sed. rate (corr.)	0-10	5	11	9
Cholesterol	135-315	250	298	279

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Laboratory Data (Cont'd)

	Normal	Employee No. 1	Employee No. 17	Employee No. 23
Urinalysis				
Glucose	0	0	0	0
Albumin	0	0	0	0
Sp. Gr.	1.005-1.022	1.004	1.010	1.016
Ph	5.5 - 8.0	8.0	5.0	7.0
WBC	0	rare	rare	occ
		Cal. Phos. crystals Slight amorphous Few bacteria	Epith, few Few bacteria	Epith, occ Few bacteria

Employee No. 1

	% of Total	Grams % of total
Total Protein	-	8.4 normal
Albumin	59.6	5.0 normal
Alpha 1	4.9	0.4 normal
Alpha 2	10.1	0.9 normal
Beta	10.7	0.9 normal
Gamma	14.7	1.2 normal
A/G Ratio	1.48	normal (Bio-Science Lab)

Employee No. 17

	% of Total	Grams % of total
Total Protein	-	8.4 normal
Albumin	64.1	5.4 normal
Alpha 1	3.0	0.3 normal
Alpha 2	8.2	0.7 normal
Beta	11.2	0.9 normal
Gamma	13.5	1.1 normal
A/G Ratio	1.78	normal (Bio-Science Lab)

Employee No. 23

	% of Total	Grams % of total
Total Protein	-	9.3 elevated
Albumin	64.6	6.0 elevated
Alpha 1	3.2	0.3 normal
Alpha 2	8.9	0.8 normal
Beta	10.5	1.0 normal
A/G Ratio	1.83	normal (Bio-Science Lab)

[redacted]

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GENERAL ELECTRIC

U. S. Atomic Energy Commission April 30, 1962

Sternum aspiration bone marrow biopsies - 4-8-62, 4-14-62, 4-23-62.
Preliminary reports negative all cases.

Peripheral blood tissue culture.
Chromosome aberration studies.
No report.

Testicular biopsy, histology, tissue culture.
Chromosome aberration studies.
No report.

Sperm counts.
Preliminary report 4-11-62. Within normal limits on Empl. No. 1 and Empl. No. 23.
Not done on Employee No. 17.

Urine estrogens and gonadatropins.
No report.
Urine assays for trace amounts of radioactive isotopes.
No report.

Slit lamp examination of lens -- all cases - 4-17-62, 4-23-62.
Preliminary reports negative.

BAIBA (Beta aminoisobutyric acid) studies.
No report.

Very truly yours,

P. A. Fuqua, M. D., Manager
Occupational Medical Operation

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RICHLAND, WASHINGTON . . . TELEPHONE WHitehall 2-1111

HANFORD ATOMIC

PRODUCTS OPERATION

RELATIONS OPERATION

July 2, 1962

U. S. Atomic Energy Commission
Hanford Operations Office
Richland, Washington

Attention: Mr. Carl N. Zangar (For I. C.)

Gentlemen:

CRITICALITY CASES
MEDICAL PROGRESS REPORT

Employee 1 (110 rem ± 14). Has complained of fatigue mild and intermittent described by employee as "no gas" or "no get up and go". May or may not be directly related to exposure. Sperm count has dropped from 199 million to 45 million.

Employee 17 (43 rem ± 14). Some mild complaints referable to fatigue. The relationship to exposure is questionable.

Employee 23 (19 rem ± 6.7) Testicular biopsy site did not primarily heal as in the other cases. Surgical excision of indurated area resulted in post-operative hemorrhage into scrotal tissues requiring hospitalization. As of 6-30-62 secondary healing of biopsy site was almost complete and there was little interference with his usual activities.

LAB STUDIES

Analysis of leukocyte chromosome aberrations in all cases are considered extremely valuable as they appear to provide the only direct quantitative measurements we have of the sensitivity of human chromosomes to ionizing radiation. A complete summary of these studies will be included in the final medical report.

Sternum aspiration bone marrow biopsies have not revealed significant findings. Dr. Andrews of the ORINS is presently further studying this material.

Peripheral blood counts have not revealed significant changes but are in process of further statistical analysis.

[redacted]

[redacted]

GENERAL ELECTRIC

No report has been received on bi-lobed lymphocyte study or on BAIBA (Beta aminoisobuteric acid) studies. Urine estrogens and gonadatropins have been reported within normal limits in all cases.

Very truly yours,

P. A. Fuqua, M. D., Manager
Occupational Medical Operation

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APPENDIX 8

PHYSICAL ANALYSIS OF THE EXCURSION

Reconstruction of the Power History of the Excursion

No complete record of the power level history of the excursion has been discovered. The best available information comes from recordings of two BF_3 counters located in a waste incinerator building at a distance of about 350 feet from the K-9 tank. A portion of this chart is shown in Exhibit 8-A. The less sensitive of the two counters remained off scale for a period of about 28 minutes following the initiation of the excursion. Prior to going off scale, the recorder which prints a data point every 30 seconds recorded three on-scale points which are suggestive that the initial excursion consisted of a pulse, following which the power dropped to a very low level before it again rose and carried the recorder off scale. Following the return of the recorder on scale 28 minutes later, the power level dropped exponentially with a period of about 18 minutes until approximately noon on April 7 (Exhibit 8-B). Some pulse-type variations were superimposed upon the general exponential decay.

The excursion then continued for a period of about 36 hours. The later portion of the recorder trace can be matched to neutron flux measurements taken initially outside of the entrance to the 234-5 Building at a location designated as checkpoint 3 and later to neutron flux measurements obtained with a moderated BF_3 counter placed in corridor 2 of the building adjacent to Room 221. The neutron flux dropped rapidly after 10 P.M. on April 8 and reached background levels by midnight of April 9. Subsequent analysis of the decline of neutron level suggests that the material in the tank went subcritical at about midnight of April 8 and that the neutron flux levels after this time were the result of subcritical multiplication of the naturally occurring source neutrons in the plutonium solution.

Samples subsequently obtained of the material in the K-9 tank were analyzed to obtain a measure of the total fissions which occurred during the course of the excursion. In this reconstruction we have used the values obtained from Ru^{103} and $Zr\text{-}Nb^{95}$, rejecting the value from Ba^{140} because of possible losses of one of the precursors, Xe^{140}, from the reacting solution. In this way a value of 8.2×10^{17} fissions was obtained for the total excursion corresponding to an energy release of 2.7×10^{7} joules or 6.4×10^{6} gram calories. This figure was used to calibrate the recorder chart, including the missing portion reconstructed by the exponential extrapolation to the time of initiation of the excursion. This extrapolation is believed to be a fair representation of the average power during this early period although the actual power was undergoing wide oscillations about this mean value. It should also be noted that the reconstructed portion represents only 20% of the total energy release and that the uncertainties here contribute correspondingly small uncertainties to the chart calibration.

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[redacted]

The reconstructed power history is shown in Exhibit 8-C.

One additional piece of evidence indicates that this calibration is reasonably correct. A collection of threshold foil detectors (Hurst dosimeter) was located about 26 feet from the K-9 tank in the same room, and these foils were retrieved at 12:35 P.M. on April 7. Analysis of the foil activations to determine the number of fissions occurring up until the time of foil removal is subject to considerable uncertainty. There are indications that a significant number of neutrons, especially of lower energies, were scattered to the dosimeter by other tanks and structures in the room so that the fluxes do not decrease with the inverse square of the distance. An estimate of the number of fissions based on this law is therefore higher than the correct value. Such an estimate gives 4.1×10^{17} fissions up until 12:35 P.M. whereas the value calculated from the curve calibration process is 3.5×10^{17}. In view of the uncertainties, this is regarded as reasonable agreement.

One further piece of information has been used in reconstructing the incident. The neutron dose to employee #1 indicates that 8×10^{15} fissions occurred before he left the room. The average initial fission rate of 2×10^{16} fissions/minute implied by the reconstruction presented here is not inconsistent with this magnitude of exposure. This rather low initial fission rate will be used again below to throw some light on possible mechanisms for initiating the excursion.

Estimates of Criticality

A) Value Derived from In Situ Neutron Multiplication Measurements

Critical Mass Physics personnel set up three complete neutron monitoring channels in the 234-5 Building. The electronics and associated recorders were located in Corridor 912 near the entrance to Corridor 3.

The Robot Monitor positioned the first two counters on the floor behind the SE hood at about 8 feet from vessel K-9 (the criticality vessel) on April 13. These counters were perhaps the only units in the area sensitive enough, and at the same time strategically located, to obtain any useful information on vessel K-9 while in the subcritical state.

These two units were the constituent elements of channels No. 1 and No. 3 from the safety circuits at the Critical Mass Laboratory. These are low level startup channels for use in the critical experiments with plutonium nitrate solutions. One detector was a fission chamber, and the other a neutron sensitive scintillation crystal (sensitive to both neutrons and gamma rays). The detectors were mounted in paraffin moderators similarly as used in criticality experiments at the Critical Mass Laboratory.

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As used in criticality experiments, the fission chamber was normally positioned about one foot from the surface of the vessel; the scintillation detector, being more sensitive, was positioned about 15 to 18 feet from the vessel. Thus, the fission chamber was $\sim$7 feet farther away while the scintillation counter was actually about 7 to 10 feet closer in comparison to K-9.

During the draining of vessel K-9, it was possible to obtain an estimate of the critical volume from the change in neutron flux, i.e., from the inverse multiplication curve. Since the draining process was not continuous, but somewhat intermittent, it was difficult to obtain an accurate correlation of the observed flux values with solution volume in K-9. Also, there was some question concerning the holdup in the line from K-9 to the receiver vessel.

During the draining process, weight measurements were made of the solution in the receiver vessel. From these measurements, and a correlation in time with the flux measurements, it was possible to associate the proper flux values with solution volume remaining in vessel K-9 (subject to the line holdup uncertainty).

From the neutron flux measurements during the draining process, the critical volume in K-9 is estimated to be $\sim$ 44 ± 1 liters. The inverse multiplication curve is shown in Exhibit 8-D. This would then be the critical volume for solution of the same composition as existed in vessel K-9 at the time of draining--for a solution containing $\sim$35 g Pu/ℓ and $\sim$ 2M nitrate.

For this solution the critical mass in K-9 would be $\sim$ 1.54 Kg Pu--or the vessel contained $\sim$ 90% of the critical mass.

Since the total amount of plutonium in solution in K-9 (39 liters at $\sim$35 g Pu/ℓ) was $\sim$1.36 Kg, the vessel was obviously critical at a lesser concentration. It could also have been critical with 1.36 Kg of Pu at 35 g Pu/ℓ if reflected by a solution on top of the plutonium rich solution--such as might be brought about by phase separation between an organic and aqueous solution.

B) <u>Calculated Values of Criticality From Multi-Group Diffusion Theory</u>

The calculated values for criticality in K-9 were determined from the 9-Zoom and the HFN codes. The critical radii of bare spheres were calculated for $Pu(NO_3)_4$ solutions with nitric acid molarities of one and two in order to cover possible cases of interest; the acid molarity of the solution in K-9 was $\sim$ 2.0 and the total nitrate concentration was $\sim$120 g NO_3/ℓ. The effect of Pu^{240} was also accounted for in these calculations.

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The critical radii of the bare spheres were used to obtain buckling values as a function of the solution concentration. These values were then in turn used to compute the critical solution height as a function of Pu concentration in vessel K-9, through use of the following relationship:

$$\text{Material Buckling} = \frac{(2.4048)^2}{(R_c + \lambda_r)^2} + \frac{\pi^2}{(h_c + \lambda_o + \lambda_b)^2}$$

with

$R_c = 22.07$ cm

$\lambda_r = 3.0$ cm

$\lambda_o = 2.2$ cm

$\lambda_b = 3.0$ cm

The extrapolation length was assumed to be 2.2 cm + the thickness of the vessel wall (0.8 cm). The results of the constant buckling conversions are shown graphically in Exhibits 8-E.

Estimates of criticality were also made on the basis of an aqueous reflector on top of the plutonium solution (for this case $\lambda_o = 6$ cm). The 6 cm value would be obtained for a solution reflector of 3-4 inches thickness.

With the system unreflected on top and for a Pu concentration of 35 g/ℓ with one molar nitric solution, the critical volume is calculated as $\sim$ 44 liters. This value is in agreement with the measured value.

Although the calculated critical volume ($\sim$ 45 liters) agrees with the measured volume there are some apparent discrepancies elsewhere. The minimum critical mass is calculated at 1.38 kg with one molar nitric acid and 1.48 kg at two molar, which is larger than the 1.36 kg found in solution. However, about 60 gms were found as solids on the bottom of the tank and about 100 gms in a pipeline leading to the bottom of the tank. Some of this additional material may have been suspended in the solution at the time of criticality. The calculated critical volume (for minimum mass) would be $\sim$ 55 liters of solution. The solution was slightly on the over concentrated side of the minimum in the mass curve at the beginning of criticality, if the concentration were uniform.

Because of the uncertainty in the amount of plutonium, further attempts to obtain better agreement between the computed and measured value would not produce significant results.

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On the basis of the calculations the system would have been delayed critical at a volume of ~ 50 liters with a Pu concentration of less than 30 g Pu/ℓ, and supercritical throughout the volume range to ~55 liters.

The calculations with a top reflector (layer of solution 3-4 inches in thickness) indicate that criticality could be obtained with a volume of 39 liters for the concentration of 35 g Pu/ℓ. In other words, the solution in the vessel at the time of draining could have been made critical by adding a hydrogenous reflector to the top of the solution as it existed.

Although these calculations are subject to some uncertainties it is clear that the amount of plutonium in K-9 was only slightly in excess of the minimum needed to achieve criticality and that the excess reactivity was not large at any time. The size of the initial pulse is also in agreement with this conclusion.

Analysis of Initial Pulse

The small size of the initial pulse ($\approx 10^{16}$ fissions) as indicated by the neutron doses to personnel nearby was an unusual feature of the excursion. In an effort to explore possible mechanisms for initiating the excursion, calculations were made of the burst size to be expected if solution were added to the vessel at a uniform rate. Fissions up to the peak of the burst and up to 10 seconds beyond the peak were calculated as a function of rate of addition. It was expected that these two values would allow assessment of the exposure of hypothetical personnel who left the scene promptly.

An addition rate of 1 cc/sec would produce a burst having 3×10^{16} fissions up to 10 seconds after its peak. Cutting the addition rate to 0.1 cc/sec would reduce the burst size by only a factor of the order of two. At 1 cc/sec, addition of 50 liters to the tank would require 14 hours; at 0.1 cc/sec, 140 hours would be needed, a quite improbable course of events. The final addition of reactivity must have been at a much lower rate than that at which the bulk of the plutonium was added to the tank. A plausible course of events would be the addition of $\approx$ 1450 grams of Pu at a concentration greater than 30 gm/liter. This material occupies less than the critical volume and would remain subcritical. Subsequent addition of dilute nitric acid would lead to criticality. Increase of reactivity would not be especially rapid and the total amount available would be limited to a fixed amount by the plutonium present. A low concentration of plutonium in the added liquid would not materially change this situation. Such a course of events could lead to a small and slowly developing pulse, allowing nearby personnel to escape after being exposed to only $\approx 10^{16}$ fissions. The course of events described in Section VI fits this pattern.

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Analysis of the Continuing Reaction

It is likely that repeated pulses were generated after the first. Each pulse was terminated by gas bubble formation due primarily to radiolytic decomposition of the liquid. The temperature of the solution rose through absorption of the bulk of the energy released and after about 20 minutes of operation reached the boiling point ($\approx 60^{\circ}C$ under the vacuum in the tank). The reactivity absorbed by voids in the tank and the temperature rise of the solution matched the excess reactivity available. As boiling proceeded to reduce the solution volume the excess reactivity declined forcing a decline in voids and consequently a drop in power. Such a decline would be expected to be exponential and it was this phase of the excursion that was observed as the neutron chart recorders came back on scale. The volume at the beginning of this process was 50 to 55 liters and volume reduction appears to have produced a reactivity decline through most of this period. That is, the solution concentration was most probably greater than that corresponding to minimum critical mass throughout the entire period.

After boiling off two or three liters the declining reactivity could no longer support voids and bulk boiling ceased. This occurred about noon. After the stop of boiling, evaporative cooling and heat losses to the environment reduced the temperature of the solution supplying a slight excess of reactivity which allowed the power to rise again and go through a transient oscillation before settling down to a new quasi-equilibrium in which the remaining excess reactivity was balanced by the temperature coefficient of reactivity and where the non-boiling evaporation rate was determined by the solution temperature. This produced the long slow decline in power extending over some 30 hours. At the end of this period the temperature approached that of the environment and no further reactivity gains through cooling were possible to balance the continuing losses through evaporation and the system went subcritical. During this phase several liters were evaporated. Evaporation continued until the vacuum on the tank was shut off 142 hours later. During this time some 10 additional liters were evaporated leaving the tank in the condition in which it was found when inspection became possible.

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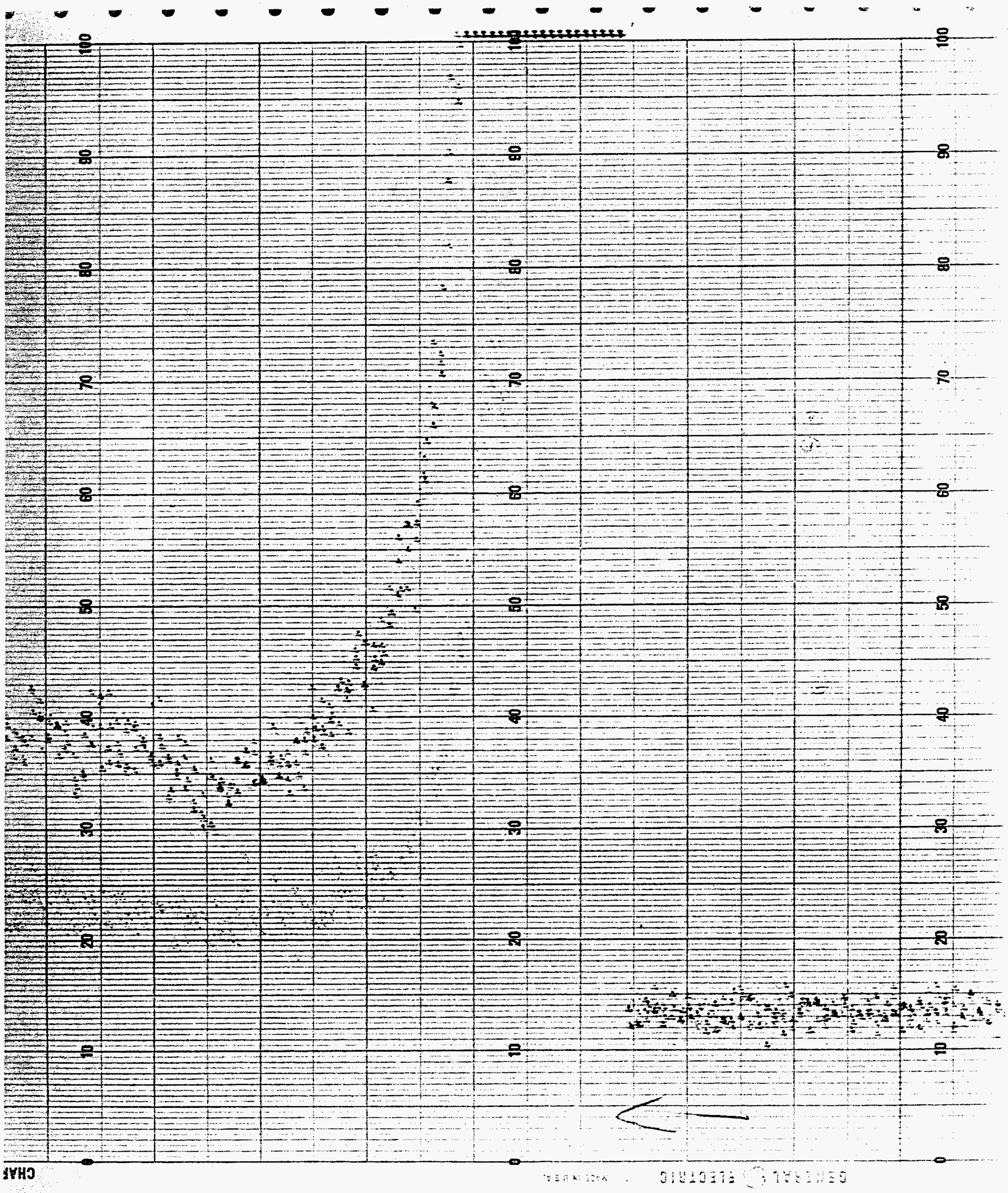

EXHIBIT 8-A (1)

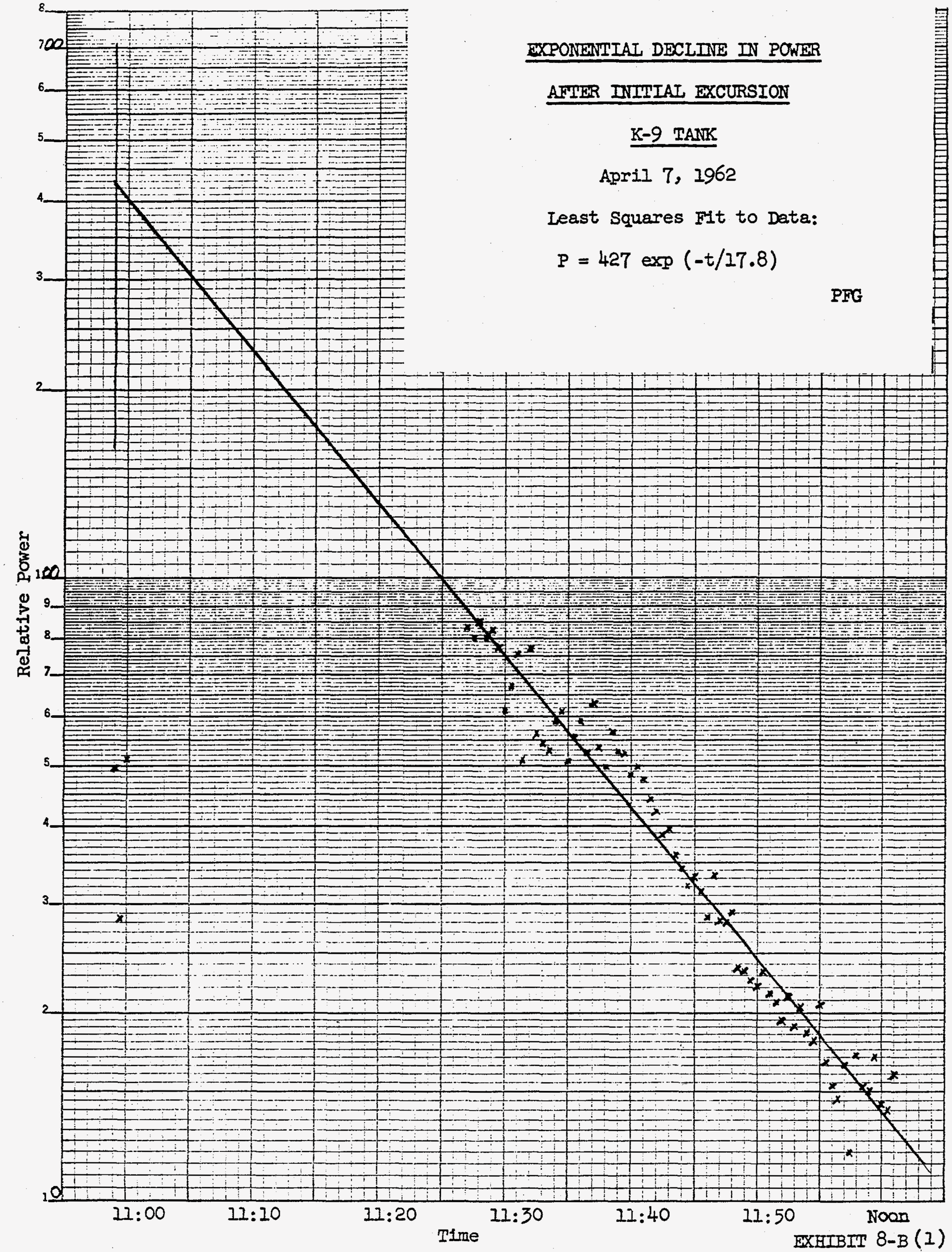
EXPONENTIAL DECLINE IN POWER
AFTER INITIAL EXCURSION
K-9 TANK
April 7, 1962
Least Squares Fit to Data:
P = 427 exp (-t/17.8)
PFG
Relative Power
Time
11:00
11:10
11:20
11:30
11:40
11:50
Noon

EXHIBIT 8-B (1)

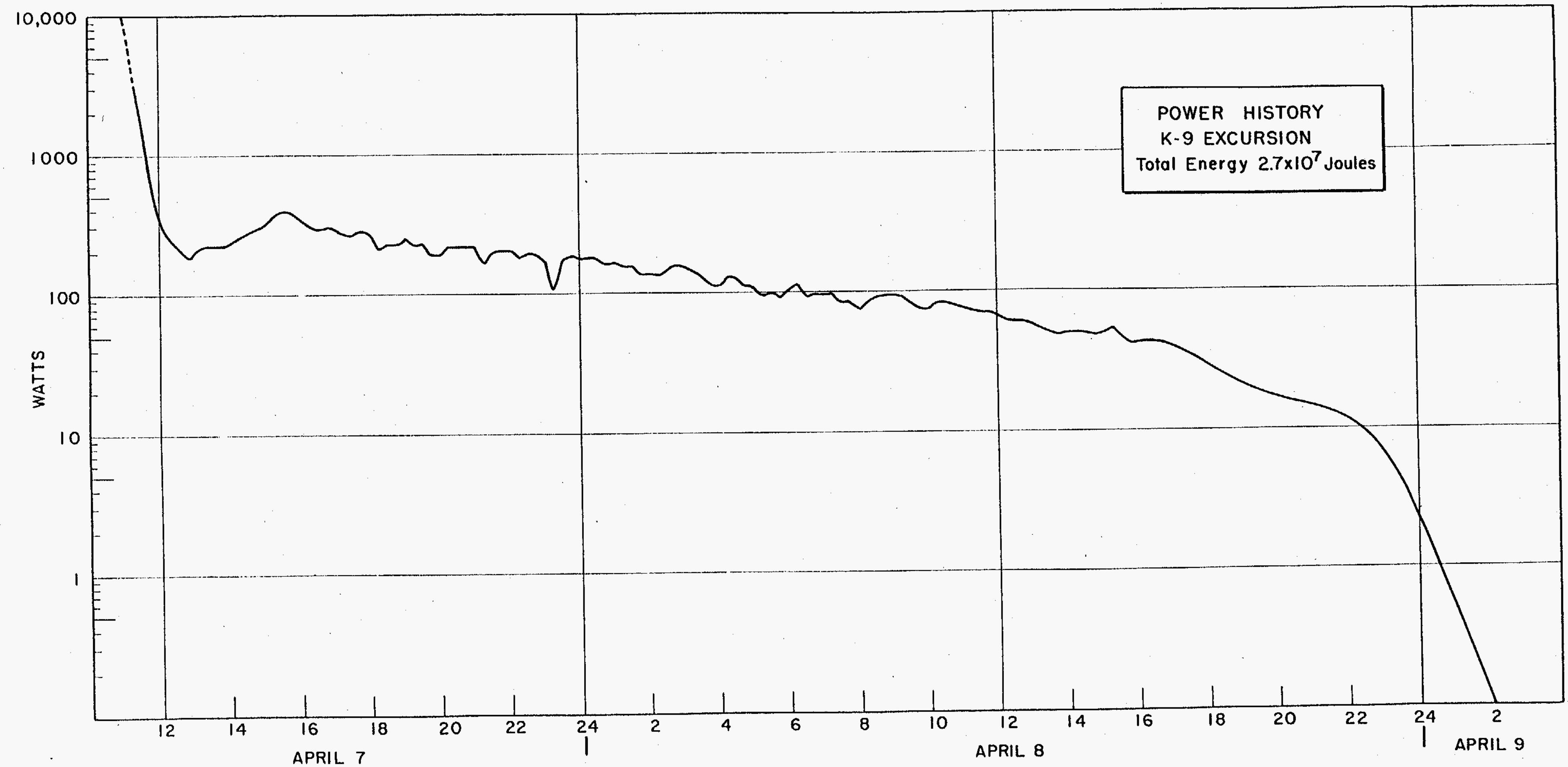
POWER HISTORY
K-9 EXCURSION
Total Energy 2.7x10^7 Joules
10,000
1000
100
10
1
WATTS
12
14
16
18
20
22
24
2
4
6
8
10
12
14
16
18
20
22
24
2
APRIL 7
APRIL 8
APRIL 9

EXHIBIT 8-C (1)

[redacted]

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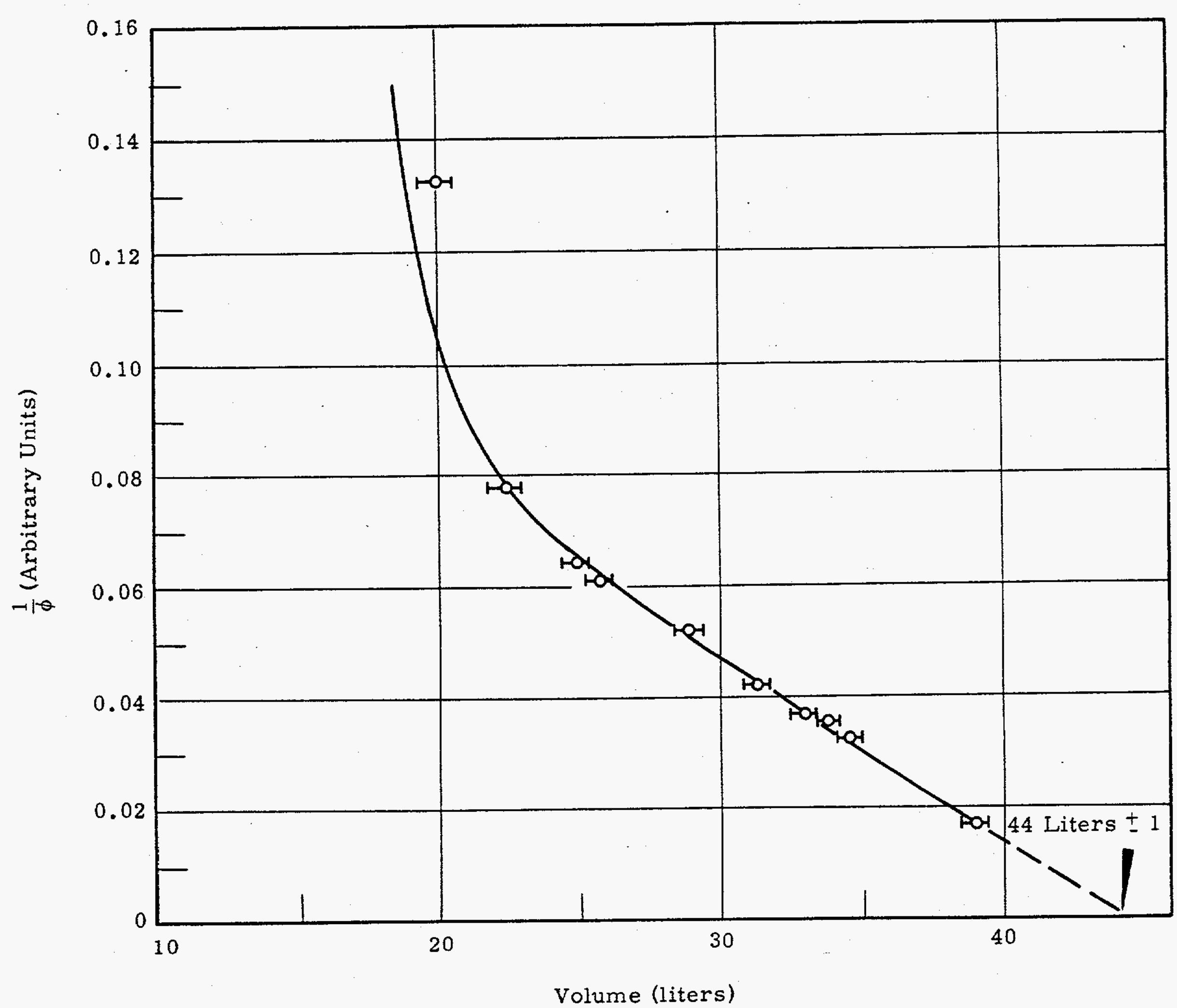

Estimate of Criticality in Vessel K-9
(35 grams Pu/liter, 120 grams NO_3/liter)

Exhibit 8-D

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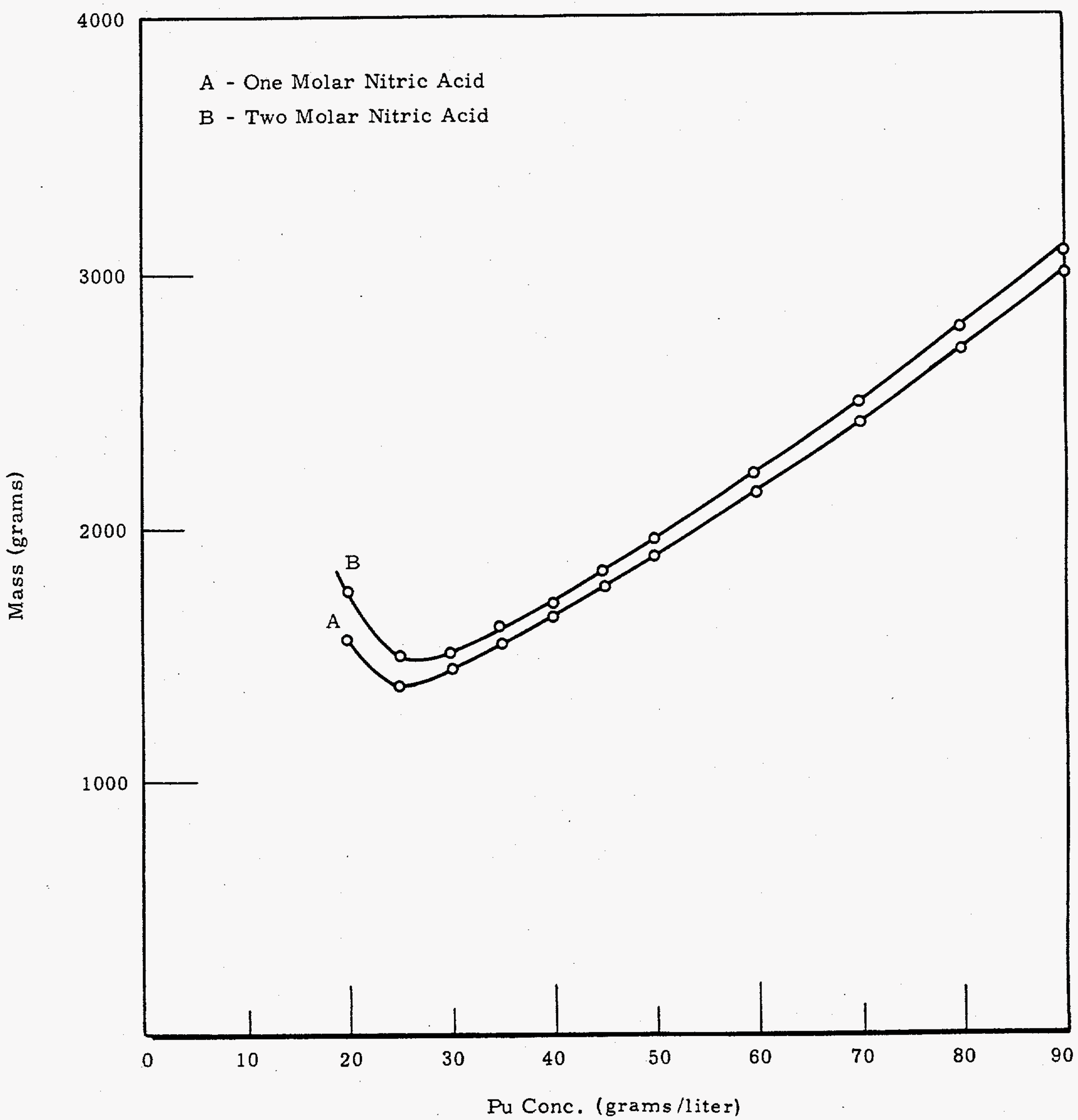

FIGURE 8-E-(1)

Calculated Critical Mass vs. Pu Concentration in Vessel K-9

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APPENDIX 9

PERSONS INTERVIEWED OR SUBMITTING REPORTS

The record shows that the following persons have been interviewed at least once each:

Recuplex Operator on duty at time of accident (Employee No. 1), GE

Supervisor in Recuplex on duty at time of accident (Employee No. 17), GE

Utility Operator on duty at time of accident (Employee No. 23), GE

Supervisor in Recuplex on duty during shift prior to accident, GE

Supervisor in Recuplex on duty during last shift of day prior to accident, GE

Operator in Recuplex on duty during last shift of day prior to accident, GE

Relief Operator in Recuplex on duty during accident (Employee No. 18), GE

Recuplex Operator working days, following maintenance activities, GE (not present at time of accident)

Engineer, Finished Product Chemical Technology Operation, GE (The senior technical person close to the process)

Engineer, Finished Product Chemical Technology Operation, GE (A less experienced technical person close to the process)

Control Laboratory Supervisor (not on duty at time of accident), GE

Manager, Facilities Engineering Operation, CPD, GE

Engineer, Facilities Engineering Operation, CPD, GE

Engineer, Facilities Engineering Operation, CPD, GE

Manager, Finished Products Operation (FPO) CPD, GE

Manager, Production Operation, CPD, GE
(Served as Field Director during emergency)

Manager, Processing, FPO, CPD, GE

Supervisor, Processing (Recovery) FPO, CPD, GE

Specialist, Planning and Scheduling (Maintenance) FPO, CPD, GE

Manager, Finished Products Chemical Technology, CPD, GE

[redacted]

[redacted]

Supervisor, Radiation Monitoring, FPO, CPD, GE

Radiation Monitor, FPO, CPD, GE

Manager, Research and Engineering, CPD, GE

Chemist, FPO, CPD, GE

General Manager, CPD, GE

Written reports have been received from:

Manager, Hanford Operations Office, AEC

Assistant Manager for Technical Operations, HOO-AEC

Engineer, Radiations Sciences Branch, HOO-AEC

Director, Information Division, HOO-AEC

Chief, Communications, Shipment & Disaster Planning, HOO-AEC

Safety Engineer, HOO-AEC

Security Inspector, HOO-AEC

General Manager, HAPO, GE

General Manager, CPD, GE

Manager, Finished Products Operation, CPD, GE

Manager, Production, CPD, GE

Manager, Relations, GE

Captain, Security Patrol, GE

Manager, Radiation Protection Operation, HLO, GE

Manager, Occupational Medicine Operation, GE

200-W Radio Operator, GE

Manager, Finished Products, Chemical Technology, CPD, GE

Director, Production Division, HOO-AEC

Deputy Director, Production Division, HOO-AEC

Manager, Finished Products, Control Operation, CPD, GE

Manager, Facilities Engineering Operation, CPD, GE

Supervisor, Processing (Recovery), CPD, GE

Manager, Research and Engineering, CPD, GE

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APPENDIX 10

GLOSSARY

(Including Recuplex Vernacular Terms)

B-PID	Book - Physical Inventory Difference.
CAP	An aqueous layer on top of organic solution.
CCl_4	Carbon tetrachloride, the solvent which is the principal component of organic solutions in Recuplex.
CONTACT ORGANIC	A CCl_4 solution of a strong extractant. The extractant being Tributyl phosphate - Dibutyl-phosphate, or Dibutyl--butylphosphonate, or a combination of both used to remove plutonium from aqueous waste solutions in tanks L-2, L-3, L-8.
CPD	Chemical Processing Department
CRIB	Open-work box buried in the ground from which liquid waste can percolate into the soil.
DBBP	Dibutyl--butylphosphonate
DBP	Dibutyl phosphate
DEMISTER	A trap in the vacuum line.
DUCT LEVEL	The floor above Recuplex where air ducts are located.
E_a^o	Distribution coefficient. An equilibrium number expressing in ratio form the concentration of Pu in the organic phase to the concentration in the aqueous phase.
FAB OIL	A machining lubricant of lard oil and carbon tetrachloride originating in the fabrication operations.
FPCTO	Finished Products Chemical Technology Operation
FPO	Finished Products Operation
FS	A mixture of ferrous ammonium sulfate, sulfamic acid, and nitric acid, often referred to as a ferrous sulfamate solution.
GEOMETRICALLY FAVORABLE VESSEL	A geometry-controlled vessel which is critically safe for solutions up to 450 grams plutonium per liter and up to at least 5500 grams plutonium total.

[redacted]

GEOMETRICALLY UNFAVORABLY VESSEL	A vessel of geometric design which may permit nuclear excursions except for operational controls such as batch size limits, solution concentration limits, nuclear poisoning, etc.
HAPO	Hanford Atomic Products Operation of General Electric Company
HF	Hydrofluoric acid solution
HLO	Hanford Laboratories Operation
HOO	Hanford Operations Office of the AEC
MEZZANINE	A gallery level (about ten feet above floor level) for convenient access to the upper levels of equipment.
MISTRON	A trade name for a magnesium silicate used as a de-emulsification agent.
ORGANIC	TPB in carbon tetrachloride
POPPY	An instrument used to detect alpha contamination. Alpha radiation causes the poppy to emit static-like sounds.
PRO	Plutonium Recovery Operation
R&E	Research and Engineering of CPD
R&B HOOD	A large glove box containing reception and blending tanks.
RECUPLEX	A multi-purpose recovery facility located in Room 221, 234-5 Building. A name derived from the words "recovery", "couple" (to connect with products of other facilities), and "extract" (solvent extraction).
S&C	Slag and crucible
SE HOOD	The large glove box containing the solvent extraction columns and other Recuplex equipment.
SKULL	Residual metal, metallic oxide, slag, etc., left in the crucible after the molten metal has been poured.
SLUDGE	Wet solids which settle and accumulate in the bottom of a vessel.
SP. G.	Specific gravity

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SUCK LEG	A dip tube used to withdraw the top layer of liquid from a vessel. These exist in tanks K-1, K-2, K-9, for example.
SUMP	The trough in the bottom of the SE hood is sometimes referred to as the hood sump. A sump such as D-6 is a large catch tank for low-level waste solution. If analyses show normal low plutonium content, the solution is discarded to the Z-9 crib.
TBP	Tributyl phosphate
WEIGHT FACTOR	A measure of the hydrostatic pressure in a dip tube used to indicate the liquid level in a vessel. It is used with the vessel calibration and Sp. G. values to determine the liquid volume.

[redacted]

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APPENDIX 11

COST

The cost of the incident as booked through June 30, 1962, is $891,000.00. These costs, shown in Exhibit 11-A, include (a) expenditures unique to the incident problems, and (b) all regular costs associated with the 200 West Area servicing and production facilities for the period each plant or process line was vacated.

It is not expected that additional costs will be charged to this incident with the possible exception of a contingent liability of $66,000.00 which existed on June 30, 1962, for the salaries of men placed on furlough as a result of the incident. The General Electric Company and the labor union are presently discussing this issue.

The expenditures "unique to the incident problems" are too numerous to list independently; however a tabulation of the major work orders for special services is presented in Exhibit 11-B. Regular operating costs incurred for processing, technical, maintenance, power, bus services, etc. plus overheads were accumulated and charged to the incident for the period each particular process facility was vacated. The depreciation expense was treated in a similar manner. All costs were included in the production inventory accounts for pricing plutonium.

Costs recorded here do not take into consideration potential expenditures which may be directly related or perhaps relative to the incident. For example, additional handling and storage costs applicable to plutonium scrap generated that can not be recovered until completion of the new Recovery Facility (Project 880) or the additional incremental expenditures incurred while handling plutonium that will be returned to the primary plants for recovery. Also, costs applicable to the "Button Line Filtrate Handling Facility" (Project 978) or the increased emphasis for technical analysis of all Hanford operating facets.

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RECUPLEX OPERATION RADIATION INCIDENT
Costs Through June 30, 1962

	Directly to Incident	Finished Products Operation: Buttons	Shapes	Recuplex	UO_3	Other	Power & General Maintenance	General & Production Operation	Redox	Purex	Total
Salaries											
Salaries		9,836	24,902	28,010	2,627	68,676	4,008	3,888	24,433		166,380
Employee Benefits		836	2,116	2,380	223	5,834	271	330	2,076		14,066
Other Direct Cost											
Travel & Living								406			406
Shop & Office Supplies	5,588							38			5,626
Electricity						2,423			866		3,289
B & O Tax								2,142			2,142
Miscellaneous Incident Costs	19,857							264			20,121
Other Indirect Cost											
Maintenance Services	65,600						120,468	2,993	582	5,809	195,452
Engineering & Technical	116,462							1,032			117,494
Laundry & Utilities	856			28	1,921	6,644	1,981		6,260		17,690
Patrol	2,500										2,500
Telephone	532										532
Inspection								1,105			1,105
Bus & Vehicle Services	154	402	773	632	116	2,569		137	1,638		6,421
Miscellaneous	5,234	28	43	18	15	277		110	179		5,904
Recovery				10,000							10,000
TOTAL	216,783	11,102	27,834	41,068	4,902	86,423	126,728	12,445	36,034	5,809	569,128
Overhead											190,000
Total Operation Costs											759,128
Depreciation Expense[a)]		37,000	36,000		12,000				47,000		132,000
TOTAL COST											891,128

a) Represents a final allocation of depreciation expense accumulated from all sources including Recuplex and other supporting facilities.

[redacted]

AEC-GE RICHLAND, WASH.

Exhibit 11-A (1)

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RECUPLEX INCIDENT COSTS - FY-1962
WORK ORDER SERVICES

Work Order	Description	Cost to Date	Estimate
A-44201	Fabricate and erect mock-up of Recuplex area	$ 8,306	$ 16,500
B-20625	Provide construction engineering personnel services	1,195	5,000
B-37527	Paint the floors in 9A room	227	312
B-41258	Provide emergency communication, equipment and labor	499	500
B-44800	Provide transportation and maintenance effort	1,102	1,102
B-44975	Provide electrical substation operator coverage	2,200	2,200
B-44976	Provide standby lineman coverage	3,259	3,259
B-59234	Assist installation of 440 volt generator	212	334
B-59237	Provide miscellaneous hauling (file cabinet to 703, instruments, etc.)	235	350
B-59241	Fabricate special card holder for badges	265	270
B-59245	Haul mock-up hood to 200 Area from 300 Area	375	622
B-59247	Set sparger & furnish air compressor	495	522
B-59251	Install hasp on Recuplex door	28	30
B-59256	Fabricate wooden box to contain ball valve from Recuplex	36	37
B-60309	Install two spots to illuminate PR can unloading pad	163	188
B-63240	Furnish a jumper between tanks	859	954
B-63330	Fabricate special fitter frame	257	356
B-64916	Mock-up vacuum transfer from K-9 tank and remote mechanism for draining and addition	1,184	1,050
B-67845	Fabricate 235 PR cans	139,292	186,400
B-67980	Realign hoods 7A & 7C to support SNT transfers in recovery facility	6,383	7,184
B-68192	Instrument work on BF-3 neutron counter	223	244
B-68199	Provide maintenance and electrical work on lab. dissolver	1,437	2,446
B-68292	Analyze contents of tanks and sump in Recuplex	6,952	6,500
B-68701	To provide medium of costing interruption of work on Project 912 "Waste Treatment Facility - Z Plant" per AEC	2,221	4,000
B-69620	Fabricate sample bottle	31	31
B-82001	Provide technical services from laboratories	18,462	18,500
K-06910	Provide CPD Facilities engineering services	41,829	50,000
R-65511	Provide reactor engineering remote manipulator and technical services	$ 13,473	13,000
		$251,200	$321,891

[redacted]

Exhibit 11-B (1)

STANDARD FORM NO. 64 [redacted]

Office Memorandum • UNITED STATES GOVERNMENT

TO : C. N. Zangar, Director
Health & Safety Division

DATE: [illegible]

FROM : J. E. Travis, Manager
Hanford

SUBJECT: APPOINTMENT TO INVESTIGATION COMMITTEE

Effective immediately a formal Investigating Committee is established pursuant to AEC and HA Manual Chapters 0703 to conduct an investigation and submit an investigation report on the criticality incident which occurred on April 7, 1962, within the 234-5 Building.

You are hereby appointed as Chairman. Members of the Committee will be as follows:

HAPO	HOO
M. C. Leverett	M. J. Rasmussen
C. C. Gamertsfelder	
P. F. Gast	
O. H. Greager	
W. N. Mobley	

As Chairman of the Committee you will have complete authority and be responsible for determining the extent and scope of the investigation, for arranging committee assignments in connection with the investigation, and for assuring the preparation of a complete formal Investigation Report as specified in AEC Manual Appendix 0703-041.

[redacted]

UNCLASSIFIED

Exhibit 18-A

STANDARD FORM NO. 64

[redacted] UNCLASSIFIED

Office Memorandum • UNITED STATES GOVERNMENT

TO : J. E. Travis, Manager
Hanford Operations Office

DATE: April 13, 1962

FROM : Carl N. Zangar, Chairman
Investigation Committee

SUBJECT: INVESTIGATION RECUPLEX INCIDENT OF APRIL 7, 1962

H:CNZ

The Investigation Committee appointed by your memorandum of April 9, 1962, immediately initiated an investigation of the subject incident. The Committee's investigation will be directed toward the following:

1. Cause of and responsibility for the incident.
2. Nature and extent (including costs) of the incident.
3. Recommendations for corrective action, if indicated.
4. Probability, amounts, and validity of claims against the Government, to the extent this is practicable.
5. The effectiveness and proprietiness of actions taken to insure safety to personnel and Government property, and to restore the recuplex operation.

To determine answers to the above, the Committee will:

1. Inspect the site of the incident as soon as entry is authorized.
2. Interrogate operators and responsible supervisors.
3. Inquire into the events leading up to the incident.
4. Inquire into the actions taken at the time of the incident.
5. Inquire into actions taken immediately following the incident.
6. Review the standard and special operating procedures, safety training and drill program, log books, and internal and external audits conducted.
7. Study the process and equipment and determine the effects of the incident on the equipment, if any.
8. Study the effect on and the treatment and disposition of the men involved in the incident.
9. Review the associated emergency plans.

The Committee hopes to complete their investigation and render a report within 30 days, if possible. If important data cannot be obtained for a final report within the stated time, an interim report will be issued.

[redacted]

Exhibit 12-B