70-820 UNC RECOVERY SYSTEMS

NUCLEAR INCIDENT AT UNITED NUCLEAR CORPORATION

Rec'd w/ ltr dtd 8/24/64

AA-2

UNITED NUCLEAR
CORPORATION

P. O. BOX 1883
365 WINCHESTER AVENUE
NEW HAVEN, CONN. 06508
777-5361

August 24, 1964

Director of Regulations
U. S. Atomic Energy Commission
Washington 25, D. C.

Attention: Mr. Harold L. Price

Gentlemen:

In accordance with requirements of The Code of Federal Regulations, Title 10-Atomic Energy, Chapter 1-Atomic Energy Commission, Part 20 - Standards for Protection against Radiation, the following report is submitted to you as a result of the nuclear criticality incident at United Nuclear Corporation's Fuels Recovery Plant in Wood River Junction, Rhode Island. This incident occurred on July 24, 1964.

The report constitutes the direct effort of an Investigation Committee of United Nuclear, which was appointed after the incident to examine and analyze all aspects of the incident. This report therefore represents United Nuclear Corporation's independent findings.

Since the report submitted complies with the 30 day requirement of the above regulations, some data, particularly in the physics area, is not yet available. It is the intention of the United Nuclear Corporation to submit a Supplemental Report at a later date when this data is available.

Appreciation is expressed to Atomic Energy Commission personnel for their cooperation and presence during the days following the incident.

Very truly yours,

JALindberg

J. A. Lindberg
Vice President

JAL:jh

c.c.: Manager
U. S. Atomic Energy Commission
New York Operations Office
376 Hudson Street
New York 14, New York

70-820
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NUCLEAR INCIDENT

AT

UNITED NUCLEAR CORPORATION
WOOD RIVER JUNCTION
RHODE ISLAND

JULY 24, 1964

2 cys sent 8/31/64

AUGUST 21, 1964

UNITED NUCLEAR
CORPORATION

FUELS DIVISION
P.O. Box 1883
365 Winchester Avenue
New Haven 4, Connecticut

DOCKET NO. 70-820

August 28, 1964

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NOTICE TO AEC PUBLIC DOCUMENT ROOM

APPENDIX F TO UNITED NUCLEAR CORPORATION'S REPORT OF AUGUST 21, 1964 IS BEING WITHHELD IN ACCORDANCE WITH 9.4 of PART 9.

NUCLEAR INCIDENT

AT

UNITED NUCLEAR CORPORATION
WOOD RIVER JUNCTION
RHODE ISLAND

JULY 24, 1964

BY

W. L. Allison, Chairman

M. M. Shapiro

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August 21, 1964

W L Allison

W. L. Allison
Chairman of Investigation

UNITED NUCLEAR CORPORATION

365 Winchester Avenue
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I SUMMARY

On July 24, 1964, at approximately 6:06 PM, a nuclear-critical incident occurred in a process tank at the Wood River Junction, Rhode Island plant of United Nuclear Corporation. One employee was exposed to lethal radiation and died some 48 hours after the incident. The investigation has provided evidence that the nuclear excursion resulted from the pouring of a high-concentration uranyl nitrate solution from a geometrically-safe bottle into an unsafe sodium carbonate make up tank.

This report of the investigation committee has been prepared in accordance with paragraph 20.405 of 10CFR20 and describes the operational background leading to the incident, the prompt evacuation of the plant, the re-entry into the plant, the subsequent decontamination of the plant and the extent of exposure of persons to radiation. The planned corrective actions to assure against a recurrence are summarized.

This report does not contain many of the detailed nuclear calculations and analyses and some of the medical investigations which will continue for some time in the future. Those additional findings and conclusions will be reported as soon as they are available.

II OPERATIONAL BACKGROUND

A. The Wood River Junction Fuels Recovery Plant

1. Location (See Appendix A)

   The Fuels Recovery Plant is situated on a 1200 acre woodland site in southwestern Rhode Island, adjacent to mainline of New Haven Railroad. Pawcatuck River flows through northwest corner of the site. Population within five miles is estimated to be 7,120, in summer much higher.

2. License

   The plant is operated exclusively for recovery of enriched uranium from cold scrap, under license SNM-777, issued March 5, 1964. The maximum allowed inventory is 2000 kg. Production operations commenced on March 16, 1964.

3. Operations

   The plant is designed and equipped to recover uranium from acid solutions, aluminum and zirconium alloys, ceramics and miscellaneous burnables. (See process schematics on pages 4 and 5 following.) All equipment which contains uranium is safe geometry or poisoned with the following exceptions:

   a. pickle liquor adjustment tank

   b. two raffinate - filtrate neutralization tanks

   c. two ammonium di-uranate (ADU) drying ovens

   d. tube for reactor furnace

   Acid solutions from the dissolvers or pickle liquor storage tank are fed to solvent extraction columns, extracted as uranyl nitrate, concentrated by evaporation, precipitated as ammonium di-uranate (ADU), filtered, dried and converted in N_2, NH_3 and steam atmosphere to UO_2 which is the final product.

4. Manning

   The plant is operated on three-shift five-day week and the normal shift crews are composed of three (3) operators (1 head ends, 1 extraction column, 1 precipitation and drying), one (1) shift supervisor and one (1) security guard. Supporting personnel include the plant superintendent, plant chemist, health physics technician, two mechanics, secretary and a clerk-typist. All supervision and the chemist are graduate chemists or chemical engineers. The total plant complement at the time of the incident was twenty-one (21).

A. The Wood River Junction Fuels Recovery Plant - (Continued)

5. Uranium Inventory

NOTE: All weights as total uranium; all material is 93.15% enriched.

a. Cumulative shipper's value of received material 137,941g.

b. In-process to date (cumulative receiver assay) 82,312g.

c. Contracts in process to date:

73P-312110-M	(Proj. PNR-40101-02-1)	50,952g.
AT (36-1)-115	(Proj. PNR-40704-01-20)	
AT (36-1)-103	(Proj. PNR-40704-01-18)	
AT (36-1)-123	(Proj. PNR-40731-01-11)	31,360g.
AT (30-3)-528	(Proj. SNR-40714-01-6)	
AT (30-3)-528	(Proj. SNR-40714-01-7)	
73P-319714-M	(Proj. PNR-40101-01-1)	

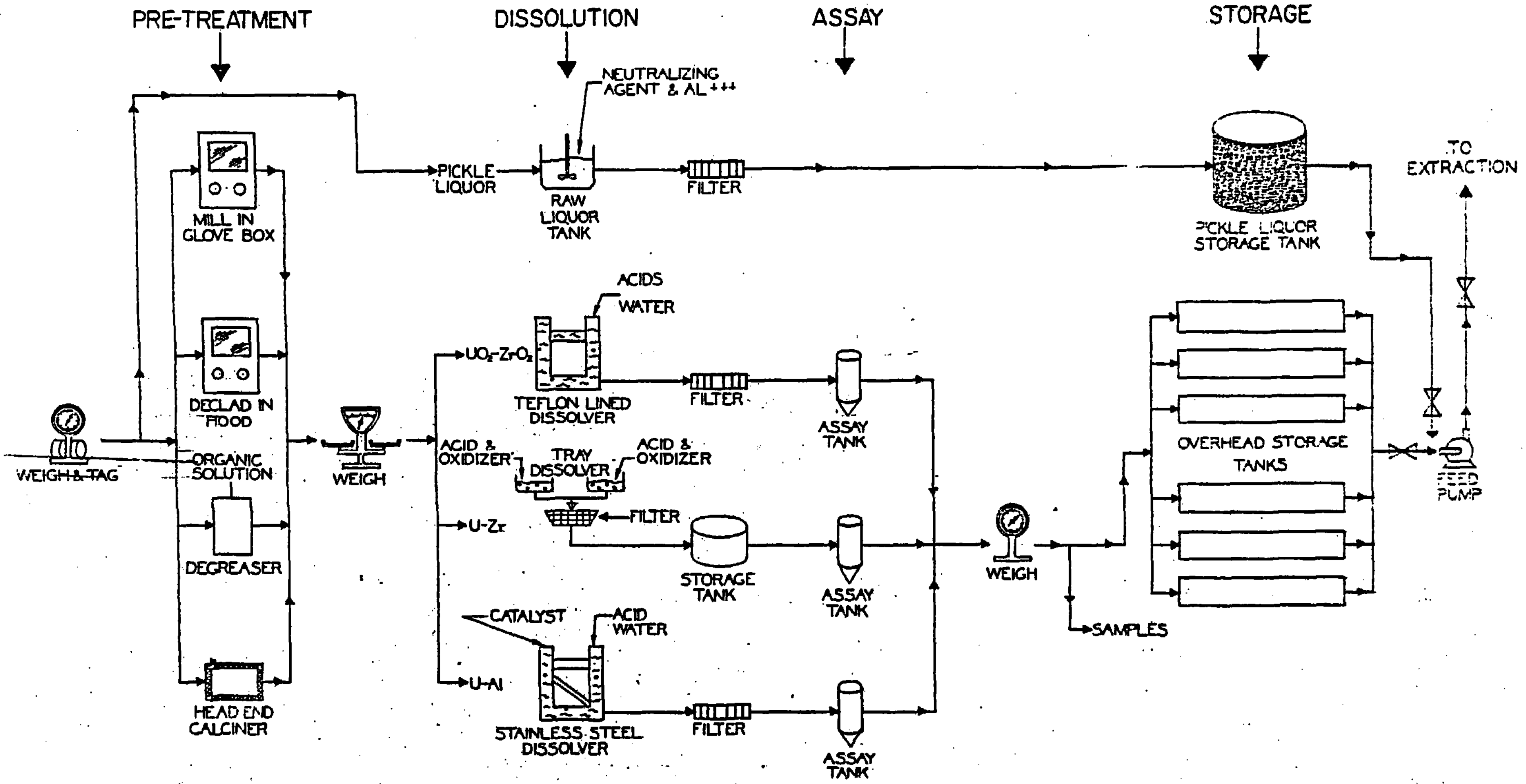
d. Approximate distribution of in-process material at time of accident:

	Uranium
Dried ADU in product storage	23,621g.
In bottles and drums (mostly from evaporator)	16,069g.
In-process equipment	42,176g.
In lagoon (waste)	234g.
As analytical samples	212g.
Total	82,312g.

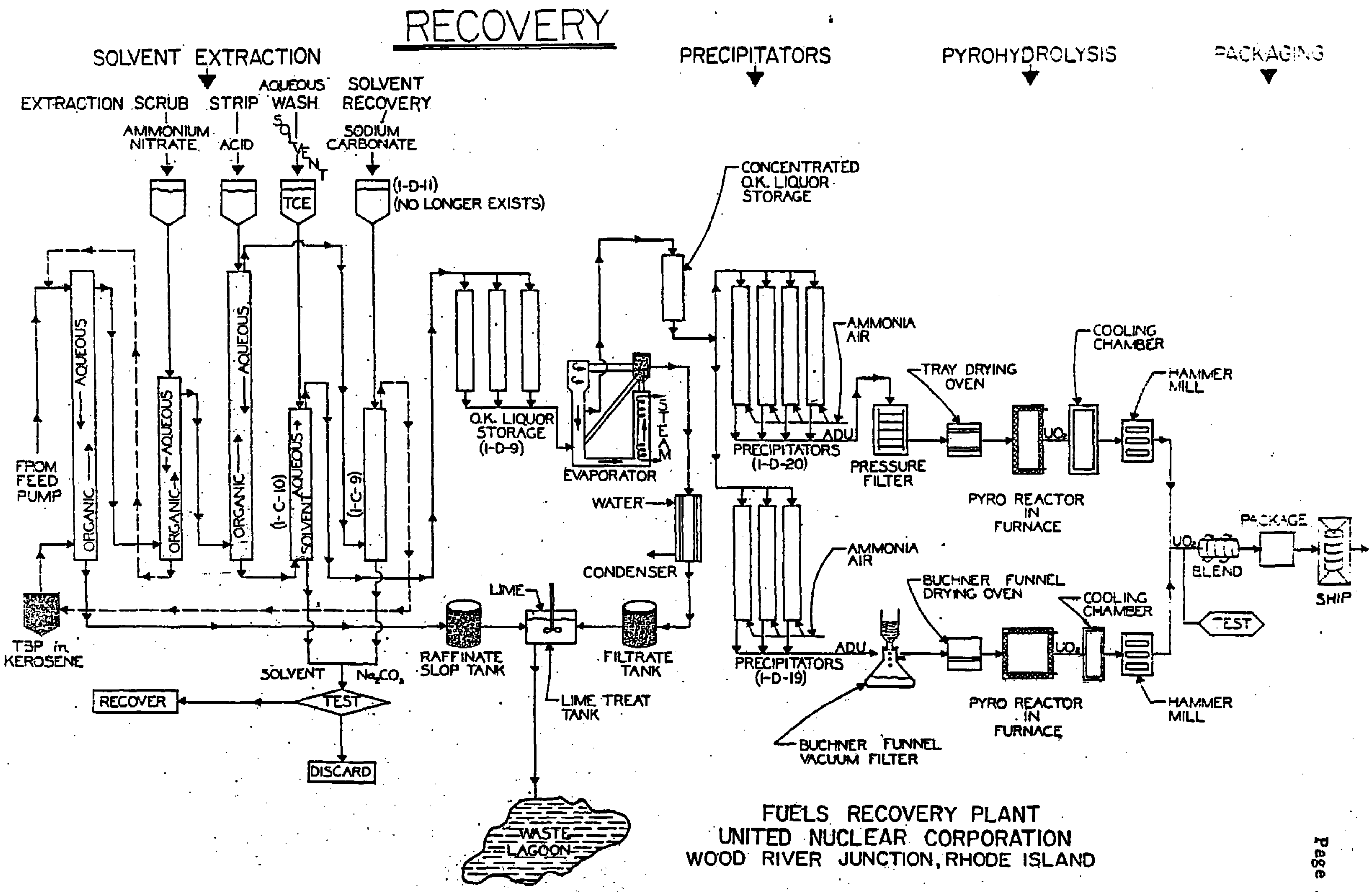
e. No material yet shipped as product.

f. Irradiated material (solution and solids which were in the vessel when criticality occurred, were later drained) 2-3kgs.

HEAD ENDS TREATMENT



FUELS RECOVERY PLANT
UNITED NUCLEAR CORPORATION
WOOD RIVER JUNCTION, RHODE ISLAND



FUELS RECOVERY PLANT
UNITED NUCLEAR CORPORATION
WOOD RIVER JUNCTION, RHODE ISLAND

B. Criticality Control

The general criticality control procedures used in the plant follow the recommendations included in such recognized publications as:

TID-7028	"Critical Dimensions of Systems Containing U-235, Pu239 and U-233".
TID-7016, Rev.1	"Nuclear Safety Guide"
K-1019, Rev.5	"Guide to Shipment of U-235 Enriched Uranium Materials"

The primary criticality control procedures observed are either limited safe batch, limited safe geometry or limited safe volumes. "Limited Safe" means that the unit is safe by limits on one or more of the following: Enrichment, volume, geometry, mass, concentration. In some specific cases, the nuclear safety of a piece of equipment or a process is evaluated on the basis of actual critical data published in the many AEC reports. In any event, each process, equipment item or storage area in which enriched uranium is handled is to be approved by the AEC Division of Licensing and Regulation (as required by 10 CFR, Part 70) or the appropriate AEC Operations Office.

Each person handling enriched uranium has the responsibility of nuclear safety in that he is responsible for following approved procedures. When a new piece of equipment or modification of existing equipment is planned, the person responsible for the installation and operation contacts the Nuclear Safety supervisor. At this time the nuclear problems are discussed. The design then progresses taking into account the recommendations of the Nuclear Safety Supervisor. When the design and basic operating procedures have been finalized, the Nuclear Safety supervisor prepares the license application and/or feasibility report outlining the method of operation and basis for nuclear safety. The Superintendent prepares detailed operating procedures which include any special nuclear safety requirements such as batch size, equipment spacing, work area, handling procedures specified in the license application or feasibility report. These procedures are carefully explained to the Supervision and by the Supervisor to the operator.

The Standard Operating Procedures used by the supervisors and all operating personnel also emphasize the basic ground rules for nuclear safety in the plant. The following is quoted from the Standard Operating Procedures:

> "Compliance with nuclear safety procedures is mandatory. A single mistake is one too many.
>
> Each operator will familiarize himself with the following safe mass and safe geometry containers, etc.
>
> a. A mass of no more than 350 grams of uranium.
>
> b. A five inch (5") diameter cylinder.

B. Criticality Control - (Continued)

c. A one and one-half inch (1-1/2") slab.

d. A container with a total volume capacity of four (4) liters.

e. A solution with a uranium concentration of five (5) grams per liter.

Even though a container is safe geometry, adequate spacing must be maintained between two containers or between a container and a piece of equipment containing uranium. If in doubt about the spacing required ASK.

In process material will be handled as if they were loaded with uranium until the material is analyzed for uranium content. For example, ADU filtrates will be clear and water white and by experience could be assumed to be low in uranium. Do Not make such an asumption!"

C. Systems and Procedures in Use at the Plant

1. The Standard Operating Procedures (SOP's)

The technical operating procedures used in the plant were based on United Nuclear, Hematite, Missouri plant procedures. They were written by United Nuclear experienced supervisory personnel in the form of detailed operating procedures (See example in Appendix B), hereafter referred to as the SOP's.

These Standard Operating Procedures were collected into five (5) bound SOP Manuals, one master copy, one for the supervisors and three for use by the operators themselves. The SOP Manuals were not "controlled copies" inasmuch as they were not numbered nor were they kept at a document center or at a particular area on the process floor. All personnel in the plant understood that the procedures were approved and authorized by management even though the manual did not show evidence of authorizing signatures and date of issue. In addition to the forty-four (44) detailed operating procedures contained in the manual, copies of the SOP's were attached to two (2) specific pieces of equipment which had been giving trouble - the calciner and the stainless steel dissolver.

Regarding the equipment and process piping itself, the tanks and vessels are each identified with a serial number consistent with the plant design drawings (e.g., 1-D-41) and most equipment also was labeled with a descriptive name (e.g., Strip Acid Tank). Valves and pipes are not labeled as such and the process piping is not color coded as to contents but does have serial numbers shown on the pipes. Plant utility piping (water, steam) is not color coded.

2. The License Application Manual

The SOP Manual is an internal document and not subject to approval of any extra-company authority. However, the technical content of the SOP Manual was also contained in the license application "General Information and Procedure Applicable to the Handling of Special Nuclear Materials", hereafter referred to as the Manual. The Manual was prepared by United Nuclear Corporation and submitted to the Atomic Energy Commission for approval.

3. Communicating the Process to the Operators

The SOP's appear to provide adequate detail to permit an operator to perform production tasks following a training period. Prior to start-up there was such a training period during which the experienced supervisors operated the equipment and the inexperienced operators acted as helpers. The operators also familiarized themselves in detail with the SOP's and were tested on their knowledge of the technical contents. This technical training was in addition to

3. <u>Communicating the Process to the Operators - (Continued)</u>

the nuclear safety, health physics and accountability and security training given all employees. Actual production was started using uranium-zircaloy pickle liquor as raw material. Shift assignments were verbally given by the supervisor at the beginning of the shift. The more routine the operations of the plant were, the less explicit the assignment needed to be. In the case of non-routine operations, assignments were far more specific.

An Operators Logbook and a Supervisors Logbook were maintained from the outset although the physical format of the Supervisors Logbook was revised in June 1964. These ledger-type logs were used essentially to record non-routine information; when equipment and process problems developed, however, the logbooks were used to record details of actions taken or yet to be taken. The operators were not required to make entries each work shift, but, on the average, two of the three operators each shift made an entry in the log. The supervisors were required to make an entry each shift and that was done. Written communication in both logbooks were augmented by inter-shift verbal communications by operators and supervisors. The logbooks were periodically (perhaps weekly) reviewed by the plant superintendent; his review of the supervisors logbook is evidenced by his comments written in that logbook. The total plant operating force (9 operators, 3 supervisors, 1 superintendent, total 13) was small enough that verbal communication was feasible and adequate for most purposes.

Two additional logbooks are maintained:

a. Sample logbook used by production to log samples sent to the laboratory.

b. Laboratory log used to log in samples from production and record assay values.

The use of these two logbooks appears to be a satisfactory method of controlling samples and analytical results. Further details on their use is included under discussion of labeling. (Section II.D following). The operators, when interviewed since the incident have given the opinion that the training received was adequate from the process and also from the nuclear safety aspects.

In addition to the SOP's and the four (4) logbooks, Log Sheets were used to record the actual process data such as times, temperatures, weights, etc. Log Sheets were in use on the following operations:

a. Dissolver

b. Pickle liquor preparation

c. Extraction system

d. Evaporator system

3. Communicating the Process to the Operators - (Continued)

e. ADU precipitation

f. Assay tanks

g. Raffinate wastes

There was also a Daily Report logsheet for the supervisors to complete. Since the plant had only recently started up, the final process parameters for some operations had not yet been established and until that time, the specific values had been omitted from the SOP's. A review of the log sheets that had been filled in indicates that they were adequately filled in with the possible exception of the extraction system where data were sometimes omitted.

It should be noted that whereas the SOP's appear technically adequate for those operations which are included, they do not explicitly prohibit all other operations from being performed.

D. System for Identification of Eleven-Liter Bottles

Two types of labels are used in the plant for identifying contents of bottles:

1. Log Tag which indicates the prior history of the bottle and whether the contents have been sampled or not.

2. Sample Tag which provides for weight and assay of the contents, the job number, etc.

The Log Tag is not a preprinted tag but instead is the reverse of the sample tag. Columns are provided on the Log Tag for:

1. Description of the contents.
2. Whether the material has been sampled for analysis.
3. The disposition of the material as it was removed from the bottle.

The tag remains with the bottle until the tag is used up; it is thus a "Route Card" or "Shop Traveler" for the particular bottle and at the end of that time it is destroyed. A review of existing log tags indicates that signatures and dates were not always shown and some tags did not show columns for "Sampled" and "Disposition".

The sample tag does not necessarily come into existence until the 11-liter bottle is sampled. When a 4 oz. sample bottle is filled, the sample tag is filled out and is delivered, with the 4 oz. sample to the supervisors' office; the supervisor enters the sample in the Sample Logbook. The log tag is annotated "sampled" and the Sample Log Book entry number is also entered on the log tag. The sample and sample tag are picked up from the supervisors' office by the laboratory chemist who entered the sample in the Laboratory Log, assigns it a laboratory number, writes that laboratory number on the sample tag and assays the sample. He enters the results in the laboratory log book and also on the bottom of the sample tag itself. Sample and completed tag are returned to the supervisor who thus decides the disposition of the contained material. That disposition is recorded in the sample logbook and, when disposition has been effected by an operator, an entry to that effect is made on the log tag. When the material is poured or removed from the bottle into process equipment, the sample tag is destroyed. If the material is to remain in the bottle, the sample tag is usually retained with the bottle.

The standard 11-liter polyethylene bottles (5" diameter) are widely used in the plant as are 4-liter plastic jars. The bottles were generally given five-digit serial numbers by marking with "Flo-Pen" or equivalent. A review of in-plant

D. System for Identification of Eleven-Liter Bottles - (Continued)

bottles indicated the following:

Total bottles purchased and deliv ered		36
Loaned to New Haven plant	2	
Burned in calciner (#11009)	1	
In stores, not issued (no numbers)	3	
In use, serially numbered (#11001 through #11008, #11010 through #11015)	14	
In production use, no serial number	9	
In non-production use as overflow reservoirs	6	
In Chemistry Laboratory, not serialized	1	
Total	36	

The 4-liter jars were not serially numbered. In general, their use was restricted to solid product (ADU and UO_2) and spills, etc.

Labels were originally affixed to 11-liter bottles with adhesive backed labels. Exposure to the moisture on bottle exterior soon rendered such labels illegible. The procedure was changed to employ pressure-sensitive tape which did not always adhere. The method of attaching was changed to use of rubber bands to hold the tag onto the bottle. Present method of labeling 11-liter bottles consists wholly of rubber band affixing of sample and log tags. Tags are not physically attached to the 4 oz. sample bottles, but merely accompany the bottle.

E. The Washing of Trichloroethane

Trichloroethane (TCE) is used in the extraction system to remove traces of organic solvent from the uranium-bearing aqueous solution (OK liquor). The original plant design predicted a life of six months to one year for the TCE without it having to be itself purified. The actual life of the TCE did not meet expectations after the plant started operations in March 1964. Due to unanticipated carry-over of solvent from the strip column and higher pickup of uranium, the TCE became contaminated and discolored after approximately one week of use.

In early April 1964 therefore, the operation of washing TCE (pure TCE is water white, S.G. 1.3) to remove uranium values was instituted. The uranium concentration in contaminated TCE was normally 400 ppm to 800 ppm. The original procedure for washing TCE consisted of the physical contacting of TCE with a one molar aqueous solution of sodium carbonate so that uranium values are extracted from the solvent phase into the aqueous. This procedure was originally accomplished in eleven liter bottles by manual shaking or rocking of the bottle. After a certain time to permit settling out of the two phases, the organic was separated from the uranium-containing aqueous by means of a separatory funnel and retained until chemical analysis indicated it was suitable for discard. (In some cases the washing was repeated until the TCE was adequately free from the characteristic yellow color.) The uranium was recovered from the aqueous phase by acidifying, air sperging, precipitating as ADU and filtering. This recovery operation was covered by a brief written procedure (see XI.B.4.c of SOP Manual) which did not delineate equipment to be used. The general method is also described in detail in XI.B.1 of the SOP although that procedure is written explicitly for TBP-kerosene solvent rather than for TCE washing. The carbonate solution workup procedure is described in detail in XI.B.2 of that Manual.

This somewhat laborious method for recovery of uranium from contaminated TCE was used through the month of April 1964. By the end of that period, process improvements in the strip column had been made and the carry over of uranium-bearing solvent was minimized. During May and June 1964, the problem of flooding and the demand for washing of TCE was significantly reduced.

In July 1964 the rework of impure UO_2 again changed conditions in the extraction system by introducing a high-concentration, low-volume condition. As a result, the flooding of the TCE column resulted in a greater amount of contaminated TCE and a greater need to perform the laborious TCE washing by hand-shaking of the 30-40 pound bottles. It is not surprising therefore that a plant operator devised a mechanical method for washing to replace the manual method. On July 16, 1964, for the first time an operator asked his supervisor if it was permissible to use the carbonate make up tank to mechanically agitate contaminated TCE with aqueous sodium carbonate. He was told that it would be all right but, because of the unsafe geometry involved, the uranium content of the TCE had to be known. An 800 ppm limit was informally established and five TCE bottles were taken to the third floor. The Supervisor personally analyzed samples from each of the five and one bottle (@~750 ppm uranium) was selected for washing.

The first mechanical washing was thus performed on July 16, 1964, by agitating 10-11 liters of TCE with ~6 gallons of sodium carbonate solution for 45 minutes. The emulsion was then drained into the TCE column (1-C-10), which was empty at the time, allowed to settle for 20 minutes and drained into 11 liter bottles. The next day, July 17, 1964, the Supervisor and Operator worked out the proper proportions of carbonate, water and TCE and an entry was made in the Operator's log book.

The new procedure was communicated to one other Operator and these two Operators washed 10-12 bottles each by the method in the week between July 16 and July 24. One other Supervisor, when first informed of the procedure, was indignant that such a procedure had been instituted but was later convinced that adequate controls existed and permitted the procedure to be performed. The third Supervisor and the Plant Superintendent did not know that the mechanical washing of TCE was being performed at any time.

It is pertinent to note here that optimum use of the procedure required that the aqueous wash column 1-C-10 be empty so that it could serve as a separatory funnel. The use of the carbonate tank for this purpose was not impossible with column 1-C-10 operating, but the resulting separation was less precise because it had to be performed on the second level where the interface between phases was not readily visible in the metal piping below the carbonate tank. It should also be pointed out that the method was not appropriate for use with small amounts of TCE which could be more easily washed by the manual method. The incentive to use the mechanical method existed when more than a few 11 liter bottles required washing as was the case in July when column flooding and carry over recurred. It may also be pertinent to note that the specific gravity of high-concentration uranium solutions are 1.2-1.4 and thus in the same range as the TCE specific gravity. The weight of a bottle of uranyl nitrate could probably not be distinguished from that of a bottle of TCE without weighing.

The carbonate make-up tank (1-D-11) is a 30 gallon stainless steel (304L) tank, diameter 18", vertical wall 26" with standard dished bottom, 3/8" wall. A removable 1/4 HP Lightning mixer with a small propellor can be mounted on the rim; the shaft length places the impeller approximately 1" above the weld between the dished bottom and the vertical side. Mixer speed is 1750 rpm. The rim of the vessel is 60" above the floor; the vessel stands on angle-iron legs on a 6" concrete pad. The room dimensions are approximately 25' x 18' and the nearest wall is approximately 2' from tank axis. All walls are high density concrete block. A roof exhaust fan exhausts the third floor room to atmosphere (1800 cfm, 775 rpm, 1/4" static pressure).

F. Details of Plant Operations 7/22/64 to 7/24/64

In the week preceding the accident, the plant was running rework UO_2 and ADU to reduce impurity levels of the initially-recovered material. No new pickle liquor was undergoing recovery. Equipment running at time of accident included: stainless steel dissolver, pulse columns, evaporator, precipitators and calciner.

1. Wednesday Operations - 7/22/64 (Refer to plant layout Page 18)

   a. First noticed black organic type material in 1-D-20 precipitators, 12-8 shift, 1-D-19 precipitators were not in use. Attempted to identify black material and began to filter material in precipitators.

   b. Nuclear alarm sounded in the second floor tower, (the assigned operator was the victim of the later excursion), due to splashing of water onto contacts, 4-12 shift, water was being used to wash down outside of columns. Plant was evacuated and re-entry made under controlled conditions, highest radiation seen by instrument was 0.06mr/hr.

   c. Changed extractor feed pump.

   d. All other operations routine.

2. Thursday Operations - 7/23/64

   a. 12-8 shift evaporators not functioning, would not get hot or pump out, attempted to repair trap, changed trap, cleaned strainer, began work on steam control valve. Black organic type material still visible in precipitators (1-D-20-B). Washed out precipitators 1-D-20-A, B, C, D with nitric and filtered the wash, transferred wash to 1-D-9. Charged a new batch into 1-D-20 precipitators. Shut down extraction columns due to 1-D-10-A, B storage tanks being full due to evaporator being down.

   b. 8-4 shift, evaporator shut down, disassembled and uranium solution drawn off from feed-leg, first floor flange disassembled, solid uranyl nitrate removed mechanically and by melting with steam, concentrated material put into 11-liter bottles. Criticality safety was maintained by using slab-geometry drip pan and by using only volume-safe 4-liter jars to transfer to the 11-liter bottles. Evaporator cleaning task not completed at end of shift. Also changed evaporator steam traps, installed new steam conductivity cell and repaired reducing valve and temperature control valve. Found evaporator steam control valve had been opened too far and broken. Filtering of concentrated liquor in precipitators continued. Added nitric to material in 1-D-20 to re-dissolve ADU, attempted to filter out black organic type material, then filled 1-D-20-B to

2. Thursday Operations - 7/23/64 - (Continued)

b. (Continued)

top and skimmed material off top, then 1-D-20-A. Installed new air and ammonia filters and filter between 1-D-10's and 1-D-20 precipitators to prevent black material from entering precipitators.

c. 4-12 shift, completed cleanout of evaporator and reassembled. Repaired leaks. Began to charge uranyl-nitrate cleaned out by day shift into stainless steel dissolver, charged half of one 11-liter bottle. Continued to filter material in precipitators and skimmed from top, pumped the material to 1-D-20-A from 1-D-20-B through filter and then skimmed back to 1-D-20-B precipitator and skimmed, etc. back and forth.

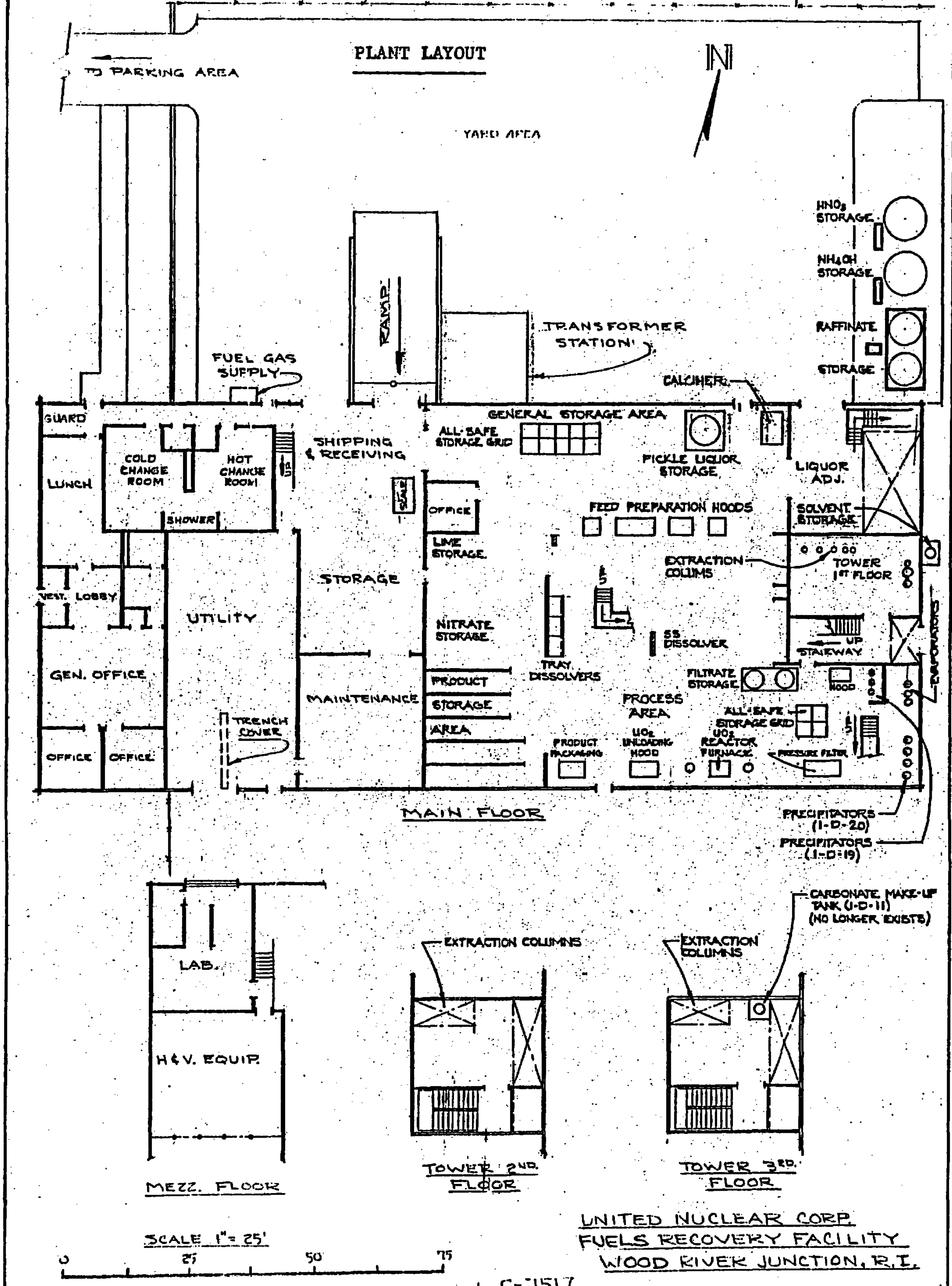
3. Friday Operations - 7/24/64

a. 12-8 shift, started up pulse columns which had been shut down Thursday. The high-concentration material charged into the dissolver was assayed at 450 grams per liter; approximately 6-liters of that material was drained into 11-liter bottle #11011 and a proper dissolver batch was calculated. Evaporator operating for part of shift but shut down due to lack of feed material. Evaporator specific gravity control was apparently not properly calibrated. In precipitation area, continued to filter to remove black organic type material, drained and cleaned 1-D-20-A and B precipitators, filtered and began to transfer filtrate into 1-D-19-B precipitator.

b. 8-4 shift, drained 1-D-20's into two 11-liter bottles; columns B and C of 1-D-19 precipitators full. Began to precipitate in 1-D-19-B. Evaporator down all shift. Completed precipitation of 1-D-19-B and began to filter, began precipitation of 1-D-19-C. Left 1-D-20's for more cleaning. Extraction columns running OK. Completed charging three more batches of concentrated evaporator material to stainless steel dissolver and transported to overhead storage tanks.

c. 4-12 shift, prepared to wash out the 1-D-20's with nitric acid to remove uranium and then with TCE to remove black material. Evaporator was started up. Extraction columns were operating. (See additional detail Section III A).

PLANT LAYOUT



UNITED NUCLEAR CORP.
FUELS RECOVERY FACILITY
WOOD RIVER JUNCTION, R.I.

C-7517

G. Evaporator and Precipitator Clean Out Details

The details of cleaning out the evaporator and the precipitator are presented here in some detail because these clean-out operations caused five (5) bottles of highly-concentrated uranyl nitrate to be generated. In fact, it represented the first time in operation of the plant that such highly concentrated solutions had ever been put into 11-liter bottles.

1. Thursday 7/23/64 8-4 Shift

The evaporator had not functioned on the previous shift (12-8, Supervisor A). That shift had attempted to re-operate the evaporator by working on the steam equipment, i.e, changing trap, repairing trap, cleaning strainer, etc. Actual dismantling of the evaporator however did not begin until the Superintendent was present to direct operations beginning at 8:00 AM on Thursday. With Supervisor B and the three (3) assigned operators, the evaporator was shut off (steam off, feed off), the feed leg flange on the second level was disassembled and uranium solution was drawn off into a flask using plant vacuum.. (See detail, next page). This solution was poured into an 11-liter bottle; the size of the feed leg indicates that the volume of material removed would occupy 4-1/2 - 5 liters.

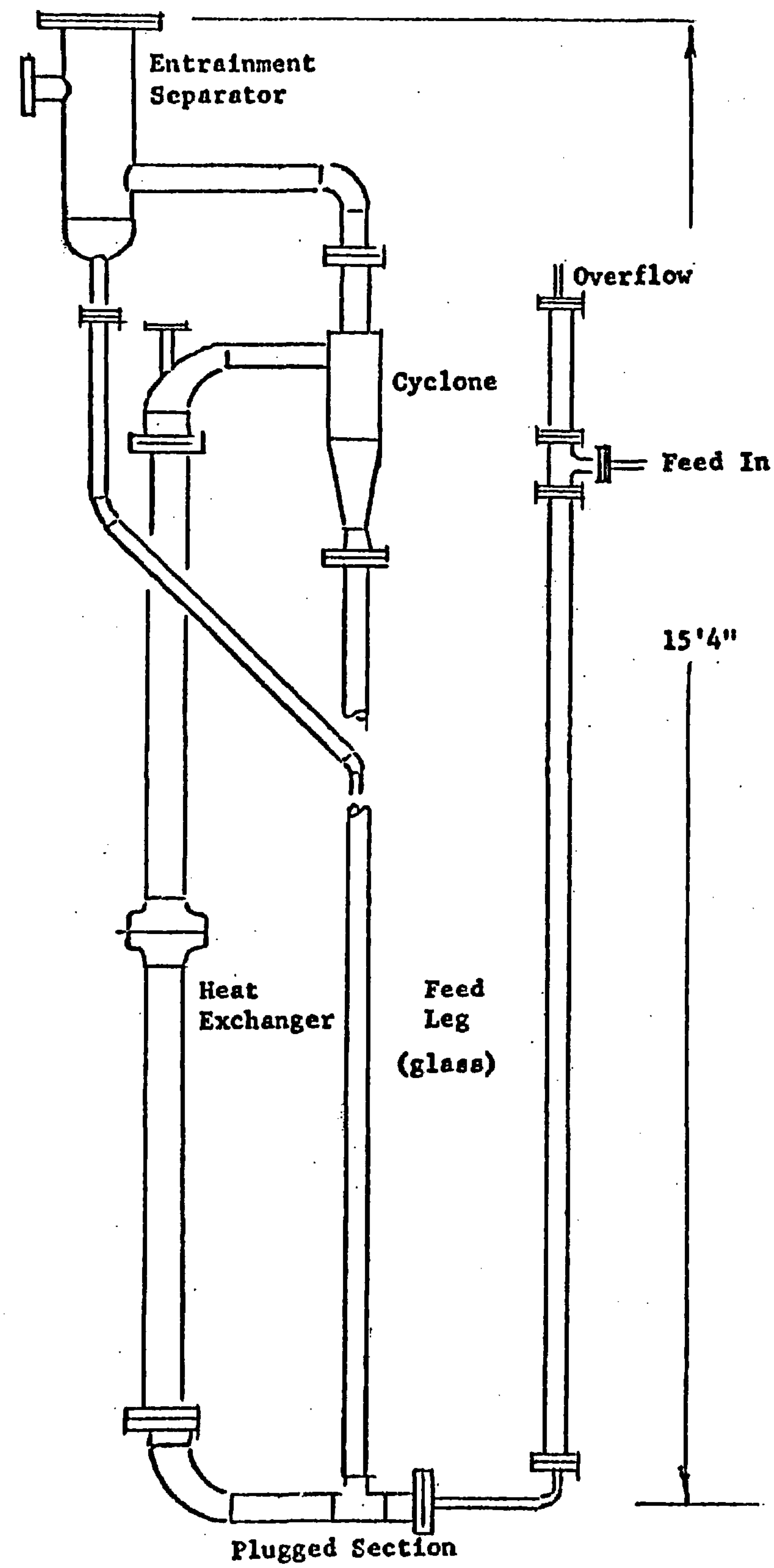
Having removed most (not all) of the solution from the feed leg, the flange on the horizontal member was disassembled on the first level. A drip pan (slab safe geometry), 1-liter stainless beaker and a 4-liter jar were employed to transfer the solid uranyl nitrate, which was plugging the horizontal member of the unit, from the evaporator to 11-liter bottles. The removal of crystals by melting and/or diluting with direct steam proceeded in a direction away from the feed leg and the small amount of material contained in the elbow below the feed leg was left to be removed by the next shift. Removal of the crystals and solution from the evaporator on 8-4 shift resulted in the filling of two 11-liter bottles and the leaving of the 4-liter transfer jar partially full, near the evaporator. The remainder of the clean-out task was left for the 4-12 shift.

The postulated inventory of concentrated uranyl nitrate and bottles at end of 8-4 shift is as follows:

a. Bottle Y had been utilized to hold the solution aspirated from feed leg. The feed leg solution occupied approximately 5-liters of the bottle and then the bottle was removed down to the first level for filling with additional material.

b. At end of shift, Bottle Y was filled and Bottle X was also filled. Bottle Y was labeled by Operator P as "Bottle Y, concentrated liquor from evaporator"; Bottle X was labeled by Operator Q as "Conc. liquor from evaporator". Bottle Y was of lower concentration than Bottle X because Bottle Y contained the less concentrated feed-leg solution, whereas

EVAPORATOR DETAIL



G. Evaporator and Precipitator Clean Out Details - (Continued)

1. Thursday 7/23/64 8-4 Shift - (Continued)

b. (Continued)

Bottle X was essentially solid crystals plus some condensed steam. As Bottle X cooled, it solidified to solid crystals on the bottom with a "sludge" of crystals and solution on top.

c. Both bottles were put in all-safe carts and were moved to the storage area at the north side of the process area. Operator "P" labeled and moved Bottle Y and when he reached the storage area, placed the bottle in cart near the north wall rather than on a space in the storage grid. (Refer to plant layout). Stanchions and rope were placed around the bottle by Operator "P" as a special precaution for this concentrated material. Bottle Y was moved to the storage before Bottle X. Operator "Q" recalls that Bottle Y was there when he placed Bottle X in the same area in an all-safe cart. (See Label - Bottle Y, Appendix I.)

2. Thursday 7/23/64 4-12 Shift

The evaporator clean-out was completed by Supervisor C and the operators assigned who took over at 4:00 PM. The Superintendent had decided to stay until the task was completed and he had secured a third bottle to a near-by support for the operator to fill or partially fill. The evaporator material handled by the 4-12 operator was significantly less than the day shift; the only material left was that contained between the flange and the glass column of the feed leg. This volume is estimated to have filled no more than 5-liters and probably less. When the evaporator was cleaned out (at approximately 5:00 - 5:30 PM), the Superintendent and Supervisor B from the day shift left; Supervisor C was in charge of the shift which included Operators M, N and O.

The bottle to which Operator "M" transferred the remainder of the concentrated evaporator material is postulated to have been Bottle #11011. That bottle was transferred to the dissolver area or to the product storage area by Operator "M" during the 4-12 shift Thursday. The bottle was labeled by Operator "M" "Conc liquor from evaporator 7/23/64" and that label is still on the bottle. The re-assembly of the evaporator involved details which are not pertinent and will not be detailed here.

During the 4-12 shift, Supervisor C and Operator "N" began to feed back into the system the concentrated uranyl nitrate taken out of the evaporator. This was accomplished by selecting Bottle X, full of solids and "slush" labeled "Conc liquor from evaporator" and charging what solids he could pour

G. Evaporator and Precipitator Clean Out Details - (Continued)

2. Thursday 7/23/64 4-12 Shift - (Continued)

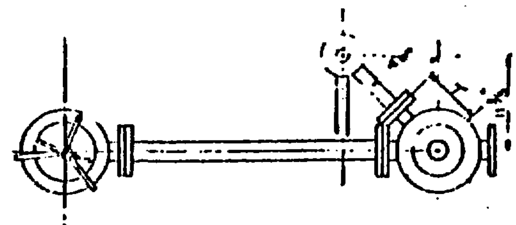
into the stainless steel dissolver. (See detail on following page). Bottle X, as it was found after the incident near the dissolver, was in an all-safe cart, partially full (40-50%) of crystals. By that time, it was leaking at the bottom seam. Approximately 6-liters were charged to the dissolver. Other than that transfer, the material from the evaporator at the end of 4-12 shift was still contained in three 11-liter bottles, Bottle Y in the general storage area, labeled "Concentrated liquor from evaporator", Bottle #11011 near the dissolver or in product storage area labeled "Conc. liquor from evaporator 7/23/64, and Bottle X on the process floor near dissolver labeled "Conc liquor from evaporator".

3. Friday 7/24/64 12-8 Shift

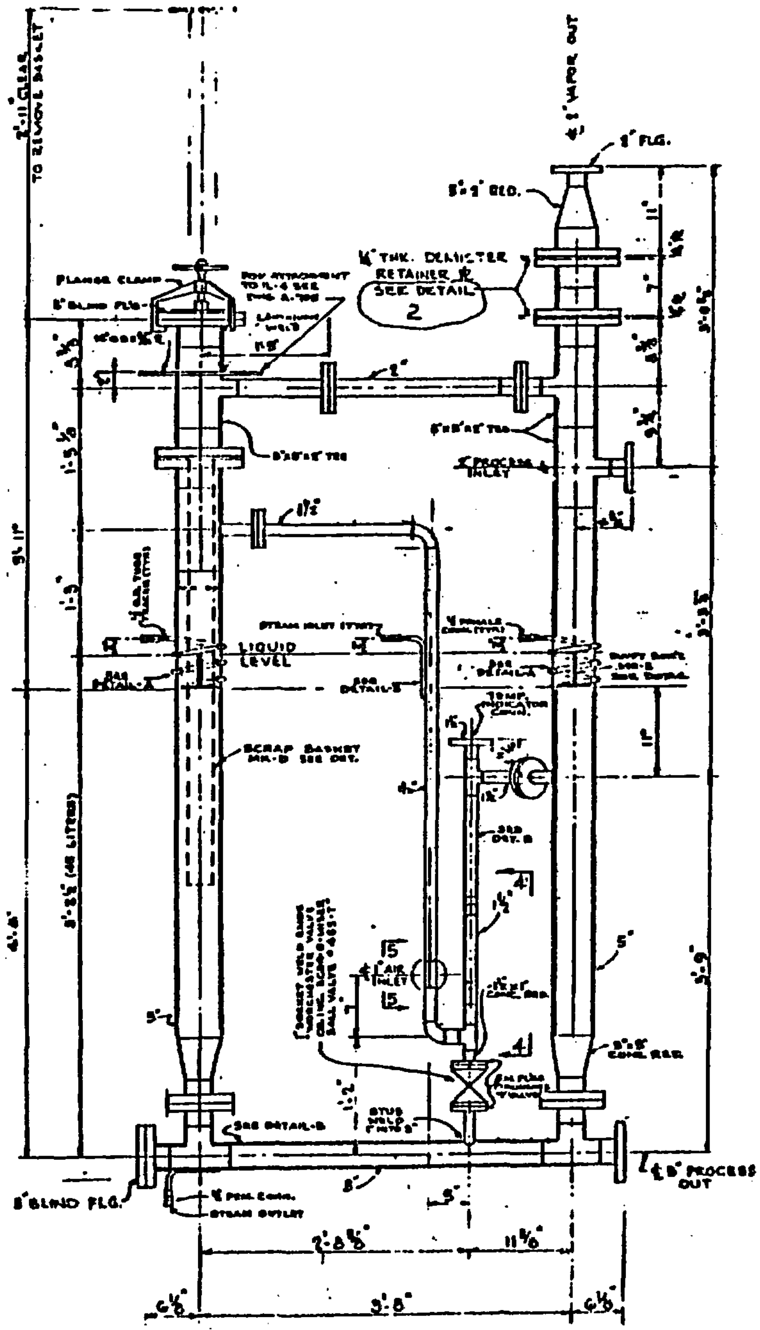
When Supervisor A arrived Thursday nidnight to cover the 12-8 shift he ascertained that Supervisor C did not know the concentration of material loaded from Bottle X into the dissolver and that a correct dissolver batch (1.5 kgs. uranium) could therefore not be accurately calculated. In order to determine the concentration of the material in the dissolver, Supervisor A and Operator R sampled it by draining 1/2 gallon from valve, taking a sample, returning the 1/2 gallon to the dissolver. Supervisor A personally analyzed the sample during that shift (See sample log book, entry 1-15-2) and ascertained that the concentration was approximately 450 gm/liter uranium. In order to charge back a proper amount to the dissolver, he decided to drain what he could from the dissolver and then recharge three liters of the 450 gm/l solution as a dissolver batch.

The dissolver as constructed does not permit complete draining; an estimated 3-5 liters is retained below the valve and cannot be drained. Supervisor A instructed Operator R to drain the material "into 11-liter bottles". The available 11-liter bottle in the dissolver area was Bottle #11011, half full of concentrated solution, the same bottle into which Operator M had previously loaded evaporator material. It is postulated that Bottle #11011 was originally placed in the dissolver area by Operator M or later removed from product storage area to the dissolver area near Bottle #X so that both could be recharged into the system. Supervisor C and Operator N did not recall Bottle #11011 being near the dissolver but Supervisor A and Operator R found it there half full; Supervisor A's log entry identifies the contents after he filled #11011. (As described later, Bottle #11011 was promptly emptied into the dissolver before 1:45 PM on the day shift 7/24/64 and was then taken to precipitation area where it was available for filling with material from precipitators.) Bottle #11011 thus figures in both the evaporator and precipitator cleanouts.

STAINLESS STEEL DISSOLVER



PLAN



S.S. DISSOLVER

G. Evaporator and Precipitator Clean Out Details - (Continued)

3. Friday 7/24/64 12-8 Shift - (Continued)

Supervisor A assumed that the material charged by Operator N to the dissolver was the same as in #11011 and therefore he instructed Operator R to drain the dissolver into #11011. When the dissolver had been drained; Bottle #11011 was full and was thought by Supervisor A and Operator R to contain 4.9 kgs. of uranium. At 6:35 AM Operator R charged three liters of solution from #11011 back into the dissolver as Dissolver Batch #37 (The date on log sheet for Batch 37 apparently should read 7/23/64 instead of 7/22/64 and some of the times entered on the sheet are apparently incorrect by one hour, e.g., 0635 should read 0735). Supervisor A and Operator R. then went off shift.

4. Friday 7/24/64 8-4 Shift

Operator S unloaded Batch #37 and moved it to the overhead storage tanks 1-D-9A, B, C and then proceeded to process dissolver Batches 38, 39 and 40 in precisely the same manner. Bottle #11011 was thus emptied by 1:45 PM on the day shift at which time Bottle #11011 was made available for draining the precipitators. Bottle #11011 is still labeled with a notation in Operator M's handwriting "Conc. liquor from evaporator 7/23/64". That notation was crossed out to permit use of Bottle #11011 for material from the precipitators. When filled from precipitators on day shift, Friday, Bottle #11011 was then re-labeled "OK liquor that has been filtered".

The significant operations involving the evaporator material were thus completed on 8-4 shift on Friday, 7/24/64. At that time an inventory of that concentrated evaporator material would have shown:

a. Bottle #Y in all-safe cart located in general storage area, full of concentrated solution and so labeled.

b. Bottle #X full of uranyl nitrate crystals and solution located in all-safe cart near dissolver, possibly leaking onto floor, labeled.

c. Bottle #11011, the third bottle from evaporator clean-out had been emptied into dissolver and the label notation "Conc liquor from evaporator 7/23/64" had been crossed out and supplanted by "OK liquor that has been filtered" as described above.

d. Overhead tanks 1-D-9A, B, C contained what at that time was thought to be 4.9 kgs. of uranium from evaporator clean-out (11-liters from #11011 @ 450 gm/l.); the amount may have been less because the material in Bottle #11011 into which Operator R poured 450 gm/l. material, may not have been that concentrated.

G. Evaporator and Precipitator Clean Out Details - (Continued)

4. Friday 7/24/64 8-4 Shift - (Continued)

The day shift operations also included the draining of material back and forth between 1-D-19 and 1-D-20 precipitators in an effort to remove the black organic material. Similar activity had been going on since Wednesday, 7/22/64, but no material was actually removed from the system into bottles until Friday, 7/24/64. These operations resulted in the draining of concentrated solution from 1-D-19's into two 11-liter bottles. These two bottles (#11011 and #11021) still contain concentrated material which has since been assayed @ 103 gm/liter and 150 gm/liter, respectively. At the end of the 8-4 shift on Friday the two 11-liter bottles from the precipitators had been labeled and were located on the all-safe grid near the evaporator. Bottle #11021 was labeled "Conc liquor from precipitators that has been filtered" and was located in the northeast square of the grid; Bottle #11011 was labeled "OK liquor that has been filtered" and was located diagonally from #11021 in the southwest square of the grid. (See photograph, Appendix J).

At that time, Bottle #11010 was also in the grid (southeast corner) labeled "ADU filtrate" but was not in an all-safe cart. Bottle #11010 is not considered pertinent to the inquiry in view of its low-concentration contents. Bottle #11023 was in the general area, not in an all-safe cart, labeled "0003 job, mop up from around 1-D-12 pump 7/7/64". This bottle is also considered not pertinent to the investigation in view of the date and low concentration of contents. (NOTE 1-D-12 is the pickle liquor adjustment tank, the first operation after receipt of 1-2 gm/liter liquor from New Haven plant).

At the end of the 8-4 shift on 7/24/64 the 29 11-liter bottles on the production floor were located as follows:

6 On floor as overflow reservoirs - no numbers.

8 In product storage area containing TCE in some form: #2 (now #11027), no number (now #11026), #11012, #11002, no number (now #11025), #11008, #11006 and #11024.

1 In product storage area, ADU filtrate - #11015.

1 In product storage area, ADU dissolver overflow leached in HNO_3 from insulation - #11001

1 In product storage area, HNO_3 leach of ash - #11003.

5 In area of all-safe grid near evaporator, no number (now #11021, precipitator material, in all-safe cart), #11011 (precipitator material, in all safe cart), #11010 (ADU filtrate, not in cart), #11005 (old wash from evaporator in all safe cart, this bottle #11005 may have been in general storage area), no number (now #11023, spill from pickle liquor adjustment, not in cart)

G. Evaporator and Precipitator Clean Out Details - (Continued)

4. Friday 7/24/64 8-4 Shift - (Continued)

1 Near dissolver - Bottle #X, in cart (now #11020).

5 Near general storage area all-safe grid, north side of process area - no number (HNO_3 wash of dissolver filters, in all-safe cart, possibly was leaking, now #11022); #11013 (in all-safe cart, empty, no label, now contains decontamination washings); #11004 (Boiled TCE, in all-safe cart); #11007 (Stoddard solvent, not in cart); Bottle #Y (concentrated liquor from evaporator, in all-safe cart, now #11014, contains decontamination washings).

1 Empty bottle, no number (now #11028), location not known.

At 4:00 PM on 7/24/64, the plant inventory of all-safe carts totaled ten (10) carts. So far as is known, they were located as follows:

4 General storage area with bottles #11022, #11013, #11004, #Y (now #11014).

3 In storage grid near evaporator with bottles #11021, #11011, #11005* (*this cart may have been located in general storage area at 4:00 PM).

1 Near dissolver - Bottle #X (now #11020)

2 Location not known

Thus to summarize the evaporator and precipitator activities,

1. The evaporator clean out yielded three 11-liter bottles of hightly concentrated solution, Bottles #X, #Y and #11011.

2. The precipitator clean out yielded two 11-liter bottles of highly concentrated solution, Bottles #11011 and #11021.

   (NOTE: Bottle #11011 was emptied of evaporator material by Friday 1:45 PM and was then filled with precipitator material).

3. All five (5) bottles were labelled.

4. Bottle #Y was given special handling by the operator who filled and labelled it in that it was surrounded by a set of yellow stanchions and yellow rope.

5. There were no high-concentration 11-liter bottles stored in the product storage area; all bottles in that area were TCE, filtrate, or the like.

6. All high concentration (greater than 5 gm/liter) 11-liter bottles were on the process floor, rather than in the product storage area.

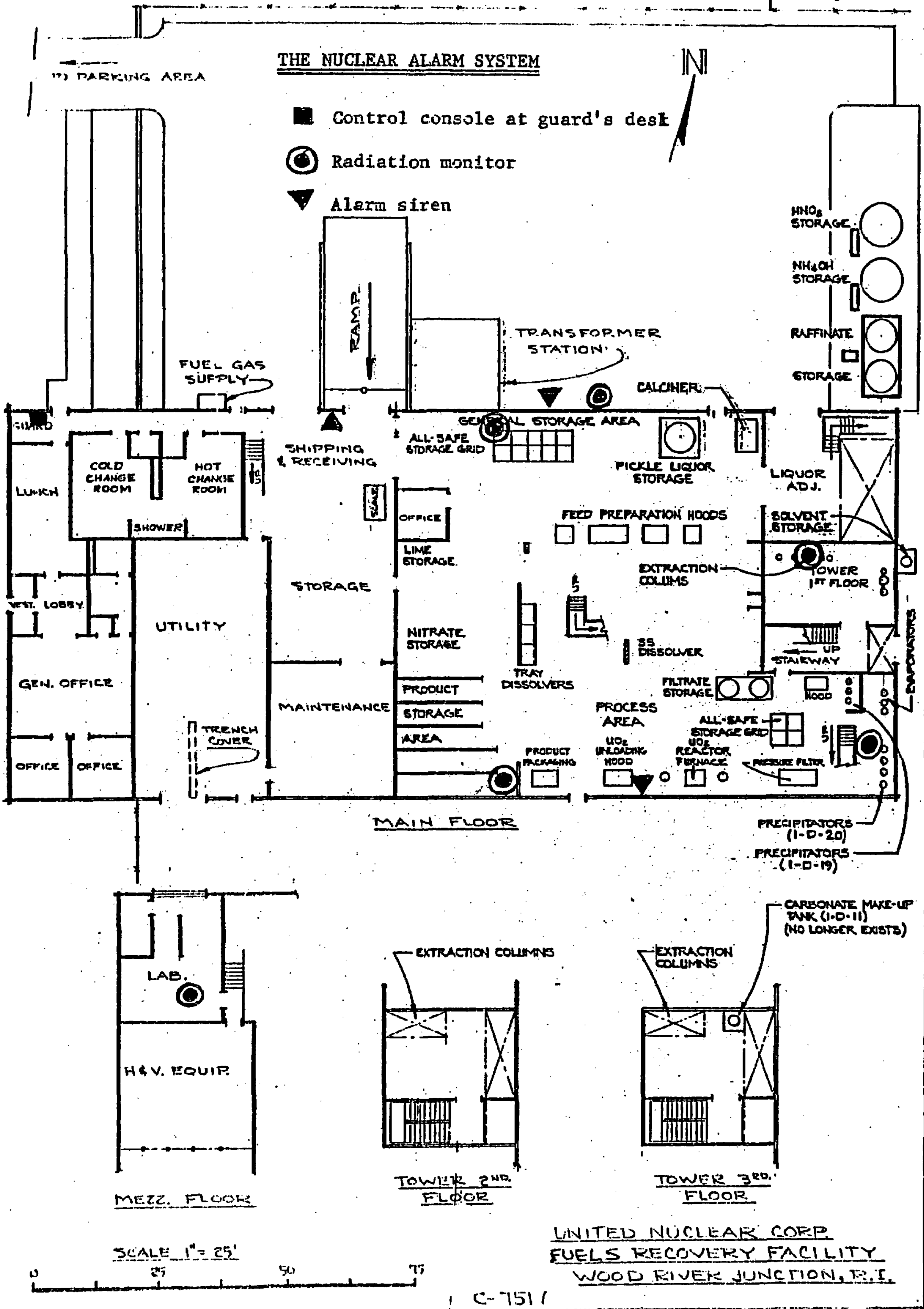
G. Evaporator and Precipitator Clean Out Details -(Continued)

4. Friday 7/24/64 8-4 Shift - (Continued)

7. These activities represented the first time that uranium solutions of such high concentrations had existed in 11-liter bottles in the production area.

H. Nuclear Alarm System

The nuclear alarm system consists of six gamma detectors which are tied into a central console in the guard station. Radiation striking any of these detectors in excess of 10 mr/hour will sound three sirens which are located inside and outside the building. Location of the detectors and sirens is shown on the following page: Additional details are found in Appendix C.


THE NUCLEAR ALARM SYSTEM
Control console at guard's desk
Radiation monitor
Alarm siren
N
TO PARKING AREA
RAMP
TRANSFORMER STATION
FUEL GAS SUPPLY
CALCINER
HNO3 STORAGE
NH4OH STORAGE
RAFFINATE STORAGE
GUARD
SHIPPING & RECEIVING
GENERAL STORAGE AREA
ALL-SAFE STORAGE GRID
PICKLE LIQUOR STORAGE
LIQUOR ADJ.
COLD CHANGE ROOM
HOT CHANGE ROOM
SHOWER
LUNCH
OFFICE
LIME STORAGE
FEED PREPARATION HOODS
SOLVENT STORAGE
EXTRACTION COLUMS
TOWER 1ST FLOOR
VEST. LOBBY
UTILITY
STORAGE
NITRATE STORAGE
SS DISSOLVER
UP STAIRWAY
EVAPORATORS
GEN. OFFICE
TRAY DISSOLVERS
FILTRATE STORAGE
HOOD
MAINTENANCE
PRODUCT STORAGE AREA
PROCESS AREA
ALL-SAFE STORAGE GRID
TRENCH COVER
UO2 UNLOADING HOOD
UO2 REACTOR FURNACE
PRESSURE FILTER
PRODUCT PACKAGING
OFFICE
OFFICE
MAIN FLOOR
PRECIPITATORS (1-D-20)
PRECIPITATORS (1-D-19)
CARBONATE MAKE-UP TANK (1-D-11) (NO LONGER EXISTS)
EXTRACTION COLUMNS
EXTRACTION COLUMNS
LAB.
H&V. EQUIP
MEZZ. FLOOR
TOWER 2ND FLOOR
TOWER 3RD FLOOR
SCALE 1" = 25'
0
25
50
75
UNITED NUCLEAR CORP.
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WOOD RIVER JUNCTION, R.I.
C-7517

III THE NUCLEAR INCIDENT

A. Shift Assignments on 4-12 Shift 7/24/64

As mentioned previously, at the time of the incident, the plant in general was engaged in re-purifying the first production lots of UO_2 which had been found by chemical analysis to contain excessive metal impurities. The first rework Lot #4101 had been fed back into the dissolvers on July 9, 1964 and by July 24, approximately 50 kgs. of the rework material was in process in the dissolver, extraction and precipitation areas.

Company personnel on duty in the plant on the second shift on July 24, 1964, include:

Supervisor C	Shift Supervisor, Chemist Age - 30 years
Operator M	Production Operator Age - 33 years
Operator N	Production Operator Age - 27 years
Operator O	Production Operator Age - 37 years
Guard X	Security Guard Age - 43 years

The Plant Superintendent and day-shift Supervisor B had left the plant at 5:00PM-5:15PM approximately one hour before the incident.

The normal work schedule for Friday second shift included operation of the pulse columns in the extraction area, precipitation of ADU (Ammonium di-uranate) in the precipitation area and dissolving of rework oxide or uranyl nitrate in the stainless steel dissolver. Some portion of the shift was also to be used for shut-down and clean-up inasmuch as the plant was on 5-day operation. At the start of this particular shift, the Superintendent called to the attention of Supervisor C that the in-process storage tanks between the extraction columns and the evaporator were almost full and that the extraction columns should therefore be shut down earlier than normal. This available time was to have been utilized in a plant clean-up somewhat more rigorous than usual.

Supervisor C was responsible for the plant operation in the absence of the Plant Superintendent. He had discussed in a general way the work to be accomplished on the 4:00 to 12:00 PM shift with the Superintendent and also with the day shift supervisor. The between-shift communication in this regard was normal and included:

A. Shift Assignments on 4-12 Shift 7/24/64 - (Continued)

1. Day-Shift Supervisor B reviewed precipitator problem with Supervisor C and Operator M; he requested that empty 1-D-20 precipitators be washed with nitric, then to use TCE to wash/rinse them.
2. Supervisor B told Supervisor C extraction system OK but to check concentration.
3. Supervisor B told Supervisor C concentration of OK liquor from extraction system into evaporator was 50 gm/liter.
4. Supervisor B suggested that pulse column TCE and carbonate probably needed changing.
5. Operator O asked Supervisor B regarding TCE level in aqueous wash column.

Operator O, the deceased, was assigned to the extraction area, which is a 3-floor tower room containing five extraction columns and peripheral equipment, including on the third floor, the sodium carbonate make-up tank which fed new carbonate aqueous solution to the solvent recovery column. No specific formal assignment had been made to Operator O by Supervisor C; in the absence of any formal assignment, Operator O would be expected to operate the extraction columns (commonly referred to as the "pulse columns") and perform related duties such as making-up carbonate, dumping raffinate waste from the extraction column, washing TCE, etc. On this particular shift he was also to assist in starting up the evaporator which had recently been inoperative as discussed previously.

Operator M was assigned to the precipitation area where a batch of the rework material was in the (1-D-19) precipitators. His normal scope of responsibility included operation of the precipitators where ADU is precipitated and filtered from solution. He was also responsible for the evaporator which concentrates "OK" liquor from the pulse columns. The precipitation area is immediately adjacent to the extraction tower area.

Operator N was assigned to the dissolver area where the task was the dissolving of rework oxide or uranyl nitrate by the addition of nitric acid in the stainless steel dissolver.

Sometime near 6:00 PM on 7/24/64, Operator O had asked Supervisor A whether he should wash some TCE and was told that the TCE was to be used to wash down the 1-D-20 precipitators in an attempt to remove the black organic-type material previously mentioned. To rinse the precipitators, the TCE was not to be washed; the Supervisor's instruction thus implied "No clean TCE is required for this task".

B. Description of the Incident at 6:06 PM

The following describes the postulated activities of Operator O, the victim, immediately preceeding the nuclear excursion.

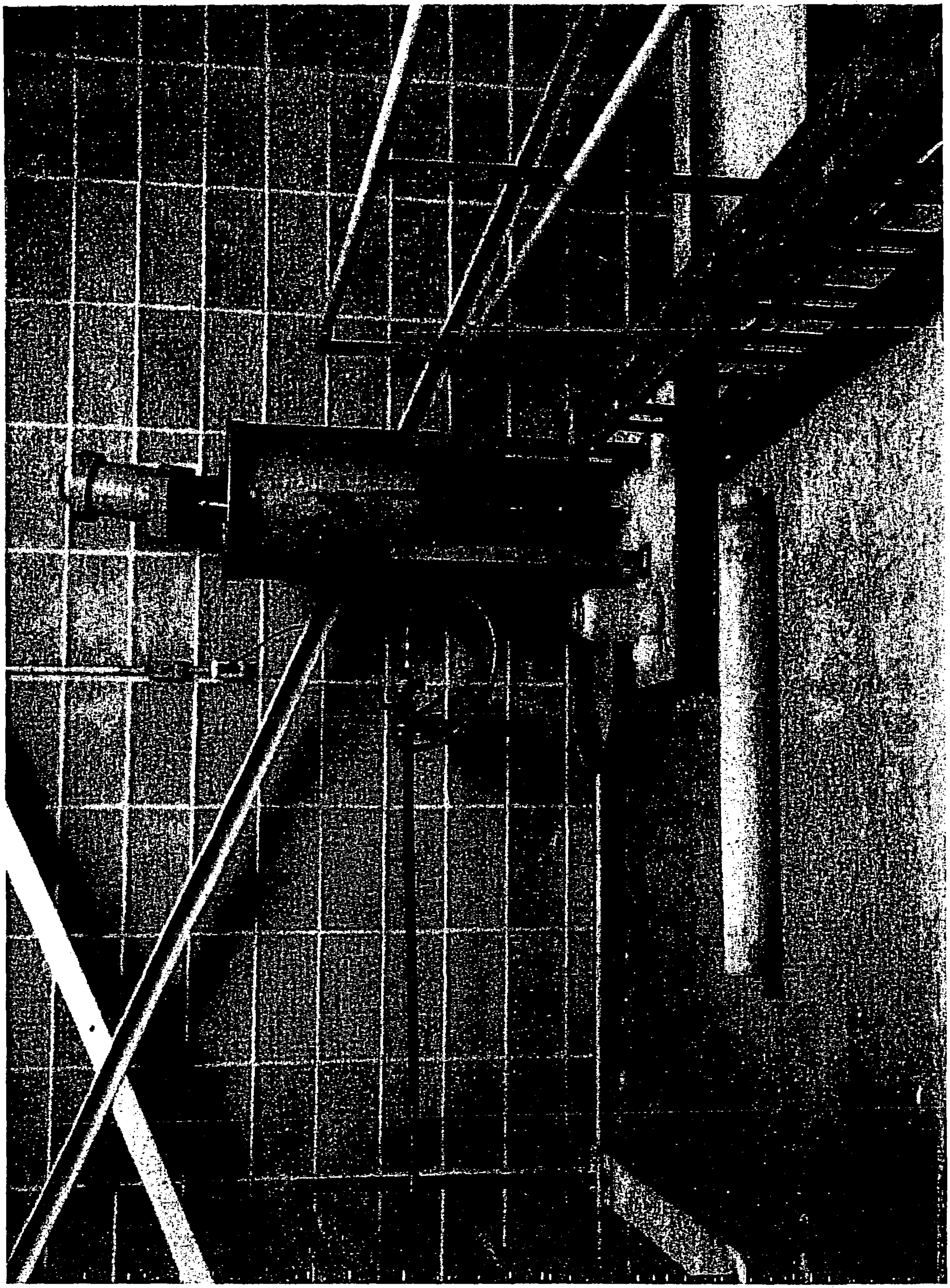
B. Description of the Incident at 6:06 PM - (Continued)

Having asked Supervisor C about whether he should wash TCE and having been told (implicitly or explicitly) that it was not necessary, Operator O nevertheless apparently set out either to wash TCE or to obtain an empty bottle. He reviewed the contents of the 11-liter bottles in the product storage area, most of which contained contaminated TCE that had been assayed at up to 700 gm/liter. In the northside storage area there was one bottle containing TCE (#11004) not assayed and also an empty bottle (#11013) in addition to Bottle #Y containing the high-concentration evaporator solution.

Operator O apparently went to the north side general storage area to locate a bottle of TCE with the intention of washing it in the third floor carbonate tank by the procedure described previously. He accidentally selected bottle #Y containing evaporator solution, transported it to the tower stair well in an all-safe cart, and hand carried the bottle to the third floor. Apparently, he also transported Bottle #11005 to the stairwell. The all-safe cart containing that bottle had to be moved from the doorway between the precipitator and stairwell when personnel later entered the plant. Bottle #11005 contained "wash from evaporator", since analyzed at 1/2 gm/liter in TCE phase and 18 gms/liter in aqueous.

The nuclear-critical incident was caused by Operator O pouring a high-concentration (200-400 gm/liter estimated) uranium solution from a manually-held 11-liter all-safe bottle into the 18" diameter not safe stainless steel carbonate make-up tank. (See photo following). The tank, at the time, contained approximately fifteen (15) gallons (57 liters) of aqueous sodium carbonate solution. The valve at the bottom of the tank (on the third floor) was open; the valve on the line at the second floor was closed. The Lightning mixer was turned on and the nearby pulse columns were operating at the time.

The lip of the carbonate tank is 60" above the floor and to accomplish the pouring of approximately 35 lbs. of solution, Operator O apparently cradled the bottle across his left arm or hand and poured into the vessel by raising the bottom of the bottle with his right hand. The excursion did not take place until the bottle was essentially empty. At that time the geometry of the material involved would have been approximately 67 liters of material in an 18" diameter cylindrical array with vortexed top surface containing at least 2 kgs. of Uranium 235. A solid precipitate of uranium may have formed prior to the incident and may have been perceivable by its characteristic yellow color.



Third Floor Carbonate Makeup
Tank After Incident.
(Bottle was removed from
tank during re-entry).

B. Description of the Incident at 6:06 PM - (Continued)

The excursion caused the system to flash and solution and yellow precipitate were expelled at least 12 feet into the air. Operator O was "thrown back" from the vessel in such a manner as to leave the 11-liter plastic bottle upended at an angle in the vessel, mouth down, tank agitator still on. The radiation from the nuclear-critical incident activated all six gamma detectors which were located between 25 and 140 feet from the excursion. They were set to be activated by gamma radiation of 10 mr/hour.

The best estimate of time of criticality is 6:06 PM on July 24, 1964, two hours after the start of the shift. At that time, the other in-plant personnel were located as follows:

1. Supervisor C was on ground level near stainless steel dissolver (55-65 feet away).
2. Operator O was on the third floor at carbonate make-up tank (0-4 feet away).
3. Operator M was near 1-D-19 precipitators (40-50 feet away).
4. Operator N was near second level of stainless steel dissolver (40-50 feet away).
5. Guard X was at guard's desk (160-170 feet away).

IV ACTIVITIES SUBSEQUENT TO THE INCIDENT

A. Evacuation of the Plant and On-Site Operational Controls

The following section of this report sets down an approximate chronology on the chain of events starting at 6:06 PM on July 24, 1964, and ending 8:00 PM on Monday, July 27, 1964.

1. Evacuation of the Plant

At the sounding of the nuclear alarm at 6:06 PM, the company personnel in the plant (five) immediately evacuated per the United Nuclear Emergency Procedure. The evacuation routes used by the five persons is shown on the following page. All personnel arrived at the emergency shack, 450 feet southwest of the plant by 6:10 PM (estimated). Operator "O" removed all his clothing enroute to the emergency shack leaving the clothes south of the building inside the perimeter fence. The first actions upon entering the shack were to:

a. Notify company, medical, AEC and state officials that incident had occurred.

b. Minimize or prevent further exposure and contamination.

2. Notification of Officials

Between 6:10 PM and 6:25 PM, Supervisor "C" notified officials as follows:

Plant Superintendent, then in Wakefield, R.I.

Plant Physician for United Nuclear manufacturing facility in New Haven, Conn.

Mr. R. C. Johnson, Acting Manager Chemical Operations, United Nuclear Corporation, company superior of the Plant Superintendent.

Hope Valley, R. I. ambulance corps.

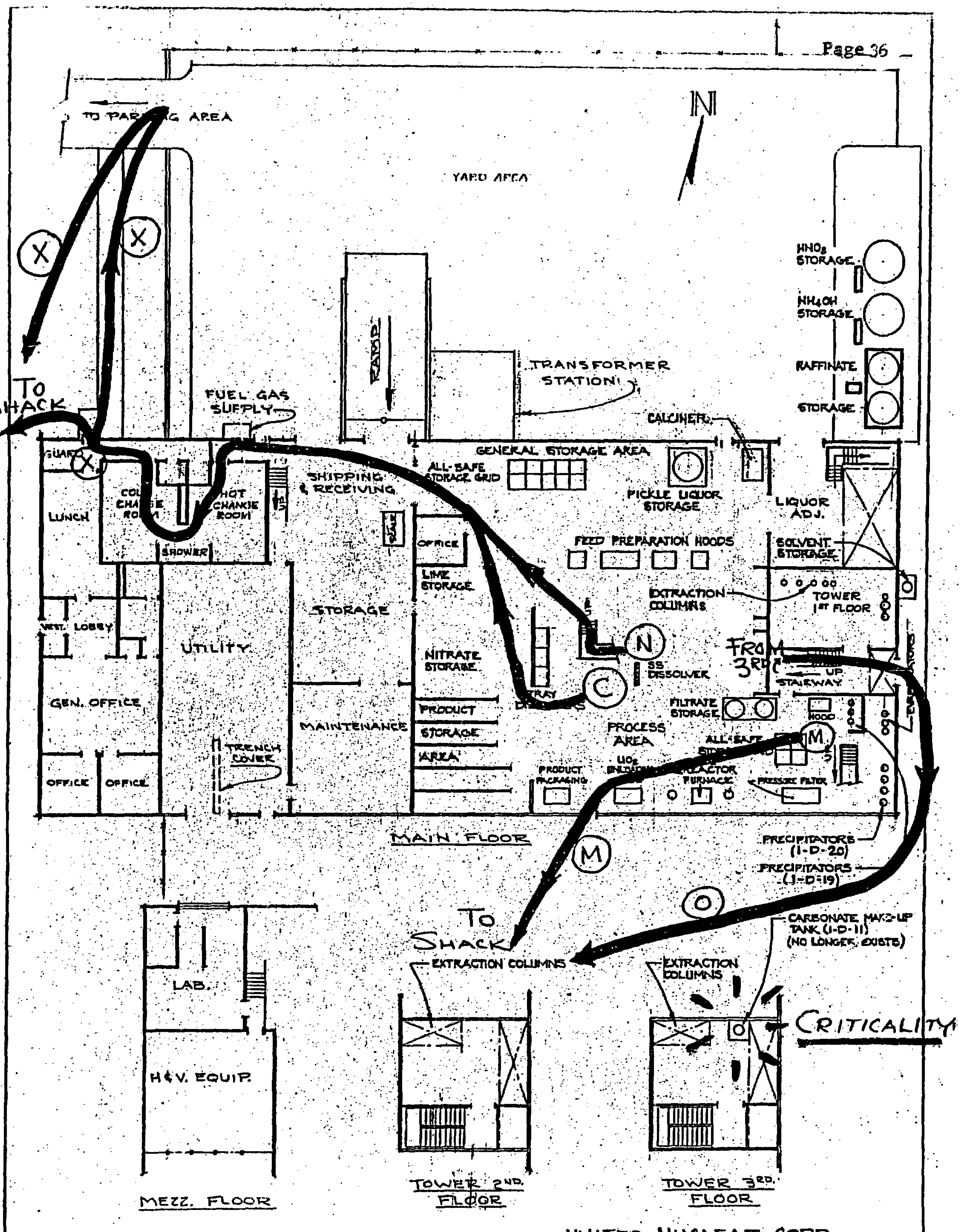
The above notified officials in turn notified other parties as tabulated below:

Rhode Island State Police, Hope Valley Barracks

Providence (R.I.) Hospital admitting office, Dr. Judkins.

Mr. R. D. Bokum, President, United Nuclear Corporation, Centerville, Maryland

Mr. N. Woodruff, Atomic Energy Commission, Washington, D. C.



UNITED NUCLEAR CORP.
FUELS RECOVERY FACILITY
WOOD RIVER JUNCTION, R.I.

C-7517

A. Evacuation of the Plant and On-Site Operational Controls - (Continued)

2. Notification of Officials - (Continued)

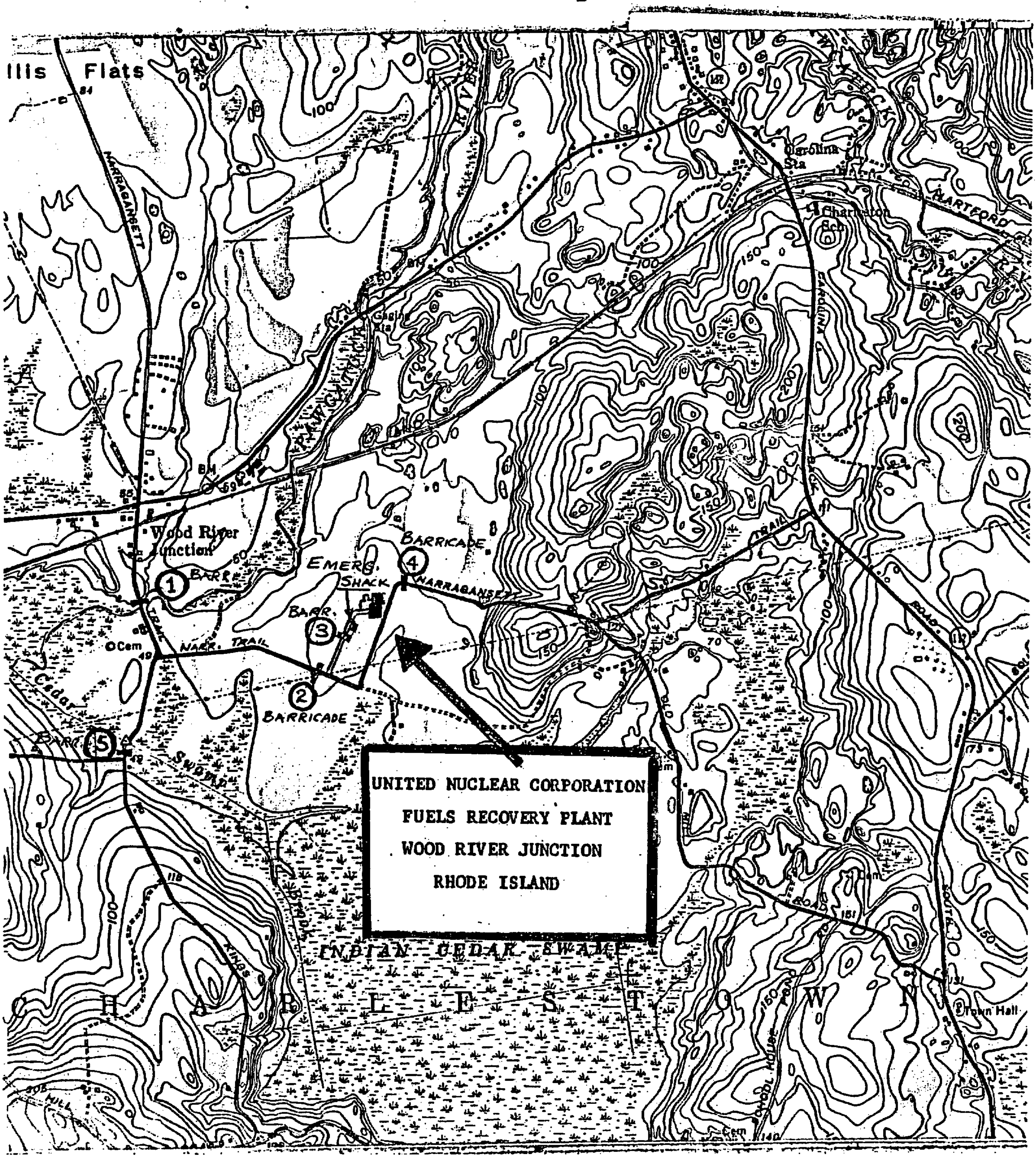
The telephone calls listed on Page 35 comprised the notification to all responsible functions that the incident had occurred; no attempt is made in this report to catalog the many additional phone calls, incoming and outgoing, made in the next twelve (12) hours.

3. Events between 6:10 PM and 12:00 Midnight, July 24, 1964

While Supervisor "C" made telephone contact, the other plant personnel had provided Operator "O", the victim who had arrived naked at the emergency shack, blankets where he was lying on the ground near the shack. Operator "O" started to vomit almost immediately and between 6:10 PM and approximately 6:50 PM when he left the scene by ambulance, he was intermittently vomiting, bleeding and had cramps. Twice in that period he arose unassisted, once returning to the blanket unassisted, once being returned to the blanket. He spoke very little during this period, none of it regarding the incident per se. At approximately 7:00 PM, Operator "O" was removed by ambulance to Rhode Island Hospital, Providence, R.I., approximately forty (40) miles away, where he was admitted at 7:45 PM. In the ambulance with him, were Operator "M" and two ambulance operators; Operator "M" sat in the back of the ambulance with Operator "O" and the two (2) contaminated blankets accompanied them in the ambulance. Additional medical comments are made in Section IV.G of this report.

Each person who had been in the plant at the time of the incident made out a map of his evacuation route; Operator "M" made one for Operator "O". The first "outsider" to arrive at the plant was the Plant Superintendent at approximately 6:45 PM. His car served as an additional barricade across the primary access road. Barricades had been set up by company personnel across the access roads at three (3) locations, approximately 1000 feet from the site of the incident. (See map - Page 38). A bridge under repair (Barricade 1) also served to prevent access. Later Barricade 5 was established by Rhode Island State Police. Arrival of other persons on the scene was as follows:

6:45 PM	Plant Superintendent
7:00 PM	Ambulance Operators
7:10 PM	Local plant doctor
7:15 PM	Rhode Island State Police and Charlestown Police personnel
7:25 PM	New Haven plant physician
7:30 PM	Charlestown Chief of Police


UNITED NUCLEAR CORPORATION
FUELS RECOVERY PLANT
WOOD RIVER JUNCTION
RHODE ISLAND
Wood River Junction
Flats
NARRAGANSETT
Carolina Sta
Charlestown Sch
HARTFORD
BARRICADE
BARR.
EMERG. SHACK
NARRAGANSETT
NARR. TRAIL
TRAIL
BARRICADE
BARR.
Cedar Swamp
INDIAN CEDAR SWAMP
CHARLESTOWN
Town Hall
SCHOOL HOUSE ROAD
ROAD
ROUTE
1
2
3
4
5

A. Evacuation of the Plant and On-Site Operational Controls-(Continued)

3. Events between 6:10PM and 12:00 Midnight, July 24, 1964 (Continued)

7:30 PM	S. Amato, Rhode Island State Radiological Officer and A. D'Ameglio, Director of Operations, Rhode Island Reactor
8:30 PM	R. Johnson, United Nuclear
8:40 PM	Additional Charlestown Police personnel
8:45 PM	E. Barton, United Nuclear health physics technician
10:00 PM	United Nuclear health physics specialists (2) and accountability specialists (2)
10:50 PM	Supervisor "A"
4:00 AM	NYOO, AEC personnel, etc.

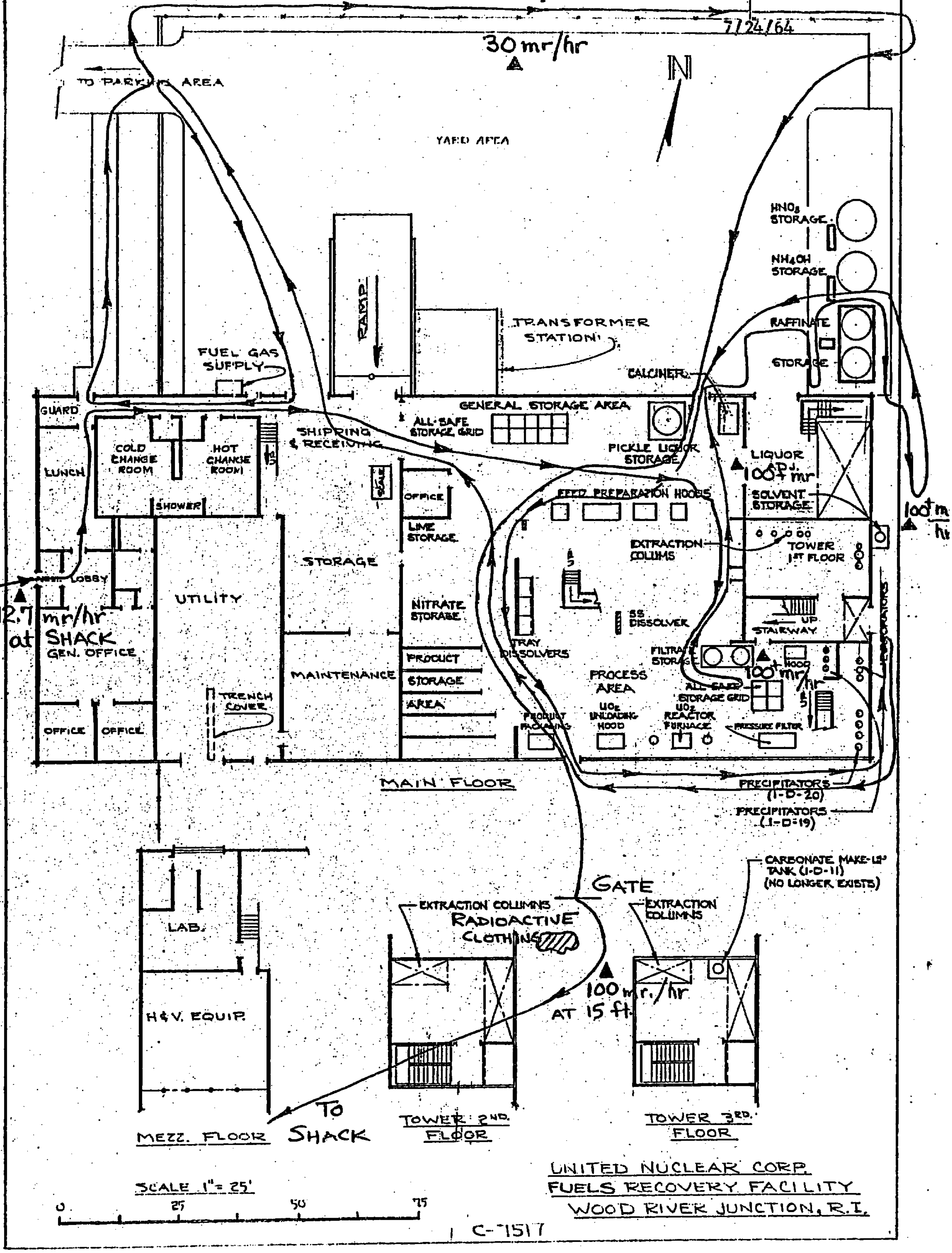
4. Re-entry into the Plant

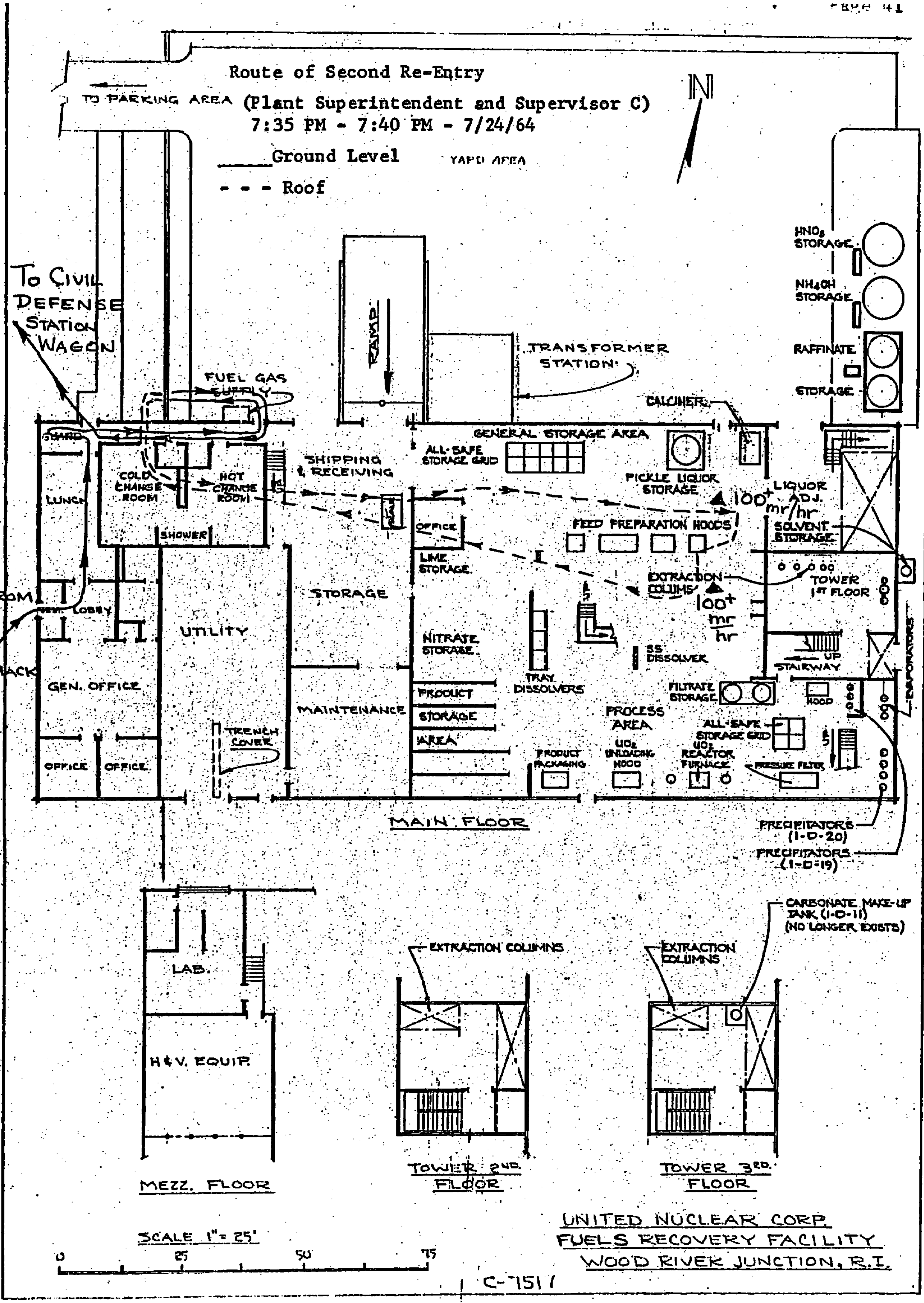
Operator "M" having accompanied Operator "O" to the hospital, the salient activity at the site between 7:00 PM, Friday 8/24/64 and 8:00 AM 7/25/64 included continuous monitoring of the vicinity and the re-entry into the plant to assure nuclear safety. The re-entry is detailed below:

At about 7:15 PM, the first beta/gamma instrument survey of the area was conducted by the Plant Superintendent in order to establish the "100 mr. boundary". The first (ground level) re-entry followed the path shown on Page 40; the exhibit also shows the approximate radiation levels that were seen by the beta/gamma instrument used. It is noted that "beams" of higher intensity radiation extended from the open doors surrounding the tower incident area. It is also noted that the 100 mr. level extended approximately 15 feet from the victim's clothing in the south yard area. Having established that in and around the extraction tower area the radiation activity was higher than 100 mr/hour, the limit of the instrument, the Plant Superintendent returned to the emergency shack. Time of first re-entry was 7:15 PM until 7:25 PM, a total elapsed time of 0.2 hours, apparently none of it at a higher exposure rate than 100 mr/hour. No film badge was worn for the first re-entry.

The second (roof level) re-entry was made by the Plant Superintendent and Supervisor "C", the former wore his regular beta/gamma film badge, the latter an idium foil badge. The path of second re-entry is shown on Page 41. This roof survey verified the first survey and established that the tower area was no more accessible by roof than by ground level. The time of the second re-entry is estimated to be 7:30 PM to 7:40 PM, no penetration of the 100 mr. boundary was attempted or effected.

ROUTE OF FIRST RE-ENTRY - Plant Superintendent 7:15 PM - 7:25 PM





Route of Second Re-Entry
(Plant Superintendent and Supervisor C)
7:35 PM - 7:40 PM - 7/24/64
Ground Level
- - - Roof
TO PARKING AREA
YARD AREA
N
To Civil Defense Station Wagon
From Shack
FUEL GAS SUPPLY
GUARD
LUNCH
LOBBY
GEN. OFFICE
OFFICE
OFFICE
COLD CHANGE ROOM
HOT CHANGE ROOM
SHOWER
UTILITY
TRENCH COVER
SHIPPING & RECEIVING
RAMP
TRANSFORMER STATION
STORAGE
MAINTENANCE
OFFICE
LIME STORAGE
NITRATE STORAGE
PRODUCT STORAGE AREA
ALL-SAFE STORAGE GRID
GENERAL STORAGE AREA
CALCINER
PICKLE LIQUOR STORAGE
100+ mr/hr
FEED PREPARATION HOODS
EXTRACTION COLUMS
100+ mr hr
TRAY DISSOLVERS
SS DISSOLVER
PROCESS AREA
FILTRATE STORAGE
PRODUCT PACKAGING
UO_2 UNLOADING HOOD
UO_2 REACTOR FURNACE
ALL-SAFE STORAGE GRID
PRESSURE FILTER
HOOD
HNO_3 STORAGE
NH_4OH STORAGE
RAFFINATE STORAGE
LIQUOR ADJ.
SOLVENT STORAGE
TOWER 1ST FLOOR
UP STAIRWAY
EVAPORATORS
MAIN FLOOR
PRECIPITATORS (1-D-20)
PRECIPITATORS (1-D-19)
LAB.
H&V. EQUIP.
MEZZ. FLOOR
EXTRACTION COLUMNS
TOWER 2ND FLOOR
EXTRACTION COLUMNS
CARBONATE MAKE-UP TANK (1-D-11) (NO LONGER EXISTS)
TOWER 3RD FLOOR
SCALE 1"= 25'
0 25 50 75
UNITED NUCLEAR CORP.
FUELS RECOVERY FACILITY
WOOD RIVER JUNCTION, R.I.
C-7517

A. Evacuation of the plant and On-Site Operational Controls (Continued)

4. Re-entry into the Plant - (Continued)

The decision was also made not to enter again without a counter which could read over 5 R/hr.

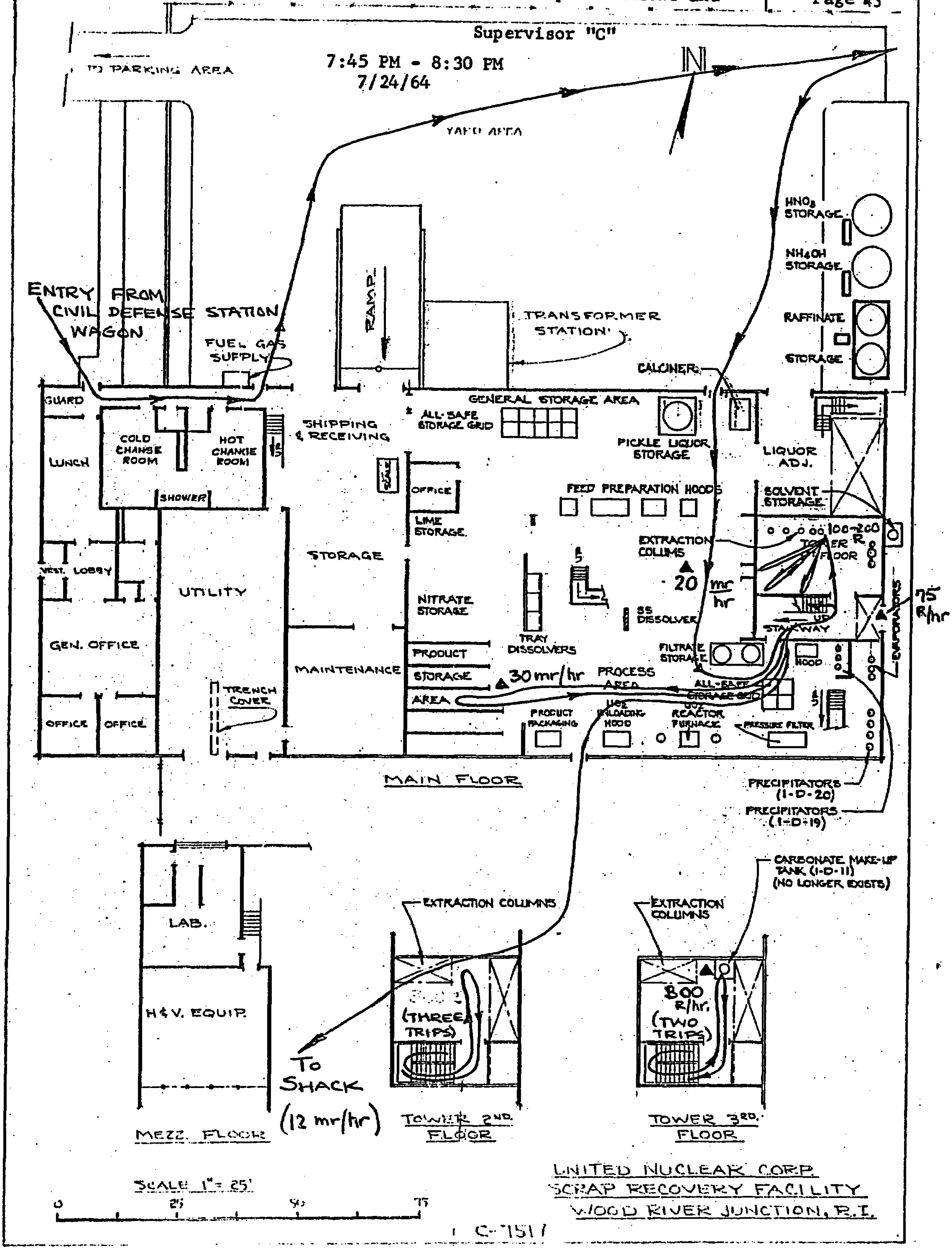
By this time (1-1/2 hours after criticality), Rhode Island State Civil Defense officials had arrived with higher range beta/gamma detectors. At 7:45 PM, the Superintendent and Supervisor "C" made the third re-entry with the objective of making the plant safe if radiation levels permitted and the State Officials accompanied them to take radiation readings. The path of the third re-entry is shown on Page 43.

The Superintendent and Supervisor "C" stayed together for the majority of the third re-entry; the State Officials did not enter the building but observed levels of 75 R/hour at the door of the tower. To make the plant safe from possible further criticality, the objective of the third re-entry was to drain all material from the 18" diameter unsafe carbonate tank into all-safe column 1-C-9. This material transfer also required that the 1-C-9 material be drained from that column prior to introduction of any material from the carbonate tank. At this time (7:50 PM estimated) they were able to view the site of the incident as left by Operator "O". They noted the 11-liter bottle in the tank with the open end down. The valve immediately below the carbonate tank was open and yellow liquid and precipitate were evident on the floor, ceiling and walls.

The Superintendent approached the tank, lowered the bottle to the floor and shut off the agitator. On the 500 R scale, no significant reading on the instrument was seen until it was held over the edge of the tank at which time it read 200-300 R/hour. They then proceeded to the second level where they noted that the valve below was closed and that the tubing between the valve and the funnel to 1-C-9 was in place. They proceeded to the first floor and proceeded to drain the 1-C-9 column into 4-liter jars by holding the jars at the drain valve. These jars were dispersed around the tower first floor area. All handling of the liquid into bottles was done by Supervisor "C".

When the material normally in the 1-C-9 column had been drained, the Superintendent returned to second level and opened the valve at the bottom of the piping from the 1-D-11 carbonate tank. When he did so, nothing drained out and he therefore went to the third level and re-started the agitator. From that point on, the Superintendent was on all three levels and Supervisor "C" on the first level only. They were both occupied in draining the 30-40 liters of irradiated material that remained into volume-safe 4-liter jars. This

ROUTE of THIRD RE-ENTRY - Plant Superintendent and Supervisor "C"



A. Evacuation of the Plant and On-Site Operational Controls-(Continued)

4. Re-Entry into the Plant - (Continued)

period of time included forays from the tower area into the product storage area for the purpose of obtaining additional empty jars. The draining of the column and tank included a dropped bottle (first level) and dropped tubing (second level); each occurrence resulted in spillage of irradiated material. The make-safe operation was concluded by a final trip to the third level to assure that the carbonate tank was empty of material, then visual assurance at the second level that all the irradiated material had come down into all-safe geomentry. Immediately thereafter, they left the plant, having shut down the pumps in the pulse column area, the steam to the evaporator, the flows of material to the columns; evaporator feed was not turned off resulting in an over-flow condition which was corrected later in the evening. The third re-entry occupied 45 minutes from 7:45 PM - 8:30 PM of which 20 minutes had been spent in the building.

The make-safe operation yielded 12 gallon jugs of material, eight (8) of which were deposited in tower first level area and four (4) of which were deposited along the south bay all-safe line. (See photo - Appendix H). The material as drained was a slurry of yellow precipitate which later (by 7/27/64) had settled out of solution so that a clear yellow supernatant liquid and an interface were apparent. The material retained in the 1-C-9 column was similar in appearance. (See photo - Appendix K).

5. Personnel Treatment

Personnel who had been in the plant or had re-entered were closely monitored and contaminated clothing was removed. The radiation levels in the west (office, change room) part of the plant by this time (C + 2-1/2 hours) was reduced to ~ 20 mr/hour and the decision was made for personnel to shower in the plant rather than risk contamination of the police barracks. Operator "M", Guard "X", Supervisor "C" (who had been in the plant at criticality) and the Superintendent showered and changed clothes before being taken to the Rhode Island Hospital by State Police for medical checks at approximately C + 4 hours.

Following additional scrubbing at the hospital, all personnel except Operator "O" were released and returned to the plant in the same police car. Activity during the remainder of the night included:

a. Press release shortly after midnight.

b. Re-entry by Supervisor "A" and health physics technician to turn off feed to evaporator and stop overflow onto floor.

c. Monitoring the plant area and surrounding environment.

A. Evacuation of the Plant and On-Site Operational Controls-(Continued)

6. Levels of Radiation Immediately After Incident

The first radiation readings taken after the gamma alarm system was activated at 6:06 PM on 7/24/64 were taken by Supervisor "C" on the 100 mr. instrument at the emergency shack. At C + 5 minutes, levels of 90-100 mr./hour were read, at C + 10 minutes the level was 50-60 mr./hour. By C + 30 minutes the levels at the shack were 10-20 mr./hour and that level apparently continued for some two (2) hours. The shack is located approximately 450 feet from the incident.

In the plant as described previously, levels were less than 100 mr./hour at C + 2 hours except in the vicinity of the tower where levels of 75 R/hour were in evidence. At C + 3 hours the indicated level at the emergency shack was still at 12 mr./hour and when approaching the building that level appeared to be constant as checked on more than one instrument. At C + 9 hours the level at the emergency shack was down to 2-3 mr./hour.

7. Activities on Saturday, 7/25/64 and Sunday, 7/26/64

By Saturday 1:00 PM (C + 19 hours) the office area of the plant had been cleaned, monitored and released for occupancy. Decontamination by washing was continued throughout the west part of the plant so that the laboratory, stores, utility areas could also be released for occupancy on 7/25/64.

During this period, health physics monitoring was continued by means of direct instrument readings of radiation levels and smear surveys and air samples. Due to the possible interference because of high background, air samples were transferred to Narragansett Reactor Station (Rhode Island Reactor) for reading by United Nuclear health physics personnel.

No access to the high-radiation area was permitted by anyone on 7/26/64 pending the start of decontamination by a formally organized decontamination squad on Monday, 7/27/64. United Nuclear Vice-President, J. A. Lindberg, had been in charge of activities since his arrival Saturday morning. AEC representatives continued to arrive 7/25/64 and 7/26/64. The primary AEC effort at this time was health physics monitoring of radiation levels and contamination.

B. Establishing the United Nuclear Investigational Task Force

At 8:00 AM on Monday, 7/27/64, a company task force was formally established to:

1. Investigate and report on the cause of the incident.
2. To control entrance to the plant until it was decontaminated.
3. To decontaminate the plant.
4. To provide health physics and medical controls.
5. To provide communications with the public and other interested functions.

Technical experts including Dr. M. Shapiro, Dr. A. Edelmann and Mr. P. Clemons had arrived from other United Nuclear sites and from outside consulting agencies. Dr. Shapiro headed up the nuclear investigation. R. Johnson was named acting plant manager. An independent investigation by AEC was also underway by 7/27/64 including primarily personnel from Region I, New York Operations Office but also representatives from Washington, D. C.

C. <u>Methods of the Investigation</u>

The methods of collecting data for the investigation included:

1. Survey of the entire plant to observe conditions as left by the incident. Photographs were taken.
2. Collection of samples from several categories of material including the residue of the material that had gone critical.
3. Observation of labels, tags, spills and location of bottles, carts, etc.
4. Collection of hardware samples (Coins, screwdriver, hoseclamp, watch, etc.) for activation studies.
5. Collection of film badges and blood and urine samples.
6. Performing material balances.
7. Interviewing personnel.
8. Review of process documents and logs, data sheets, etc.

All interviews were taped and later transcribed.

The decontamination effort was deliberately controlled so that evidence would not be destroyed. No uranium-bearing material was moved in the plant until its relevance to the incident had been established. On the other hand, health physics personnel controlled all entry to the radiation area and constantly monitored contamination and exposure.

The basic method used for investigating the nuclear aspects was, of course, activation studies of all possible material. In addition to the empirical measurements, theoretical calculations were performed to establish the amount of uranium needed for the system to go critical.

D. Methods of Decontamination

The criteria for decontaminating the plant were established as:

2000 dpm removable alpha

2000 dpm removable beta/gamma

666 dpm per cubic meter airborne beta/gamma

220 dpm per cubic meter airborne alpha

Continuous monitoring of radiation levels and contamination was performed in plant and the surrounding environment.

Methods of decontamination included water wash, water and detergent wash, nitric acid wash, permanganate wash, tile removal, material removal from plant for safe storage and disposal and storage of non-disposable material in shielded environment. Rate of decay was taken into account, in particular regarding the walls and concrete floors in tower where some radioactivity was subsurface and therefore essentially fixed. The methods of fixing such radiation which was not removable included painting and retiling. Fixing was employed only in tower area and only for concrete surfaces. The uranium-bearing wash solutions were stored in 4-liter plastic jugs until chemical analysis permitted consolidation into plastic lined 55-gallon drums under controlled conditions.

The decontamination proceeded from "clean" to "dirty" areas. Cleaned areas were released but kept clean by personnel control. Decontamination control points and degrees of protective clothing required were set up at three (3) primary points in plant. Supplies of clean shoe covers were located at required points in plant.

The material which had gone critical and had later been drained from the carbonate make-up tank through the solvent recovery column, was placed in 4-liter jars which were stored in shielded storage rack. The material left in the column was also drained by decontamination personnel on C + 5 days into 4-liter jars. Removal of this material to a shielded environment significantly reduced radiation levels in the plant.

E. Results of Decontamination

Representative radiation and contamination levels at site at various times after criticality are tabulated below and compared to later levels.

Date	Time	Location	Radiation (mr per hour)	Contamination Alpha (dpm)	Contamination Beta-Gamma (dpm)
7/24	C+2 hrs.	Shack	10-20		
		Process area	100		
		Tower 1st	50,000-75,000		
7/25	C+18hrs.	Office	<0.4		
		Process area	50		
		Tower 1st	100-200		
		Tower 3rd	250-300		
7/27	C+3 days	Process area		24,000	120,000
7/30	C+6 days	Tower 3rd		21,098	577,000
8/1	C+8 days	Tower-3rd		3,700	54,000
		Process area		13,300	10,300
8/5	C+12 days	Tower-3rd floor	20		
		Tower-3rd curb	100+		
		Process area	1-2	4,700	3,900
		Tower-3rd (unwashed concrete)		14,000	45,760
		Tower-3rd (washed concrete)		7,500	45,000

By 8/13/64 (C + 20 days), the plant had been decontaminated, except for localized areas, to the cleanliness criteria established by the task force.

E. Results of Decontamination - (Continued)

The reduction in radiation levels in the third floor tower are shown graphically on the following page.

No specific decontamination of the environment was performed other than decontamination of vehicles involved. At C + 3 days the highest level of radiation at the perimeter fence was 0.2 mr/hour. Monitoring of 21 vehicles indicated that only the ambulance had been contaminated. That vehicle was decontaminated early Saturday morning, 7/25/64, by United Nuclear personnel, monitored by United Nuclear and State Officials and released. No off-site building other than the Providence Hospital required decontamination. Decontamination of the hospital was performed by hospital authorities and no details are available here.

Effectiveness of decontamination in reducing contamination of the plant are shown in Appendices G-1, G-2.

Air sampling in the tower third floor area is shown in Appendix G-3. The rise in airborne activity reflects the increased decontamination activity in the area which resulted in a peak at the time the tile was removed.

V. Health Physics Aspects

At the time of the incident there were five (5) people in the plant. In addition to those five, two (2) additional people were significantly exposed, the Plant Superintendent and the plant Health Physics technician. All other personnel were off-site and did not receive significant radiation from the excursion. The exposures of these seven (7) people are tabulated on Page 51A of this report entitled "Radiation Exposures: and in Appendix F

In the period since the incident, the health physics controls have included the continuous monitoring of the area plus maintenance of accumulative dosimeter readings for all personnel involved. The greatest accumulative amount of radiation received since 7/25/64 is 166 millirems per dosimeter readings received by one of the decontamination squad from handling the irradiated material in bottles when contact readings indicated 1-2 R/hour.

Entry into the plant was permitted by the security guard only upon an authorized health physics signature from 7/27/64 until 8/11/64. Dosimeters were in use until 8/7/64.

Health physics control of environment surrounding the plant included the taking of 75 environmental samples (water, soil, mud, telephone smears, etc.) between the time of the incident and 8/8/64 (C + 15 days). The locations of the samples in effect duplicated the April 1963 environmental survey performed by United Nuclear. Not all of these samples have been counted but all results to date fall within the range of the pre-operational survey. The post incident environmental survey conducted by the Rhode Island State Department of Health on July 26, 1964 (C + 2 days) indicates post-incident levels within the range established before the plant was operational.

The first air sample was taken at approximately C + 3 hours and showed no significant positive findings. However, based on radiation levels at the emergency shack within minutes after the incident and based further on finding uranium precipitate deposited in the exhaust fan which was operating on the roof directly over the excursion, it is concluded that some radioactivity may have been released to the atmosphere with the first few minutes. The air sample results at C + 3 hours indicate that the radioactivity was rapidly dispersed and the post-incident environmental surveys substantiate that conclusion.

EXTERNAL EXPOSURES TO RADIATION

Personnel Identification	Exposure	Basis
1. Operator "O"	>700 rems. gamma 2000-4800 rads.	Film badge dosimetry Blood sodium
2. Superintendent	50 rems. gamma(1)	Film badge dosimetry
3. Supervisor "C"	50 rems. gamma(2)	Assume gamma exposure equal to Superintendent
4. Operator M"	2.5 rems. gamma	Film badge dosimetry
5. Operator "N"	3.5 rems. gamma	Film badge dosimetry
6. Guard "X"	270 millirems gamma	Film badge dosimetry
7. Health Physics Technician	1.8 rems. gamma	Estimated based on known radiation levels and exposure times.

(1) Possibly also exposed to neutrons, dose unknown.

(2) Possibly also exposed to neutrons, dose unknown, but less than Superintendent.

G. Medical Aspects

1. Operator "O", the Victim

The initial symptoms of exposure to radiation appeared within minutes in the case of Operator "O". Vomiting, headache, bleeding, chills and abdominal pains were apparent within one hour after the exposure. Upon admission to the hospital, blood pressure was 160/180, pulse was 100 and breathing was 20 respirations per minute. Therapy was started immediately upon admission to the hospital at C + 1 hour, 40 minutes. (Westerly Hospital, some minutes closer than Providence Hospital, had been unable to admit him as a patient due to the fact that no beds were available.)

Instrument readings at C + 4 hours were 40 mr./hour at a distance of two feet from victim's chest and face and 10 mr./hour at a distance of two feet from lower extremities. Counts of body fluids yielded the following results:

Urine specimen	C + 4 hours - 4 ccs	124,000cpm
	C + 6 hours - 4 ccs	62,200cpm
Blood	C + 6 hours - 8 cc	82,400cpm
Vomitus	C + 5 hours - 8 cc	68,700cpm
Gastric tube drainings	C + 7 hours - 16 cc	66,800cpm

Blood pressure continued to drop and the left hand exposed to greatest radiation began to swell on 7/25/64. The patient died at 7:20 PM on July 26, 1964, a little over 49 hours after the exposure. Details regarding increased white blood count, unchanged platelet count, bilirubin and uric acid increases, etc., may be found in the hospital report.

2. Other Exposed Personnel

Medical examinations were made at approximately C + 6 hours of the Plant Superintendent, Supervisor "C", Operator "M", Operator "N" and Guard "X". They were released and returned to the site to assist in decontamination. On 7/25/64, the local plant physician performed thorough physical examinations on Health Physics Technician "T", Supervisor "C" and the Plant Superintendent. These initial examinations revealed no deviations from normal.

The initial report by Landauer on the film badge worn by the Plant Superintendent when he re-entered the plant, indicated that he had received 400 R. This figure was later revised (11:00 PM 7/26/64) to 50 R. However, because of this erroneous high reading, he was admitted to Rhode Island Hospital for observation on 7/26/64. Supervisor "C" who had accompanied the plant Superintendent when he re-entered the

2. Other Exposed Personnel - (Continued)

plant was also admitted. Although no film badge reading was available for him, it was considered that he could have received the same dose as the plant Superintendent.

Supervisor "C" and the Superintendent were released on Friday, July 31, 1964, because no positive findings were obtained. They were completely symptom free except for slight rises in bilirubin and uric acid which returned to normal (Supervisor "C") or showed a minimal rise (Plant Superintendent) by the time of discharge. Bone marrow, blood and urine studies were completely negative except for the above mentioned bilirubin and uric acid. Blood samples were drawn for chromosome studies. Upon request of Oak Ridge National Laboratory, 24-hour urine samples were sent for analysis. Aliquots were removed for hospital studies and for radioactivity measurements by Nuclear Science and Engineering Corporation.

July 30, 1964 (C + 6 days) Supervisor "C" and the Plant Superintendent were examined and placed in the whole body counter at M.I.T., Cambridge, Massachusetts. A barely discernible peak at about the Na24 energy was evident. They were requested to return the next day with Operator "N" who also had been in the plant at the time of the incident; by that time the Na24 should disappear. Results of the second count are not yet available.

Blood counts and blood chemistry will be performed on Supervisor "C" and the Plant Superintendent on an outpatient basis at Rhode Island Hospital for a period of at least 2-3 months. Operator "M" and Operator "N" will also be periodically tested. Arrangements are being made to perform sperm counts on Supervisor "C" and the Plant Superintendent.

Blood studies were conducted on Operator "M", Operator "N", Guard "X" and Health Physics Technician "T" at Rhode Island Hospital and all were normal. Monthly studies on these men will be performed for at least the next two months.

V NUCLEAR ASPECTS

A. Preliminary Findings

Based on experimental results and theoretical calculations completed so far, the following preliminary statements are made regarding the nuclear aspects of the excursion.

1. Operator "O" poured about ten liters of $UO_2\ (NO_3)_2$ solution containing more than 1.5 kg of U-235 into a tank which at that time contained 50-60 liters of 1 molar Na_2CO_3 solution.
2. The solution in the tank went prompt critical and ejected an unknown amount of material. In the process, Operator "O" was exposed to the radiation resulting from $\sim 10^{16}$ fissions and received a neutron dose of $10^3 - 10^4$ rad.
3. After Operator "O" evacuated the room, the solution in the tank was still in a critical condition and probably operated in the kilowatt range until subsequent action by Superintendent and Supervisor "C".
4. When the Superintendent entered the room containing the tank it was critical and operating at about 1 kilowatt. He stayed in the vicinity of the tank for about 5 seconds.
5. The total number of fissions from the beginning of criticality to its termination when the tank was drained was $\sim 5 \times 10^{17}$.
6. In the system involved, criticality can be achieved with ($1.60 \pm .10$) kg of U-235 over all ranges of volumes considered. This would correspond to a concentration of $UO_2\ (NO_3)_2$ in the original solution of (23.25 ± 1.25) w/o.

   (Note: Analysis of the remaining solution of $UO_2\ (NO_3)_2$ in the bottle showed a concentration of 230 g/l of U-235. Hence, a realistic range of U-235 concentration in the original liquid is:

   $$160\ g/l < C(U\text{-}235) < 230\ g/l.)$$

These preliminary statements are based on activation measurements made at United Nuclear (Pawling, N.Y., laboratories), Nuclear Science and Engineering, Oak Ridge National Laboratory, Massachusetts General Hospital, Radiation Physics Division of HASL, AEC.

Specific data are tabulated in Appendix D and Appendix E.

B. Further Work

Further investigational work not yet completed includes:

1. Fission Product Activation Measurements

The number of fissions will be estimated by determining disintegration rates of isolated fission products: Mo^{99} and La^{140}. Measurements are being made at

Nuclear Science and Engineering Corporation and ORNL.

2. Chemical Analysis of the Stainless Steel Clamps

   Content of Ni and Cr of the two stainless steel clamps are being measured. At the present time, only the type of steel has been determined.

3. Na^{23} analysis in Solution Samples

   At the present time, only an analysis of Na^{23} content in one of the solution samples has been measured. Analysis of the other samples should be obtained shortly. Sodium activation has been measured in all samples (22).

4. Analysis of Induced Activity in the Tank Wall

   Analysis of the activity induced by the neutron in the stainless steel tank wall in the vertical direction will yield at least relative values of the neutron exposure and hence, of the neutron flux at various elevations along the side of the tank. The relation between height and volume of the solution in the tank will be obtained by experimenting with the stirrer on.

5. Film badges worn by Superintendent will be re-examined for neutron tracks. Stainless steel watch worn by Supervisor "C" will be examined for neutron activation.

6. Condition for the formation of the uranium precipitate found in the tank after the accident will be investigated.

7. Hair from victim will be analyzed for P32 to provide total dose received by victim.

VI CONCLUSIONS

Results of the investigation have lead to the following conclusions:

A. The nuclear-critical incident was caused by the pouring of a high-concentration uranyl nitrate solution from an 11-liter all-safe bottle into a not-safe 18" diameter tank.

B. The bottle poured into the not-safe tank contained highly concentrated solution that had been cleaned out of the plugged evaporator some 30 hours previously. The bottle was accurately labeled as to its high-uranium contents.

C. The excursion resulted in approximately 5×10^{17} fissions and the victim was exposed to 2000 - 4800 rads.

D. A total of six (6) persons, including the victim, were exposed to radiation in excess of 1.25 rems.

E. Evacuation from the plant per the United Nuclear emergency procedure was prompt and orderly.

F. Operational controls as instituted would have precluded the excursion had they been rigorously adhered to as mandatory rules.

G. Training of employees was adequate and was not a direct cause of the incident.

H. Re-entry into the plant, made on the judgment of the Plant Superintendent, was to prevent the possibility of additional uranium solution from the 11-liter bottle from entering the not-safe tank in which the criticality occurred.

VII CURRENT PLANS AND FUTURE ACTIVITIES

A. After the Investigation Team was formally organized, certain other actions were taken to prepare for better knowledge of circumstances surrounding the nuclear incident, to analyze methods of operation, and to impose on the operations prerequisites for resumption of production. These actions included preparation of outlines for penetrating reviews in the following areas:

1. Operating Procedures - assigned to a member of the Naval Core Engineering Department of the Fuels Division.
2. Criticality Limits and Control - assigned to a member of the Development Division.
3. Uranium Accountability and Material Balance - assigned to a member of the Production Planning and Material Control Department of the Fuels Division.
4. Health Physics Procedures and Controls - assigned to a member of United Nuclear's consultant's staff, the Nuclear Science and Engineering Corporation, and also assigned to a member of the Development Division.
5. Training - assigned to a member of the Industrial Relations Department of the Fuels Division.
6. Technical Consideration of Irradiated Material - assigned to Plant Superintendent of the Fuels Recovery Plant and to a member of the Development Division.
7. Emergency Procedures - assigned to Plant Superintendent of the Fuels Recovery Plant and to a member of the Industrial Relations Department of the Fuels Division.
8. Medical Service - assigned to a member of the Industrial Relations Department of the Fuels Division.

B. The outlines for these reviews have been prepared and the programs resulting therefrom are in the analysis and execution stage. Significant areas of consideration included in these reviews and some of the actions being taken are:

1. Operating Procedures

   The flow of product is being examined to determine where control points exist. The control points being established include those process functions which must be controlled for necessity of process revision, non-process material handling, identification of product, quality assurance that the product meets requirements to be suitable for further processing, nuclear safety and health physics requirements, appearance of abnormal foreign material, uranium accountability measures, production rates and production scheduling, functioning of equipment and emergency plant conditions such as power failure.

1. Operating Procedures - (Continued)

b. To utilize the establishment of these control points it is planned that all technical operating documents be examined for completeness of description of expected results. Performance by operators of work outlined by process parameter sheets will be signed off by the operator. Summary log sheets will be prepared by operators of abnormal conditions, reviewed, approved and dispositioned by supervision with instructions passed to succeeding shifts. Request for Engineering Changes to the process will be formally incorporated where the necessity for process revision is apparent. These will require the approval of the Plant Superintendent and the Process Engineer before work begins on process revisions. Operating Instructions for specific pieces of equipment will be prepared, authorized and posted. Means for full identification of the product at all times is necessary. This requires modification of the present system of container and equipment labelling; provision for the approved passage of material from one central control point to another, and a running account of material assays made for a complete plant picture available at a glance to all personnel. A system for assurance checks on the dependability of laboratory results will be instituted.

c. All plant personnel will be exposed to the Plant Operating Procedures sufficiently for full understanding and adherence. Failure to comply with these Procedures will result in disciplinary action and will so be posted on the Plant Personal Conduct Rules.

2. Criticality Limits and Control

a. A review of the existing nuclear safety analyses is being made. This review includes assurance of the validity of present calculations.

b. An inventory and inspection of equipment and plant structure will be carried out to assure the as-built plant conforms to the basis of calculations made.

c. Each piece of equipment and plant layout will be examined from a nuclear safety standpoint independent of existing safety calculations. Special attention will be given to the effects of possible accidents or maloperation of equipment on process conditions within each piece of equipment, the criticality safety of the equipment under these conditions, the minimizing of administrative controls for nuclear safety, the consequence of violation of administrative controls and the minimizing of these consequences.

3. Uranium Accountability and Material Balance

   a. Request has been made to begin operations which will permit the sampling, assaying and disposition of all categories of material to obtain a material balance in the plant. This request includes the procedures to be used in this work.

   b. This work is necessary to arrive at a uranium loss figure resulting from the incident.

   c. This work is necessary to permit the categorization of material at all stages of the process for future processing.

4. Health Physics Procedures and Controls

   a. A comprehensive review of the currently-approved Health Physics Manual is being made.

   b. This review encompasses areas of written health physics procedures, the use of in-plant permissible limits, the enforcement of these limits, the sampling and testing program, the counting and auditing program, the use, adequacy and familiarity with necessary instrumentation, the staffing and training of personnel to carry out these programs, including enforcement and record keeping.

   c. Personnel who received dosage greater than 1.25 rem will return to work in process areas with no limitations on October 1, 1964, pending only confirmation that beta/gamma activity in the plant and particularly in the tower area will not exceed Maximum Permissible Limits.

5. Training

   a. A comprehensive training program for all personnel has been inaugurated. Subjects being covered and the manner of coverage are:

   - Fundamental Nuclear Physics - In five one-hour classroom type meetings, one held each week, a member of the faculty of the University of Rhode Island will instruct personnel in:

     The atom as a source of radiation

     Definition of terms

     Nuclear Reactions

     Nuclear Fission

     Criticality

   - Emergency Control Plan - During the week of August 10th a seminar critique of the emergency control plan was conducted. During the weeks preceding resumption of operations, several drills will be conducted under simulated circumstances of both nuclear and non-nuclear occurrence. The drills will be by shift groupings with remaining personnel exercising critical review or assuming roles as non-employee participants. The drills will include evacuation and re-entry.

5. Training - (Continued)

- Instruments and Methods for Radiation Detection - A representative of an instrument manufacturer will be utilized to train personnel in instrument operation. In addition, personnel will be given first-hand experience in taking and counting samples.

- Survey of Nuclear Industry - Films from the motion picture film library of the AEC will be available for utilization as a change of pace and for instruction in the spectrum of nuclear activities. Films for possible use are:

  Radiation in Perspective

  The Petrified River (mining and milling uranium)

  Power and Promise (Shippingsport)

  Pioneering with Power (Yankee Atomic)

  The SL-1 Accident, Phases 1 and 2

  Regulation of Atomic Energy

  Criticality

  A field trip to at least one reactor facility will be arranged.

- Levels, the NCRP, Biological Effects - A one day seminar will be held with a prominent member of the medical profession to discuss:

  Permissible levels - personnel exposure

  The organizations involved in establishing standards

  Techniques for measuring exposure

  Biological effects

  Safety factors inherent in standards

- First Aid Training - On-site training in first aid by standard Red Cross training methods will be conducted, aimed at qualifying all personnel by start-up time. This will be done in 1-2 hour meetings held at least once each week.

- The 7/24/64 Incident - Responsible personnel from UNC investigating team will upon completion of the investigation review the findings and answer employee questions.

- The Health Physics Manual - A complete review and critique of the health physics manual will be conducted by health physics personnel with demonstrations and practice in personal monitoring and procedures for entering and leaving contaminated areas. This will require at least two one-hour meetings.

5. Training - (Continued)

- Fire Fighting - A review of fire hazards and types will be conducted and practice fire fighting using appropriate equipment will be held in conjunction with local fire department personnel. The objective will be to qualify personnel to operate as plant fire brigade. It is expected that four meetings, including use of equipment, will be required.

- Procedures - Supervisory personnel will hold skull sessions and in-plant review of all procedures. These sessions will be held on a daily basis when other activities are not in process.

- Personnel Policies - Industrial Relations will review completely personnel policies, company rules, benefit programs and company philosophy on employer-employee relationship.

- Tests - Tests will be administered to insure knowledge of:

  Operational hazards relative to criticality

  Use of monitoring equipment

  Evacuation and Re-entry procedures

  Health Physics practices

  Operating Procedures

- Follow-Up - Observation of the results of this training by the Training Director of the Fuels Division will be made. Areas where reiteration may be of value will be noted and followed up. Further necessary exposure of this outline to new hires will be made.

6. Technical

   a. Consideration of alternate plans for further processing of irradiated material is being made. Upon completion of the analyses made during the uranium accountability work, resolution of the disposition of this material can be made.

   b. Exact procedures for plant start-up are being prepared for each process step and each category of material.

   c. Technical consideration is being given the metallic contamination of the product which gave rise to the necessity for reprocessing preceeding the incident. The actions to overcome this difficulty will be incorporated into the Plant Operating Procedures with development work done to precede actual recovery operations

   d. A piece by piece trial of all equipment will be conducted before actual operations will begin. Necessary equipment modifications to overcome any difficulties encountered will be made. A check list composed of future Operating Instructions for each piece of equipment will be made, serve as guide for the check-out, serve as documentary evidence of the checkout signed by the person(s) and when the check-out was performed.

7. Emergency Procedures

A check of the procedure versus actual happenings during the critical incident for degree of accuracy and degree of coverage in the event of an emergency will be done. Conduct liaison with existing local, state and Federal organizations in regard to their assistance to UNC in an event of an emergency.

Ambulance

State Police

Civil Defense

Local Law Enforcement

Hospitals

Doctors

Other consultants as necessary at the request of UNC

Atomic Energy Commission ——— New York Operations Office

Review existing physical emergency facilities with a view toward modification and/or improvement.

Larger emergency building

Expand facilities to include shower, additional instruments, personal monitoring devices and communication facilities

Building plan for plotting of information

Housing of counting equipment

Revise and publish a new Emergency Control Plan

Publish a plan for re-entering plant to include categorizing nature of emergency, establishing boundary limit, obtaining samples of air, smear, soil and water, establishing headquarters in evacuated facility as soon as possible and planning method of decontamination or clean-up.

8. Medical

Engage consultant physician experienced in medical aspects of radiation accidents who will assist by reviewing procedures, advising local physicians serving Company facilities and be on call for emergencies requiring specialist treatment.

Establish well-defined relationship with Fuels Recovery Plant and provide educational materials which familiarize him with medical aspects of radiation accidents.

Contact area hospitals (Westerly, South County-Wakefield, and Rhode Island) to insure their understanding of hazards and our knowledge of capability for handling emergency possibilities

8. Medical - (Continued)

stemming from plant operations. This contact is aimed to:

- Arrange with hospitals for nurse training in radiological accidents, such as that available from Radiological Health Laboratory of the Public Health Service.
- Define clearly accident types which each hospital may not be geared to handle.
- Establish accident criteria from radiation/contamination standpoint (radiation vs. non-radiation) within which the hospitals will treat victims.
- Define accident dispositions consistent with the Emergency Plan
- Establish training program for ambulance corps serving the plant including understanding of hazards and decontamination procedures.
- Include first-aid training in training program for plant personnel.
- Emergency Procedures - Review adequacy and preclude deterioration of emergency supplies to insure availability of sufficient containers for patient excretion at site, cover materials for patient transportation and personnel dosimeters for personnel handling patient.

C. Organization

1. A reorganization of control areas to preclude recurrence of this nuclear incident will be made. Significant control areas involved are process engineering, plant operating procedures, chemistry control laboratory, criticality requirements, health physics requirements and licensing requirements. This reorganization will be made to accomplish three objectives:

   a. To assure adequate staffing and current attention to plant situations.

   b. To assure the proper technical and managerial capabilities of the personnel doing the reviewing and decision making.

   c. To provide for an avenue of audit and compliance review independent of plant operations.

2. A final "Go-No Go" committee composed of the Vice President, Manager of Chemical Operations and Investigation Committee Chairman has been formed. This committee will decide whether or note the adequacy and execution of each review for start-up purposes has been achieved.

D. License Review

1. When the Current Plans and Future Actions described above have been sufficiently completed, the present license SNM 777 will be reviewed. It is expected that changes in at least the following operational sectors will be effected in a manner that will require the license to be revised.

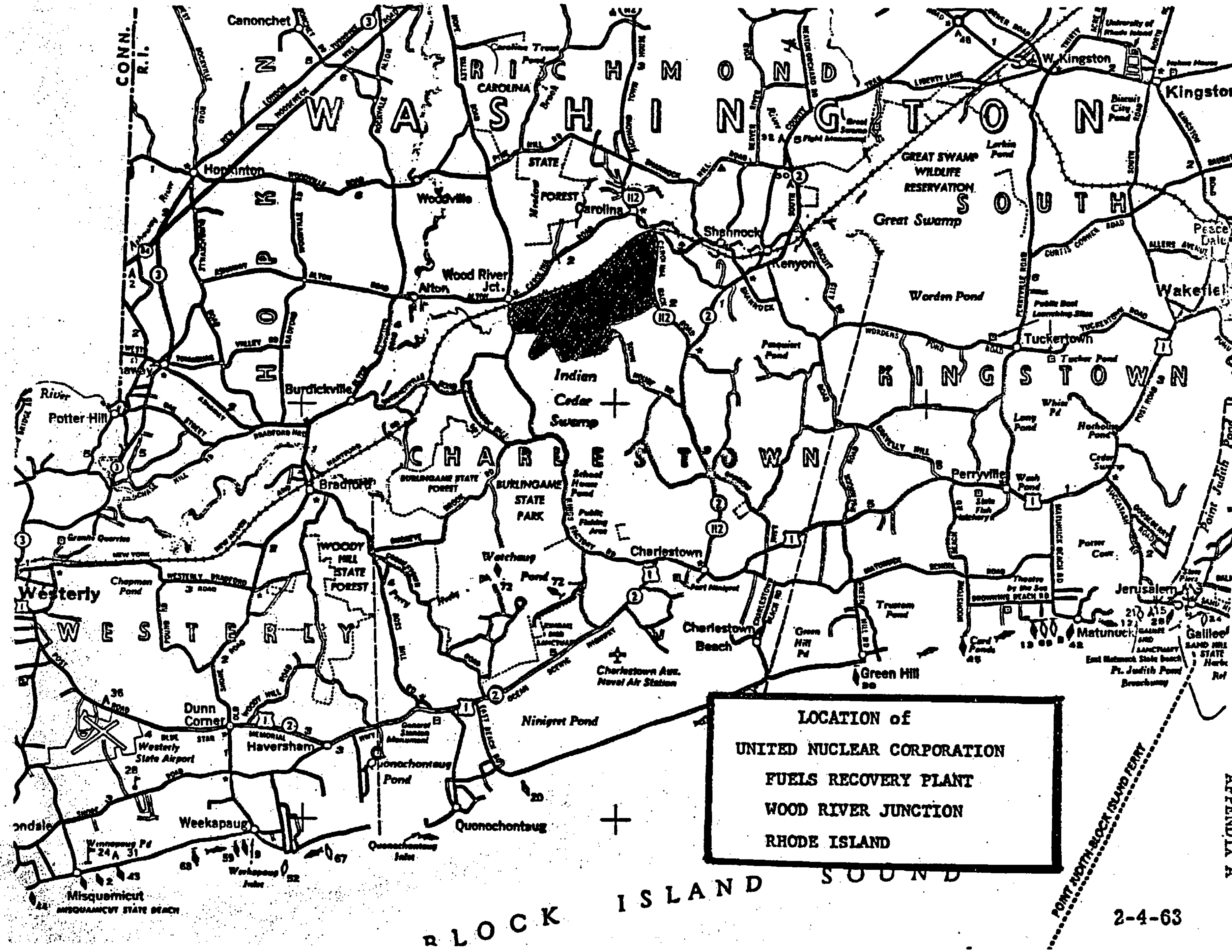
   - Plant Procedures Manual
   - Criticality (nuclear safety) calculations
   - Health Physics Manual
   - Emergency Control Plan

   An application for License Modification will be submitted upon completion of this work.

2. In accordance with United Nuclear Corporation letter dated July 30, 1964, the Fuels Recovery Plant has ceased operations of a production nature. This cessation of these operations will be maintained until License Modification has been approved.

3. The cessation of operations of a production nature will further be maintained until the "Go-No Go" committee mentioned above is satisfied that these operations may be resumed.

VIII APPENDIX



LOCATION of
UNITED NUCLEAR CORPORATION
FUELS RECOVERY PLANT
WOOD RIVER JUNCTION
RHODE ISLAND

2-4-63

APPENDIX A

APPENDIX B SAMPLE STANDARD OPERATING PROCEDURE

A. Unlined Dissolver Charge Procedure

1. Charge Procedure

   a. Since the dissolver operation normally limits the scrap reprocessing rate, this operation has the highest priority unless specific modifying instructions are given by the process supervisor.

   b. Advance preparation will be made during the previous dissolution batch to minimize the time lost between batches. This preparation is to include but not to be limited to such items as:

      1. Make sure the HNO_3 and water gage tanks are full.
      2. Obtain the next container or containers of scrap to be dissolved and check weigh same.
      3. Weigh out the $Hg(NO_3)_2$ catalyst if required.
      4. Clean and remove any empty safe geometry scrap containers from the dissolver charge glove box.

   c. Make sure the dissolver discharge valves are closed and that the dissolver is empty. Make sure the dissolver vent valve is open, the vent condensate receiver is empty and the discharge valve of the receiver is closed.

   d. Remove the cover from the dissolver charge port and decant the supernatent liquid from the "Dissolver Acid Insolubles" storage bottle into the dissolver.

   e. Remove the teflon bag insert from the dissolver charge port transfer any acid insolubles contained in this bag into the safe geometry "Dissolver Acid Insolubles" storage bottle, inspect the teflon bag for rips or tears, return the bag to the dissolver and decontaminate and remove the storage bottle containing the acid insolubles from the glove box.

   f. As an alternate to the above, the process supervisor may direct that the acid insolubles be left in the dissolver as part of the charge of the next batch.

   g. Introduce one scrap container into the charging glove box through the air lock and then transfer the scrap from the container to the teflon bag in the dissolver. After the first scrap container is emptied, another container, if required, can be put in the glove box emptied etc.

h. Add the mercuric nitrate catalyst if required.

i. Replace the charge port cover on the dissolver.

j. Add the required amounts of nitric acid and water to the dissolver from the respective gage tanks.

k. Record the acid volumes, scrap charge weights, bottle number or numbers of scrap, times operations are complete, etc. on the dissolver batch sheet.

APPENDIX C   NUCLEAR ALARM SPECIFICATION DETAILS

The detectors used are Nuclear Measurements Corporation Model GA-2(1). Specifications for the detectors are:

Activity Detected:	Gamma, 30 KV up
Precision:	± 20% at all levels
High Voltage Supply:	Adjustable - 800 to 1000 V
Sensitivity:	Basic range 0.05 to 50 mr/hr, logarithmic. Other ranges optional.
Time Constant:	20 seconds.
Stability:	± 2% of full scale deflection.
Special Features:	Large phosphor volume provides essentially body equivalent wave length sensitivity. Power supply totally regulated. Alarm and alert points separately adjustable over all scale. Insensitive to line transients.

The GA-2(1) detector does not keep up with an almost instantaneous rise in radiation, but lags to the extent that only 63% of a sudden change is read two seconds after the change has occurred. Thus, if the change is to a point only slightly above 20 mr/hour, the detector will probably not set off an alarm until some three or even four seconds after the change has occurred. On the other hand, should the change be to the region of, let us say, 1000 mr/hour, the detector will trip in a very small fraction of a second after the advent of the radiation. This means that the response is practically instantaneous in the case of any severe outburst of radiation, although it is slightly delayed in the minimum cases.

The instruments are so constructed that while some electrical failures will cause the general alarm to sound, others will merely actuate signal lights. In this way, supported by close routine inspection of the system, it is hoped that false alarms and the confusion and anxiety they would cause may be avoided while still providing immediate awareness of any irregularity in the system.

The instruments are set to operate normally at a very low range of gamma radiation, most of which is provided by a tiny radiation source within each instrument case. A high level electrical contact is actuated if the range being measured by any one of the detectors rises to 20 mr/hour, and a low level contact is actuated if the range falls to the neighborhood of approximately 0.1 mr/hour. If the high level contact is actuated, the alarm sounds for evacuation of the work area and office. If the low level contact is actuated, a light on the main panel of the alarm system comes on, indicating which detector sent in the signal. In addition, an amber light shows in the panel of the detector itself.

The placement of the detectors is such that the maximum distance to any stored or in-process fissionable material inside the building is < 70'. Outside storage is <100' maximum from the storage yard detector.

The sirens which give the evacuation signal in event of a reading in excess of 20 mr/hour are Edwards #315, rated at 108 decibels. Two inside and one outside will provide an unmistakable warning.

Power supply for the radiation monitors is designed to keep them operable despite general plant power failure. A 4.5 kv Empire Model 4-5DFA8 diesel generator provides auxiliary power for the radiation alarm circuits, as well as for emergency perimeter lighting and the fire alarm system.

Total Fission Yield in Incident

Source of Information	Reaction or Isotope Involved	Preliminary Results	Estimated Yield
Fission product	Mo^{99}(1) , La^{140}(2)	Not yet available	
Sodium activation of solution samples	$Na^{23}(n,\gamma)Na^{24}$	(2) Na^{24} activities in 22 samples (3) No Na^{24} activity observed; Na^{23} analysis of 1 sample	$> 2 \times 10^{17}$ *
Screwdriver on side surface of tank	$Fe^{58}(n,\gamma)$ FE^{59} $Fe^{54}(n,p)Mn^{54}$	(1) T.I.T.F. = 7×10^{12} n/cm^2 (1) T.I.F.F. (>1 Mev) = 2.2×10^{13} n/cm^2	6×10^{17} ** 4.3×10^{17} **
Aluminum sample, 174" from tank	$Al^{27}(n,\alpha)Na^{24}$	(1)&(2) no activity observed (3) T.I.F.F. = 1.4×10^{10} n/cm^2	5×10^{17}
Austenitic S.S., 9" from tank	$Ni^{58}(n,p)Co^{58}$	(2) T.I.F.F. = 4.5×10^{12} n/cm^2*** (3) No activity observed	3.2×10^{17}
Martensitic S.S., 174" from tank	$Ni^{58}(n,p)Co^{58}$ $Cr^{50}(n,\gamma)Cr^{51}$	(1) T.I.F.F. $< 5 \times 10^{11}$ n/cm^2 + (1) T.I.T.F. = 9×10^{10} n/cm^2 ++	$< 3 \times 10^{18}$ $2 \times 10^{17} < Y$ $< 2 \times 10^{18}$ +++

T.I.T.F. = Time Integrated Thermal Flux
T.I.F.F. = Time Integrated Fast Flux

* Based on the assumption that the ratio of Na^{24}/Na^{23} concentrations for all samples is equal to the ratio which has been measured in one sample.

** Based on calculations with 60 liter volume; smaller volumes increase the disagreement between the derived yields.

*** Based on an assumed 10% Ni content.
\+ Based on an assumed 1% Ni content.
++ Based on an assumed 18% Cr content.
+++ Upper limit from an unreflected tank leakage spectrum, and low limit from fully reflected tank leakage spectrum.

Neutron Exposure by Operator "O"

Source of Information	Reaction	Preliminary Results	Estimate of Fission Yield	Estimate of Neutron Dosage (rads)
Na^{24} in blood	$Na^{23}(n,\gamma)Na^{24}$	(4) $2.64 \times 10^{-2} \mu c/ml$ serum	$\cong 10^{16}$	> 2000 * < 4800 **
Indium foil	$In^{113}(n,\gamma)In^{114}$	(5) $1.1 \times 10^{6} \frac{dpm}{gr\ of\ In}$ 113	$> 3.5 \times 10^{15}$ * 4×10^{16} **	$> 10^{3}$ * $< 10^{4}$ **
Gold ring	$Au^{197}(n,\gamma)Au^{198}$	(1) $> 5.3 \times 10^{11}$ n/cm^{2} +	$> 6 \times 10^{15}$ * $< 6 \times 10^{16}$ **	$> 10^{3}$ * $< 10^{4}$ **

* Lower limit using fully reflected tank leakage spectrum

** Upper limit using unreflected tank leakage spectrum (at surface of tank)

+ Not corrected for self absorption

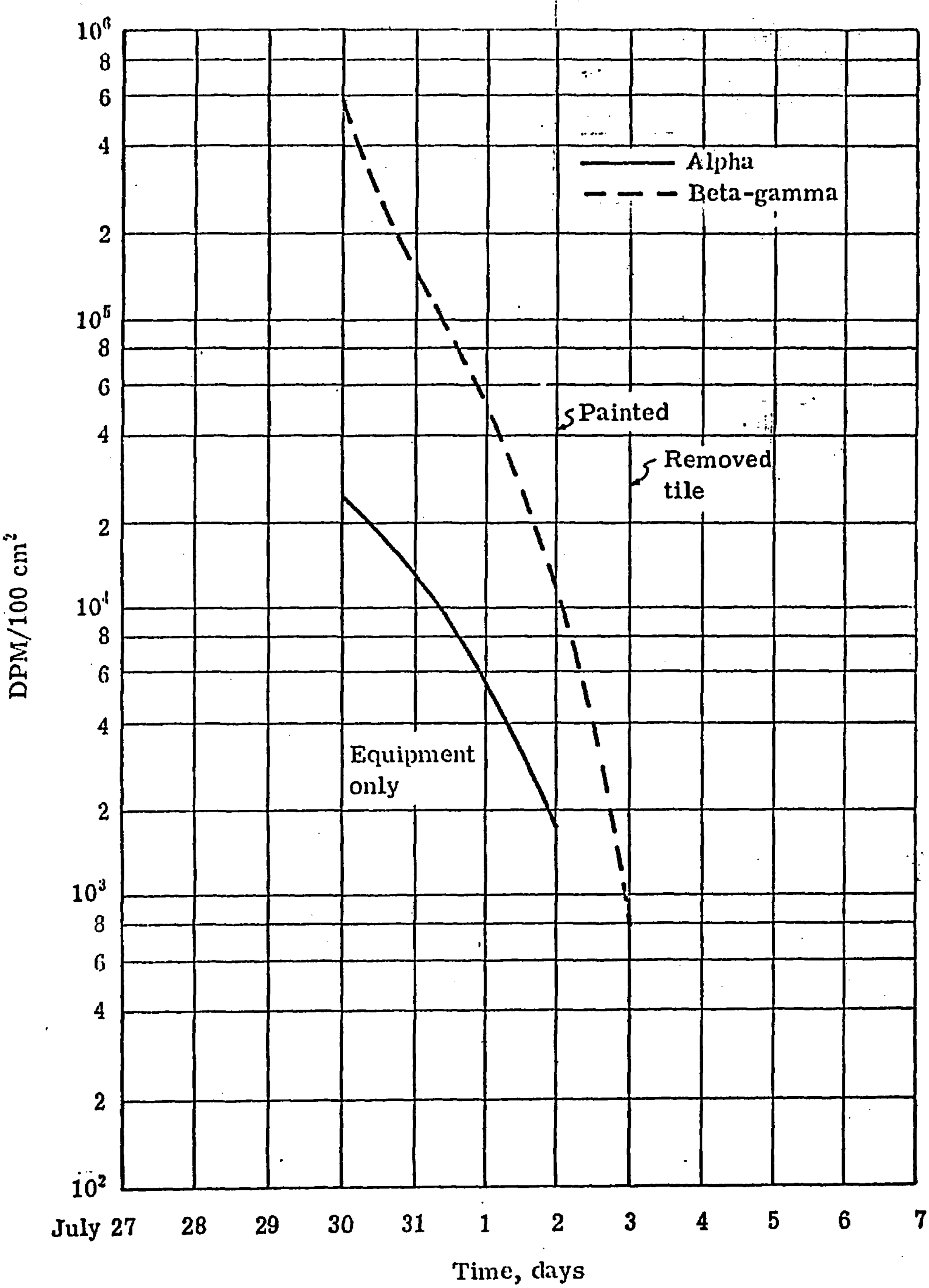
Ex. 6

EXTERNAL EXPOSURES TO RADIATION

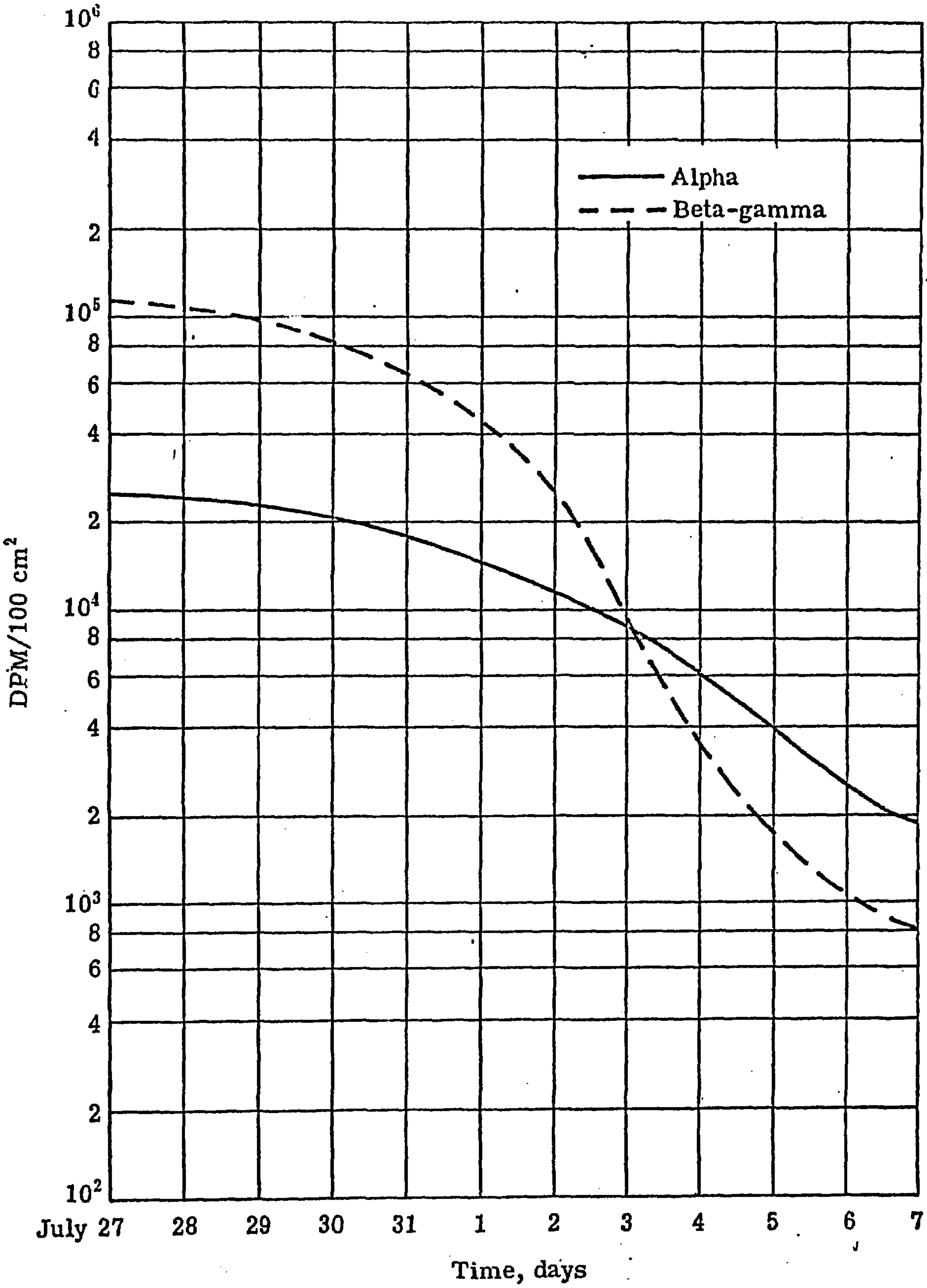
Personnel Identification	Exposure	Basis
Robert Peabody, deceased	>700 rems. gamma 2000-4800 rads.	Film badge dosimetry Blood sodium
		Film badge dosimetry
		Assume gamma exposure equal to Superintendent
		Film badge dosimetry
		Film badge dosimetry
		Film badge dosimetry
		Estimated based on known radiation levels and exposure times.

(1) Possibly also exposed to neutrons, dose unknown.

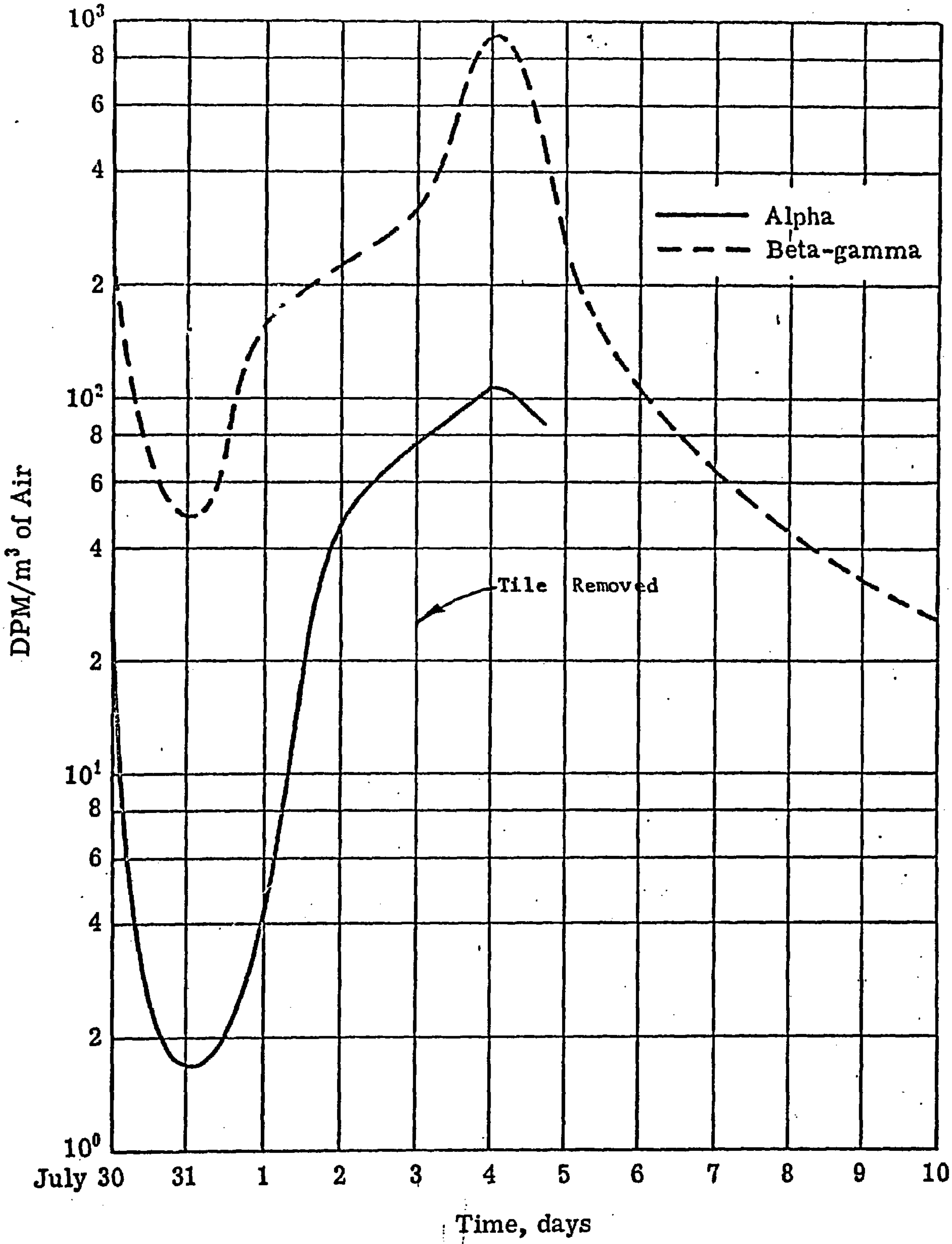
(2) Possibly also exposed to neutrons, dose unknown, but less than Superintendent



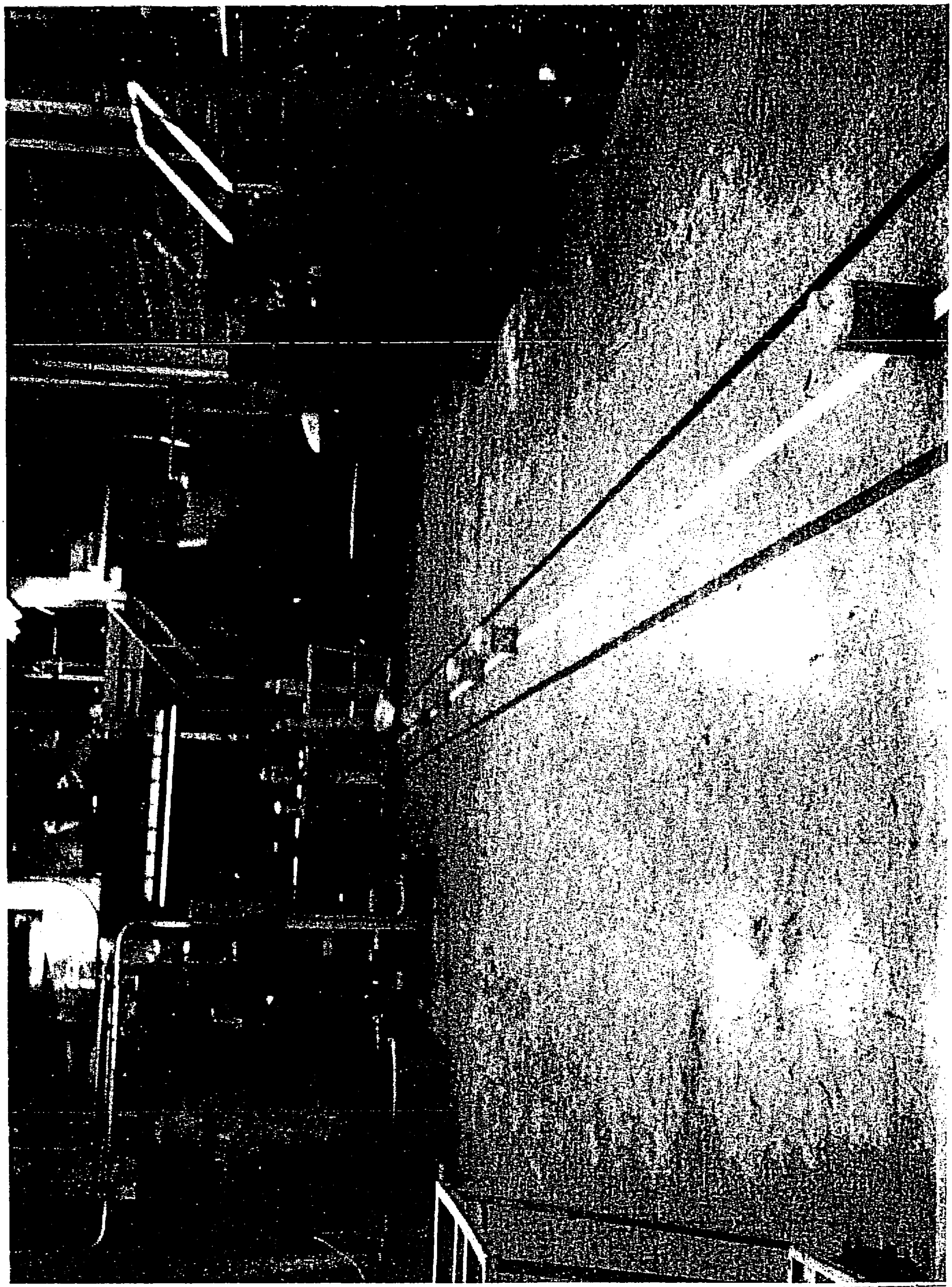
Smear Data Summary – Tower Area – Floors and Equipment



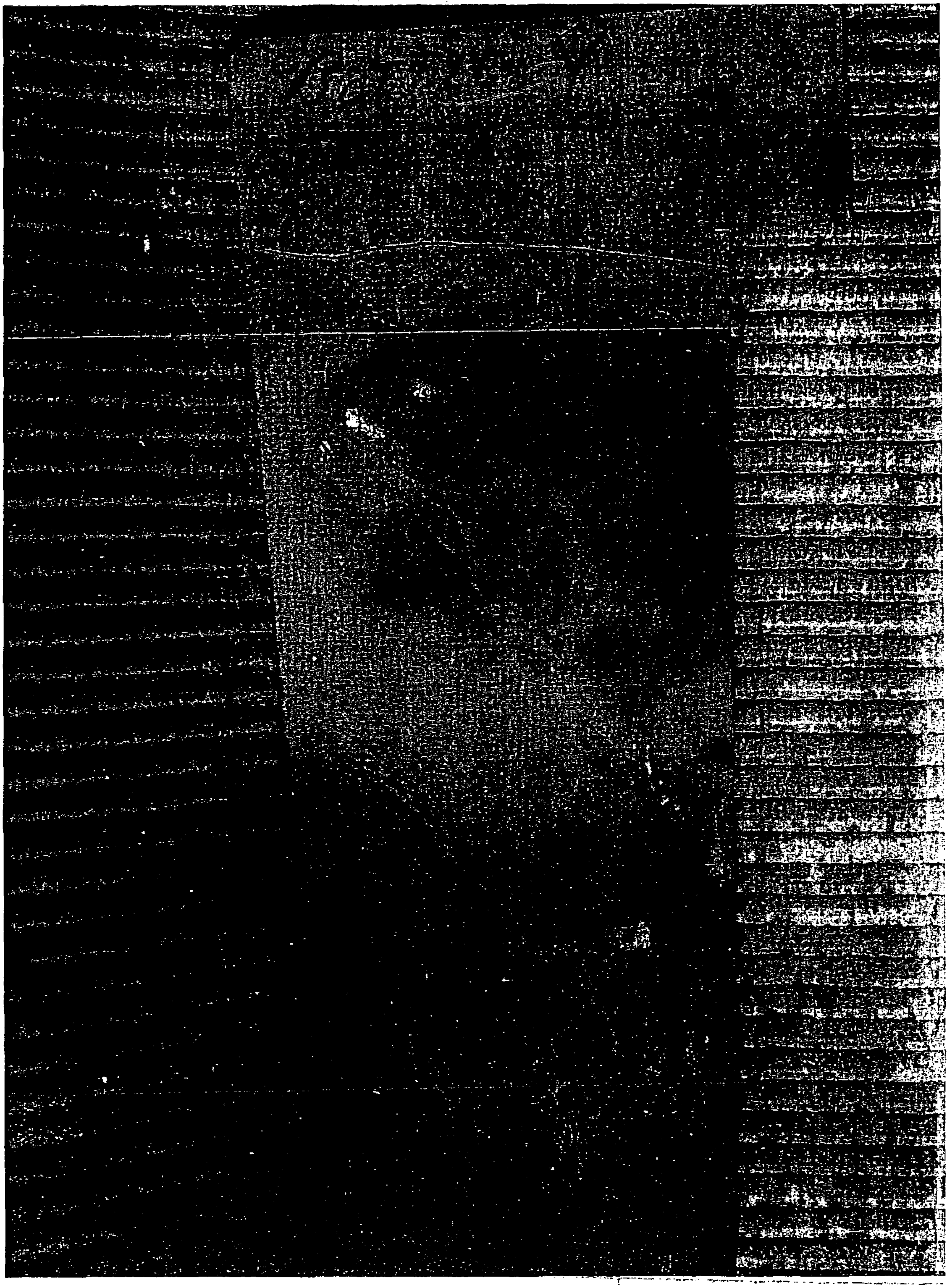
Smear Data Summary – Process Area



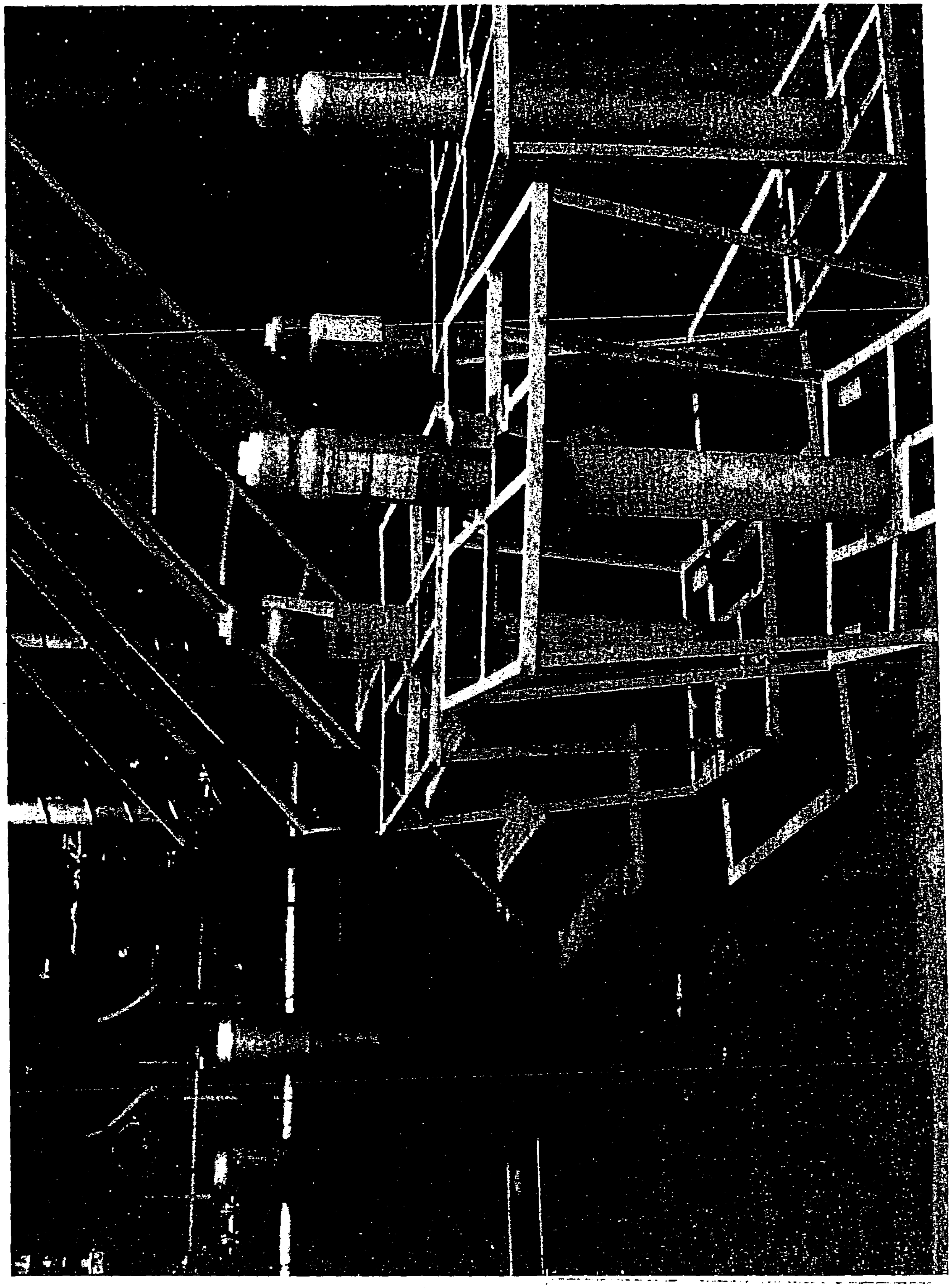
Air Sampling Summary - Third Floor Tower
MPC (alpha) = 220 DPM/m³; MPC (beta-gamma) = 666 DPM/m³



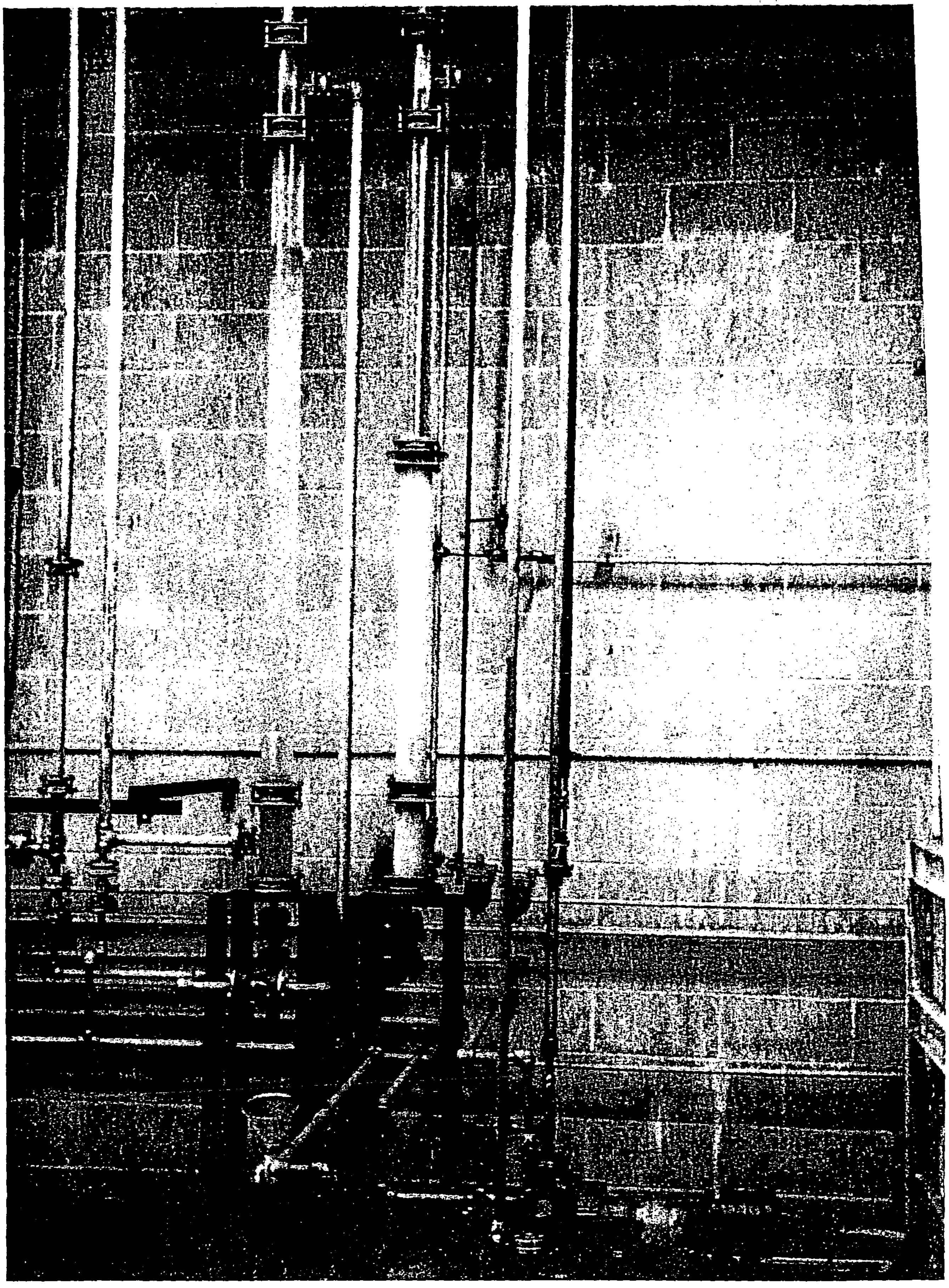
Jars of Irradiated Material
Drained from Tank After Incident
(Looking east toward Evaporator
(Precipitator) area).



Tag Found in Stair Well Near
Empty All-Safe Cart.
(Part of tag removed for
activation studies).



Bottles Near
Evaporator/Precipitator Area at
Time of Incident. Spill
from Evaporator Seen ...



The Solvent Recovery Column (1-C-9) as Seen after Make-Safe Operation (Right hand column showing yellow precipitate and clear