HEALTH AND SAFETY

Report Number: ORNL-2102

Contract No. W-7405, eng 26
CHEMICAL TECHNOLOGY DIVISION

ANALYSIS OF THOREX PILOT PLANT RADIATION EXPOSURES DURING 1955

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DATE ISSUED:

NOV 16 1956

Price $ 0.55

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1.0 ABSTRACT

The Thorex Pilot Plant at Oak Ridge National Laboratory was operated during 1955, processing reactor-irradiated thorium slugs to recover U^{233} and thorium and 12 MTR fuel elements to recover U^{235} and Np^{237}. The radiation exposure received by operating personnel during this period averaged 60 mrep/man-week.

Most radiation exposure was received in areas that were intended to be only slightly or nonradioactive. However, because insufficient decontamination of process solutions was achieved and equipment surfaces became contaminated from equipment failures, these areas became primary sources of personnel exposure. The installation of additional shielding where needed and the prompt removal of surface contamination successfully reduced the radiation levels and exposures in these areas. Remote control of processing equipment and sampling of very radioactive solutions from process equipment was successfully accomplished, and assisted in the reduction of exposure to operating personnel.

2.0 SUMMARY

During 1955, 44 persons worked for varying numbers of weeks in the Thorex Pilot Plant. The radiation exposure received by this group during the year totalled 71 rep in 1200 man-weeks of labor, an average of 60 mrep/man-week. Although the goal of 50 mrep/man-week was not quite reached for all of 1955, this goal was surpassed during the last half of the year after additional shielding was installed and operating procedures were improved.

Twenty-three of these 44 persons averaged 50 mrep/week or less of exposure, 16 averaged between 51-100 mrep/week, 4 averaged 100-200 mrep/week, and 1 person averaged 210 mrep/week over a 5-week period during startup of the pilot plant. Thirteen overexposures (in excess of 500 mrep/week) were received by 11 persons.

Higher-than-anticipated radiation levels in various plant areas occurred when activity was unexpectedly carried over from highly radioactive equipment to downstream equipment which was not shielded for large amounts of radioactivity, when equipment failed and process solutions contaminated the external surfaces in the vicinity of the failure, and when special feed materials were processed in equipment for which it was not primarily designed.

Low radiation exposures to the operating personnel in the pilot plant resulted when the shielding, as originally designed, was adequate to protect the personnel and when proper equipment spacing and orderly arrangement of piping permitted the installation of additional shielding as required. Radiation protection was also aided by remote control of equipment, remote sampling of process solutions with the newly developed sampling facility, and more efficient decontamination facilities and procedures. The collection and analysis of radiation exposures and plant radiation levels also aided in reducing personnel exposures; operators were informed of these facts and were instructed in proper techniques to minimize the exposures they received.

As a result of this study, the following will be done to further reduce personnel exposures: drain pans will be installed under all pumps handling process solutions to prevent spread of contamination when leakage occurs; adequate purge facilities will be designed and installed; and health physics surveys will be continued and additional shielding will be installed as required.

3.0 INTRODUCTION

An important consideration in the design and operation of any radiochemical plant is the assurance that the plant can be operated efficiently for a long period of time without exposing the plant personnel to undue radiation dosages. Although the permissible tolerance for radiation exposure in the Thorex Pilot Plant is 500 mrep/week of soft, nonpenetrating radiation, it was desired to operate the plant with an average exposure of 50 mrep/man-week. This goal was set not only to show that a radiochemical plant could be operated at 10% of permissible tolerance, but also to be sure that more highly irradiated, shorter-decayed feed material could be processed in the plant without exposing the operating personnel to radiation above the permissible dosage.

During 1955, records were kept on the radiation received by all operating, maintenance, and analytical personnel associated with the Thorex Pilot Plant. The radiation exposures were measured by: (1) film badges which were worn each week by each person and monitored weekly by the Personnel Monitoring Group of the Health Physics Division at ORNL; (2) special film badges which were worn during a special job or in special locations by each maintenance person and monitored weekly; and (3) by quartz-fiber, direct-reading dosimeters which were worn by each operating person and the radiation dosage received was recorded on a special form each day. The radiation levels throughout the plant were measured daily by Health Physics surveyors with paper-shell cutie-pies.

The over-all objective of this work was to determine where and why personnel received radiation in the plant and to determine what shielding, equipment, piping, or operating techniques needed to be improved to reduce the exposures and to make available more information that would possibly help to improve the design of new plants. The following were specifically studied:

1. Radiation levels and exposures in a directly maintained plant.
2. The effect of Thorex Pilot Plant design on radiation levels and exposures.
3. Radiation exposures as related to equipment performance and operational procedures.
4. Effectiveness of the radiation control program in the Thorex Pilot Plant.

4.0 CONTROL OF RADIATION EXPOSURE

4.1 Plant Design Philosophy

4.1.1 Plant Description

The Thorex Pilot Plant is a directly maintained radiochemical plant for processing irradiated thorium metal through one solvent extraction cycle to recover U^{233} and thorium. The plant contains equipment for dissolution of the irradiated metal in nitric acid; feed adjustment and acid recovery; solvent extraction, partitioning, and stripping columns; continuous solvent recovery; and semicontinuous isolation of U^{233} by sorption on Dowex-50 resin. The plant was installed in 1954 in cells 5, 6, and 7 of Building 3019 (Figs. 4.1 and 4.2).

4.1.2 Shielding

The cell area in Building 3019 was originally constructed on the basis of a "group shielding" philosophy for radiochemical processing equipment in that cells were sized to house a number of major elements of process equipment. Direct maintenance of any element of the process equipment required extensive decontamination of all process piping and equipment within the cell to a low enough background to permit sufficient working time without overexposure to personnel. This decontamination requirement was time-consuming, costly, and a source of radiation exposure to the decontaminating personnel.

Accordingly, a philosophy of "unit shielding" was adopted for the Thorex Pilot Plant. Under this philosophy each major element of radioactive process equipment was installed inside an individual shield. Application of the "unit shielding" philosophy to the Thorex cell area (cells 5, 6, and 7) involved subdividing the existing cells into smaller shielded areas termed "cubicles." The physical dimension of a cubicle was determined by the equipment it was to contain. Each cubicle was formed by the erection of concrete partitions, while allowing an open space to remain for installation, inspec-

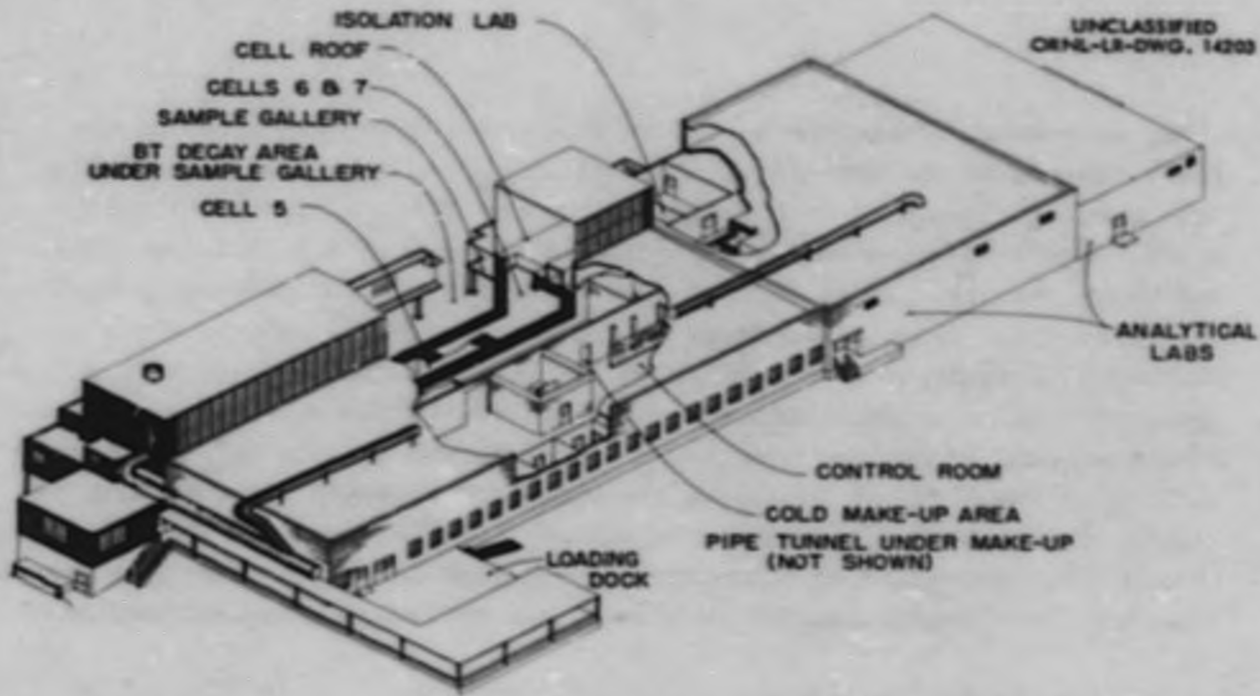

Fig. 4.1. View of Thorex Pilot Plant in the Radiochemical Processing Pilot Plant Building.

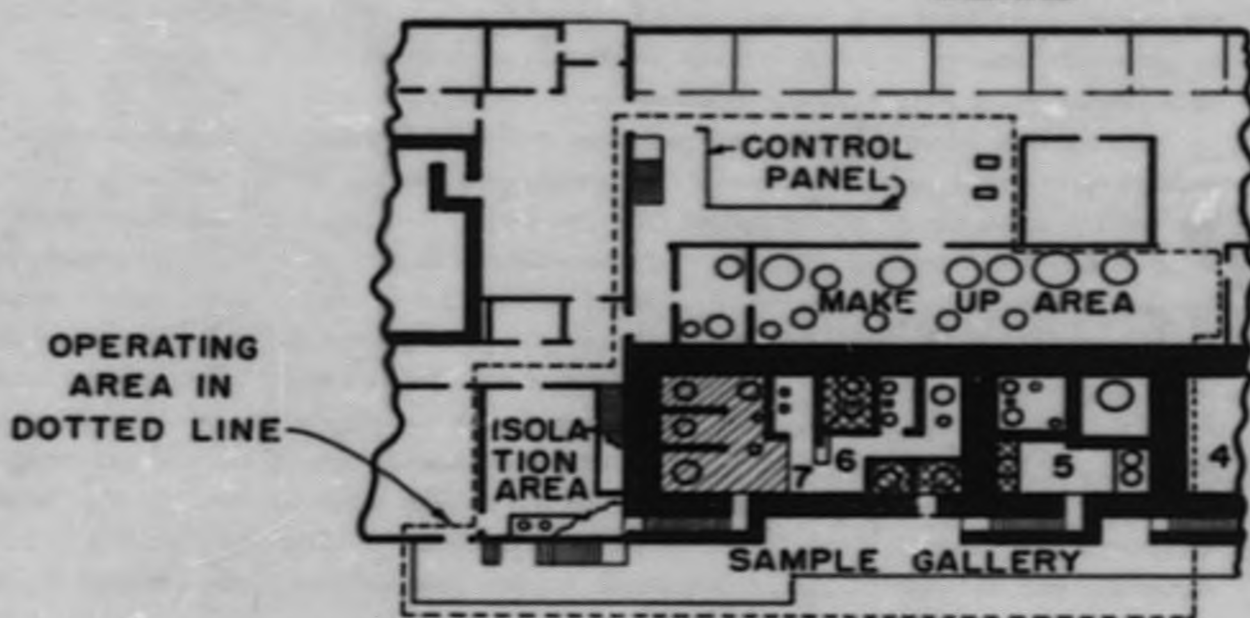

Fig. 4.2. Plan of Thorex Operating Area.

tion, or removal of equipment. Loose concrete blocks were used for the final closing of the cubicles. All cubicle floors were lined with stainless steel and equipped with individual drains leading to central cell sumps. Built-in decontaminating equipment was provided for all cubicles and major vessels. Spray nozzles were installed in each cubicle so that the cubicle and exterior surfaces of the vessels in the cubicle could be flushed with water or decontaminating reagents. Each major vessel was equipped with an internal jet recirculation system so that decontamination reagents could be sprayed over the internal surfaces. The unit shielding philosophy was expected to reduce the spread of activity by containing all leakage within the cell, reduce the expense and time required for decontamination prior to repair or alteration by eliminating the need for decontaminating all theequipment located in a cell, and to reduce personnel exposure.

4.1.3 Remote Operation

Remotely controlled operation in conjunction with adequate shielding of very radioactive process equipment is essential to the control of radiation exposure to personnel. In the design of the Thorex Pilot Plant an effort was made to eliminate as many manual operations of radioactive equipment as possible and to provide remote controlling devices in an operating area or control room sufficiently removed from the cell area.

Extensive instrumentation, required for control and performance evaluation of pilot plant processing equipment, was installed in the control room. Formerly, the sensing element and the recording mechanism of an instrument were connected directly together by instrument lines; with this arrangement it was possible for radioactive process solutions to reach the control room. In the Thorex Pilot Plant, a transmitter was interposed between the sensing element and the receiver-recorder; process solutions cannot pass beyond the transmitter to the panelboard. The transmitter measures the process quantity and converts this reading to a 3-15 psig air signal, which is transmitted to the receiver-recorder instrument mounted on the control panel. All transmitters were installed on the roof above the cells so that if radioactive material was forced up the probe lines to the transmitter, the radiation would be limited to the roof area.

The collection of pilot plant data necessary to the development of a process requires frequent sampling of the materials at various stages of the process in addition to the sampling required for control of the process and accountability of the materials. Direct sampling of radioactive process vessels poses a serious radiation hazard to operating personnel. For this reason, a sampling gallery isolated from all process equipment was designed for the Thorex Pilot Plant. This gallery was provided with steel-shielded sampling facilities with which all radioactive process equipment could be remotely sampled. The samples were transported in lead carriers from a central unloading station in the gallery to the analytical laboratory only a few yards away.

4.2 Plant Operation Safeguards

4.2.1 Control of Individual Exposures

A radiation exposure goal of 50 mrep/man-week was set by the Thorex Pilot Plant, and a radiation control program was established to attain this goal.

The quantitative measurement of radiation received by operating personnel is essential to any program for radiation exposure control. A complete exposure record for each individual was kept, giving a cumulative and a weekly average throughout 1955.

Three types of radiation-recording devices were used by Thorex Pilot Plant personnel during 1955. A film badge was worn by each person, and the films were removed and read each week or when an overexposure was indicated by the individual's pencil meters. Two pencil meters were worn by each operator and were read daily by Health Physics personnel. Records of individual exposures, which were measured with the film badges and pencil meters, were maintained by Health Physics surveyors and issued to the Thorex Pilot Plant each week. Daily radiation exposures, as measured with dosimeters, were recorded by each operator. The construction of the dosimeter enabled the operator to read the meter before and after a particular area was visited or operation was performed. This allowed a more useful and informative record of radiation exposure to be accumulated.

4.2.2 Health Physics Surveys

Health Physics personnel made daily surveys throughout the Thorex Pilot Plant with a paper-shell cutie-pie to determine radiation levels and discover contaminated areas. The results of these surveys were recorded and posted in the control room for ready reference by the operating personnel. A Health Physics representative was present at the daily meeting of Thorex personnel to report on existing radiation hazards. Health Physics surveyors checked for surface contamination by means of smear tests at routine intervals. Any contaminated areas found were promptly cleaned and then smear-tested again to determine the degree of decontamination. Before operating or maintenance personnel were allowed to work in a contaminated area, the area was surveyed and working time was determined by Health Physics surveyors. Strategically located instruments in the Thorex Pilot Plant continuously monitored the air to detect any accumulation of air-borne contamination. Health Physics survey results together with personnel exposure records were published in a weekly report for the purpose of conveying timely information on radiation hazards and exposure to Thorex personnel.

5.0 THOREX PILOT PLANT RADIATION LEVELS

5.1 Operating Summary

After the pilot plant was tested for three weeks with nonirradiated thorium feed, the processing of irradiated thorium was begun on December 27, 1954 (Table 5.1). During 1955, 14 runs were made using irradiated thorium for feed, and 5 runs were made using contaminated thorium or uranium products from earlier runs to obtain further decontamination or to test newly installed second thorium cycle equipment. In November and December,

Table 5.1. Summary of Operations, 1955

Month and Date	Type of Operation
1/1-1/10	6 irradiated feed runs
1/11-1/16	2 cleanout runs
1/17-1/20	Decontamination
1/21-2/10	4 recovery runs
2/11-3/15	Decontamination and construction
3/16-3/20	1 recovery run
3/21-4/7	1 irradiated feed run
4/8-4/21	Shutdown
4/22-5/2	1 irradiated feed run
5/3-5/6	Shutdown
5/7-5/13	1 irradiated feed run
5/14-5/18	Shutdown
5/19-5/28	1 irradiated feed run
5/29-6/8	Shutdown
6/9-6/21	1 nonirradiated feed run
6/22-7/5	Shutdown
7/6-7/10	1 nonirradiated feed run
7/11-7/18	Shutdown
7/19-7/30	2 nonirradiated feed runs
7/31-8/9	Shutdown
8/10-9/8	1 irradiated feed run
9/9-9/15	Shutdown
9/16-10/8	2 irradiated feed runs
10/9-10/17	Shutdown
10/18-11/3	1 irradiated feed run
11/4-11/10	Shutdown
11/11-11/14	1 nonirradiated Heptex feed run
11/15-11/18	1 tracer level feed run
11/19-12/10	1 irradiated Heptex feed run
12/11-12/31	Decontamination

the equipment was modified slightly and 12 MTR fuel elements were processed. Downtime between runs was used for decontamination, maintenance, and modification of the Thorex process equipment.

5.2 Plant Radiation Level Surveys

A complete survey of the plant radiation levels was made each day by Health Physics surveyors. Ten areas were surveyed. The solution makeup area contains tanks for preparing nonradioactive and thorium solutions and pumps for transferring the solutions to the processing equipment in the cells. The solvent room contains a tank for preparing fresh solvent and two tanks for holding solvent recovered from the process. The solvent is pumped to the solvent extraction system in the cells. The isolation laboratory contains ion-exchange resin columns for sorption of U^{233} product and auxiliary equipment for eluting the uranium and other materials from the columns. The roof area over the cells contains the dissolver off-gas control valves, dissolver condenser, a decontamination solution makeup tank, the quick-disconnect panel for routing decontamination reagents to the cell equipment, a transmitter rack, and many other small vessels and piping. Process solutions are sampled by means of newly developed sampling equipment located in the sampling gallery. In the BT decay area, three tanks contain thorium product solution from the process. The dissolver, feed preparation equipment, feed tank, extraction column aqueous waste catch tanks, and recycle equipment are contained in cubicles in cell 5. Cells 6 and 7 contain the partitioning and stripping columns, solvent recovery system, second thorium cycle, and many tanks and small vessels necessary to the process. The pipe tunnel contains the column pulsers and several pumps.

5.2.1 Makeup Area

Generally the radiation levels were about 2-3 mr/hr. No radiation above 11 mr/hr was measured in the makeup area, except during the fifty-second week, 95 mr/hr was measured when irradiated thorium that had been processed through one cycle of solvent extraction was recycled back to the head tanks in the makeup area for reprocessing.

Drums of nonirradiated thorium nitrate solution which had never been processed read 25-35 mr/hr per drum. Drums of thorium nitrate solution which had been recovered from the process read from 100-4000 mr/hr. These radiation levels are too high to allow manual handling of the drums; instead, remotely operated equipment should be provided to recycle thorium solutions. Head tanks containing thorium solutions should be shielded in order to keep the background in the solution makeup area at essentially zero radiation level.

5.2.2 Solvent Room

Radiation levels in the solvent room were greater than 20 mr/hr during 19 weeks of the year. On one occasion, 493 mr/hr was measured (Fig. 5.1). High readings occurred when aqueous carbonate solution was pumped from the solvent recovery system to the solvent head tanks along with recovered solvent. When this occurred, operators drained the aqueous layer from the head tanks. A second cause of high radiation levels was insufficient decontamination of the solvent. Particularly during the Neptex program, the spent solvent from the Thorex process became highly contaminated from fission products and the solvent recovery system could not sufficiently decontaminate the solvent. Solvent leakage from two Milton-Roy pumps caused surface contamination in the solvent room.

5.2.3 Isolation Laboratory

Isolation laboratory radiation levels increased rapidly during the first 5 weeks of operation. The contaminant column, which removed traces of thorium and ionic contaminants from the U^{233} product, reached a high of 6.2 r/hr in the fifth week (Fig. 5.2). A temporary 1/4-in. lead shield, installed in the seventh week, reduced the radiation level to less than 400 mr/hr. Permanent shielding, consisting of a 1-in. lead front, 1/2-in. lead sides and top, and 1/4-in. lead back, was installed during week 13, and the radiation levels remained essentially below 100 mr/hr for the remainder of the year. Surface contamination during the first 7 weeks of operation resulted when solution that leaked from process lines was tracked throughout the isolation laboratory by operating personnel.

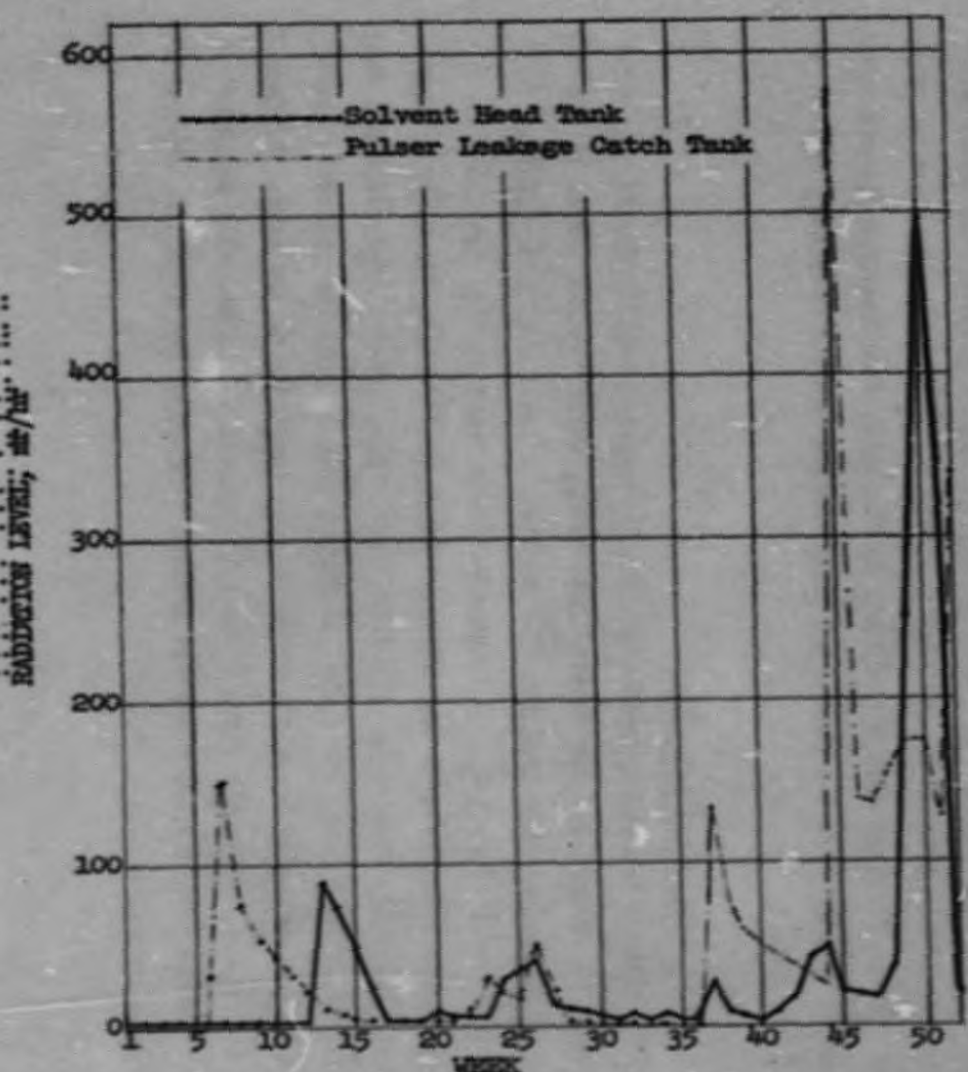

Fig. 5.1 Solvent Head Tank and Pulser Leakage Catch Tank Radiation Level Surveys, Weekly Averages.

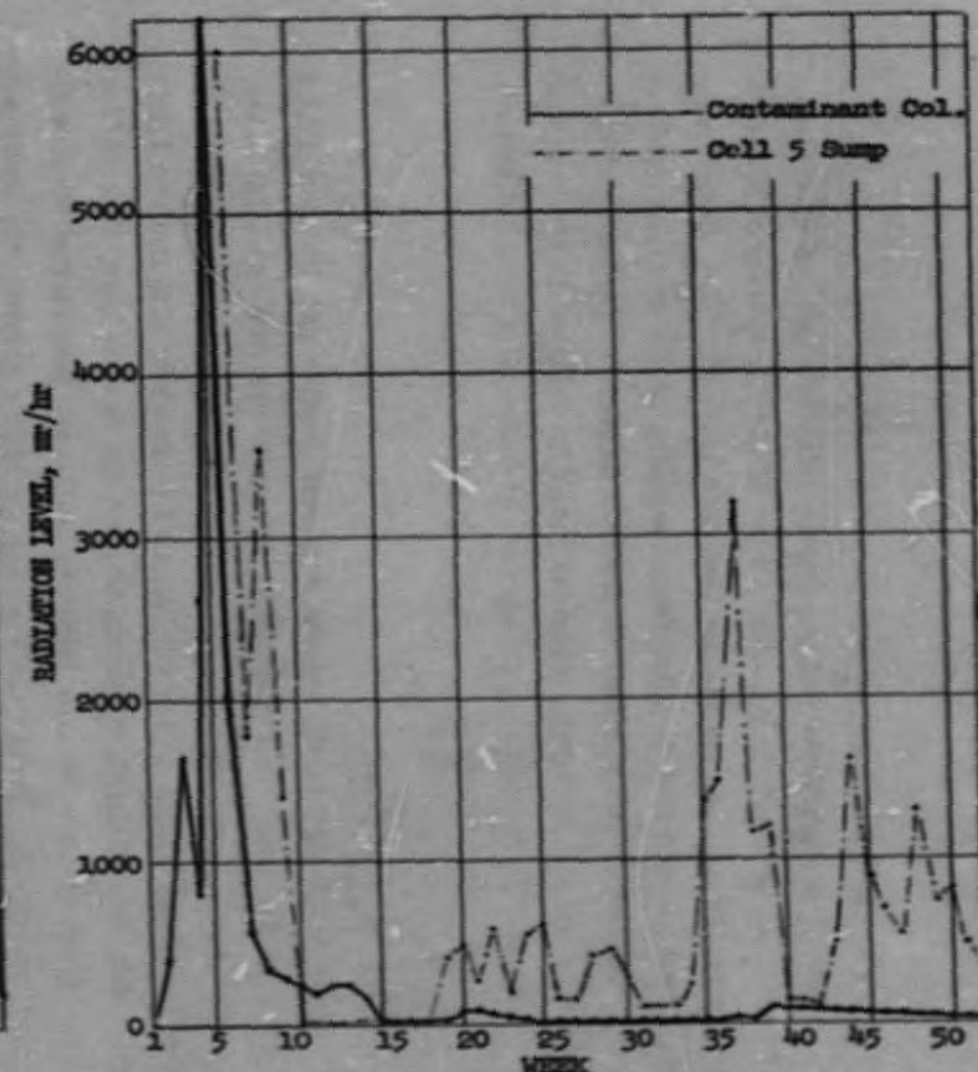

Fig. 5.2 Contaminant Column and Cell 5 Sump Radiation Level Surveys, Weekly Averages.

During week 20, air contamination to levels greater than 25,000 alpha c/m occurred when the Tygon sight glass on the product receiver ruptured from the pressure of gas generated during an attempt to unplug the discharge of the product receiver with nitric acid.

5.2.4 Roof Area

In the roof area (Fig. 5.3), radiation from the dissolver off-gas control valves increased to a weekly average of 1500 mr/hr during the second week. Decontamination reduced the radiation level to below 200 mr/hr, but subsequent slug dissolvings doubled this value. Shielding with 1/2-in.-thick lead successfully reduced the radiation level of the dissolver off-gas control valve to less than 5 mr/hr except for two occasions when levels of 75 and 50 mr/hr were recorded during slug dissolvings. A weld leak in the dissolver condenser (S-3) allowed radioactive solution to contaminate the roof area floor to a level of 900 mr/hr during week 19. During subsequent runs with nonirradiated feed, radiation from the condenser decreased to approximately 100 mr/hr and was not shielded. The drain pad under the quick-disconnect panel was contaminated on two occasions (weeks 36 and 44) to a level of 2-3 r/hr by solution spills. Air contamination exceeding tolerance was detected on several occasions during the jetting of the extraction column waste catch tank (N-2) to the tank farm. It was suspected that this air contamination came from the drain line under the quick-disconnect panel, as this line is connected directly to a header which leads to the ORNL storage system.

5.2.5 Sampling Gallery

The sampling blisters and unloading station in the sampling gallery generally read less than 5 mr/hr, usually 1-2 mr/hr. However, sampling lines carrying concentrated thorium solutions frequently plugged and required blowing down with either air or steam before samples could be taken, and on seven occasions radioactive solution was spilled, contaminating the sampling gallery floor up to a maximum of 10 r/hr. The newly developed semi-

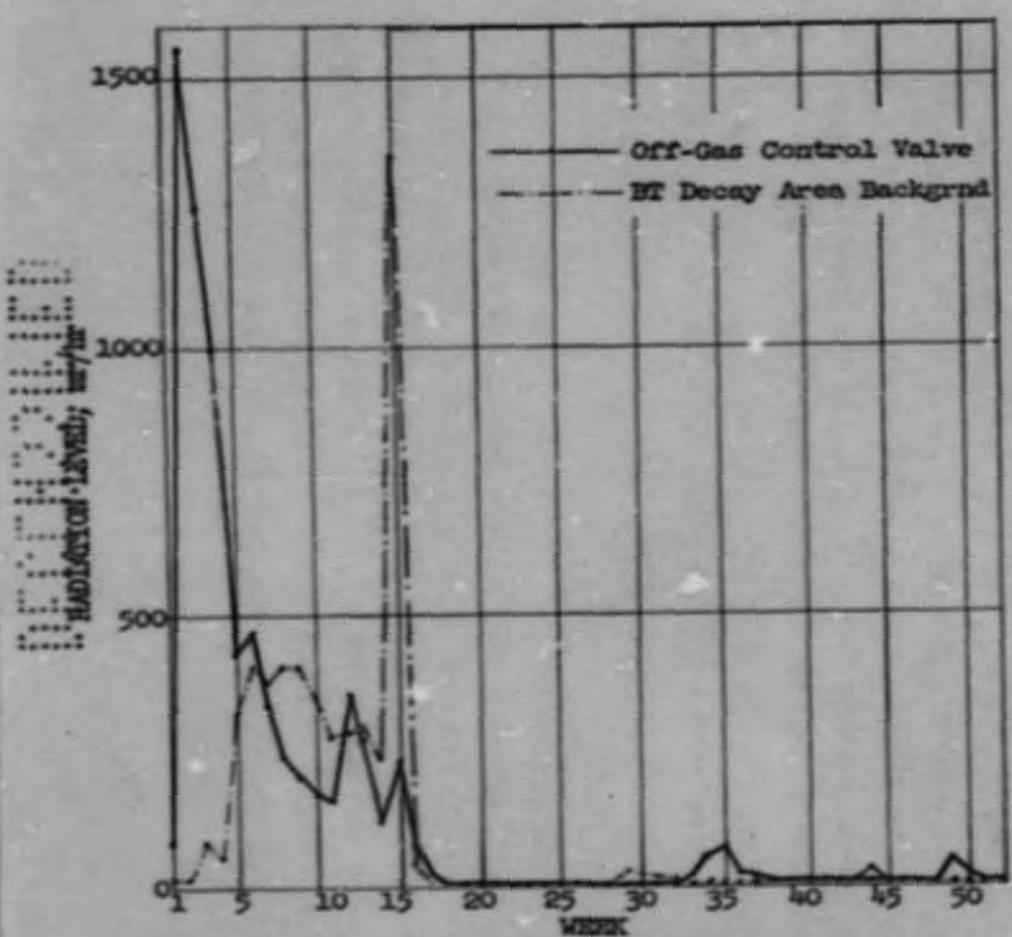

Fig. 5.3 Off-Gas Control Valve and BT Decay Area Background Radiation Level Surveys, Weekly Averages.

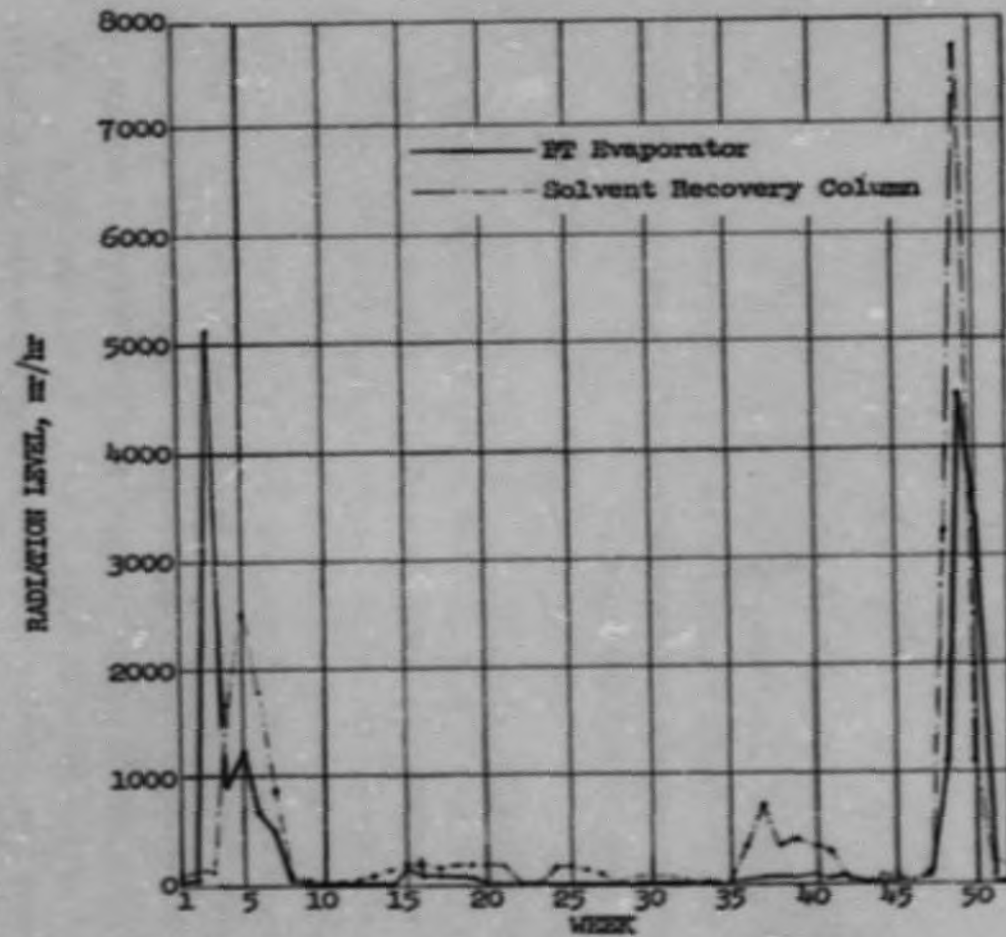

Fig. 5.4 BT Evaporator and Solvent Recovery Column Radiation Level Surveys, Weekly Averages.

automatic samplers worked very well. Several thousand samples were taken easily and with practically no exposure.

5.2.6 BT Decay Area

In the BT decay area, located outside the pilot plant, concentrated thorium product containing residual fission products from the process was stored in three 950-gal tanks. Leakage from the BT transfer pump contaminated the area up to 1350 mr/hr during week 15 (Fig. 5.3). The doorway to the area was shielded with 6-in. barytes blocks, which reduced the background through the door to 5-30 mr/hr.

5.2.7 Cell 5

Drainage from the various radioactive cubicles in cell 5 to the cell sump produced radiation levels exceeding 1 r/hr for 11 weeks, and a maximum reading of 6 r/hr was recorded during week 6 (Fig. 5.2). The trend in sump activity corresponded with the plant processing schedule. The sump was shielded with a 1/2-in. lead cover.

Radiation from the feed pump (S-4-P) cubicle, measured through a 4-in. lead shield, generally was less than 50 mr/hr and on two occasions was 2 and 5.5 r/hr. No reason was found for the first high value during week 2, but solution leakage from the S-4-P Cuno filter was responsible for the reading of 5.5 r/hr during week 20.

5.2.8 Cell 6

During week 3, the background reading at the cell 6 doorway rose to 1.5 r/hr because activity was carried over from the extraction column to the partitioning column and BT evaporator (the evaporator read 5.1 r/hr) and solution leaked from a seal on the thorium product transfer pump (P-3-P). After the first 8 weeks of plant operation, radiation from the BT evaporator remained below 200 mr/hr for the remainder of the year except during the Neptex program in December, the highly concentrated U^{235}-Np^{237} product in the BT evaporator increased the evaporator radiation level up to 4.5 r/hr (Fig. 5.4).

5.2.9 Cell 7

In cell 7, during processing of highly contaminated solvent in the Neptex program (weeks 48-50), the radiation level of the solvent recovery column increased to 7.6 r/hr (Fig. 5.4).

The centrifuge, used for removing solids from the recovered solvent, required shielding. During the first irradiated feed runs, the radiation level from the centrifuge reached 8 r/hr but after lead shielding was installed, the centrifuge radiation level was 0.1-1.1 r/hr during the remainder of the year.

5.2.10 Pipe Tunnel

In 11 weeks of the year, the radiation level of the pulser leakage catch tank exceeded 100 mr/hr, and during most of the remaining weeks was below 50 mr/hr (Fig. 5.1). These levels were too high for an area located outside the processing cells.

6.0 PERSONNEL EXPOSURES

6.1 Personnel Exposure Data

6.1.1 Operating Personnel

In processing radioactive materials during 1955, operating personnel in the Thorex Pilot Plant received a total exposure of 71,191 mrep (film badge measurement). This is an average of 59 mrep/man-week for this period, or 9 mrep greater than the established goal of 50 mrep/man-week. During the year 44 persons worked for various numbers of weeks in the pilot plant. Twenty-three persons averaged 50 mrep/week or less of exposure, 16 averaged between 51-100 mrep/week, 4 averaged 100-200 mrep/week, and 1 person averaged 210 mrep/week over a 5-week period during startup of the pilot plant. Thirteen overexposures (in excess of 500 mrep/week) totaling 3,775 mrep were received by 11 operating personnel during the year, with the overages ranging from 20 to 2,230 mrep/person.

The total and average weekly exposure of operating personnel increased to a maximum in the third week of processing and then generally decreased throughout the remainder of the year, except during the Neptex program in the last 9 weeks of the year (Fig. 6.1). Total radiation exposures, expressed as percentages of the total, for the first through the fourth quarters of 1955 were 43.5, 23.5, 9.3, and 23.7, respectively.

6.1.2 Analytical Personnel

Analytical personnel who worked on both Thorex and Metal Recovery Plant* samples received a total radiation exposure of 86,465 mrep during 1955, an average of 87.5 mrep/man-week (Fig. 6.2). A yearly total of 43,267 analyses was performed by analytical personnel for the Thorex and Metal Recovery Pilot Plants: 65% of these analyses were made for Thorex. Assuming that the average dosage per analysis was approximately equal for the Thorex and Metal Recovery samples, a total exposure of 56,202 mrep would have been received by analytical personnel from Thorex samples, or an average of 57 mrep/man-week.

Overexposures (in excess of 500 mrep/week) totaling 5,400 mrep were received by 27 analytical persons during the year. Total radiation exposures received from both Thorex and Metal Recovery samples, expressed as percentages, for the first through the fourth quarters of 1955 were 29.9, 24.2, 17.2, and 28.7, respectively.

6.1.3 Maintenance Personnel

Maintenance personnel involved in Thorex first cycle maintenance and modification (including Neptex modification) received a total radiation exposure of 30,180 mrep during weeks 23 through 52 (Fig. 6.3). During this time, 96.8 man-weeks of work was performed, giving an average exposure of

*The Metal Recovery Plant at ORNL processes irradiated fuel elements to recover uranium and plutonium. Samples from this plant are analyzed along with Thorex samples by the Pilot Plant Analytical Control Unit.

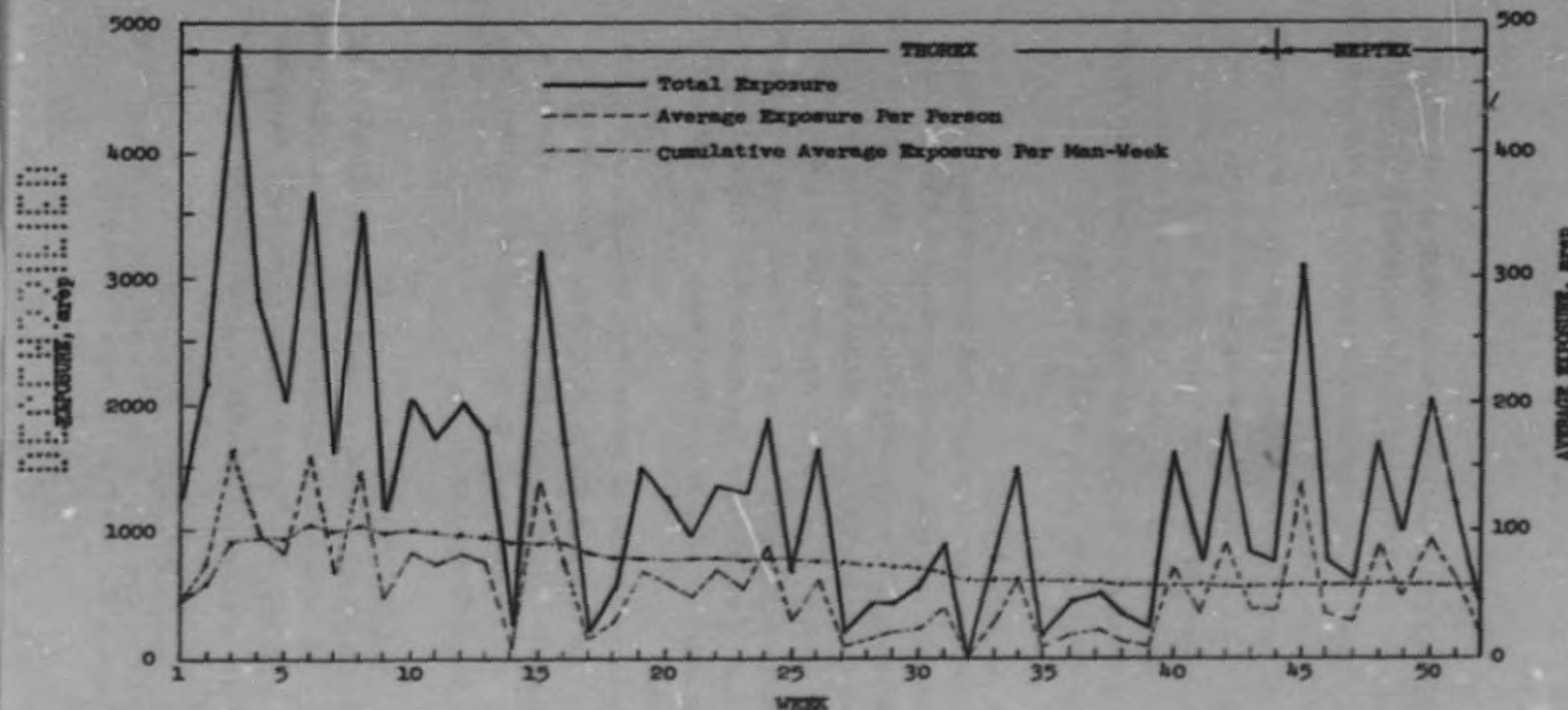

Fig. 6.1 Radiation Exposure Received by Operating Personnel, 1955.

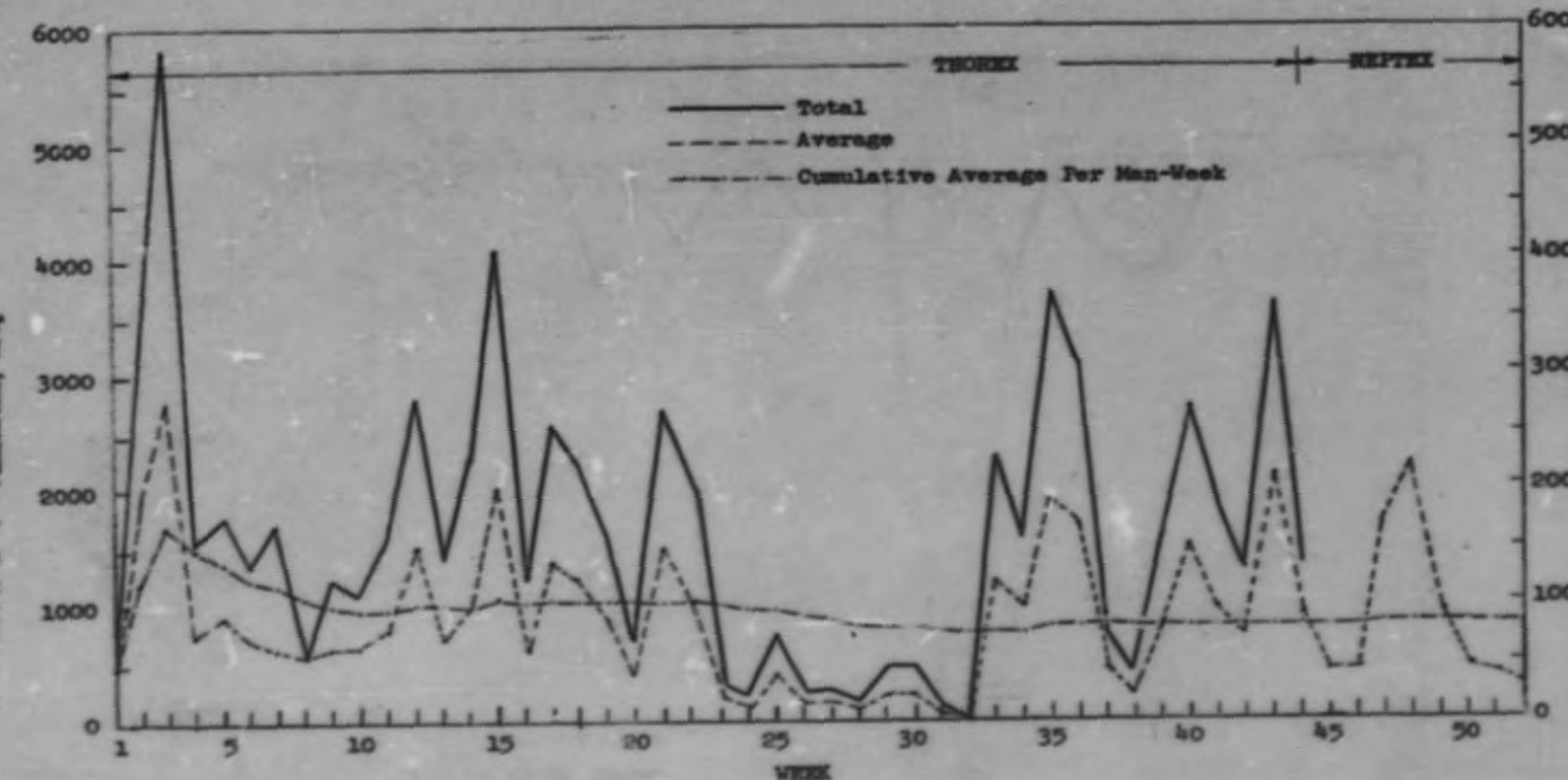

Fig. 6.2 Radiation Exposure Received by Analytical Personnel, 1955.

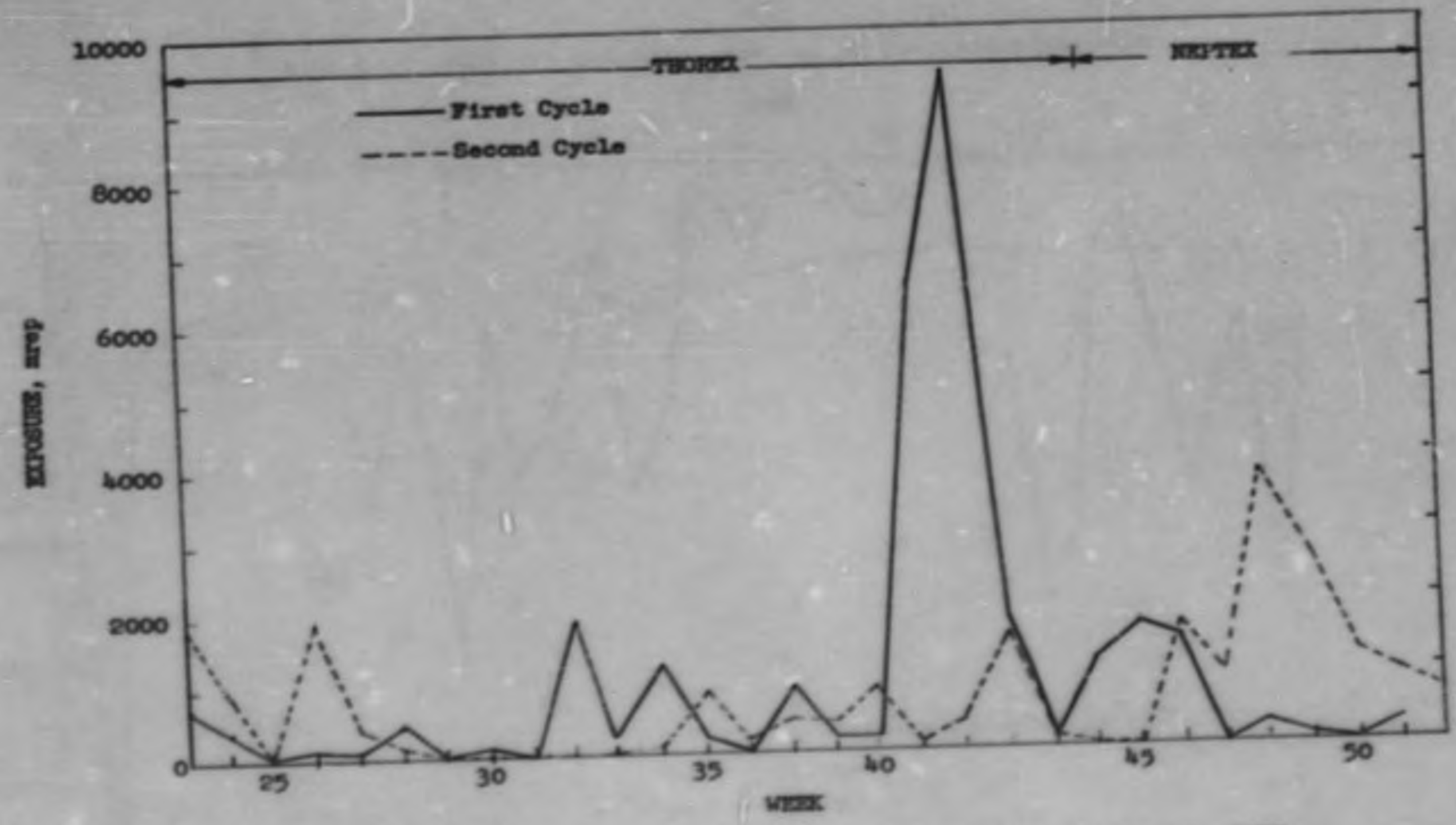

Fig. 6.3 Radiation Exposure Received by Maintenance Personnel, 1955.

312 mrep/man-week. Seventeen persons of this group were overexposed a total of 3,900 mrep. All overexposures were received within two consecutive weeks, during the installation of an alternate solvent recovery system. The installation of this system was rushed to completion, prior to the startup of irradiated feed run HD-13, and 60% of the total exposure received by first cycle maintenance personnel for the last 30 weeks of 1955 was received during this installation. Neglecting the high exposure received by maintenance personnel while installing this system, the average exposure received by craft personnel while doing maintenance work on other first cycle equipment during this period, weeks 23 through 52, was 166 mrep/man-week.

Maintenance personnel engaged in the installation of second cycle equipment received a total radiation exposure of 22,866 mrep during weeks 23 through 52 (Fig. 6.3). During this time, 144.2 man-weeks of work were performed, giving an average exposure of 169 mrep/man-week. Six persons were overexposed a total of 995 mrep.

6.2 Sources of Personnel Exposure

6.2.1 Total Exposure Received During 1955

Operating personnel radiation exposure, as measured by direct-reading quartz-fiber dosimeters, totaled 24,635 mr (film badge readings totaled 71,191 mrep) during 1955. Although the dosimeter readings differed greatly from the more sensitive film badge readings, the quick-reading feature of the dosimeter made it possible to measure the radiation exposure received in each location and during various operational jobs (Table 6.1).

A major portion (40%) of the radiation exposure was received by operating personnel while in the radioactive cell areas (cells 5, 6, and 7). Other major exposure areas were the isolation laboratory (18%) and the sampling gallery (8%). Exposure received in unspecified locations accounted for 10% of the total.

Personnel received the largest amount of exposure (21.2%) while inspecting equipment. Following closely were decontamination (16%), sampling

Table 6.1 Radiation Exposure to Thorex Pilot Plant Personnel, by Location and Operation, from Dosimeter Readings, 1955

Total Exposure: 24,635 mr

Location	Exposure, % of Total									
	Sampling	Equipment Inspection	Solution Makeup	Slug Loading and Charging	Product Handling	Equipment Operation	Equipment Service	Decontamination	Misc.	Total
Control Room	0	0.10	0	0	0.05	0	0	0	0.09	0.24
Makeup Area	0	0.13	0.12	0	0	0.02	0	0.14	0.62	1.03
Isolation Laboratory	4.95	1.34	1.45	0	5.72	0.44	0.10	3.13	0.68	17.81
Roof Area	0.12	1.32	0.76	1.85	1.11	0.29	0.55	1.08	1.35	8.43
Sampling Gallery	7.28	0.06	0	0	0	0.13	0.14	0.46	0.32	8.39
BT Decay Area	1.37	1.58	0	0	1.60	4.23	0.01	0.85	1.19	10.83
Cell 5	0.08	6.02	0	0	0	1.75	1.90	4.60	0.07	14.42
Cells 6 and 7	0.50	9.75	0	0	3.08	5.36	1.04	4.84	0.82	25.39
Basement	1.14	0.22	0	0	0.24	0	0.21	0.41	0.24	2.46
Pipe Tunnel	0.02	0.59	0	0	0	0.06	0.24	0.39	0.16	1.46
Unspecified	0.42	0.07	0	1.38	0.21	0.04	0.04	0.08	7.30	9.54
Total	15.88	21.18	2.33	3.23	12.01	12.32	4.23	15.98	12.84	100.00

(16%), equipment operation (12%), and product handling (12%). A significant amount (13%) of radiation was received during the performance of miscellaneous operations.

6.2.2 Locations Where Radiation Was Received

Radioactive Cells. The Thorex Pilot Plant was designed to permit placing highly radioactive equipment (dissolver, feed adjustment tank, extraction column, etc.) in cell 5 and less radioactive equipment in cells 6 and 7. The design philosophy of cubicle and unit shielding was carried out to a high degree in cell 5 and to a lesser degree in cells 6 and 7, in keeping with the radiation level of the equipment. Although remote operation was a primary consideration in the design of the Thorex Pilot Plant, it became necessary on many occasions to enter and work within the radioactive cell areas. No records of how many times the processing cells were entered were kept during 1955; however, a minimum estimate was obtained from the dosimeter record sheets by the summation of the number of times radiation was received in the cells (Table 7.7). The total of 668 times that radiation was received in the cells was approximately equally divided among the three cells, and an average of 43 mr/exposure was received in these areas during 1955.

The weekly variation of radiation received in cell 5 during 1955 is shown in Fig. 6.4. The accumulation of exposure increased slowly during the first 18 weeks of the year, although radiation levels in the cells were occasionally 2-6 r/hr. The radiation received during this period occurred during routine inspection of equipment and decontamination operations. During week 19, a leak developed in the feed pump (S-4-P) Cuno filter, which contaminated the cell 5 floor and S-4-P cubicle, and inspection and repair of the feed pump filter caused the rapid accumulation of exposure during weeks 20 through 24. Radiation exposure was received on 62 occasions in this period, and three persons became overexposed. The peaks in the curve of Fig. 6.4 occurring during weeks 26 and 34 resulted from testing and servicing the feed pumps. Column operation during run SC-1 was frequently interrupted because of malfunctions of the extraction column feed head pot

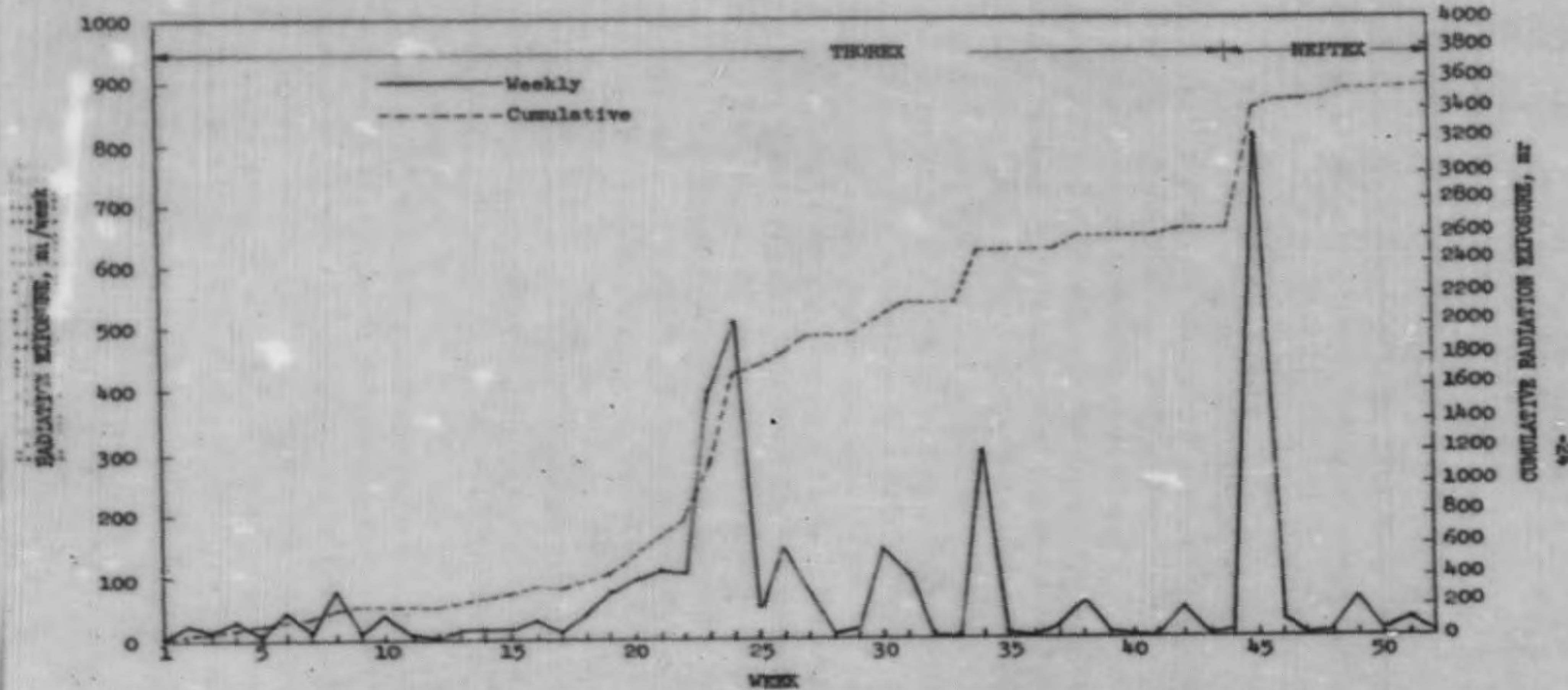

Fig. 6.4 Radiation Exposure Received by Operating Personnel in Cell 5.

and phase separator. This situation was corrected by removing the phase separator from the system. Decontaminating operations and maintenance work associated with the removal of this phase separator resulted in the increased radiation exposure during weeks 30 and 31. In preparation for the Neptex program, it was necessary to accomplish the following repairs in cell 5: replace the agitator in the feed adjustment tank (S-2), unplug the jet suction line on the S-2 outer jacket, and unplug the vapor line from S-2 to the acid fractionator (S-9). This maintenance work, together with the necessary decontamination and equipment inspection, accounted for the highest weekly exposure (dosimeter readings of 810 mr) in cell 5 during the year. The radiation exposure received in cell 5 accounted for 14.4% of the total exposure received by Thorex operating personnel during 1955. Operations performed, which resulted in this exposure, were equipment inspection, decontamination, and equipment operation and service.

The weekly variation of radiation exposure received in cells 6 and 7 during 1955 is shown in Fig. 6.5. Activity carryover from the extraction column to the partitioning column and BT evaporator increased the radiation in cell 6 to relatively high levels (the BT evaporator averaged greater than 5 r/hr one week) during the first four weeks of the year. As a result, routine inspection of equipment in cell 6 exposed operating personnel to considerable radiation; an average of 133 mr was received per exposure during this period. Subsequent decontamination reduced the radiation levels in cell 6; however, radiation levels of the solvent recovery system in cell 7 increased rapidly during week 5, again exposing personnel to considerable radiation while doing routine inspection and operation of equipment. Decontamination, together with the installation of lead shielding around individual pieces of equipment such as the centrifuge and the bottom of the solvent recovery column, reduced the radiation levels during week 10, and exposure of personnel during normal routine equipment inspection and operation in cell 7 was relatively low for the remainder of the year. A sharp peak in the radiation exposure curve occurred during week 13 when decontamination and maintenance work was required to repair weld leaks in the base of the partitioning column and in a transfer line connecting the

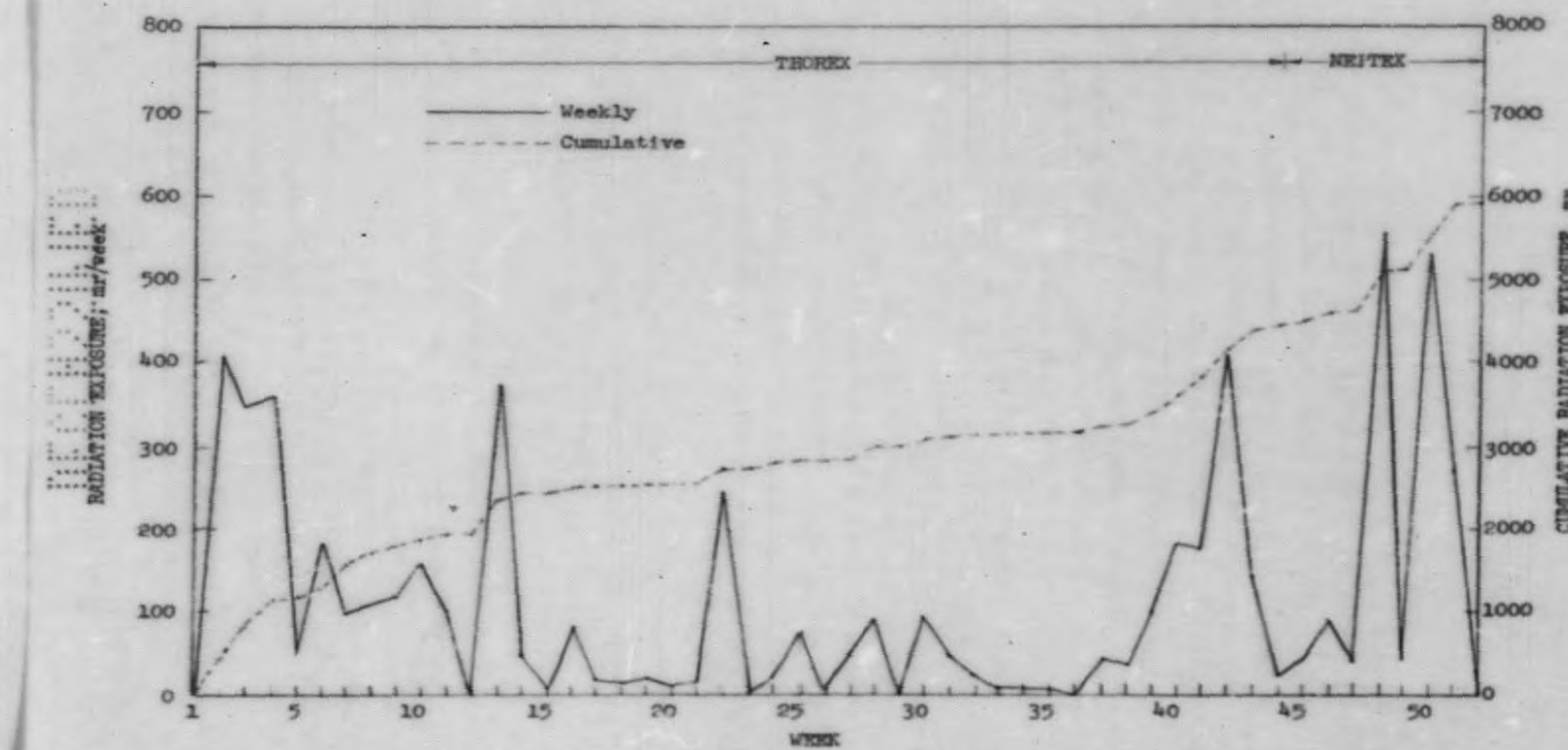

Fig. 6.5 Radiation Exposure Received by Operating Personnel in Cells 6 and 7.

CW catch tank (T-4) and the rework tank (N-8). There was another peak in the curve during week 22 when extensive decontamination was carried out in cells 6 and 7 prior to the installation of second cycle equipment. Personnel exposure received in cells 6 and 7 increased rapidly in the five-week period from week 39 through 43. During this period, the alternate solvent recovery system, consisting primarily of two glass spray columns, was installed in the stripping column cubicle and was operated during runs HD-13 and -14. This system was not designed for remote operation, and frequent inspections were necessary to ensure that the columns were operating properly. Radiation exposure was received on 56 occasions in the five weeks by personnel inspecting the system, with an average of 38 mr/exposure.

During the Neptex program (weeks 44 through 52), two sharp peaks appear in the curve representing exposure received in cells 6 and 7. This exposure was for the most part received while handling Neptex product. The recovered U^{235}-Np^{237} product was concentrated in the HT evaporator and drained into a stainless steel drum, which gave a reading of 13 r/hr on a cutie-pie. It was necessary for operating personnel to handle this drum on several occasions, and the average amounts of radiation received were 357 and 191 mr/exposure for weeks 48 and 50, respectively. These averages are considerably above the yearly average of 38 mr/exposure in the processing cells. Radiation received in cells 6 and 7 amounted to 25% of the total exposure accumulated by Thorex operating personnel in 1955. Operations that resulted in this exposure were equipment inspection, equipment operation and service, decontamination, and product handling. All radiation received while handling product occurred during the Neptex program.

Roof Area. Curves representing the radiation exposure received in the roof area are shown in Fig. 6.6. During the first 30 weeks of 1955 personnel exposures were accumulated at a low rate (approximately 2 mr/man-week), while during the last 22 weeks exposures were accumulated more rapidly (9 mr/man-week). This rapid accumulation during the latter part

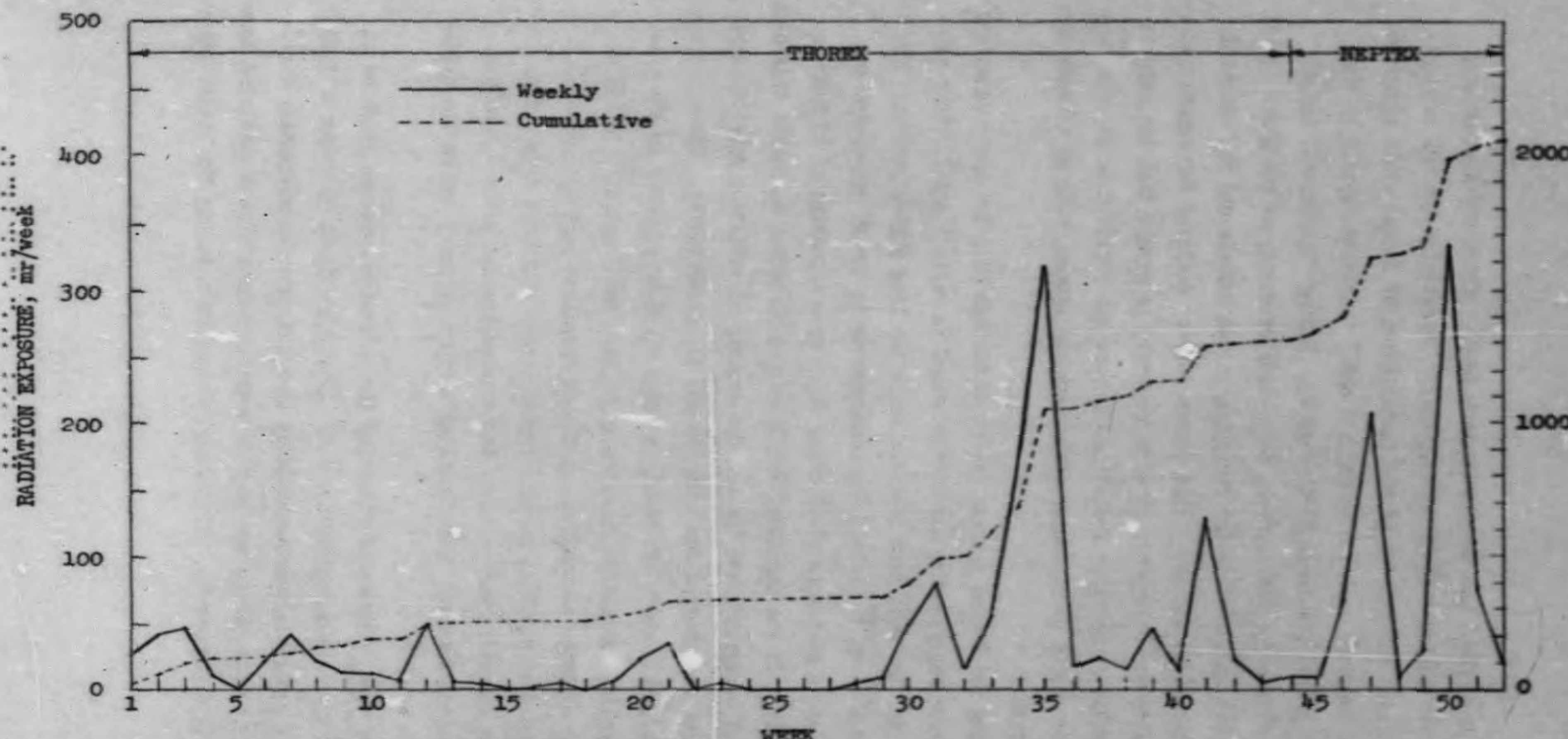

Fig. 6.6 Radiation Exposure Received by Operating Personnel in Roof Area.

of the year was due primarily to four periods of relatively high exposure. During weeks 34 and 35, the quick-disconnect panel drain pad became contaminated, 10 r/hr, because of drainage from the off-gas condensate trap tank, and the radiation level of the dissolver condenser (S-3) rose to 375 mr/hr. Decontamination of the drain pad and miscellaneous work in the vicinity of the S-3 condenser accounted for 76% of the radiation received in the roof area during weeks 34 and 35. The peak in the curve at week 41 resulted from solution makeup and equipment servicing necessary for the operation of the alternate solvent recovery system. The loading and charging of the MTR assemblies during the Neptex program accounted for the high exposure in week 47. On one occasion an MTR assembly would not drop through the slug loading chute, and it was necessary to raise the slug charger approximately 2 in. and push the assembly with a long rod before it would drop into the dissolver. Neptex product, which was concentrated in the BT evaporator and drained into a stainless steel drum, was returned to the evaporator for additional concentrating by raising the product drum from cell 6 to the roof area and draining its contents back to the evaporator through a connection on the quick-disconnect panel. This handling of the radioactive product drum (13 r/hr) accounted for 80% of the radiation received in the roof area during week 50. Radiation received in the roof area amounted to 8% of the total exposure accumulated by Thorex operating personnel in 1955. No single operation was primarily responsible for the exposure received in the roof area, and the operations that resulted in exposure were slug loading and charging, miscellaneous operations, equipment inspection, product handling, and decontamination.

Isolation Laboratory. A significant portion (18%) of the radiation exposure to Thorex operating personnel occurred in the isolation laboratory. Approximately 75% of the total exposure in the isolation laboratory occurred during the first 6 weeks of the year, which represents an average exposure of 73 mr/man-week for this period (Fig. 6.7). The installation of unit shielding around the resin columns and the product receiver greatly

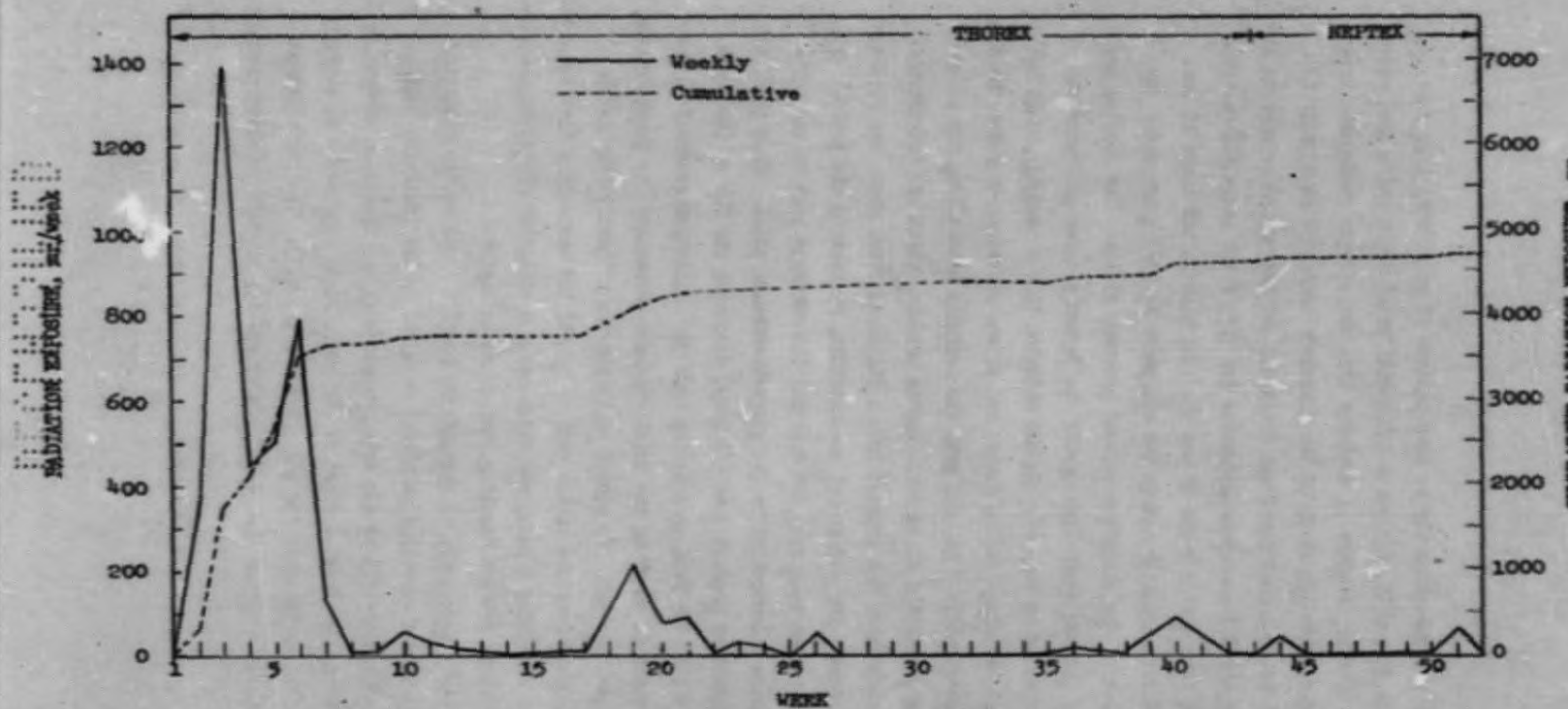

Fig. 6.7 Radiation Exposure Received by Operating Personnel in Isolation Laboratory.

reduced the radiation levels in the isolation laboratory (Fig. 5.2), and, as a result, the average exposure decreased to 3 mr/man-week for the remainder of the year. Operations primarily responsible for exposures in the isolation laboratory were product handling, sampling, and decontamination.

Sampling Gallery. The radiation exposure received in the sampling gallery accounted for 8% of the total exposure received by Thorex operating personnel during 1955. The cumulative exposure curve of Fig. 6.8 shows a relatively constant rate of exposure for 1955 except for a rapid buildup during the first 5 weeks of operation and a period of low exposure during operation with recycled thorium feed (weeks 24 through 31). The average exposure rate for the year in the sampling gallery was 5 mr/man-week. Weekly exposures in excess of 100 mr (dosimeter reading), which occurred four times, resulted when the sample gallery floor was contaminated during blowing down of sampling lines. This contamination was difficult to remove from the concrete floor, and it was necessary to cover one spot under the cell 5 sampling blister with a 0.5-in.-thick lead sheet.

BT Decay Area. The radiation exposure received in the BT decay area accounted for 11% of the total exposure received by Thorex operating personnel during 1955. Operations that resulted in this exposure were chiefly equipment operation, product handling, equipment inspection, sampling, and miscellaneous operations. The cumulative exposure curve of Fig. 6.9 shows that approximately 80% of the total exposure in the BT decay area occurred during the first 15 weeks of the year, which represents an average exposure of 15 mr/man-week for this period. The doorway to the BT decay area was shielded with 6-in. barytes blocks during week 16, and the average exposure decreased to 1.5 mr/man-week for the remainder of the year. Leakage from the BT transfer pump (P-19-P) contaminated the BT decay area to 1350 mr/hr during week 15, and operation (product handling and equipment modification) in the vicinity of this contamination produced the highest weekly exposure, 580 mr (dosimeter reading), for 1955 in this area.

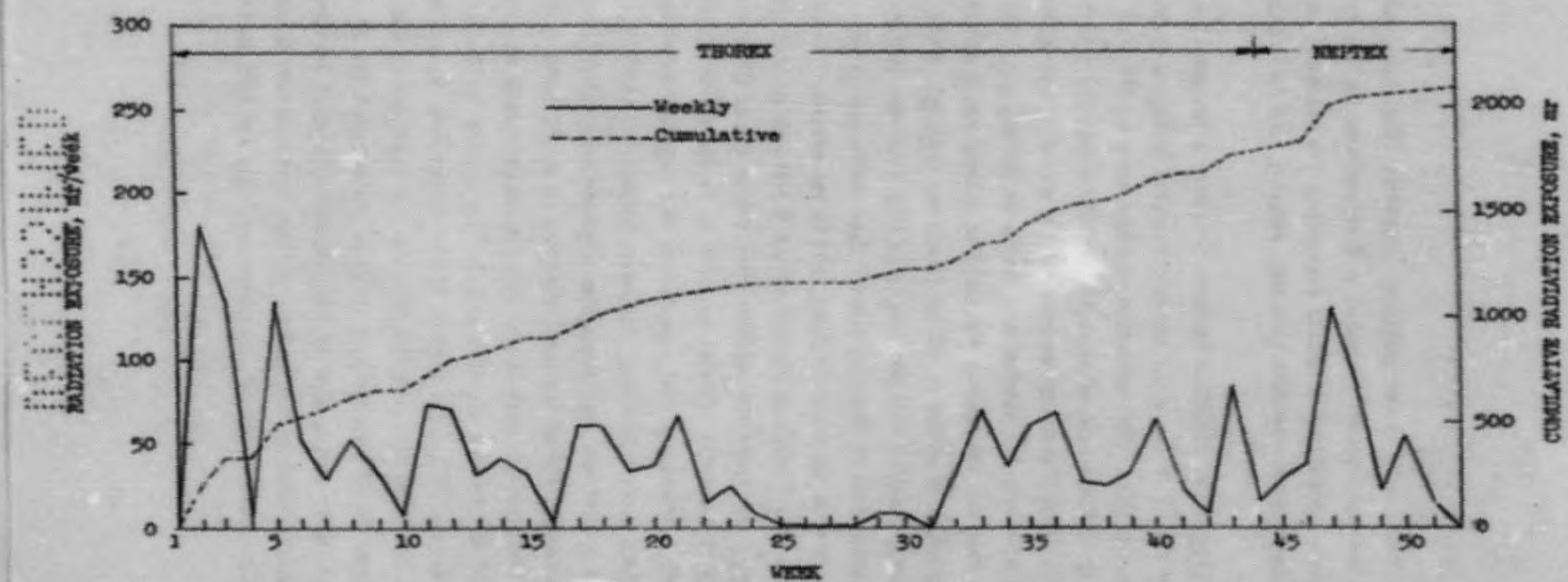

Fig. 6.8 Radiation Exposure Received by Operating Personnel in Isolation Laboratory.

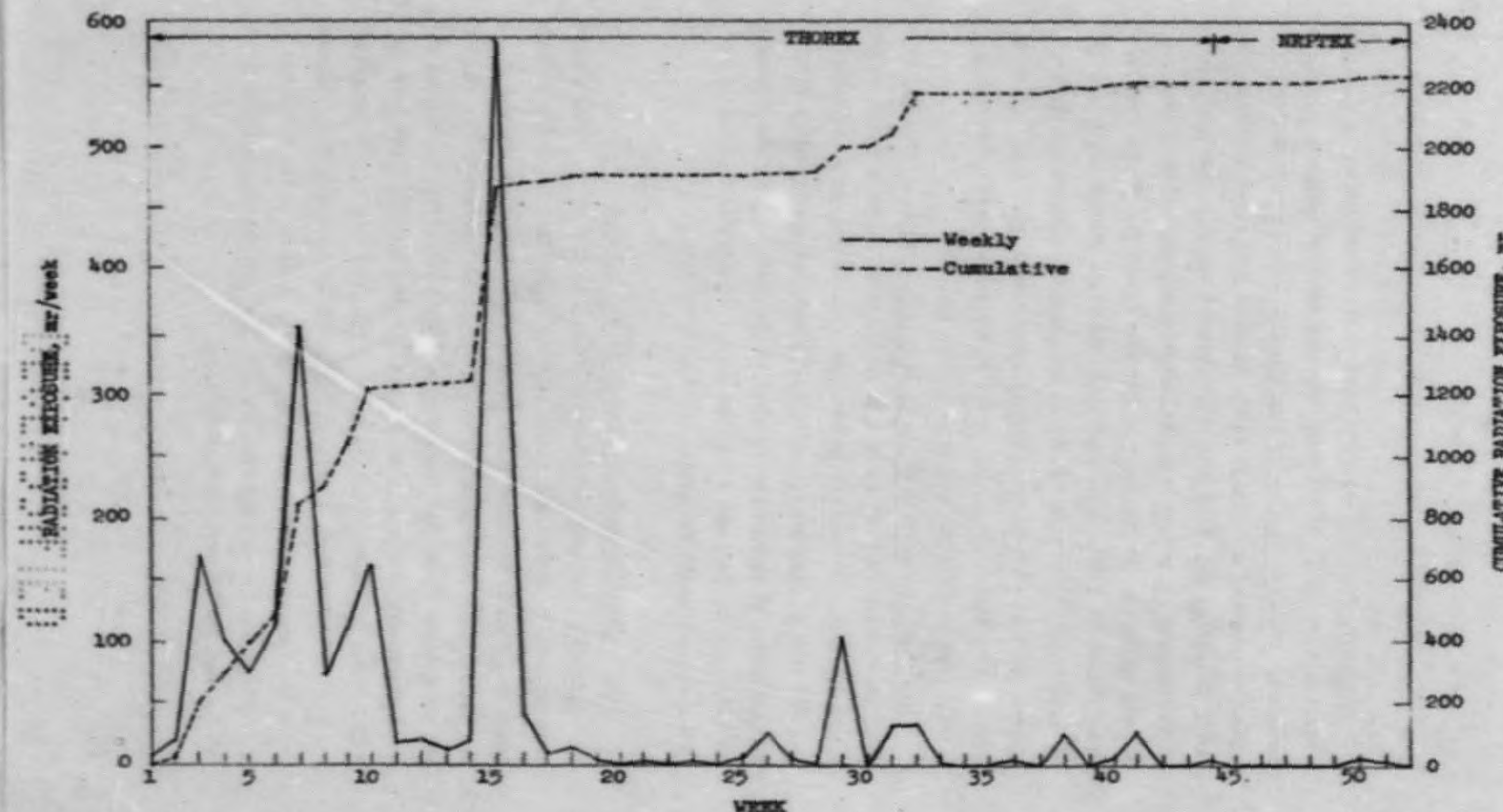

Fig. 6.9 Radiation Exposure Received by Operating Personnel in BT Decay Area

<u>Basement.</u> Radiation exposure received in the basement area was only a small portion (2.5%) of the total exposure received by Thorex operating personnel. The major portion of this exposure was received when thorium product was drummed and sampled in the basement with background radiation levels as high as 260 mr/hr (Fig. 6.10, weeks 4 and 16). The handling of thorium product in this area was discontinued, and radiation exposure was negligible for the remainder of the year except for the last month. To make room for second cycle equipment, the clean solvent catch tank (T-5) was moved from cell 7 to a cubicle in the basement. During the Neptex program, this tank became contaminated, producing a reading of 1200 mr/hr through the cubicle door on one occasion, and radiation was received by personnel while servicing equipment in this area.

<u>Pipe Tunnel, Control Room, and Makeup Area.</u> Radiation received in these three areas amounted to only 3% of the total exposure to Thorex personnel for 1955. The cumulative exposure curve of Fig. 6.11 indicates that the rate of exposure accumulation corresponded approximately with the processing of radioactive material in the plant, and the average exposure rate for the year was 1.5 mr/man-week. Operations resulting in exposure were equipment inspection and decontamination.

6.2.3 <u>Operation Performed When Radiation Received</u>

<u>Sampling.</u> Sampling operations accounted for 16% of the total radiation exposure to operating personnel during 1955. This total was accumulated mainly while sampling in the gallery (46%) and in the isolation laboratory (31%). Approximately 45% of the total exposure due to sampling was accumulated during the first 7 weeks of the year (Fig. 6.12), and the average exposure rate was 31 mr/man-week for this period. Over half the exposure due to sampling in this 7-week period occurred in the isolation laboratory. After several units of equipment had been shielded, radiation exposure, including that due to sampling, was reduced in the isolation laboratory, and the average exposure rate for sampling decreased to 6 mr/man-week for the remainder of the year.

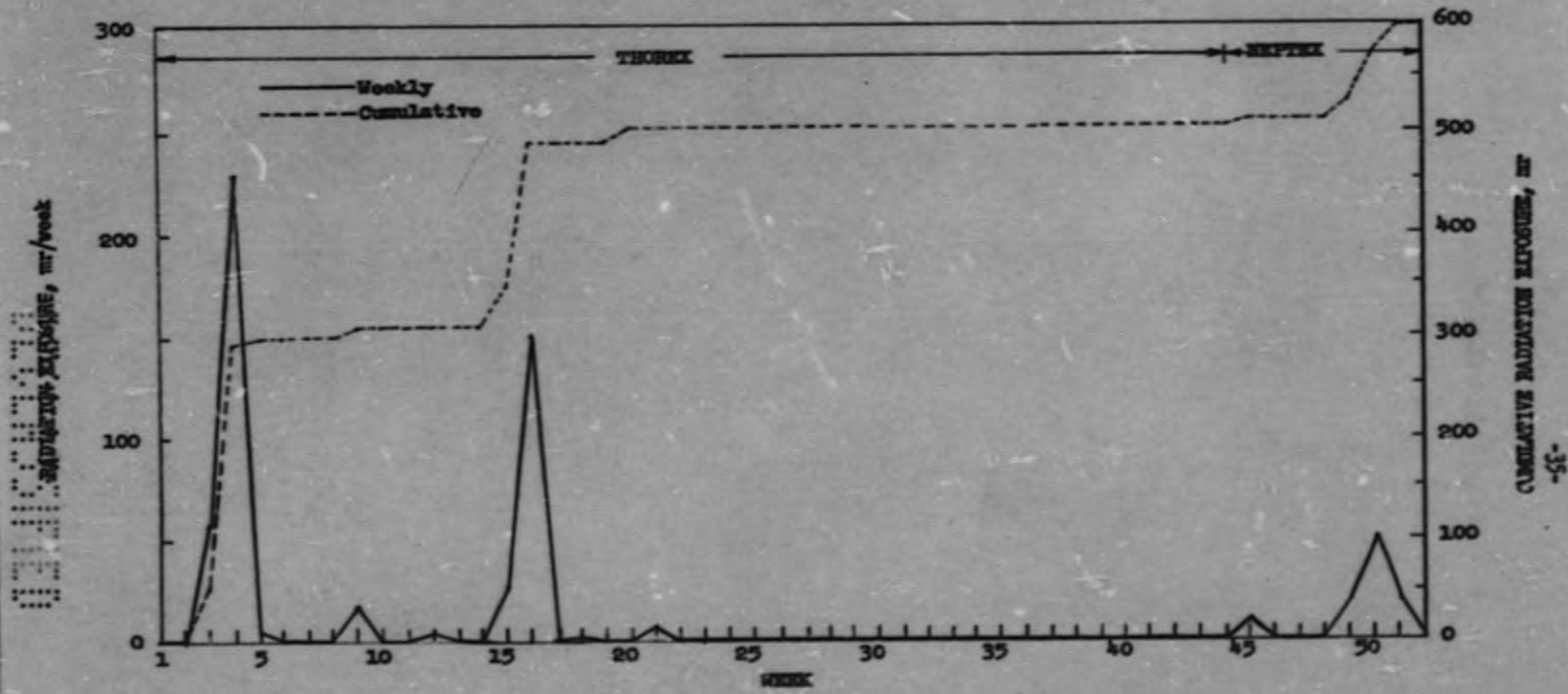

Fig. 6.10 Radiation Exposure Received by Operating Personnel in the Basement.

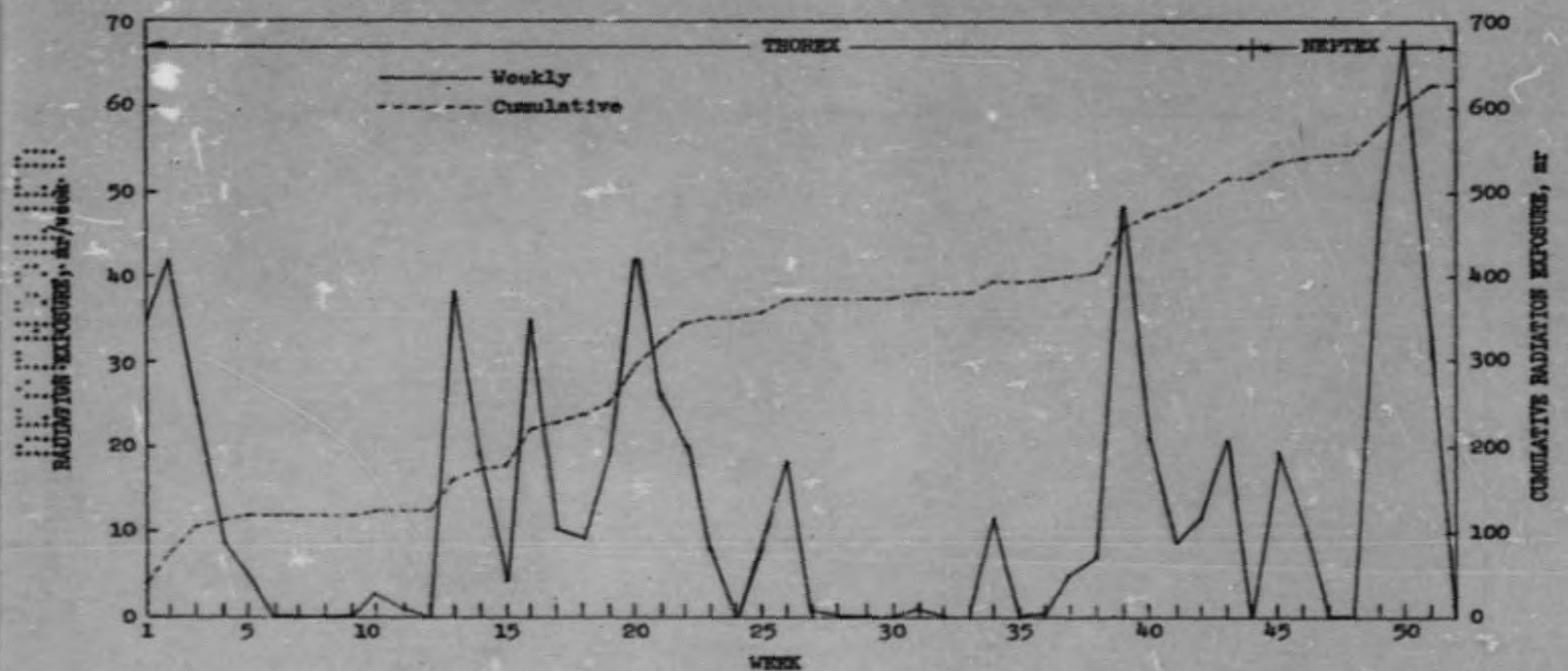

Fig. 6.11 Radiation Exposure Received by Operating Personnel in Pipe Tunnel, Control Room, and Makeup Area.

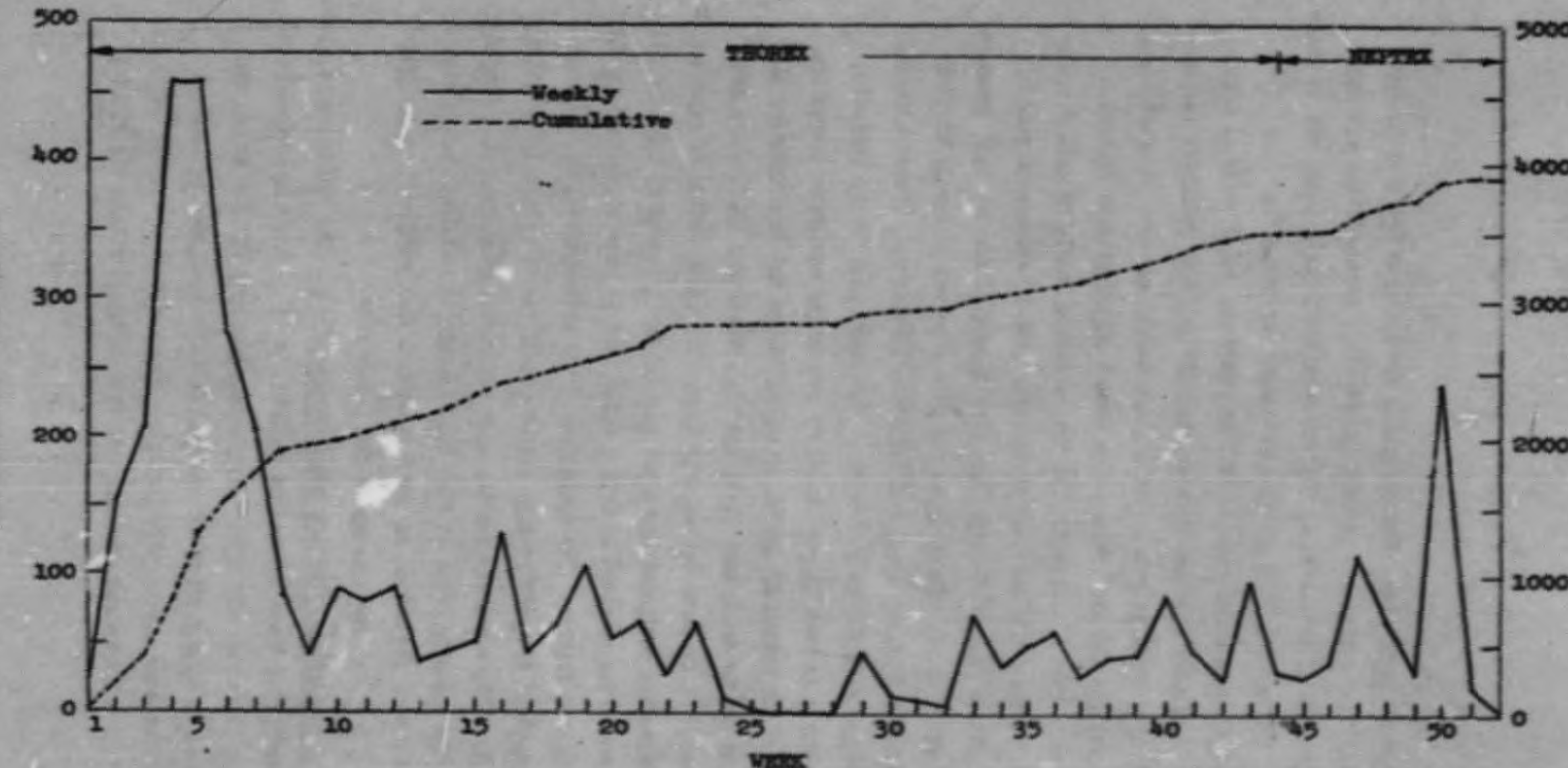

Fig. 6.12 Radiation Exposure Received by Operating Personnel During Sampling.

Equipment Inspection. The operation resulting in the greatest proportion (21%) of radiation exposure to operating personnel was equipment inspection, and of this amount, 28% was received in cell 5 and 46% in cells 6 and 7. The accumulation of exposure during the year (Fig. 6.13) was maintained at an average rate of 12.5 mr/man-week, and 8 weeks of high exposure (dosimeter readings greater than 200 mr) were primarily responsible for this exposure rate. The highest weekly exposure (dosimeter readings 430 mr) for the year occurred in week 4 during routine equipment inspection in cell 6. At this time the radiation levels of cell 6 equipment were at their highest peak of the year (the BT evaporator read 6.1 r/hr). Routine equipment inspection also accounted for the high exposures during weeks 6 and 7. These exposures were received primarily in three areas (cell 6, BT decay area, and isolation laboratory), where radiation levels ranged from 400 to 2000 mr/hr. The sharp peak in the radiation exposure curve in week 13 was caused by nonroutine equipment inspection of welds in the bottom of the partitioning column and in a transfer line connecting the CW catch tank (T-4) and the rework tank (N-8) which had leaked and were repaired during this week. The accumulation of exposure while inspecting equipment increased rapidly during weeks 23 and 24. All this exposure was received in cell 5 while repairs were being made on the feed pumps and filters. The operation of the alternate solvent recovery system required frequent routine inspection of the two glass spray columns in cell 7. This accounted for the high exposure during week 42. The high peak in the exposure curve of Fig. 6.13 in week 45 resulted from radiation received during inspection of the maintenance work performed on equipment in cell 5 prior to the startup of the Neptex runs.

Slug Loading and Charging and Solution Makeup. The radiation received while performing these operations amounted to 6% of the total exposure to operating personnel for 1955. Fifty-eight per cent of this amount was attributed to slug loading and charging and the remainder to solution makeup. Exposure during solution makeup was received primarily (62%) in the isolation laboratory, and most of this occurred within the first 7

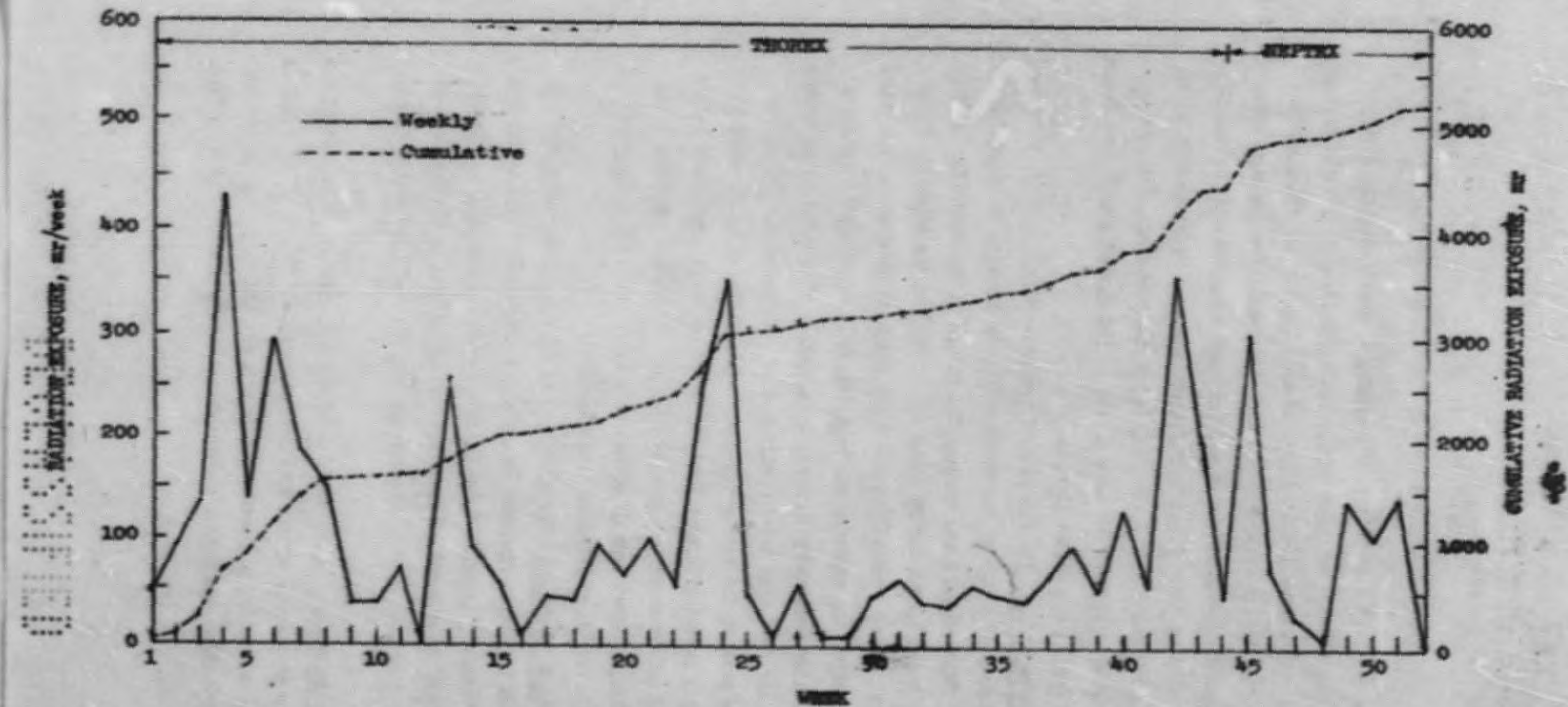

Fig. 6.13 Radiation Exposure Received by Operating Personnel During Equipment Inspection.

weeks of the year. The highest weekly exposure, which occurred during week 6, was accumulated entirely in the isolation laboratory while making up solutions. The intermittent nature of slug loading and charging is responsible for the steplike appearance of the cumulative exposure curve of Fig. 6.14. Each peak in the weekly exposure curve, except for week 6, coincides with slug loading and charging operations. Approximately 49 mr was received for each loading and charging of thorium slugs, and approximately 51 mr was received for each of the 12 MTR elements that were loaded and charged during the Neptex program.

Product Handling. The handling of product---thorium, U^{233}, U^{235}, or Np^{237}---accounted for 12% of the total radiation exposure to operating personnel. This exposure was accumulated mainly in the isolation laboratory, cells 6 and 7, and the BT decay area. Most of the exposure due to product handling was received in the first and last portions of the year. Forty per cent of the exposure was received while handling U^{233} product in the isolation laboratory in weeks 2 through 4. The handling of Neptex product in the roof area and in cells 6 and 7 accounted for 37% of the total. The peak in the weekly exposure curve of Fig. 6.15 for week 15 resulted from handling thorium product in the BT decay area where P-19-P leakage had contaminated the area to 10 r/hr. Personnel exposure rates while handling product were 37 mr/man-week (weeks 1-4), 2 mr/man-week (week 5-47), and 26 mr/man-week (week 48-52).

Equipment Operation. The operation of equipment accounted for 12% of the total radiation exposure to operating personnel. This total was accumulated mainly in cells 6 and 7, BT decay area, and cell 5. Except for the first three weeks of the year, the accumulation of exposure was relatively constant, with an average for the year of 7 mr/man-week (Fig. 6.16).

Decontamination. In order to decrease the exposure of operating and maintenance personnel, it was necessary to keep the Thorex Pilot Plant as free of contamination as possible by prompt and thorough decontaminating procedures. These operations accounted for the second highest proportion

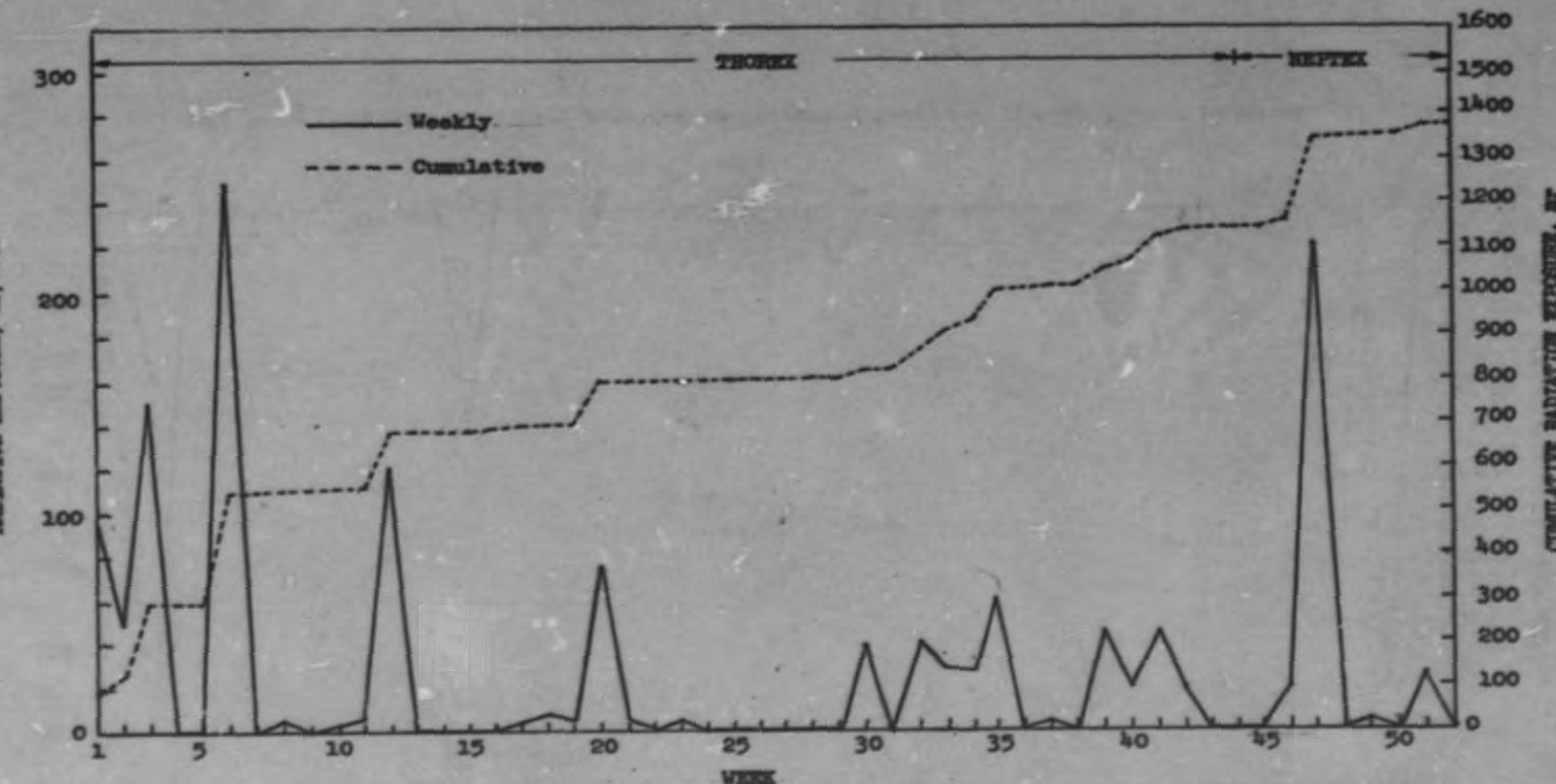

Fig. 6.14 Radiation Exposure Received by Operating Personnel During Slug Loading, Slug Charging, and Solution Makeup

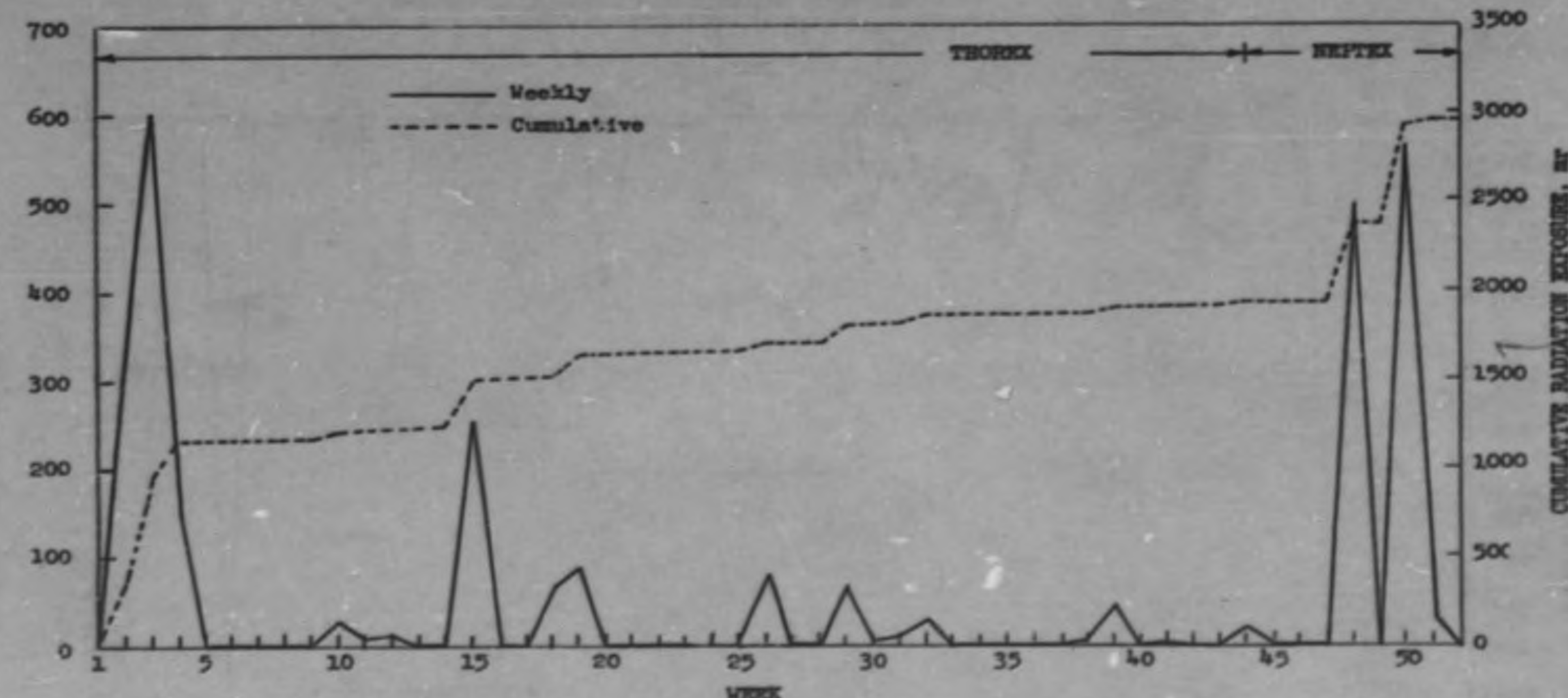

Fig. 6.15 Radiation Exposure Received by Operating Personnel During Product Handling.

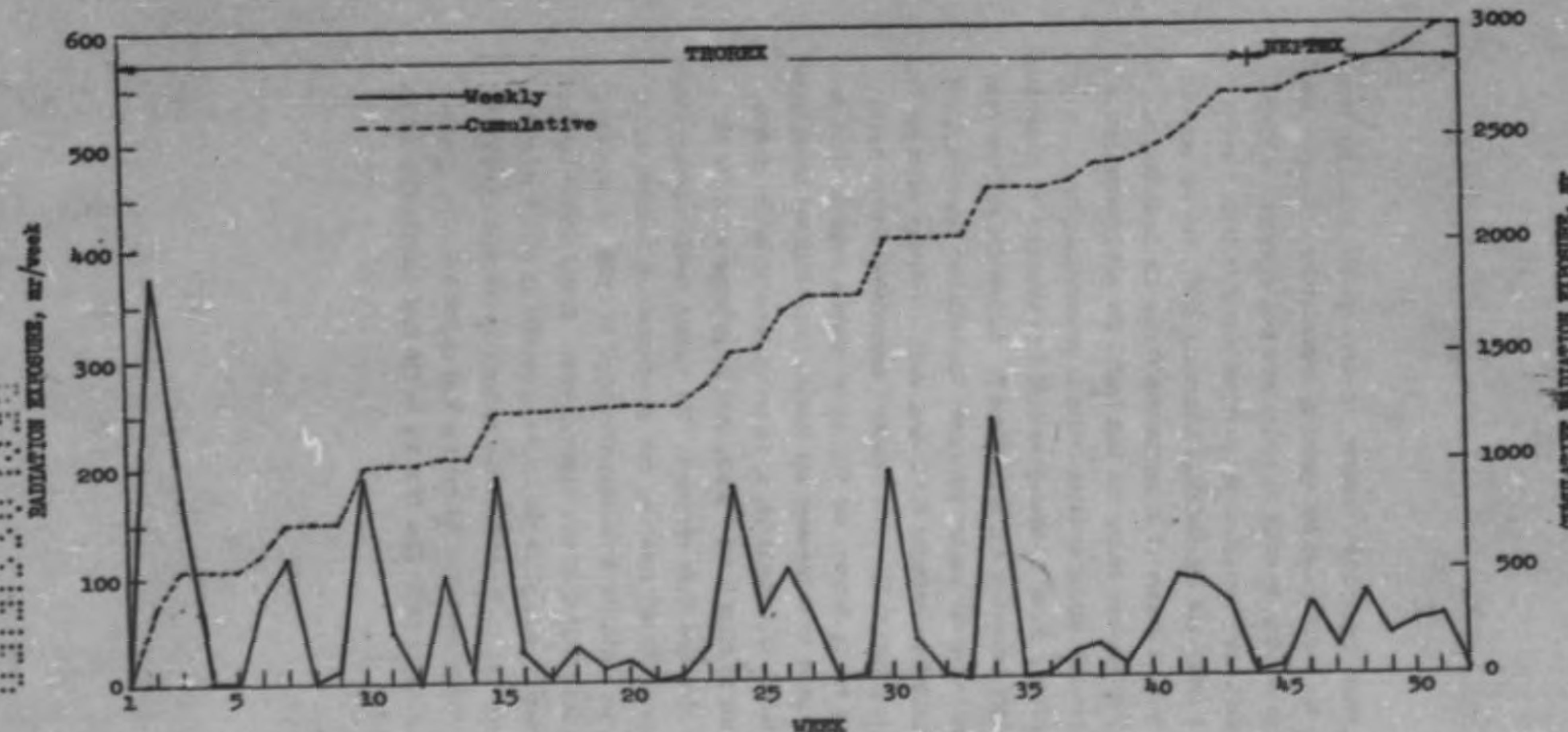

Fig. 6.16 Radiation Exposure Received by Operating Personnel During Equipment Operations

(16%) of exposure to personnel; however, if these operations had not been carried out, the accumulation and spread of contamination would have soon forced a plant shutdown to avoid excessive personnel exposure. Exposure due to decontaminating operations was received mainly in cells 6 and 7 (30%), cell 5 (29%), and the isolation laboratory (20%), and the exposure rate varied from an average of 12 mr/man-week during the first half of the year to 7 mr/man-week during the last half. The weekly accumulation of exposure received during decontamination is presented in Fig. 6.17. The high exposure received in week 3 resulted from intensive decontamination of the isolation laboratory and cells 6 and 7. Radioactive solution from a faulty check valve was tracked throughout the isolation laboratory, and this area remained contaminated for several weeks. Activity carryover from the extraction column to the other equipment accumulated rapidly during the production run in January, and this necessitated a complete plant decontamination prior to maintenance and construction. This was accomplished in weeks 7 through 11. Similarly, an intensive decontamination program was carried out in cells 6 and 7 during week 22 in preparation for the installation of second cycle equipment. The highest weekly exposure (dosimeter readings of 580 mr) resulting from decontamination occurred during week 45. Again, extensive decontamination prior to equipment maintenance and modification resulted in this high exposure. In this latter instance, it was necessary to accomplish the following repairs in cell 5 prior to the Heptex program: replacement of the agitator in the feed adjustment tank (S-2), unplugging of the jet suction line on the S-2 outer jacket, and unplugging of the vapor line from S-2 to the acid fractionator (S-9).

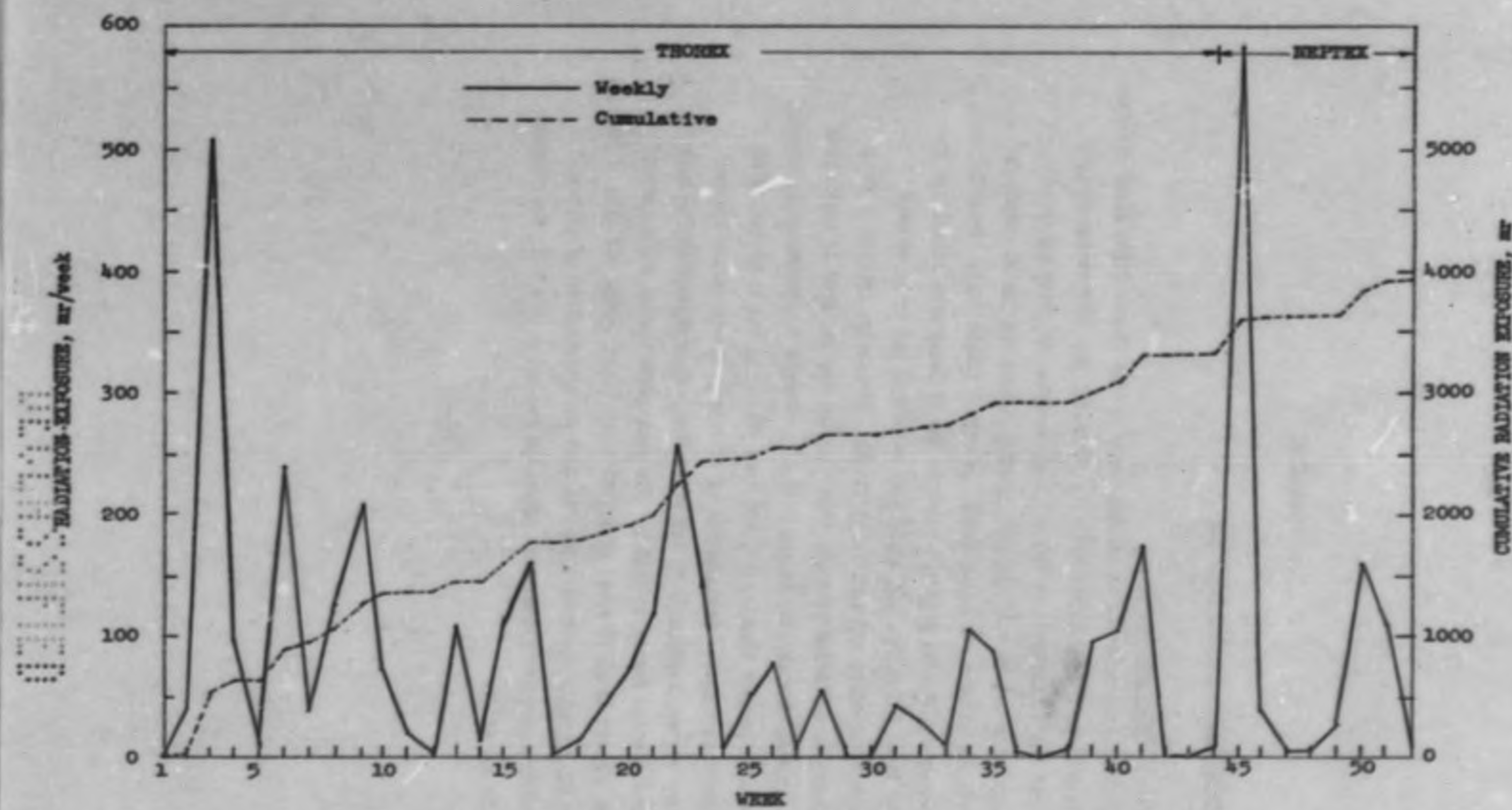

Fig. 6.17 Radiation Exposure Received by Operating Personnel During Decontamination.

7.0 EVALUATION

7.1 Radiation Levels and Exposure

7.1.1 Radiation Levels

High radiation levels in various areas of the Thorex Pilot Plant resulted for the most part from higher activity carryover into downstream equipment than was anticipated in the original design. Activity carryover from the extraction column into the partitioning column and the BT evaporator produced the highest radiation levels in cell 6 (Table 7.1). Insufficiently decontaminated thorium product stored in the BT decay area raised its radiation level 400 mr/hr, and additional shielding had to be erected to prevent excessive exposure to personnel. Similarly, uranium product containing more fission products than expected was isolated in unshielded resin columns that rapidly became radiation hazards to operating personnel. Levels were greater than 6 r/hr, and lead shielding had to be installed to protect personnel. Accumulation of fission products in the solvent recovery system, especially in the centrifuge, was responsible for much of the radiation hazard in cell 7. The centrifuge became contaminated to the highest level (8 r/hr) of any cell equipment in the vicinity of which personnel normally operated. Insufficient decontamination of solvent by the solvent recovery system also increased radiation levels in the solvent room to 493 mr/hr.

Table 7.1. Plant Radiation Levels by Areas During 1955

Area	Reading, mr/hr[a] Low	High	Reason for High Reading
Cell 5	17	6000	Drainage from cell cubicles into cell sump
Cell 6	10	5140	Activity carryover from extraction column to partitioning column and BT evaporator
Cell 7	37	8000	Accumulation of activity in solvent recovery system centrifuge
Isolation laboratory	12	6200	Accumulation of activity in the contaminant resin column (L-2)
Roof area	73	1800	Weld leak in S-3 condenser
BT decay area	< 5	1350	Pump leakage (P-19-P)
Pipe tunnel	< 5	810	Pump leakage (T-4-P)
Solvent room	< 5	493	Contaminated solvent used during Neptex program
Sampling gallery	< 5	10000	Spill resulting from blowing down S-2 sampler lines

[a]Weekly average.

The equipment failures---pump, weld, valve and filter leakage---producing the major radiation hazards to personnel performing routine operations were those which allowed radioactive solutions to contaminate operating areas. These failures not only caused high exposure rates, but the radioactive solution from the leaks was easily spread to other areas. The failure of the Cuno filters on the radioactive feed pumps caused the contamination of the floor in cell 5 to a level of 5.5 r/hr. Pump leakage on six occasions produced excessive radiation levels in cell 6, the BT decay area, the pipe tunnel, and the solvent room. Leakage from the thorium product transfer pump (P-3-P) contaminated the floor in cell 6 three times to radiation levels of 1.1-2.2 r/hr. The highest radiation level observed in the BT decay area (1350 mr/hr) resulted from leakage from the BT product unloading pump (P-19-P). Pump leakage (from T-4-P) also caused the highest radiation level (810 mr/hr) in the pipe tunnel. Solvent leakage from the solvent metering pumps (M-13-P and M-14-P) did not produce excessive radiation levels in the solvent room, but surface contamination resulting from this leakage was tracked into nonradioactive operating areas. A faulty check valve allowed radioactive solution to spill in the walk-in hood in the isolation laboratory. Personnel operating the isolation equipment in this hood subsequently tracked this solution throughout the isolation laboratory, producing a highly contaminated area. Process solution from weld leaks produced contaminated areas as follows: the base of the partitioning column developed a leak at a cross weld, resulting in a contamination of 18 r/hr in the B-column cubicle; the T-4 cubicle in cell 7 was contaminated by a weld leak in a new line from T-4 to N-8; a weld leak in condenser S-3 allowed radioactive solution from the dissolver to contaminate the roof area floor with one spot reading 13 r/hr; and the cell 5 floor was contaminated by leakage from a faulty weld in the discharge line of the jet from the feed pump discharge line to N-16. The highest radiation levels in the sampling gallery resulted from equipment failures. The frequent necessity of unplugging sampler lines by blowing them down with steam or air resulted in contamination of the sampling gallery floor on seven occasions, with the most radioactive spot reading 10 r/hr.

Processing of other materials (Neptex program) in equipment designed for the Thorex process was another source of high radiation levels. Concentrating the Neptex product U^{235} and Np^{237} in the BT evaporator increased the radiation level of this equipment to its second highest level of the year, 4.5 r/hr. Contaminated solvent used in the Neptex program raised the radiation levels of almost all the equipment in the solvent recovery system to the highest levels of the year (M-13, 7.9 r/hr; T-column, 493 mr/hr; M-14, 200 mr/hr; and T-8, 575 mr/hr). The storage of Neptex product in a drum (reading 13 r/hr) also caused radiation exposure to operating personnel.

7.1.2 Radiation Exposure

The goal of an average exposure of 50 mrep/man-week was nearly reached; the average exposure to Thorex operating personnel was 59 mrep/man-week. Overexposures to operating personnel were relatively few, and only one relatively high overexposure (2230 mrep) occurred during the year. Efforts to reduce personnel exposure by shielding, and operational and equipment changes were successful, as evidenced by the ratios of 4.7/2.5/1 of total radiation received during the first through the third quarters of 1955.

Table 7.2. Summary of Radiation Exposures to Thorex Pilot Plant Personnel for 1955

Type of Personnel	Program	Weeks	Total Exposure, mrep	Average Exposure, mrep/man-wk	Overexposures	
					Total, mrep	No. of Persons
Operating	Thorex	1-44	60,221	58	3485	10
Operating	Neptex	45-52	10,970	65	290	3
Analytical	Thorex and Neptex	1-52	56,202	57	5400[a]	27[a]
Craft	1st cycle Thorex	23-52	30,180	312	3900	17
Craft	2nd cycle Thorex	23-52	22,866	169	995	6

[a]Includes exposure received in handling of Thorex, Neptex, and Metal Recovery samples.

The program to control radiation exposure was successful as shown by the relation between radiation exposure and the amount of thorium processed in the plant (Table 7.3). Although the total exposure received in the second quarter was a factor of 1.9 less than that received in the first quarter, the amount of irradiated thorium processed decreased by a factor of 2.2, and the exposure per kilogram of irradiated thorium increased from 10.5 to 12.3 mrep. Most of the irradiated thorium processed in the first quarter was handled in a continuous production run, while processing during the second quarter was accomplished in four separate development runs. The increase in the exposure per kilogram of irradiated thorium processed of the second over the first quarter may be attributed to the exposure received in performance of miscellaneous operations during the downtime between runs when no thorium was being processed. A comparison of the second and third quarters, when approximately equal amounts of irradiated thorium were processed in similar types of development runs, shows that a decrease in total exposure by a factor of 2.5 was accompanied by a decrease of exposure per kilogram of irradiated thorium processed from 12.3 to 5.5 mrep.

Table 7.3. Relation between Radiation Received by Operating Personnel and Thorium Processed in 1955

	Exposure Received		Thorium Processed, kg		Exposure Received, mrep/kg thorium	
Quarter	mrep	%	Irradiated	Nonirradiated	Total Thorium	Irradiated Thorium
1st	30,990	51.5	2,943.7	2,326.1	5.9	10.5
2nd	16,731	27.9	1,365.1	3,770.8	3.3	12.3
3rd	6,585	10.7	1,198.0	4,589.2	1.1	5.5
4th	5,915	9.9	959.1	2,386.7	1.8	6.2
Total	60,221	100.0	6,465.9	13,072.8	3.1	9.3

The average exposure to Thorex operating personnel was itemized by location and type of operation (Table 7.4). The data were obtained from dosimeter readings, which were converted to FTR measurements by multiplying by 2.9. This factor was obtained by dividing the total film badge measurements of 71,191 mrep by the total dosimeter measurements of 24,635 mr for the year.

A comparison of the average exposure rate for the total Thorex year (weeks 1-44) and the latter period (weeks 27-44) shows a decrease by a factor of 1.5 in the two average rates. Personnel exposure rates during this latter period easily surpassed the goal of 50 mrep/man-week, with an average of approximately 39 mrep/man-week.

Table 7.4. Average Exposure Rates to Thorex Operating Personnel by Locations and Operations

Location	Average Exposure Rate, mrep/man-week		Operation	Average Exposure Rate, mrep/man-week	
	Weeks 1-44	Weeks 27-44		Weeks 1-44	Weeks 27-44
Cell 5	7	6	Sampling	10	5
Cells 6 & 7	13	11	Equipment inspection	13	10
Roof area	4	7	Slug loading and charging and solution makeup	3	2
Isolation lab	13	2	Product handling	6	2
Sample gallery	5	4	Equipment operation	8	7
BT decay area	6	2	Decontamination	9	5
Basement	1	0	Unspecified	8	8
Pipe tunnel Control room Makeup area	2	1			
Unspecified	6	6			
Total	57	39		57	39

Operating personnel engaged in the Neptex program received an average exposure of 65 mrep/man-week during the weeks 45 through 52. Three persons were overexposed to a combined total of 290 mrep in this period. Activities responsible for the increased exposure to operating personnel were decontamination and maintenance in cell 5, Neptex product handling in cell 6 and the roof area, and slug charging in the roof area.

There were 13 overexposures received by 11 persons, but details of two overexposures were not available (Table 7.5).

Table 7.5. Summary of Overexposure to Thorex Operating Personnel during 1955

		Overexposure (above 500 mrep/week)	
Operation	Location	Total, mrep	No. of Overexposures
Product handling	Isolation lab	535	4
Equipment operation (centrifuge)	Cell 7	2230	1
Equipment maintenance	Cell 5	400	5
Equipment inspection	Cell 5	20	1
Unknown	Unknown	590	2
Total		3775	13

A radiation exposure average of 57 mrep/man-week was received by analytical personnel in conducting 28,100 analyses for the Thorex Pilot Plant during 1955. The total exposure amounted to 56,202 mrep, or an average of 2 mrep per analysis.

Craft personnel involved in first cycle Thorex and Heptex maintenance and modification received a total of 30,180 mrep in weeks 23 through 52, an average exposure rate of 312 mrep/man-week. Because essentially all the craft personnel working time was spent in the very radioactive cells or slightly radioactive areas, high exposure rates were received by these persons. Seventeen craft personnel working on first cycle equipment were overexposed, all within a two-week period while completing a rush installation of the alternate solvent recovery system in cell 7. Craft personnel involved in second cycle installation received a total of 22,866 mrep in weeks 23 through 52, receiving an average exposure of 169 mrep/man-week.

7.1.3 <u>Relation between Radiation Received and Plant Radiation Levels</u>

Greatest personnel exposures generally occurred during the time and in the areas where high radiation levels existed except for cell 5. Cell 5 equipment, which is the most radioactive in the plant, was almost completely unit shielded, and the reasons for entering the cell during routine operations were few. Large exposures resulted from equipment failures and not routine operations. Prior to all maintenance work to be done in cell 5, extensive decontamination (especially in the cubicle containing the equipment to be repaired) was carried out to lower the radiation levels and allow longer working time; this resulted in the lack of similarity between the curves representing exposure and radiation levels.

The relation between exposure and radiation level in cells 6 and 7 corresponds to a greater extent than that in cell 5; however, these areas also have their exceptions. The highest radiation levels in cells 6 and 7 occurred within the first 10 and the last 5 weeks of the year. Radiation exposures were also high during these same two periods, with routine operation of equipment, equipment inspection and product handling accounting for most of this exposure. In weeks 10 through 47, there were three periods of high exposure, although the radiation levels were relatively low, which resulted from decontamination and repair of a weld leak in the partitioning column, decontamination prior to installation of second cycle equipment, and operation of the alternate solvent recovery system.

Two areas in which the relation between personnel exposure and radiation levels were striking were the isolation laboratory and the HT decay area. During the first 7 weeks of the year, the radiation levels of the contaminant columns in the isolation laboratory rose rapidly to a high of 6.2 r/hr, and exposure increased correspondingly. After the columns were shielded, their radiation levels generally decreased to less than 100 mr/hr for the remainder of the year, and the average rate of exposure decreased by a factor of approximately 22. Similarly, the installation of shielding in the HT area decreased its background radiation level from a high of 1350 mr/hr to less than 50 mr/hr, and the average exposure rate prior to the shielding installation was reduced by a factor of 10 for the remainder of the year.

7.2 Thorex Design Philosophy

7.2.1 Unit Shielding

The effectiveness of the unit shielding installed in the Thorex Pilot Plant in reducing personnel exposure is indicated by the low average rate of exposure of approximately 20 mrep/man-week received in cells 5, 6, and 7 during 1955, and the total exposure of 28,500 mrep. Although the shielding facilities, as originally designed, measurably reduced radiation levels and exposures, it soon became necessary to provide additional shielding, such as complete closure of cubicles and unit shielding of individual pieces of equipment with lead, to reduce the radiation levels and exposures to the desired levels. Fission product carryover and accumulation in equipment downstream from the feed preparation and extraction systems produced higher radiation levels than expected and necessitated installation of the additional shielding. The additional shielding in the cells reduced the exposure rate for weeks 27 through 44 to 16 mrep/man-week. As compared to the over-all rate of 20 mrep/man-week the effects of the additional shielding were felt more strongly in the isolation laboratory and HT decay area, where average exposure rates were reduced by factors of 22 and 10 over their respective averages prior to the installation of the unit shielding.

The effectiveness of the unit shielding philosophy in reducing exposure may be seen by comparing the exposures in cell 5 and the isolation laboratory. Although the uranium product gross activity was reduced by a factor of approximately 10^4 less than the feed material in cell 5, 13.5% of the total exposure to operating personnel for 1955 was received in the isolation laboratory in the first 6 weeks of the year (prior to installation of shielding), while only 14.4% of the total was received in cell 5 throughout 1955.

The individual drain facilities installed in each cubicle were generally successful in preventing the spread of activity throughout the cells, except on two occasions when the cell 5 floor was contaminated to a level of 5.5 r/hr by leakage from the feed pump filters. In cell 5, drainage from the individual cubicles into the cell sump produced radiation levels greater than 1 r/hr, and as high as 6 r/hr, in the sump for 12 weeks during the year. If this activity had been allowed to spread throughout the cell, excessive personnel exposures would have been incurred during decontamination.

7.2.2 Remote Operation

Exposure to personnel who remotely controlled the Thorex Pilot Plant amounted to only 0.24% (171 mrep) of the total exposure to operating personnel. In direct contrast, approximately 2000 mrep were received by personnel while operating the alternate solvent recovery system in cell 7. No instrumentation was furnished this system, and frequent trips into cell 7 to check the column interfaces and liquid flow rates were required. Radioactive solutions were allowed to reach the control panel through instrument lines on only one occasion. High-pressure air was employed in trying to flush heavy solution from a phase separator (N-11), and radioactive solution was forced back through the instrument lines of the extraction column interface controller to the panel board. One contaminated spot under this instrument read 3 r/hr.

A total of 5,160 mrep was received by operating personnel while sampling in the sampling gallery during 1955. This amount represents 7.3% of the total exposure to operating personnel and 45.9% of exposure received in all sampling operations. Direct sampling, specifically in the isolation laboratory, accounted for more than half the exposure attributed to sampling.

7.3 Relation of Radiation Exposures to Equipment Performance and Operational Procedures

7.3.1 Effects of Various Types of Equipment Failures on Exposures

The total of 10,346 mr received as the result of equipment failures represents 14.6% of the total exposure to operating personnel during the year (Table 7.6).

Leakage from pumps transferring slightly radioactive solution tended to contaminate wide areas in the vicinity of the pumps, and decontamination and repairs to these pumps resulted in the largest proportion (22%) of the exposure to operating personnel. Poor off-gas vacuum on the feed adjustment system was caused by plugging of the vapor line between the feed adjustment tank (S-2) and the acid fractionator (S-9) with Raschig rings from the fractionator. Considerable exposure was received in the repair of this system. Weld leaks, responsible for 14.6% of the exposure, occurred in the bottom of the partitioning column, a transfer line from the contaminated solvent catch tank (T-4) to the recycle hold tank (N-8), dissolver condenser (S-3) and in a jet line to N-16. Equipment that failed as a result of corrosion was the feed adjustment tank agitator and the acid cooler (S-13).

No detailed records of exposure to craft personnel during equipment repairs were kept in 1955.

Table 7.6. Effects of Equipment Failures on Thorex Operating Personnel

Type of Equipment Failure	Exposure Received, mrep			% of Total
	Decontamination	Equipment Inspection and Repair	Total	
Weld leaks	696	812	1508	14.6
Valve leaks	739	102	841	8.1
Pump leaks	1255	1020	2275	22.0
Filter leaks	229	493	722	7.0
Plugged sampler lines	339	232	571	5.5
Corrosion	560	832	1392	13.5
Plugged transfer lines	1123	580	1703	16.4
Feed pumps	174	1160	1334	12.9
			10346	

7.3.2 Effects of Operational Procedure on Exposure

Equipment Inspection. The operational procedure resulting in the greatest exposure to personnel was equipment inspection (15,130 mrep, or 21.2% of the total exposure for 1955), and 75% of this exposure was received in cells 5, 6, and 7. Routine equipment inspection consisted of valve and equipment checks prior to run startups and periodical inspection of equipment throughout the plant during the run to ensure proper operation or early discovery of improper operation. This type of equipment inspection accounted for exposures of 11,803 mrep, or 78% of the total. Much of this exposure was received during the first 8 weeks of the year when radiation levels were generally at their highest, and an average of 23 mrep/man-week was received in this period. After the installation of additional shielding, the average exposure rate for routine equipment inspection decreased to 7 mrep/man-week for the remainder of the year.

Nonroutine equipment inspection is associated with equipment failure and consists of diagnosing the cause and extent of the failure and checking the results of its repair. Exposure from this type of equipment inspection is sporadic and generally unpredictable, and the exposure received amounted to 3360 mrep (28% of total) from three separate occasions when major equipment repairs were made.

Decontamination. During 1955, 11,390 mrep (16% of total) was received by personnel performing decontamination operations, and this was received mainly in cells 5, 6, and 7 and the isolation laboratory. Although the average weekly exposure rate for the last half of 1955 was lower by a factor of 1.8 (9 vs. 5 mrep/man-week), this improvement was due primarily to equipment repairs and modifications that reduced the amount of contamination rather than to a change in the decontamination procedures.

Sampling. The average exposure rate due to sampling in the first 7 weeks of operation was lowered by a factor of 5 (31 vs. 6 mrep/man-week) during the remainder of the year. This reduction was due primarily to increased shielding in the isolation laboratory and not to improved sampling procedures. The total radiation exposure during sampling amounted to 11,310 mr, or 15.9% of the yearly total.

Equipment Operation. Equipment operation accounted for an exposure of 8770 mrep (12.3% of total), which was received primarily in the cells and the BT decay area. The average rate of exposure for the year was 8 mrep/man-week, and there was no significant change in this rate as a result of varying the procedures.

Product Handling. A total of 8550 mrep (12% of total) was received during handling of the thorium, U^{233}, U^{235}, and Np^{237} products during 1955. Although the average exposure rate for the year was 7 mrep/man-week, the exposure was accumulated during three distinct periods of varying exposure rates. In weeks 1 through 4, exposure during product handling was at a rate of 36.5 mrep/man-week. This resulted mainly from handling uranium product in the isolation laboratory before shielding was installed. In weeks 5 through 47, the exposure rate was 2 mrep/man-week, and the exposure was primarily accumulated in the BT decay area where pump leakage had contaminated the area. The handling of Neptex product during the last 5 weeks of the year resulted in an average exposure rate of 27 mr/man-week.

Reasons for Entering Radioactive Cells. Table 7.7 presents a minimum estimate of the number of times the radioactive cells in the Thorex Pilot Plant were entered during 1955. This estimate was obtained from the dosimeter record sheets by the summation of the number of times radiation was received in these cells.

Table 7.7. Number of Times Radiation Was Received by Thorex Operating Personnel on Entering Radioactive Cells during 1955

	No. of Exposures							
Cell	Sampling	Equip. Inspection	Product Handling	Equip. Operation	Equip. Service	Decontamination	Misc.	Total
5	2	124	1	17	29	46	5	224
6	4	120	8	8	19	49	11	219
7	4	139	0	10	16	43	13	225
Total	10	383	9	35	64	138	29	668
% of Total	1.5	57.4	1.3	5.2	9.6	20.7	4.3	100.0

7.4 Effectiveness of Radiation Control Program

The radiation control program that was instituted for the Thorex Pilot Plant succeeded in reducing the average exposure to operating personnel to 59 mrep/man-week during 1955. Although this average rate for the year was higher than the established goal of 50 mrep/man-week, the average rate for the last half of the year was 46 mrep/man-week as a result of improvements in shielding and operational procedures.

8.0 APPENDIX

Table 8.1 Radiation Exposure Received by Operating Personnel in Each Week

(measured by film badges, mrep)

Week, 1955	EXPOSURE			OVEREXPOSURE (above 500 mrep/week)	
	Total, mrep	Number of Persons	Average mrep/person	Total Overexposure, mrep	Number of Persons
1	1295	29	45	0	-
2	2195	29	76	120	1
3	4810	29	165	130	1
4	2880	29	99	190	1
5	2070	24	86	0	-
6	3715	23	162	210	1
7	1660	24	69	0	-
8	3540	24	148	2230	1
9	1190	24	50	0	-
10	2070	24	86	0	-
11	1715	24	72	0	-
12	2050	24	86	380	1
13	1800	24	75	0	-
14	390	24	12	0	-
15	3225	23	140	0	-
16	1690	23	74	0	-
17	260	23	11	0	-
18	590	22	27	0	0
19	1525	21	73	95	1
20	1266	21	60	0	0
21	950	20	48	0	0
22	1350	19	71	0	0
23	1325	20	66	70	1
24	1920	22	87	60	2
25	690	23	30	0	0
26	1650	26	64	0	0
27	235	26	9	0	0
28	460	27	17	0	0
29	455	22	21	0	0
30	590	23	26	0	0
31	890	23	39	0	0
32	0	24	0	0	0
33	760	24	32	0	0
34	1510	24	63	0	0
35	150	24	6	0	0
36	410	24	17	0	0
37	520	24	22	0	0
38	355	25	14	0	0
39	250	23	11	0	0
40	1615	23	70	0	0
41	750	21	36	0	0
42	1930	22	88	0	0
43	850	21	41	0	0
44	770	21	37	0	0
45	3100	22	141	290	3
46	790	22	36	0	0
47	620	22	28	0	0
48	1740	20	87	0	0
49	1000	22	46	0	0
50	2080	22	95	0	0
51	1230	20	62	0	0
52	435	20	22	0	0

Table 8.2 Radiation Exposure Received by Analytical Personnel in Each Week

(measured by film badges, mrep)

	EXPOSURE			OVEREXPOSURE (above 500 mrep/week	
Week, 1955	Total, mrep	Number of Personnel	Average mrep/person	Total Overexposure, mrep	Number of Persons
1	995	21	47	0	0
2	4045	21	192	280	1
3	5825	21	278	1055	4
4	1550	21	74	0	0
5	1780	19	94	0	0
6	1380	20	69	0	0
7	1665	26	64	0	0
8	505	21	24	0	0
9	1240	21	59	0	0
10	1060	17	62	0	0
11	1605	20	80	85	1
12	2765	18	154	90	1
13	1395	20	70	0	0
14	2310	23	100	0	0
15	4030	20	202	400	2
16	1220	20	61	20	1
17	2560	19	135	50	1
18	2190	18	122	0	0
19	1625	18	90	0	0
20	780	18	43	0	0
21	2665	18	148	80	2
22	1955	18	109	30	1
23	340	15	23	0	0
24	220	19	12	0	0
25	760	18	42	0	0
26	270	18	15	0	0
27	280	17	16	0	0
28	160	18	9	0	0
29	480	19	25	0	0
30	500	19	26	0	0
31	130	17	8	0	0
32	0	17	0	0	0
33	2270	19	119	660	1
34	1610	17	95	30	1
35	3670	19	193	470	2
36	3040	18	169	50	1
37	760	17	45	0	0
38	420	17	25	0	0
39	1590	19	84	0	0
40	2765	18	154	70	2
41	1845	19	97	0	0
42	1300	18	72	0	0
43	3590	17	211	70	1
44	1570	18	87	0	0
45	850	19	45	0	0
46	900	20	45	0	0
47	3590	21	171	1200	1
48	4670	21	222	760	4
49	1900	21	91	0	0
50	880	19	46	0	0
51	670	16	42	0	0
52	290	21	14	0	0

Table 8.3 Radiation Exposure Received Weekly By Maintenance Personnel Working on First Cycle Equipment

(measured by film badges, mrep)

Week, 1955	EXPOSURE			OVEREXPOSURE (above 300 mrep/week)	
	Total, mrep	Number of Man-weeks	Average for Man-week	Total Overage, mrep	Number of Personnel
23	620	2	310	0	0
24	360	0.6	600	0	0
25	0	0	0	0	0
26	150	0.2	750	0	0
27	100	0.8	125	0	0
28	540	1.6	338	0	0
29	0	0.8	0	0	0
30	130	3.2	41	0	0
31	0	6.8	0	0	0
32	1855	6.6	281	0	0
33	270	5.0	54	0	0
34	1220	5.6	218	0	0
35	260	4.8	54	0	0
36	0	0.4	0	0	0
37	1060	2.4	442	0	0
38	180	0.6	300	0	0
39	180	1.0	180	0	0
40	6505	7.2	903	845	6
41	9575	12.2	785	3055	11
42	1850	3.4	544	0	0
43	180	1.8	100	0	0
44	1140	6.0	190	0	0
45	1750	9.8	179	0	0
46	1490	3.2	466	0	0
47	0	0.6	0	0	0
48	325	0.4	813	0	0
49	85	0.4	212	0	0
50	0	1.4	0	0	0
51	355	8	44.4	0	0
52	-	-	-	-	-

Table 8.4 **Radiation Exposure Received Weekly by Maintenance Personnel While Working on Second Cycle Equipment**

(Measured by film badges, mrep)

Week, 1955	EXPOSURE			OVEREXPOSURE (Above 500 mrep/week)	
	Total, mrep	Number of Man-weeks	Average for Man-weeks	Total Overage, mrep	Number of Personnel
23	1870	4.4	425	0	0
24	930	6.6	141	0	0
25	40	3.2	13	0	0
26	1960	6.6	297	0	0
27	400	4.0	100	0	0
28	120	1.8	67	0	0
29	0	3.8	0	0	0
30	0	0.4	0	0	0
31	0	0.4	0	0	0
32	0	1.0	0	0	0
33	0	3.4	0	0	0
34	60	4.4	14	0	0
35	945	7.2	131	0	0
36	120	5.2	23	0	0
37	520	5.2	100	0	0
38	440	6.4	69	0	0
39	970	6.0	162	0	0
40	160	3.2	50	0	0
41	420	3.4	124	0	0
42	1620	7.4	219	210	1
43	150	4.8	31	0	0
44	0	1.2	0	0	0
45	0	1.2	0	0	0
46	1690	6.8	249	0	0
47	960	6.8	141	0	0
48	3815	9.4	400	475	2
49	2695	8.2	329	310	3
50	1290	8.2	157	0	0
51	1045	6.2	169	0	0
52	700	7.4	95	0	0

Table 8.5 <u>Radiation Exposure Received by Operating Personnel While Doing Miscellaneous Decontamination</u>

(measured by dosimeters, mr)

Valve Leaks	Location	Weld Leaks	Location	Pump Leaks	Location	Spills	Location	Plugged Sample Lines	Location	Filter Leaks	Location
255	Isolation Laboratory	39	Cell 6	194	Cell 6, 7 (P-3-P(T-5-P)	6	Cell 6	54	Sampling Gallery	49	Cell 5
		35	Cell 7	5	Cell 6 (P-3-P)	101	Roof Area	6	Sampling Gallery	90	Cell 5
		34	Roof Area	125	BT decay (P-19-P)	50	Roof Area	23	Sampling Gallery	90	Cell 5
		96	Cell 5	35	Pipe Tunnel (Pulser)			14	Sampling Gallery		
				29	Cell 7 (T-5-P)			20	Sampling Gallery		
				6	BT Decay (P-19-P)						
				12	Solvent Room (M-14-P)						
				27	Cell 6 (P-3-P)						
255	6.5%	204	5.2%	433	11.1%	157	4.0%	117	3.0%	139	3.5%