WASTE MANAGEMENT PROGRAM AT OAK RIDGE NATIONAL LABORATORY

by

K. Z. Morgan

The two primary objectives in waste management are radiation protection and economy. Radiation protection requirements are based upon recommendations of the National Committee on Radiation Protection (NCRP) and the International Commission on Radiological Protection (ICRP). The economics of waste disposal are of primary concern if atomic energy is to compete with present industrial power. Perhaps it should be emphasized that safety and economy are not independent entities for there is no denying that health physics protection is expensive; however, the final cost of an operation can be increased exceedingly if we fail to provide sufficient health physics protection.

There are two basic methods generally in use for the disposal of radioactive waste: (1) the waste may be concentrated and the concentrate stored, or (2) the waste may be combined with a passive medium and dispersed throughout the atmosphere soil, and/or water such that its concentration is reduced to acceptable levels.

Fortunately, the Oak Ridge National Laboratory is located in an area which affords several local advantages as follows: (1) the relative isolation of the Laboratory, (2) the large volume of water available in the Clinch River which partly surrounds the Oak Ridge area, and (3) the extensive Conasauga shale formation. The boundaries of the AEC-controlled area are, at the closest point, about two miles from the Laboratory. The nearest large city, Knoxville, Tennessee, is approximately 20 miles from the controlled area. Surveys have shown that all the surface and ground water drainage from the Laboratory and waste disposal areas leads to an impoundment fed by White Oak Creek which flows to the Clinch River. The White Oak Creek-Clinch River drainage system has been monitored for radioactive contamination since the beginning of operations at the Laboratory in 1943. Dilution afforded by the Clinch River lowers liquid waste concentration to acceptable levels. The Clinch River flows into the Tennessee River 20.8 miles below the outfall of White Oak Creek, and both rivers form a part of the TVA system of rivers and reservoirs. Thus, in case of an emergency, TVA may be called upon to adjust the flow of the river system to provide holdup and/or dilution. Seepage pits provide a safe and relatively cheap means of disposal for a significant fraction of the liquid and solid radioactive waste from the Laboratory. The Conasauga shale formation allows for seepage pits as the shale has the ability to capture and hold certain of the radioactive components while allowing water to seep through.

WASTE MANAGEMENT FACILITIES*

If you will now refer to the flow diagram (Figure 1) which you have been given, it will assist in following my presentation on Waste Management Facilities. This simplified diagram shows the types of wastes that are handled and the methods used for their disposal. Please note the numbers (1 through 7) near the top of the diagram; I shall refer to each number before describing the portion of the operation listed below that number.

Tracing the flows of material from the top to the bottom of the diagram, it is apparent that Oak Ridge National Laboratory can dispose of its wastes in four ways: (1) by discharge into the atmosphere through tall stacks, (2) by storage and decay, (3) by fixation in the soil of the waste disposal area, and (4) by discharge to the Clinch River. The continuing goal of the Laboratory in its waste disposal program is to immobilize as much of the radioactive material as possible by fixation in the soil or by deposition as insoluble sludge in tanks and pits and to hold to a minimum the amount of radioactive material discharged to the Clinch River and into the atmosphere.

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* This section has been abstracted from that part of the written record prepared by F. N. Browder et.al. for submission to this hearing.

Highly Radioactive Liquid Chemical Waste

Reading under No. 1 at the top of the flowsheet, you will note a flow of highly radioactive liquid chemical waste of 7000 gallons per day. The term "highly radioactive" is used in comparing this waste to our other Laboratory wastes and is not to be confused with the term as used by other installations. The highly radioactive waste at the Laboratory has a concentration of radioisotopes of 1/1000 to 1/100 curies per gallon, while at large production plants the concentration may be several thousand curies per gallon. I mention this not to minimize our waste disposal problems -- since we are aware that even small amounts of some of the radioisotopes when improperly handled can be extremely hazardous -- but to give you some yardstick for comparing our disposal problems to those of the production plants.

Most of the highly radioactive waste is produced in chemical processing buildings and chemistry laboratories. It is discharged from laboratory sinks and process drains through stainless steel pipes into 19 underground, stainless steel, monitoring tanks that are located near the waste-producing buildings. The rate of waste accumulation at all 19 monitoring tanks is continuously recorded at one location through a telemetering system, and to ensure that none of the tanks will overflow in case the telemetering system fails, the tank volumes are manually checked every 4 hours.

When a monitoring tank fills, the waste is pumped to three underground concrete central storage tanks that have 170,000 gallons capacity each. The material is temporarily stored in these tanks to allow the short-lived radioisotopes to decay; it is then pumped to waste pits located about 1-1/2 miles from the Laboratory. The waste pits are three 1,000,000 gallon capacity open pits excavated in the earth in a location chosen for its remoteness from the Laboratory, the type of soil, and the natural underground water drainage to White Oak Creek. This particular soil, made up of clay and Conasauga shale, removes and retains most of the radioisotopes while the solutions seep slowly through it toward White Oak Creek. The waste discharged into the pits is sampled and analyzed for radioactivity, and its movement in the soil and drainage into the Creek is monitored periodically by health physicists.

Liquid Uranium Waste

The liquid uranium waste flow (shown under No.2 of the flowsheet) is also a product of the chemical processing operations and research. This type of waste is presently produced in very small quantities averageing no more than 100 gallons per week and is not a true waste in the strict sense of the word, since it is a solution of re-usable uranium contaminated with fission products. This material is collected and stored in underground stainless steel monitoring tanks (seven in number) where a check is kept on the sources of wastes, and the volumes in all tanks are determined by manual checks and by a continuously recording telemetering system. When a tank is filled, the waste is pumped into 42,500 and 170,000 gallon underground concrete central storage tanks where it is held until transferred to a small processing plant for uranium recovery. The radioactive products separated from the uranium are transferred in solution to the central storage tanks for highly radioactive chemical waste while the decontaminated uranium is returned to regular channels for re-use.

Process Waste Water

The daily 700,000 gallons of mildy contaminated process waste water (listed under No. 3) is the least radioactive of all Laboratory wastes; yet it is the most difficult to manage because of its large volume. This waste is made up mainly of water used for cooling process equipment and water from floor drains, and under normal conditions carries a radioactive concentration of only 1/10,000 of that handled by the highly radioactive chemical waste system first described. A considerable amount of the radioactive liquid put through this system is the result of equipment failure, human error, or accidents which cause a misdirection of the radioactive waste from the system for the highly radioactive material. Whenever these incidents take place an immediate effort is made to correct the conditions in order to direct the radioactive material to the high level system.

Because of the large quantity of process waste generated per day, the storage of it for any appreciable time is impractical. This situation leaves the Laboratory practically no choice other than to dispose of it on a current basis into White Oak Creek. At one time, when the levels of radioactive material handled by the Laboratory processes were relatively very low, the procedure was simple; the low level waste was discharged to the creek without treatment and comparatively little effort was required in monitoring the waste streams before discharge to the creek. During the last 13 years, as the Laboratory expanded and the levels of processed radioactive material increased by a factor of about 100, methods had to be developed for monitoring all the waste streams and for removing most of the radioisotopes from the waste before it could be discharged safely to the creek.

Control over the discharge to the creek is accomplished mainly by continuously checking the underground network, which resembles a sanitary sewer system. This is done by frequently sampling and measuring the various waste streams and their combined waste flow before it passes through the automatic diversion valve for processing or for discharge to the creek. If the analysis of the combined waste indicates a substantial increase in radioactivity over normal conditions, samples taken out of the individual streams are then analyzed for activity to determine the source. Sometimes personnel are not aware that their operations are generating excessive radioactive waste and thus it is necessary to contact them and make appropriate corrections in their operations.

All the waste generated during the regular working hours is collected and treated before discharge to the creek. During the off-shift hours, however, the waste containing less than 50 counts/min/ml (β,γ) is diverted to the creek through a settling basin, which discharges directly to the creek.

From 53% to 87% of the total radioactivity contained in the waste diverted into the Process Waste Treatment Plant is removed with a single pass through the plant; 73% to 87% of the Sr^{90}, considered to be the most hazardous component, is removed. A higher percentage of removal can be expected by repeating the treatment.

The process employed in this plant for the treatment of radioactive wastes is new in atomic energy operations, it is the first plant built that utilizes on a large scale a standard but modified lime-soda ash process normally used for water softening. The plant has been in operation for only about a year and many variations of the process remain to be tested; therefore its full efficiency may not yet be realized. It is probable that this plant will serve as a model for other atomic energy installations having the problem of disposal of large volumes of low level radioactive wastes.

Solid Waste

The disposal of solid waste is shown under No. 4. Practically all the solid waste produced by the Laboratory consists of paper, glassware, and other pieces of laboratory equipment, much of which is contaminated with radioactive materials. Occasionally building materials such as concrete and wood that cannot be salvaged economically by any known decontamination method must be handled. As compared to the liquid wastes provoiusly described, the solid wastes usually contain an almost insignificant quantity of radioactive material, probably about 1% of the total disposed of by the Laboratory. Accurate determination of the quantity of radioisotopes in the solid waste is difficult because the waste is composed of a non-uniform mixture of many materials.

In addition to being used for disposal of Laboratory wastes, the burial grounds are used for disposal of wastes from other AEC installations and contractors and the Laboratory's radioisotope customers. Radioisotope customers contribute a comparatively insignificant volume; other installations, mainly Argonne National Laboratory, Knolls Atomic Power Laboratory, Mound Laboratories, Battelle Memorial Institute, and General

Electric in Evansdale, Ohio, account roughly for half the land area assigned permanently to this burial program. To date, 25 acres have been used by the burial ground operation. The current rate of use is approximately 5 acres per year.

Waste Gases

Before reviewing the waste gas disposal operations, it is necessary to give some explanation of the term "waste gas." Actually, a more descriptive term would be "contaminated air" since the bulk of the waste is composed of air that is contaminated with radioactive materials. The radioactive contaminants may be either gases or microscopic solid particles - usually a combination of both.

Because of extremely large volumes, it is impractical to store most gaseous wastes for any appreciable period of time. The only practical methods of disposal must, therefore, involve continuous decontamination of the gases as they are produced and discharged to the atmosphere.

The 120,000 cubic feet per minute of air used for cooling the Graphite Reactor, as shown under No. 5, is drawn through the reactor by means of two fans operating at a capacity of 60,000 cubic feet per minute. After leaving the reactor and before going through the fans, the air is put through a set of filters that remove the radioactive particulates which, if discharged into the atmosphere, would create the principal hazard from airborne radioactive contamination. The air, containing radioactive gases, is discharged into the atmosphere through a stack 200 feet high. The filters holding the radioactive particulate matter are periodically removed and buried in the waste disposal area.

The cell and hood ventilation system is a network of ducts that collects under a low vacuum a relatively large volume of exhaust air from laboratory hoods and concrete shielded cells used for processing radioactive materials. This system is illustrated under No. 6 on the diagram. The air is drawn through the system by five electrically driven fans having capacities ranging from 25,000 to 60,000 cubic feet per minute; in case of failure of the electrical equipment, three steam driven fans are used. The air from this system is discharged into the atmosphere through two stacks, one 200 feet and the other 250 feet high.

The chemical processing of radioactive materials usually results in a release of highly concentrated radioactive contaminants in a relatively small volume of gas. These gases are handled by the gighly radioactive gas (or off-gas) system shown under No. 7. The gases are collected and drawn by vacuum through a network of underground stainless steel lines and are discharged, after cleanup, through the stack 250 feet high, used for the discharge of some of the cell ventilation air previously described.

The system just described is the primary radioactive gas disposal facility, while the cell ventilation system is the secondary system for all large scale chemical processing. The off-gas system is connected directly to the processing vessels, whereas the cell ventilation system is connected only to the cell where it removes the air from the area in which the vessels are located. Unless there is a failure all the gaseous activity is removed by the off-gas system, keeping the air drawn into the cell ventilation system free of contamination. The cell ventilation system is used, therefore, as a secondary standby for preventing the spread of contamination in the event of a leak from the off-gas system. Keeping the off-gas system operationally reliable and using it properly in the processing cells so that the cell ventilation air does not become contaminated reduces the volume of gas that must be decontaminated and reduces the total radioactive material that is discharged to the filters and through the stacks.

The decontamination of the gases handled by the off-gas system is accomplished partially in the operating cells before the gases are exhausted into the system. The bulk of the chemically reactive gas is removed in the operating cells by scrubbing with caustic. The solid particles and microscopic droplets of liquid carried by the gas stream are removed by passage through an electrostatic precipitator and by filtration before the gases are exhausted into the stack. The radioactive material collected in the precipitator is periodically washed out with water that drains into the liquid waste system. The filters are disposed of in the burial ground.

THE EFFECTIVENESS OF WASTE MANAGEMENT AT OAK RIDGE NATIONAL LABORATORY (ORNL)

Let us now turn our attention to the effectiveness of waste management at ORNL. The method for determining effectiveness involves a series of monitoring techniques which will be described next.

Air Monitoring

Radioactive atmospheric pollution is monitored and controlled by the following methods: (1) Air discharged from the three stacks in the Oak Ridge area is monitored continually at the stacks for the purpose of preventing excessive discharges of radioactive contaminants to the atmosphere; (2) A system of sampling stations using air filtering techniques is maintained throughout the Oak Ridge Area, quite apart from stack monitoring, which allows for continuous evaluation of the radioactivity in the air. Figure 2 indicates the results of these measurements made within the Laboratory operating area where the highest levels of air contamination are found. The values given are the yearly averages (of the β and γ emitting radioactive contamination) which in most cases are considerably less than 1% of the MPC values given by the NCRP and the ICRP for this type of occupational exposure; (3) Fallout from all sources is monitored by means of gum paper collectors, fallout trays, and analysis of rainwater samples that are collected; and (4) Background radiation measurements are made periodically at fixed points on the ground and by aerial surveys to determine whether or not there is significant fluctuation in the background radiation.

Each of the methods of air sampling yields slightly different information relative to the nature of the airborne radioactive material. Since the filter sampling equipment is located inside a louvered enclosure, the heavier particles will settle to the ground without being collected on the filter and the sample will contain only breathable particles which might be considered small enough to become deposited in the lower portions of the respiratory tract. The fallout trays will collect the heavier particles as well as the light particles, and thus these tray samples represent the total fallout and furnish some information on the amount of radioactive material that would be inhaled and held up in the upper portions of the respiratory tract from which it would be swallowed and passed into the gastrointestinal tract. The background measurements indicate the radioactivity of the contaminated soil and of radioactive gas such as the natural radon or the reactor-produced argon-41. Rainwater samples will contain both fallout and "rainout" and will give information of the soluble as well as the insoluble fractions of the radioactive material.

From these monitoring samples, we are able to determine the general level of air and soil contamination in the area, the source of particular contamination problems, and the effectiveness of various additional radiation control measures that have been applied during the past few years. When the radioactive contamination reaches a point of significance relative to the maximum permissible values recommended by the NCRP and ICRP, investigations are made as to the source of the contamination and remedial action is taken immediately. On one occasion uranium oxide particles were found to be settling out on the Laboratory area. On still another occasion protoactinium particles were discovered. In each case investigations led to the source of the particles, and the processes causing the local fallout were stopped and remained inactive until corrective measures had been completed. The remedial action in the above cases required a number of changes, among the more important of which were the installation of additional filters in the off-gas system and a program for the routine scanning of channels in the graphite reactor for defective fuel elements. The roofs and roadways in the area were washed, and the barren areas within the Laboratory area were sown with grass to keep down the radioactive dust particles.

On some occasions in limited areas of the Laboratory and for short periods of time the air concentration has exceeded the MPC for continuous occupational exposure. However, immediate action was taken to bring the values down to acceptable values, and in no case have the concentrations, when averaged over a 13-week period as specified by the NCRP and the ICRP exceeded 10% of the maximum permissible values. The 13-week interval is given by the NCRP and the ICRP as the longest period over which the MPC values for occupational exposure may be averaged.

Radioactive particles which could be attributed to Oak Ridge National Laboratory have been detected at distances up to 40 miles from the area. Although the radioactive material carried by these particles cannot be considered hazardous, continuing vigilance is required and constant attention must be given to improving the efficiency of the monitoring stations for detecting airborne radioactive contamination and providing an early warning if high levels should be reached.

Background Measurements

Contamination of the ground in the Laboratory area is monitored by means of routine background measurements at 3 feet above the ground at some 50 locations throughout this area. Figure 3 indicates that the average level in the Laboratory area during 1958 was 0.12 mr/hr or about 10 times the average level measured 15 years ago prior to the operation of the Laboratory. However, as shown by Figure 3a this increase in the background is only 4% of the maximum permissible occupational exposure rate recommended by the NCRP and the ICRP. Nevertheless, increased efforts have been made during the past ten years to stem the gradual rise in background in the plant and neighboring areas of Oak Ridge and we feel encouraged that in spite of the fact that we have increased by several orders of magnitude the level of work with radioactive materials during these 10 years there has been no increase in the average background in the Laboratory area and the background in the neighboring areas seems to be leveling off at an average of about 0.022 mr/hr which is about twice the original background level. This increase in background in the neighborhood of our Laboratory is about 17% of the maximum permissible exposure recommended by the NCRP and the ICRP for people living in the neighborhood of such an installation.

Well Monitoring

Evaluation of the effect of liquid waste disposal with regard to the underground water table in the Laboratory area and in the area of the waste pit operation is made by means of monitoring wells. In the Laboratory area, the measurement of underground radioactivity detected by well monitoring reveals the levels to be insignificant. In the waste pit area where most of the disposable highly radioactive waste materials are sent, radioactivity has been detected in some of the monitoring wells, but it has been established that the contaminant is primarily ruthenium-106 for which the maximum permissible concentration, MPC, in water is relatively high, e.g., the MPC for ruthenium-106 is a hundred times larger than the MPC for strontium-90. A few surface seeps have developed in the pit area, but the location of the area is such that the direction of ground water and surface water flow is toward White Oak Creek and the Clinch River into which low level liquid wastes are released (as indicated by the earlier discussions) and the water in White Oak Creek and the Clinch River has been monitored since the beginning of the Laboratory operation.

Liquid Waste Monitoring

At the beginning of the Laboratory operation, a small dam was located on White Oak Creek to create a lake for impounding radioactive wastes to permit settling and decay of the radioactive material. This lake served a useful purpose in the early years and removed considerable radioactive material from the water leaving the Laboratory. However, after years of operation the lake became much less effective because the settling of radioactive waste into the mud produced a state of equilibrium so that as much radioactive material was leaving the lake as was being put into it. There existed the impending possibility of a large release of radioactive material as a result of heavy rains or floods. In addition, a fish population developed and the lake became a favorite stopover point for migratory fowl. To eliminate possible problems from the sudden failure of the dam or from contaminated fish and migratory fowl, the fish in the lake were killed and the lake was drained.

The dry White Oak Lake basin has a capacity of 10,000,000 cubic feet. In the event of an accident involving the release of large volumes of radioactive liquids, engineering studies indicate that under normal flow conditions a 23-day delay in the release could be provided by closing the gates at White Oak Dam and once the radioactive material has been confined to form a lake, a by-pass could be cut around the lake and dam, thereby providing a longer holdup time. It should be pointed out again that as a supplement to this holdup procedure TVA can release a large amount of dilutent water from Norris Lake which is located 60 miles upstream from the confluence of the White Oak Creek with the Clinch River.

Liquid wastes leaving the Laboratory are sampled at a number of locations. They are sampled routinely at the source where the effluent leaves the Laboratory, at the point where the wastes enter the public waterway (White Oak Creek Dam), and at the nearest center of population downstream from the Laboratory (the K-25 Gaseous Diffusion Plant). Stream gauging operations are carried on continuously at White Oak Creek, Melton Branch, and in the Clinch River to determine creek and river flow in order that dilution factors for evaluating the concentrations of the wastes in the river may be obtained.

Clinch River Monitoring

Routine surveys of the Clinch and Tennessee Rivers are conducted to determine the extent of dispersion of radioactive materials in river water and sediment, the levels of contamination encountered, and to evaluate the consequent hazards to humans. Periodic measurements and analyses are required to predict the rate of buildup and, consequently, determine the effectiveness of the liquid waste management program. Also, information is obtained relative to the effect on future industry of increasing the radioactive content of the water and bottom sediment in the Tennessee River System. Figure 4 gives results of some of the composite radiochemical analyses showing the principal radionuclides discharged from White Oak Creek and the buildup of these radionuclides on the silt in the Clinch and Tennessee Rivers during the past few years. Figure 5 shows the concentration of the radioactive material in the water of the Clinch River just below the outfall of White Oak Creek (assuming uniform mixing). These values are compared with the values of MPC that are applicable in the neighborhood of our operations (i.e., they are compared with 10% of the MPC for continuous occupational exposure). The calculated values were obtained by applying the latest data given in the 1959 revisions of the Internal Dose Reports of the ICRP and the NCRP. Although the levels of radioactive contamination in the Clinch River water are less than the calculated values of MPC for each year shown in Figure 5, the levels in years prior to 1954 had risen steadily and in fact the level of 1.7×10^{-7} μc/cc reached in 1954 was only slightly less than the calculated MPC of 3.1×10^{-7} μc/cc. This led to the adoption of more effective radioactive waste control measures (e.g., discontinuance of the impoundment of contaminated water in White Oak Lake in October of 1955; more extensive use of the liquid waste disposal pits; installation of the process water treatment plant in August of 1957, etc).

No specific values of MPC applicable to the population at large have been given by the NCRP and the ICRP, but the ICRP has suggested that for planning purposes ad interim average values might be used which are 1/100 of the values of MPC for occupational exposure to the gonads (i.e.,for genetic exposure) or 1/30 of the values of MPC for occupational exposure to the other body organs (i.e.,for somatic exposure). Therefore, the values of 1/100 of the calculated MPC for occupational exposure are given in Figure 5 only to serve as a guide for future planning of the levels to be maintained further downstream below the outfall of White Oak Creek and beyond the controlled area. The confluence of the Clinch River with Emory River and the Tennessee River and the silting out of the radioisotopes into the river bottom mud provide water concentrations beyond the controlled area that are less than the values suggested by the ICRP for planning purposes (i.e., they are less than 1/100 of the occupational values) and in fact they are of the order of natural background.

Cross section measurements are taken every two miles in the Clinch River and approximately every 10 miles in the Tennessee River and its reservoirs. These measurements are ordinarily made to a distance of about 100 miles downstream from the Laboratory and on one occasion they were made downstream for a distance of about 590 miles (all the way to the Ohio River). A cross section study consists of making measurements of the radioactivity of the water and river bottom sediment and collecting sediment samples at predetermined intervals along the traverse from one bank to the other. The samples are analyzed radiochemically for the long-lived radioactive isotopes that are present. The radioactive contamination found in river bottom sediment is usually much higher than that found in the river water. The highest average radioactive contamination of river bottom sediment (resulting in an average dose rate of about 0.1 mr/hr on the river bottom) is about 18 times background and as shown by Figure 6 is located about 12 miles below the outfall of White Oak Creek into the Clinch River. The concentration of radioactive material in the sediment of the Clinch River drops off materially after the first

20 miles; it is about twice background at 100 miles and approaches background at 150 miles downstream where fission products are still detectable by silt analysis. As shown by Figure 7 the level of radioactive contamination in the river sediment drops off suddenly below each dam in the Tennessee River, increases again as the next dam is approached, and again drops suddenly beyond the dam where the water velocity is too great for much settling of the mud to take place.

Samples of water from the Clinch River at the Oak Ridge Gaseous Diffusion Plant and at Kingston, Tennessee, the nearest population centers downstream, have indicated detectable amounts of fission products, but levels well below those permitted by the NCRP and the ICRP for water used for continuous drinking. In fact, the drinking water for the employees at the Gaseous Diffusion Plant is obtained from the river at a point approximately 8 miles below the outfall of White Oak Creek.

Conclusion

In conclusion, Oak Ridge National Laboratory is contributing some radioactive materials to the local environment and continuing vigilance must be maintained to determine the nature and extent of these radioactive materials. To date, the data from the health physics monitoring systems presently in use indicate that the radioactive material released is below the levels recommended by the National Committee on Radiation Protection and the International Commission on Radiological Protection.

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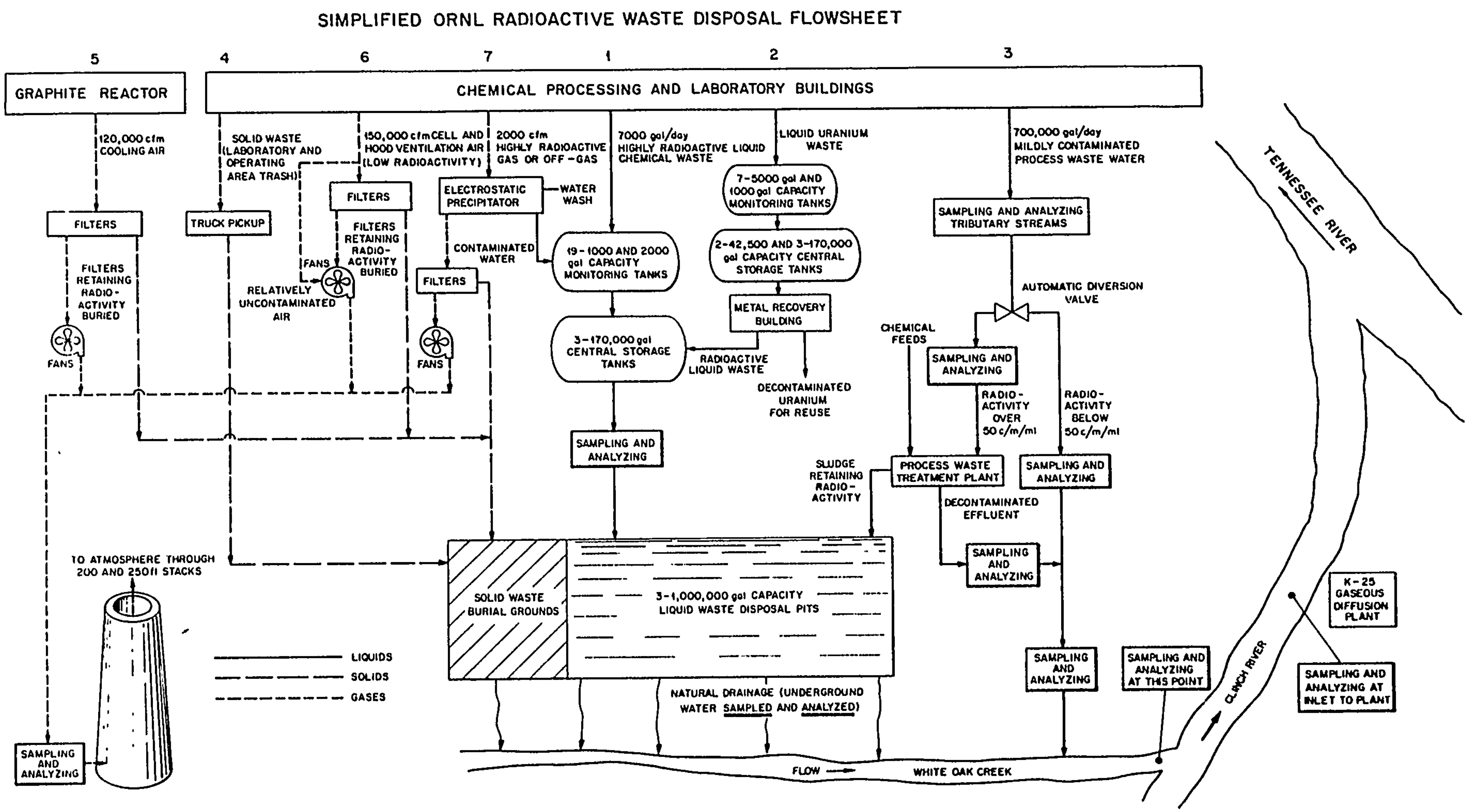

FIGURE 1

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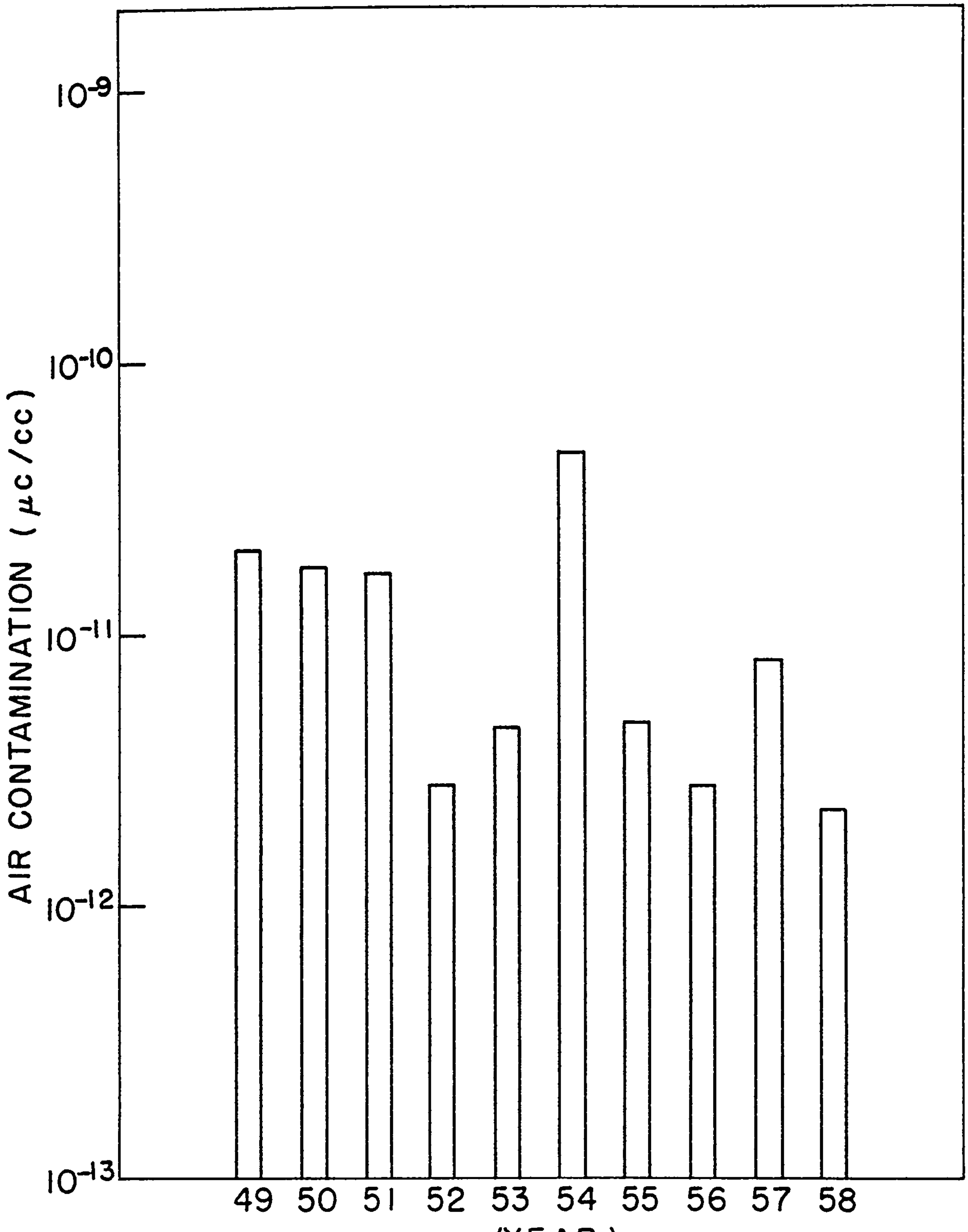

YEARLY AVERAGE OF THE RADIOACTIVITY OF AIR IN THE ORNL PLANT AREA

FIG. 2

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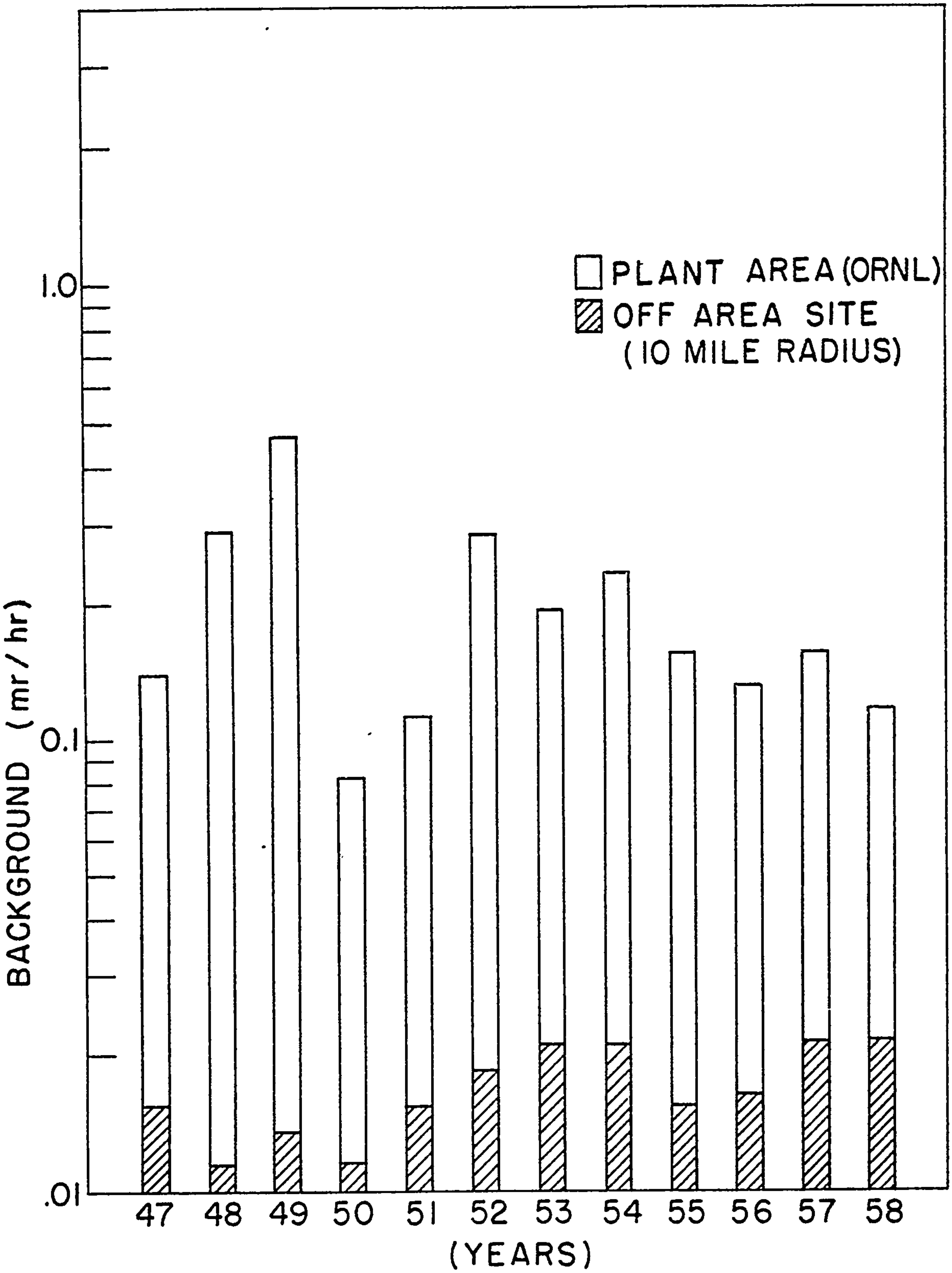
ORNL-LR-DWG 35352



BACKGROUND MEASUREMENTS IN ORNL AND VICINITY

FIGURE 3

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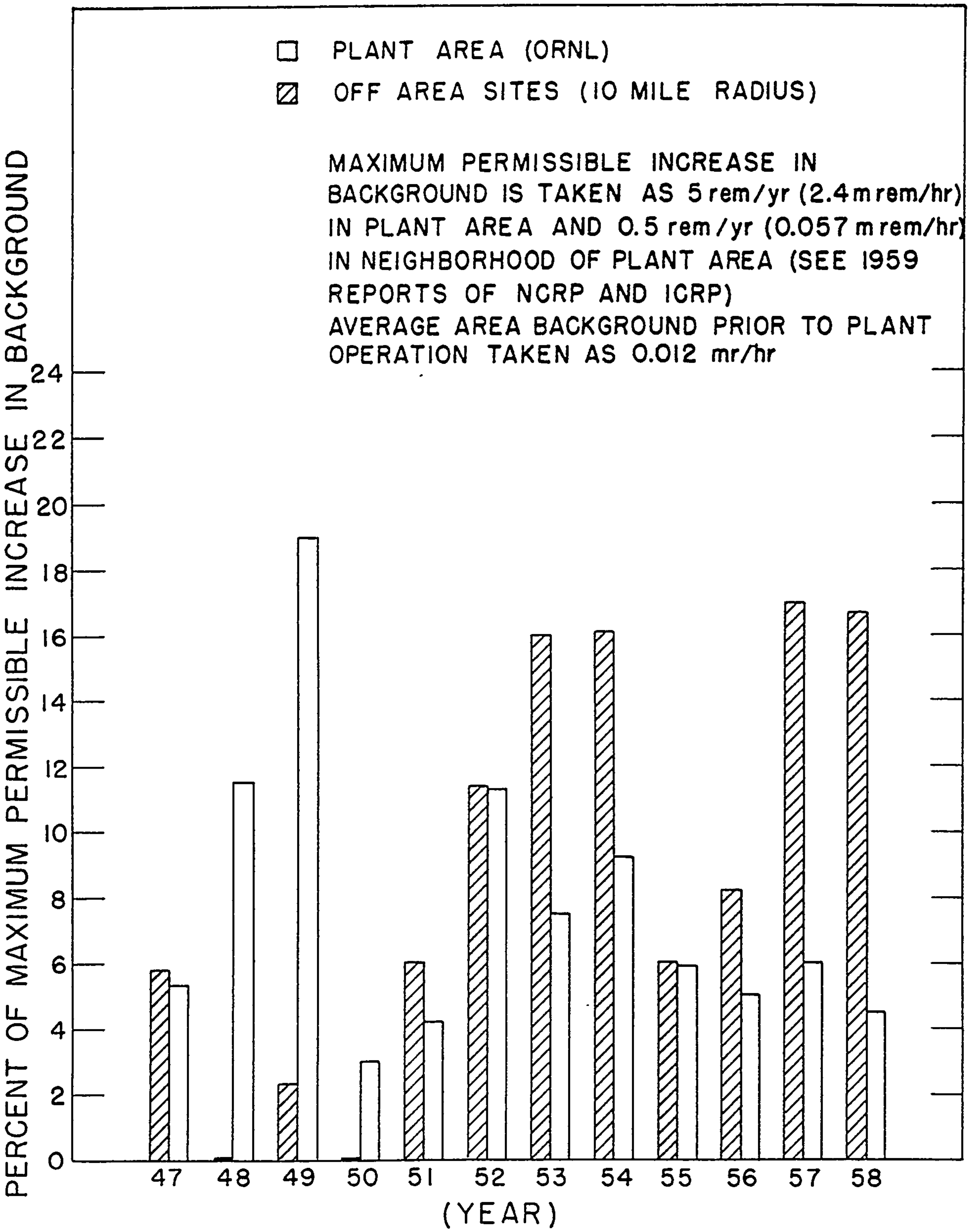

FIG. 3A PERCENT OF MAXIMUM PERMISSIBLE INCREASE IN BACKGROUND IN ORNL AND VICINITY

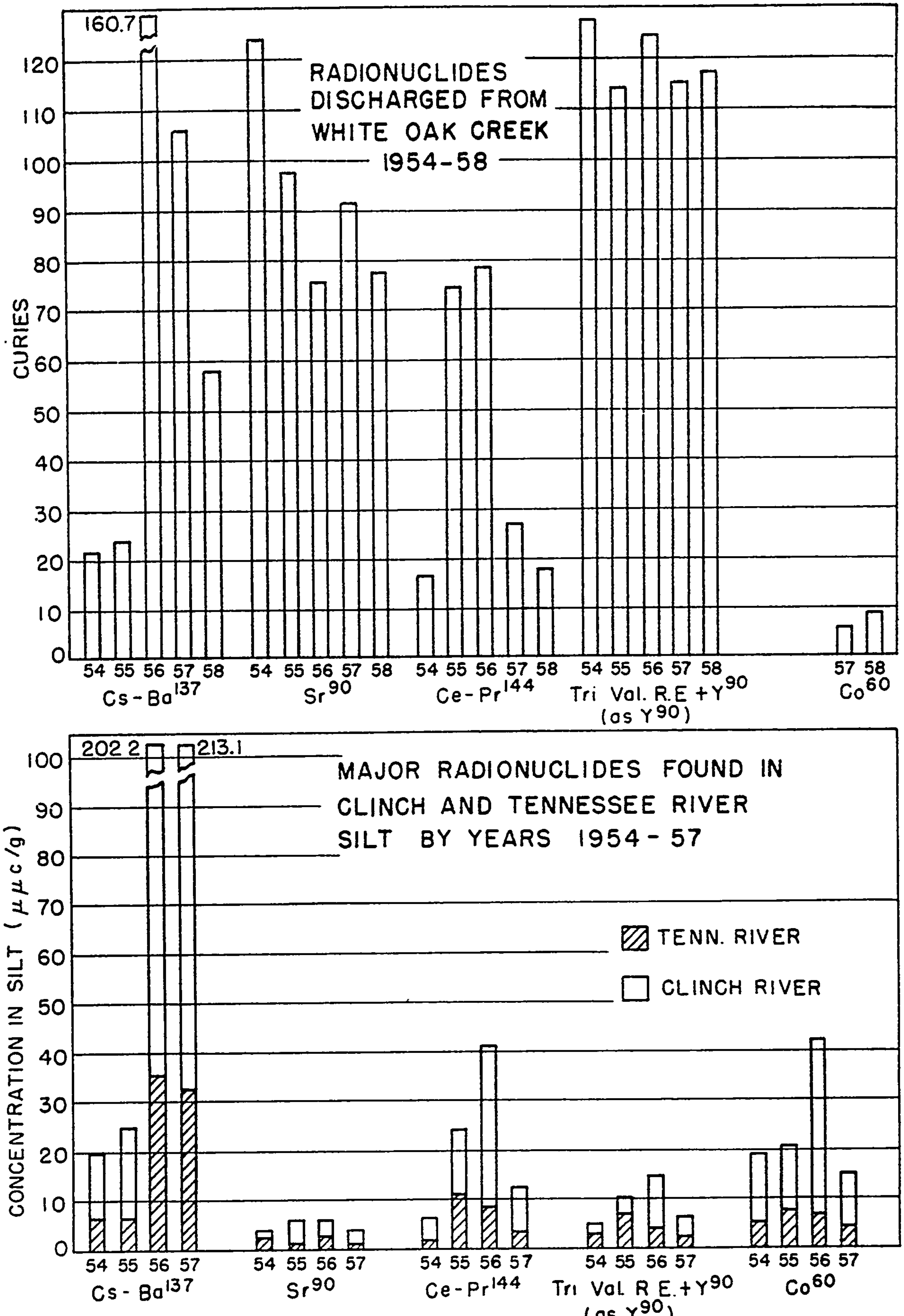
RADIONUCLIDES DISCHARGED FROM WHITE OAK CREEK 1954-58
CURIES
160.7
0
10
20
30
40
50
60
70
80
90
100
110
120
54 55 56 57 58
Cs-Ba137
54 55 56 57 58
Sr90
54 55 56 57 58
Ce-Pr144
54 55 56 57 58
Tri Val. R.E + Y90 (as Y90)
57 58
Co60
MAJOR RADIONUCLIDES FOUND IN CLINCH AND TENNESSEE RIVER SILT BY YEARS 1954-57
CONCENTRATION IN SILT (μμc/g)
202.2
213.1
TENN. RIVER
CLINCH RIVER
0
10
20
30
40
50
60
70
80
90
100
54 55 56 57
Cs-Ba137
54 55 56 57
Sr90
54 55 56 57
Ce-Pr144
54 55 56 57
Tri Val R E.+Y90 (as Y90)
54 55 56 57
Co60

FIGURE 4

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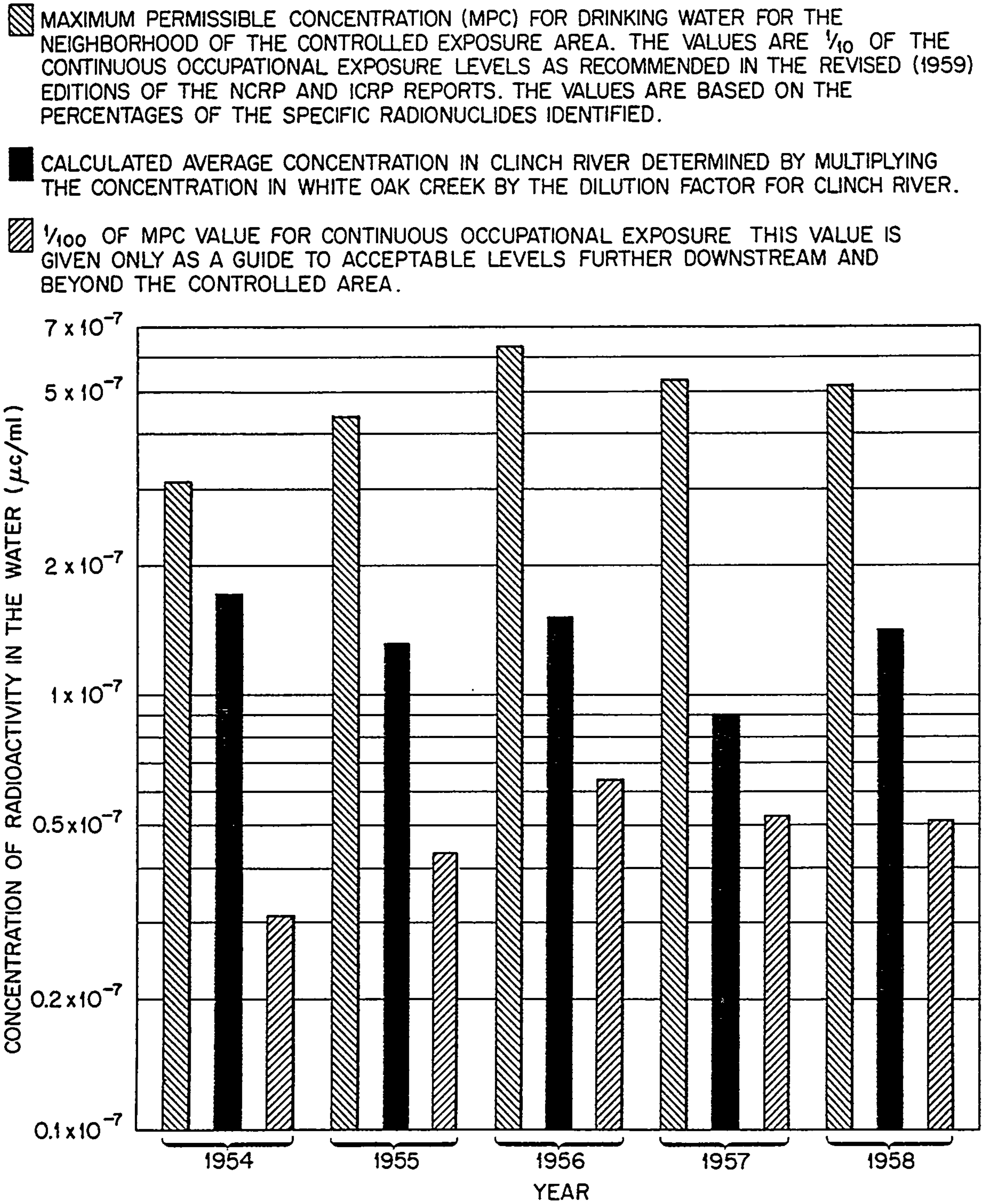

Fig. 5. Concentration of Radionuclides in Clinch River (1954–1958) and the Calculated MPC Values.

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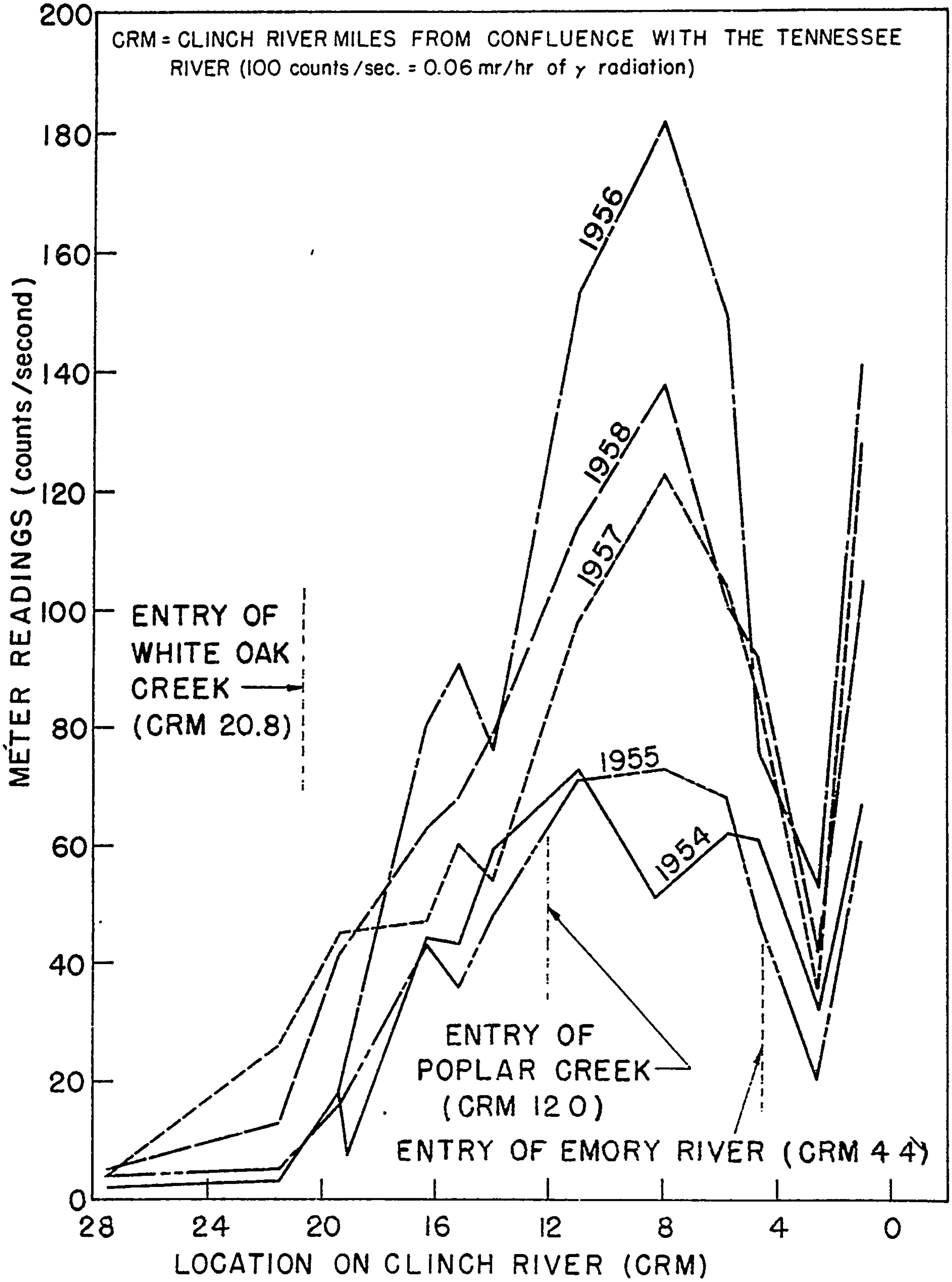

AVERAGE READING ACROSS A TRAVERSE OF RIVER BOTTOM SURVEY METER "FLOUNDER"

FIGURE 6

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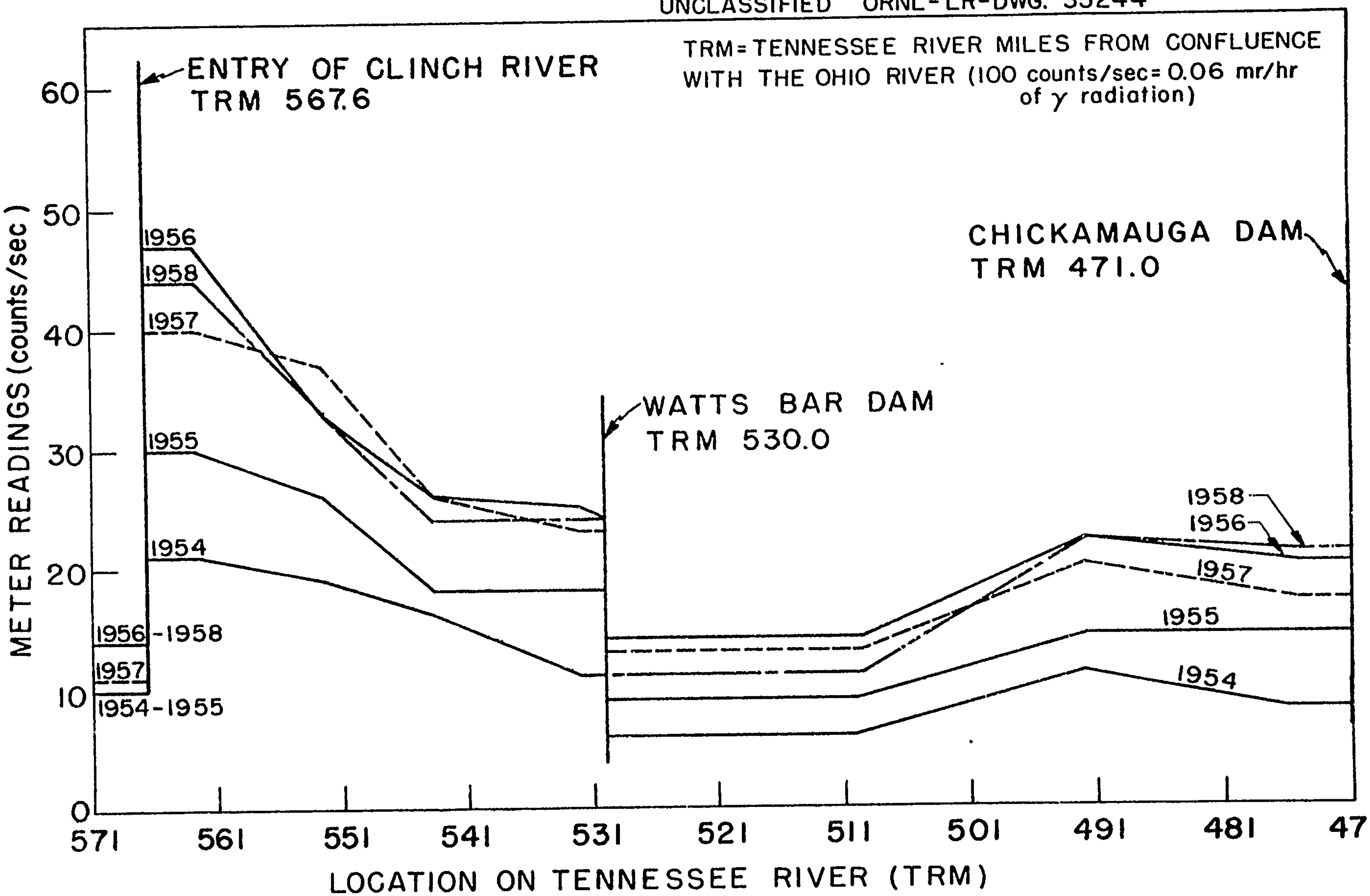

AVERAGE READINGS ACROSS A TRAVERSE OF RIVER BOTTOM SURVEY METER "FLOUNDER"

FIGURE 7