LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:
 A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or
 B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.
 As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission, or his employment with such contractor.

UNCLASSIFIED

This document is
PUBLICLY RELEASABLE

H. Kinner
 Authorizing Official

Date: 1/25/10

NAA-SR-MEMO-408(Del.)

Issue Date:
 August 1, 1952

A STUDY OF THE HAZARDS ASSOCIATED WITH THE

WITH AMERICAN AVIATION WATER BOILER NEUTRON SOURCE

Deleted Version

Classification changed to Unclassified
 by authority of Ed. Remley date 9/25/09
 by H. Kinner date 9/25/09
 and B. Lantieri date 1/25/10

by

E. Remley

ABSTRACT

~~Available from the
 Office of Technical Services
 Department of Commerce
 Washington 25, D. C.~~

A description of a low power water boiler type reactor in operation at the Atomic Energy Research Department of North American Aviation, Inc. is presented. A study of the potential hazards associated with the operation of this reactor in its present location has been made. In particular, the information necessary to permit a safety evaluation of the reactor installation is reported. It is concluded that the operation of the reactor at a power level of 1 watt constitutes no significant hazard to the personnel directly connected with the experimental program in which the reactor is used, to the production of the adjacent laboratories in the North American Aviation organization, or to the population residing in the surrounding area.

LEGAL NOTICE

This report was prepared as an account of Government sponsored work. Neither the United States, nor the Commission, nor any person acting on behalf of the Commission:

A. Makes any warranty or representation, express or implied, with respect to the accuracy, completeness, or usefulness of the information contained in this report, or that the use of any information, apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liabilities with respect to the use of, or for damages resulting from the use of any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or contractor of the Commission to the extent that such employee or contractor prepares, handles or distributes, or provides access to, any information pursuant to his employment or contract with the Commission.

UNCLASSIFIED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency Thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

I. INTRODUCTION

A low power water boiler type reactor has been recently placed in operation at the Atomic Energy Research Department of North American Aviation, Incorporated. This unit, called the Water Boiler Neutron Source, or WBNS, was designed primarily as a neutron source for exponential experiments, but it is also to be used for other measurements which are important to the field of reactor technology. It is the purpose of this report to give the results of a study of the potential hazards associated with the operation of the WBNS and, in particular, to present the information necessary to permit an adequate safety evaluation of the reactor installation.

II. DESCRIPTION OF THE REACTOR

The WBNS is a simplification of the water boiler type reactor in use at Los Alamos.¹ The core consists of a homogeneous water solution of enriched uranyl nitrate in a 1 foot diameter stainless steel sphere. This sphere is incased in a cylinder of graphite 5 feet in diameter which serves as a reflector and thermal column. The exponential tank is placed on top of the vertical graphite cylinder. The entire cylinder is surrounded by a concrete shielding wall 2 feet thick.

Design of the reactor is indicated in Fig. 1. In addition to the thermal column experiments, it is planned to use the reactor for cross section measurements by the danger coefficient and pile oscillator methods. Also, the WBNS might be used for instrument and material testing, shielding measurements and biological experiments.

The WBNS is located in a separate steel frame fire proof building adjacent to the general laboratory area inside the Atomic Energy Research Department restricted area. This building is approximately 20 feet x 40 feet x 30 feet high.

A. Graphite Reflector

The graphite reflector is a right circular cylinder of AGOT pile

grade graphite 5 feet in diameter and 6 feet high. It is formed by stacking 4 3/16 inches x 4 3/16 inches x 48 inches graphite bars horizontally inside a steel tank with the bars in alternate layers, placed orthogonal to each other. The stainless steel sphere is supported by the graphite which was machined to form a spherical cavity at the center of the reflector. The steel tank holding the graphite has walls 1/4 inch thick and is supported by 6 inch channel beams welded to the bottom.

Eight of the graphite bars close to the sphere may be removed to accommodate various instruments or materials required for experimental purposes (see Fig. 1). Parallel to the eight removable bars is a small test hole (1 1/8 inch ID) which passes through the stainless steel sphere. This hole permits access to the region of highest flux with small samples.

B. Reactor Core and Fuel Handling System

The fuel system consists of the water boiler sphere, a filling tank, and a gas accumulator tank. It is located within the concrete shield. Except for the teflon seats in the valves and a neoprene rubber pressure bag, the entire fluid system is constructed of 347 stainless steel. Prior to the loading with a uranyl nitrate solution, the system was leak tested with a mass spectrograph leak detector and further tested by pressurizing to 150 pounds per square inch. The designed ultimate strength is 720 pounds per square inch. A schematic diagram is given in Fig. 2, while Fig. 3 shows the installed fuel handling system.

The water boiler sphere is constructed from two hemispherical spinings of 1/16 inch stainless steel sheet and has a volume of 14,385 cubic centimeters. The hole through the sphere is about 1 inch below center and is formed of 1 1/8 inch ID, 1/16 inch wall thickness stainless steel tubing. A 1/8 inch ID tube at the bottom of the sphere connects to the filling tank and 1/2 inch ID tube at the top of the sphere leads to the accumulator tank.

The filling tank, which has a volume of approximately 3 liters, has a removable cover with a stainless steel flared tube fitting. A vacuum seal between the cover and the filling tank is accomplished with a teflon gasket. Solution may be added to the system by pipetting into the filling tank and then allowing it to flow by gravity into the stainless steel sphere.

Any decomposition and fission product gases that are evolved during operation will be collected at atmospheric pressure in the gas accumulator tank. The inside of this tank is divided into two parts by the neoprene rubber bag. The gas is collected between the outside of the bag and the inside of the tank. The decomposition and fission gas is regularly sampled. When necessary, it can be removed by transferring the gas from the accumulator tank to a storage vessel for eventual disposal. In order to sample the gas or remove the fluid from the system, the inside of the neoprene bag may be pressurized with helium to force the fluid in the sphere back into the filling tank or to force the gas out of the accumulator tank.

A Bourdon type gauge connected to the system measures the gas pressure. The level of the fluid in the sphere is measured by an electrical probe which can be inserted through the fluid mixing tank into the small filling pipe. Water may be removed from the system by vacuum distilling from the filling tank. The mixing of the fluid after an addition of solution may be accomplished by bubbling helium into the sphere through the filling tank or by pressurizing the neoprene bag, forcing the fluid back and forth between the water boiler sphere and the filling tank.

Since the water boiler is operated at a very low power level, no provision is required for chemical processing of reactor products. One disposal problem is inherent, and this has been adequately provided for in the design of the fuel handling system. This consists of removing the accumulated gas products from the gas accumulator system by pressurizing the neoprene bag and forcing the accumulated gas into an external disposal chamber.

C. Shield

A concrete block wall surrounds the reactor to protect personnel from the fast and slow neutron flux and the gamma radiation. The blocks are ordinary concrete 24 inches x 24 inches x 21 inches high and weigh approximately 1000 pounds each. Four layers of these blocks are used to make a wall 24 inches thick and 7 feet high with the top left unshielded. A higher shield is undesirable because of scattering of fast neutrons into

the exponential tank.

D. Control and Safety Rod Mechanisms

The reactor is controlled by a system of 4 rods. These consist of two safety rods, a coarse control rod and a fine control rod. These rods move horizontally through the concrete shield and through the graphite reflector adjacent to the stainless steel sphere. Each safety rod is constructed of two 1/4 inch thick strips of Boral attached to aluminum channel beams. This forms an I-beam about 3 feet long by 4 inches high. The two safety rods control a total of about 3 per cent in reactivity. The rods slide in and out of holes in the graphite reflector and are held in the "out" position by magnetically actuated catches. If the holding magnets are de-energized the safety rods are pulled into the reflector in approximately 1/2 second by weights suspended from cables placed over pulleys. Interruption of the electric power or depression of a "Scram" button will release the safety rods.

The coarse control rod is constructed similarly to the safety rods but with cadmium sheet instead of Boral for the absorber. It controls approximately 1 per cent in reactivity. The fine control rod consists of a 1 inch diameter steel pipe with provision at the end for insertion of varying amounts of cadmium. At present, this rod controls approximately 0.1 per cent in reactivity. Reversible electric motor drive systems are used to move the control rods. Each control rod is provided with a selsyn remote indicator. The traverse of the coarse control rod is 80 centimeters, and approximately 155 seconds are required for the motion from the "in" position to the "out" position. The traverse of the fine control rod is 50 centimeters, and the time for this complete motion is approximately 26 seconds. The installed control and safety rod mechanisms are shown in Fig. 4.

E. Instrument Control Panel

Fig. 5 shows a view of the instrument control panel which is located in the laboratory area immediately adjacent to the WBNS building. Five neutron flux measuring instruments placed at different positions around the graphite reflector are used for monitoring the power level of the reactor. Two of these are BF_3 ionization chambers connected to vibrating reed electrometers.

Two others are Boron lined counters whose outputs are connected to counting rate meters. The last is a BF_3 proportional counter with the amplified output connected to a scale of 128 scaling unit. To permit reasonable counting rates from the latter three instruments, the counters are covered with cadmium sleeves. A Brown Recorder located in the instrument panel continuously records the signal from one of the ionization chambers to provide a permanent record of the reactor power level.

Sensitrol relays are connected to the output of each electrometer and to one of the counting rate meters. Operation of any one of these three relays will release the safety rod latches and shut down the reactor. The operation of the WBNS control system is described in detail in Appendix A.

F. Critical Assembly

The approach to criticality employed a procedure paralleling that used in Los Alamos.¹ The fissionable material was available in the form of highly concentrated uranyl nitrate solution. It was transferred to two specially constructed dispensing burrettes and was diluted with enough distilled water to give approximately 2 liters of uranyl nitrate.

As the U^{235} was added to the solution during the approach to criticality, measurements were made on the change of reactivity produced by the multiplication of a 5.7 curie Po-Be neutron source inserted in the re-entrant tube in the stainless steel sphere. Plots of the reciprocal counting rates determined during these measurements as functions of the amount of U^{235} in the

[REDACTED]

solution permitted an extrapolation to the critical mass. This was determined to be 633.9 grams of U^{235} . If a correction of 1.3 grams for the fuel in the filling pipe is made, a critical mass of 632.6 grams is obtained. After the loading of the core with fuel, the volume of solution in the sphere was 13.38 liters which left a space 5 centimeters high between the liquid level and the top of the sphere. The Po-Be source of neutrons used during the criticality procedure is now normally kept in the center of one of the removable graphite bars near the base of the reflector. At present, this source has about 3.6 curies of polonium and is adequate for safe and rapid start up of the reactor.

G. Inherent Safety Features

First, it should be noted that considerable experience in the operation of water boiler type reactors has been gained by the Los Alamos Reactor Group. As of March, 1950, the Reactor Safeguard Committee concluded that their water boiler was the safest reactor which had been studied to that time.² The present reactor has been designed so that inherent safety features are kept to a maximum.

A major contribution to this inherent safety is the small amount of excess mass of U^{235} in the solution. This amount which corresponds to a 0.2 per cent excess reactivity insures that a prompt critical condition can never occur without the deliberate addition of fissionable material or addition of a better reflector to the assembly. The control system described in a previous section, and in Appendix A, is so interlocked that practically any conceivable error in operation will shut down the reactor and ring the alarm bell. Such a relatively simple and fool-proof control system is possible because of the low power and inherently safe characteristics of water boiler type reactors. When the reactor is not in operation the safety rods are locked in place inside the reflector with individual small padlocks. The keys for these padlocks are kept in a safe, available only to two senior technical personnel immediately responsible for the operation of the water boiler. The building in which the reactor is located is also locked during non-working hours.

There are three mechanisms which can lead to the stopping of a runaway condition in a water boiler type reactor.³ These include the negative temperature coefficient of reactivity, the negative power coefficient of reactivity

[REDACTED]

resulting from gas evolution from fission fragment decomposition of the core solution and finally, the actual vaporization of part of the solution leading to frothing by steam formation.

Appendix B presents a calculation of the effects of 1 and 2 per cent increases in reactivity when the reactor is operating at 0.1 watt and is just critical. The effects when the operating level is 1 watt are comparable. These calculations indicate that the inherent safety features of the water boiler, namely the negative temperature coefficient of reactivity and negative power coefficient, are sufficient to reduce the reactivity and, hence, shut the reactor down. The effect of a 1 per cent step increase in the reactivity is to increase the temperature of the solution by approximately 35° C after which the reactivity decreases. The total energy released in this type of step increase is computed to be about 5 million joules. If very large amounts of reactivity could be released, the result would be a frothing of the solution in the stainless steel sphere and a possible removal of the solution through the top pipe into the gas storage system. Thus, an automatic safety valve is provided for reducing the reactivity.

Further, it is to be noted that the group at Los Alamos have experimental data which indicate that the temperature coefficient of reactivity is sufficient to shut down the reactor in case of a runaway. Their data obtained in a recent communication from L. D. P. King show that the negative temperature coefficient varies from 0.72 grams of U^{235} per degree C at room temperature to 1.25 grams of U^{235} per degree C at just below the boiling point of the solution. Their experiences include the accidental addition of an excess of 18 grams U^{235} equivalent for an estimated time of 5 seconds. This corresponds to an approximate excess reactivity of 0.6 per cent which should have resulted in a reactor period of about 0.25 second. The only available datum from this was a rise in the solution temperature of 25° C. Using the above temperature coefficient of 0.72 grams of U^{235} per degree Centigrade, this result indicates that the temperature coefficient actually compensated for the excess reactivity.

The water boiler type reactor is also inherently safe from possible nuclear explosions. The conclusions of the Reactor Safeguard Committee as given in Appendix J of Ref. 2 as to possible nuclear blast effects on the Los Alamos Water Boiler indicate that these effects would be very small. The total possible heat released in such an explosion would be just sufficient to vaporize the water contained in the reactor. The effects in the water boiler described here should certainly be comparable.

III. REGIONAL CHARACTERISTICS

To be considered in a safety evaluation of the reactor installation are regional characteristics which include:

1. Population density
2. Industrial installations
3. Meteorological conditions
4. Hydrological conditions.

A. Population Density

The reactor is located approximately 1.5 miles southeast of the center of the community of Downey, California, which is about 11.5 miles from Los Angeles. Downey has a population of about 57,000 contained in an area of approximately 15 square miles. Fig. 6 shows a sketch of the immediate surrounding area.

B. Industrial Installations

Vital war industries are not prevalent among those in the Downey community. The most prominent is North American Aviation, at which the reactor is located. A much smaller installation located approximately 0.5 mile from the reactor is that of the Rheem Manufacturing Company.

C. Meteorological Conditions

In most of the Los Angeles region throughout the summer and during most of the days in the winter, a temperature inversion occurs with the elevation of the base of the inversion averaging about 1500 feet and its top averaging about 4000 feet. In parts of the area during July and August there is, on the average, only one day in each month in which there is no inversion below 3000 feet. In September, the inversions will be present less frequently but the effects are more pronounced when they are present. In March, most of the days are free from temperature inversions. In May and June there are more frequent inversion periods but many are at high levels where the effect is considerably less.

The Los Angeles region rises along the coast and, therefore, the surface wind is governed by the typical land and sea breeze effects. Along the coast, a sea breeze starts during the morning after the land surface has

become sufficiently warm. At night when the water surface is relatively warm and the soil cool, the direction of the surface wind is reversed. In addition, the land breeze which occurs at night is usually weaker than the daytime ocean breeze. During the spring, summer and fall months the surface winds flow from the ocean toward the land about 2/3 of the 24 hour day, reversing during the rest of the day. During the winter months, the directions are reversed. Consequently the overall prevailing wind is from the ocean to land from a yearly standpoint. Fig. 7 shows the prevailing air current flow in the region from a yearly standpoint. The average prevailing wind velocity is approximately 6 knots.

D. Hydrological Conditions.

The primary factors to be considered in the hydrologic characteristics of the area are the rainfall frequency, maximum rainfall during any storm, the type and path of run-off and the location of surface and sub-surface water supply basins.

In the Los Angeles area about 20 storms producing rainfall of 0.01 inch or more can be expected to occur during the season, with rain occurring during 35 to 40 days depending upon the exact location. While the yearly frequency may remain near normal, the occurrence varies greatly with some months receiving rainfall six times more often than normal.

Rainfall intensities are generally light in this area with a few scattered locations receiving more than 1 inch per hour. An isohyetal map is shown in Fig. 8 from which it can be seen that the yearly average rainfall in this area varies from 4 to 40 inches. Fig. 9 is an isohyetal map showing the amount of rainfall that could be expected to fall during a 24 hour period with a possible frequency of once in 50 years. This map, therefore, indicates the maximum amount of rainfall that might be expected during any storm in the area under consideration.

Fig. 10 shows the principal sources of water in the area under consideration. The key wells are indicated, and the principal ground water basins are shown which would present a problem if contaminated. The reactor is located more than one mile from the nearest key well.

The storm drainage in the area consists primarily of surface drainage

which flows into the San Gabriel and Rio Hondo Rivers (see Fig. 10) and finally on out to the ocean.

IV. NORMAL REACTOR OPERATION

The WBNS is principally used as a source of neutrons for the exponential assembly.⁴ This exponential assembly consists of an aluminum tank 5 feet in diameter by 6 feet high which contains the D_2O uranium lattices and is mounted on the top of the graphite pedestal of the reactor. The bottom of the exponential tank is approximately 1 meter above the center line of the water boiler sphere. The 1 meter of graphite between the tank and the WBNS sphere is adequate to isolate the reactor from the sub-critical exponential assembly. The Po-Be neutron source used during the critical assembly is used in conjunction with the WBNS for the exponential measurements. Thus, in many respects, the water boiler may be considered as a multiplying assembly rather than a critical assembly. The multiplication factor is then of the order of a few hundred.

In addition to the exponential measurements, an experimental program is planned to use the WBNS for cross section measurements employing the danger coefficient technique along with the pile oscillator. The exponential experimental program requires periods of operation of approximately 3 hours daily. The proposed nuclear experimental program is expected to require about the same amount of operation as soon as the complete program is in progress. This latter program will be somewhat limited because of the small amount of reactivity (0.2 per cent excess) available for experimental purposes. This limitation requires careful planning of experimental equipment which is to be placed inside the graphite reflector. In planning these experiments, extreme caution will be exercised in designing equipment which might result in an increase in reactivity when inserted into the re-entrant tube in the water boiler sphere.

V. POTENTIAL HAZARDS

A potential hazard is present in the possible release of the radioactive fission products in the gases in the core of the reactor. In the extreme case of continuous operation of 1 watt for a period of 100 hours, the total fission product activity in the assembly would be approximately 10 curies. After a cooling period of 1 hour it will have decayed to about 2 curies. From the Los Alamos experiences,¹ about 30 per cent of this activity is in the gaseous state.

Among the potential hazards which include the possible means of release of these radioactive products and which must be considered in the operation of the WBNS are the following:

1. Operational accidents
2. Sabotage
3. Natural phenomena
4. Activity of the solution
5. Formation of explosive mixtures of decomposition gases.
6. Excessive radiation exposures to personnel.

These will be considered in order.

A. Operational Accidents

It is realized that a possibility of hazards from accidents during normal operation is existent, but this has been minimized by the strict adherence to an operations procedure. This procedure limits the operation of the reactor to a group of individuals who are cognizant of the hazards associated with the reactor and who have been specifically trained in the emergency procedures necessary in case of an accident. A minimum of two qualified personnel is required to be present during each start up of the reactor, and an operator is always in attendance while it is in operation. The operations procedure requires a complete check of all of the safety interlocks in the control system before the reactor is brought up to power. This includes the automatic shutdown of the reactor by each one of the three independent safety circuits. In addition, changes in the shield and the reactor plus changes in experimental procedures are made only with the consultation and permission of the supervisory individual immediately responsible for the operation of the reactor. Coordination between the reactor personnel and the Health Physics group is continually maintained to prevent accidents.

Planned emergency procedures include the removal of one of the removable graphite bars by forcing this out through the shield with tubes containing cadmium sheet. These aluminum tubes containing the cadmium are located in a standby position adjacent to the reactor where they are readily accessible. With the present amount of fissionable material in the core of the reactor, the removal of one of the graphite bars is alone sufficient to place the reactor in a sub critical condition with all rods retracted.

However, in the event of an operational accident, no catastrophe can occur because of the inherent safety features of the water boiler as outlined in the results of a runaway in Section II-G.

B. Sabotage

It is recognized that the possibility of sabotage is always present, and proper precautions must be taken to eliminate this type of hazard. The WBNS is located inside the Atomic Energy Research Department security area inside the fenced North American Aviation plant area. The building containing the reactor is further restricted to those people associated with the experimental program in which the WBNS is employed.

Minor forms of sabotage might result in damage to the safety interlocks of the reactor. This contingency is adequately covered by the complete check of all the safety circuits at the beginning of each period of operation. Other possibilities include some form of addition of fissionable material or better reflector (such as beryllium) which would increase the reactivity of the reactor and, in particular, produce a prompt critical condition. However, none of these will result in a disaster as has already been pointed out in an earlier section.

Prime consideration should be given to the possibility of the insertion of explosives or some other type of sabotage which could result in the rupture of the fuel system and permit a spread of the radioactive

solution over the surrounding area. If the solution were contained within the water boiler building, the cleaning of the area could be accomplished with standard laboratory procedures.

Of major importance in the evaluation of a disaster of this type is the possibility of contamination of the surrounding area resulting from the release of the radioactive fission products and the solution. First consider the possibility of contamination from a cloud containing all the reactors fission products. An equation for calculating the accumulated radiation from this type of accident is given in Appendix A of Ref. 2. Assuming previous steady operation of the WBNS at 1 watt, taking the average prevailing wind velocity of 6 knots, and using the average height of the local inversion layer of 1500 feet, the calculation for an exposure of 300 roentgens shows that this could occur only inside the reactor structure. This also indicates that at a distance of 50 meters from the reactor, the accumulated radiation resulting from the above assumed conditions would be only 0.2 milliroentgen. This is probably not realistic at these short distances from the reactor, but it does show that the exposure to individuals outside the immediate area is not a major problem.

One should also consider the probable hazard from inhalation of the radioactive material in such a cloud. Immediately after steady operation for a long period of time at 1 watt, the activity released in a cloud containing all the fission products would be approximately 10^{13} disintegrations per second. Assuming the cloud to cover an area 500 feet by 500 feet and to extend up to 1500 feet in height, and assuming that the wind velocity to be 6 knots, air containing about 10^{-6} microcuries per cm^3 will pass any point in this vicinity for a period of 50 seconds. This radiation level is just the public emergency tolerance level prescribed by the Atomic Energy Commission for the weapons testing program at the Nevada Test Sites. Further, attention should be called to the fact that this condition would be present for a short period of time, not only because of dispersal but also because of the rapid decay of part of the radioactive material.

Now consider the contamination which might occur if the active content of the reactor were deposited over the area. Assume steady operation at 1 watt and consider the radiation level resulting in an area of 300 yards radius, which would essentially cover the North American Aviation plant area in Downey. Using the equations in Appendix B of Ref. 2, it is found that at a time 20 minutes after the explosion (assuming total deposition of the active content) the

radiation level would be only 0.2 mr/hr of gamma radiation and 1.2 mr/hr of beta radiation. These radiation levels are also subject to decay of the radioactive material.

Calculation further shows that the water collected from a rainfall of about 0.1 inch over the area is sufficient to dilute the deposited activity to 10^{-2} microcuries per cm^3 of water. This is the emergency tolerance level for drinking water, if the water is to be drunk for a period of 2 weeks.

A review of the above results indicates that even well planned sabotage cannot result in effects of catastrophic proportions.

C. Natural Phenomena

Consideration of hazards resulting from natural phenomena should include possible effects from fires, earthquakes, tornados and hurricanes. The possibility of direct damage to any part of the reactor by fire is minimized by the type of building in which the reactor is presently housed. This building is constructed entirely of a steel frame with sheet metal covering, insulated on the inside with noninflammable material. The floor directly under the water boiler pedestal and shielding is a single slab of reinforced concrete 18 inches thick. The reactor itself, plus the associated exponential experimental equipment, contains no inflammable material. Also the adjacent laboratory buildings are of fireproof design.

Fig. 11 shows the active earthquake faults which are presently located in the Southern California area. One of immediate interest is the Norwalk fault which, according to this diagram, appears to end in the immediate locality of Downey. However, further consultation with Dr. J. T. Buwalda, of California Institute of Technology, has indicated that the exact location of the Northwestern end of the Norwalk fault is open to considerable question. The fault has never actually been located from surface effects in the Downey region but rather from profiles of that particular area. It appears on the basis of present information that the fault actually extends north of the community of Downey which would place it of the order of 2 miles from the present location of the water boiler.

The evaluation of the earthquake risk is a broad question, since one cannot consider the possible effects of a single active fault. Rather a more or less integrated risk over the entire Southern California area must be

considered. It is very difficult to arrive at a meaningful calculated risk for danger resulting from an earthquake in this vicinity. Information to date indicates that earthquakes of magnitude approximately six can be expected somewhere in the general Southern California area on the order of about every 6 to 8 years.

Although an accurate earthquake risk can not be determined, the effects of such earthquakes as are prevalent in this immediate area would not be of major proportions. Any type of rupture of the fuel system or dislocation of the reflector would be of such as to reduce the reactivity of the reactor. Further, if the release of the fission products or a runaway condition were to result it has already been shown that these can produce no disaster.

Potential risks from tornadoes and hurricanes are practically non-existent based on reports from Dr. M. Neiburger of the Meteorology Department at U. C. L. A. that there has been no history of damage by either these types of windstorms in the Southern California area. Further, records of the Los Angeles Weather Bureau show that the maximum wind velocity at the weather station during the past 75 years has been 49 miles per hour.

D. Activity of the Solution

Calculations based on data obtained during operation of the Los Alamos Water Boiler have been made⁵ and indicate that the radioactivity of the reactor solution will not exceed 80 millicuries of hard gamma radiation (above approximately 2 Mev) after extended operation at 1 watt. This amount of activity offers no major problem in the handling of the solution for laboratory testing or other experimentation.

E. Formation of Explosive Mixtures of Decomposition Gases

All of the decomposition gases produced during operation of the water boiler are accumulated in the stainless steel gas accumulation system which has a volume of approximately 40 liters. Of primary concern is the possible accumulation of sufficient hydrogen and oxygen inside the accumulator system to produce an explosion. This potential hazard is eliminated by a schedule for the removal of the decomposition gases at regular intervals. A definite schedule has not been completely ascertained because of lack of information about the rate of gas evolution from reactors operated at the power level of the NAA Water Boiler. However, information is being gathered

on the rate of gas evolution during our present operation. Up to July 14, total operation of the water boiler has been 23 watt hours. The hydrogen evolved during this operation was sufficient to give a concentration of 1 per cent in the accumulator. Since at least a mixture of 15 per cent hydrogen plus oxygen is required to produce an explosion,⁶ a reasonable schedule of flushing the gas accumulator system appears to be at the end of approximately each 100 watt hours of operation.

Calculations⁵ show that in the event of an explosion of a mixture of 85 per cent helium, 10 per cent hydrogen and 5 per cent oxygen in the accumulator system, the pressure rise will be only about 5.8 atmospheres (neglecting shock pressure). Since the stainless steel sphere has been designed to contain a pressure of 49 atmospheres, there is a safety factor of approximately eight.

F. Excessive Exposure to Personnel

Aside from the possible excessive exposures to personnel as a result of a major catastrophe, one must also consider possible radiation exposures during daily operation. A radiation survey has been made throughout the immediate surroundings of the water boiler location in cooperation with the Health Physics staff. This survey has been made with operation both at approximately 0.1 watt and at 0.5 watt power levels. The results of these surveys are described in detail in Appendix C.

With the shielding presently employed the radiation level at the control desk is somewhat less than the AEC permissible exposure rate when the WBNS is operated at 475 milliwatts. It is planned to extend the shielding over the top portion of the reactor well to reduce the scattered radiation from this source to a level which will permit continuous operation at 1 watt.

VI. CONCLUSIONS

The potential hazards associated with the operation of a low power water boiler type reactor located in the Atomic Energy Research Department of North American Aviation have been carefully reviewed. The results of this study show that operation of the reactor at a power level of 1 watt does not constitute a significant hazard to the personnel directly connected with the experimental program in which the reactor is used, to the production of the adjacent laboratories in the North American Aviation organization, or to the population residing in the surrounding area.

REFERENCES

1. King, L.D.P., "Water Boilers", Chapter 4, LA-1034, December 19, 1947.
2. Reactor Safeguard Committee, "Summary Report of Reactor Safeguard Committee", WASH-3, March 31, 1950.
3. Mills, M.M., "A Study of Reactor Hazards", NAA-SR-31, December 7, 1949.
4. Biehl, A.T. and E. R. Cohen, "The NAA Exponential Assembly - Part-I, Apparatus and Preliminary Procedure, NAA-SR-103, June 22, 1951.
5. Biehl, A.T., "Criticality Procedure and Hazards Associated with the North American Aviation Water Boiler Neutron Source, NAA-SR-MEMO-278, April 17, 1952.
6. Kuhn, D.W., F. L. Daley, A. D. Ryon, A. A. Palko, and W. R. Grimes, "Explosion Limits in Mixtures of Hydrogen, Oxygen, Steam and Helium", Y-731, Oak Ridge National Laboratory, March 1, 1951.

SECTIONAL ASSEMBLY - WATER BOILER NEUTRON SOURCE

23

FIG. 3

24

CONTROL RODS

CONTROL ROD
DRIVE MOTORS

SAFETY ROD CATCHES

SAFETY RODS

HOUSING FOR SAFETY
ROD WEIGHT

NORTH AMERICAN AVIATION, INC.
PHOTOGRAPHIC DEPARTMENT
CHICAGO, ILL.

3-19-52

SRP 277C

FIG. 4

SECRET

25

FIG. 5

SECRET

FIG. 7 PREVAILING AIR CURRENT FLOW

NOTE: PREVAILING FLOW REVERSES DURING WINTER MONTHS

LOS ANGELES.
AND
VICINITY
LEGEND

SRP-50F

FIG. 11 ACTIVE EARTHQUAKE FAULTS

LOS ANGELES
AND
VICINITY

LEGEND

APPENDIX A

WBNS CONTROL SYSTEM

by

D. Howard

Operation

The operation of the WBNS is explained with the aid of Fig. A-1 with assumed conditions existing. The following is a list of these assumptions, each explained separately.

- 1) Assume WBNS shutdown all conditions normal and all rods "in".
Operation - Start-Up.
- 2) Assume normal operating conditions i.e. safety rods "out", control rods in some intermediary position;
Operation - Auto Shutdown.
- 3) Assume final conditions of (2) above with trouble cleared.
Operation - Start-Up after Shutdown.
- 4) Assume normal operating conditions: Operation - Power Failure.

(1) Start-Up

The air circuit breaker is closed, thus providing ac power for rectifier, motors and solenoids (when operated). A.C. relay (R_1) will be energized, thereby opening contacts R_{1A} and R_{1B} and closing contact R_{1C} . Rectifier switch (S_1) is closed which energizes the dc bus. Simultaneously, the alarm reset push button (S_{16}) is depressed (momentarily and then released) energizing relay R_7 , which remains energized thru contacts R_{7A} and normally closed contact R_{8C} , and opens contact R_{7B} , thus preventing the alarm from ringing. When the 28 volt dc line is energized and the shut-down system has not been set, relay R_{21} will be de-energized. Thus, current will flow through the coarse rod "in" limit switch contacts (S_8) through normally closed R_{21A} and will then energize relay R_4 , thereby causing the coarse rod motor to move all the way to the "in" position until the "in" limit switch (S_8) opens and stops the motor. The battery switch (S_{17}) is closed to allow trickle charging of the battery and put the battery in stand-by. Indicator lights Nos. 1 and 3 will be energized indicating that the coarse rod and both safety rods are all "in". Solenoid push button (S_{14}) is depressed momentarily, energizing relays R_6 and R_8 and R_{21} thru switch S_8 and contacts R_{1C} . This closes

33

contacts R_{6A} and R_{6C} , energizing both safety rod holding solenoids. Contact R_{6B} closes and completes a holding circuit thru normally closed push button S_{15} . Contact R_{8C} opens, de-energizing relay R_7 (results see below). Contact R_{8A} opens to prevent the alarm from ringing. Contact R_{8B} opens also to prevent the alarm from ringing when the safety rods are in the "out" position. When relay R_7 is de-energized, the holding circuit contact R_{7A} opens and contact R_{7B} closes thus arming the alarm. Now the safety rods may be withdrawn and held in the "out" position with the holding solenoids. Indicating light No. 4 will light indicating safety rods "out". Micro switch S_{10} (NC) and S_{12} (NC) will close but the alarm will not sound as contact R_{8B} is open. The water boiler may now be controlled by controlling both the fine and coarse rod motors with momentary contact switch S_4 . The motor runs only as long as the switch is depressed. Limit switches S_6 , S_7 and S_8 , S_9 are provided to prevent overtravel on control rods. Momentary contact switch S_4 is double pole double throw with its common contacts always in the normally open position. Contacts are used as interlocks to prevent running the motor in both directions at the same time if both "in" and "out" buttons are depressed simultaneously. S_8 and S_9 also operate indicator lights for the all "in" and the all "out" position the coarse rod.

(2) Operation: Auto Shutdown

When one of the ion chambers or counters signals a shutdown, contact R_{9A} , R_{10A} or R_{11A} opens and contact R_{9B} , R_{10B} or R_{11B} closes. The latter contact operates an annunciator thereby giving visual indication of trouble location. When contact R_{9A} , R_{10A} or R_{11A} opens relays R_6 and R_8 and R_{21} are de-energized. Contacts R_{6A} and R_{6C} open de-energizing the safety rod holding solenoids allowing the safety rods to go to the full "in" position. Indicator light No. 4 goes out as switches S_{11} and S_{13} open and light No. 3 goes on as switches S_{10} and S_{12} close. (These switches are micro switches operated by a boss on the safety rods.) Contact R_{8A} closes ringing the alarm thru normally closed contact R_{7B} . The alarm may be shut off by depressing push button S_{16} . At the same time that relays R_6 and R_8

34

are de-energized, time delay relay R_{21} is de-energized. After a suitable time delay of a few seconds contact R_{21A} closes and contact R_{21B} opens, thus causing relay R_4 to be energized which causes the coarse rod to be inserted all of the way in. The time delay is necessary to enable the 110 volt a.c. single phase drive motor to come to a stop before it is reversed. Since the safety rods are inserted in about .6 seconds, the amount of time delay of the insertion of the coarse rod is unimportant. The WBNS is now shut down. Manual shutdown is similar only normally closed push button S_{15} is depressed. Also, push button S_{16} should be depressed simultaneously to prevent the alarm from ringing.

(3) Operation: Start-Up After Shutdown

The annuciation is reset by raising the manual reset button at the bottom of the annunciator. The indicator light for the coarse control rod will be on if the rod is in the "in" position. The full "in" position will be indicated by light No. 3. Relay R_6 is now energized thru switch S_8 and the same procedure as outlined in (1) Operation: Start-Up to be followed (S_8 is closed by a boss on the coarse control rod when the rod is all "in"). In the event that an attempt is made to move either of the safety rods before the coarse control rod is "in" the alarm will be energized by either S_{10} or S_{12} thru normally closed contacts R_{8B} . The alarm cannot be reset in this case. Only releasing the safety rod and allowing it to go to the all "in" position will turn off the alarm.

(4) Operation: Power Failure

When the ac bus becomes de-energized relay R_1 will be de-energized. Contacts R_{1A} and R_{1B} will close and R_{1C} will open. Contact R_{1A} will put the battery on the dc bus to supply power for indication and alarm. Contact R_{1B} will turn on light No.5 to indicate that the battery is on the line. Contact R_{1C} will de-energize relays R_6 and R_8 in the event that they do not drop out during transfer from rectifier to battery. Immediately upon loss of ac power, the safety rod holding solenoids will be de-energized allowing the safety rods to go to the full "in" position. The alarm will sound and may be reset as previously described. Light No.3 will indicate the safety rods are both "in". When ac power is again obtained, the procedure outlined in (3) Operation: Start-Up after Shutdown must be followed,

[REDACTED]

except that the alarm reset button S_{16} must be depressed to prevent the alarm from ringing.

The sensitive strip located in the lower right hand side of the control schematic shows the connections between the instrument current meters and their sensitrol shut down meters. The toggle switches when closed are used to change the range of the sensitrols to twice their normal current rating.

NOTICE OF CHANGE			
1 MAY BE REWORKED	2 RECORD CHANGE	3 PARTS MARK OK	
4 CANNOT BE REWORKED	5 NEW SHOP PRACTICE	6 DISPOSITION & REVISIONS	
EFFECT ON			
A			
1. CHANGED SWITCH S4			
2. ADDED RELAY R1			
3. ADDED SENSITROL STRIP			
4. ADDED CURRENT METER			
5. CONNECTED R1 CONTACTS AT SWITCH S4			
3	J.A.M.		
3	3-20-52

NOTE: - ALL CONTACTS SHOWN ARE IN DEENERGIZED POSITION.

FIG. - A-1											
SRD 25773		1								1	
PART NO.	NO. REQ.	PART NO.	NO. REQ.	DESCRIPTION		SIZE	ZONE	SPECIFICATION		NO. REQ. SHIP	TEST ASSEM.
R. H. ASSEM.		L. H. ASSEM.		MATERIAL							
HEAT TREAT		CALC. WT.		DRAWN BY		VLC		B 30		CHECKER	APPROV.
TOLERANCES EXCEPT AS NOTED				NORTH AMERICAN AVIATION, INC.							
ANGLES 1/2 DEG.				DRILLED HOLES				INTERNATIONAL AIRPORT			
FRACTIONS 1/16				.040 TO .125 DIA. +.001, -.001				LOS ANGELES 48, CALIFORNIA			
DECIMALS .010				.125 TO .375 DIA. +.001, -.001				10934			
7" SURFACE				.375 TO 1.0 DIA. +.001, -.001				WBNS ELECT.			
ROUGHNESS PER				32/64 TO 3/4 DIA. +.001, -.001				SRD-25773			
NATL. AIRCRAFT				49/64 TO 1" DIA. +.001, -.001				SCHEMATIC DIAGRAM			
STANDARD #20				1.1/64 TO 2" DIA. +.001, -.001				104			

[REDACTED] 40

APPENDIX B

THE EFFECT OF STEP INCREASES IN REACTIVITY

by

E. Weisner

In the event of a step increase in reactivity of the water boiler large enough to cause the power to rise out of control of the delayed neutrons, the boiler will shut itself off by one of two means before the safety mechanism will have had time to operate. One of these means is a reduction in core density due to gas generation, and the other is a temperature rise of the soup. M. M. Mills in NAA-SR-31, A Study of Radiation Hazards, indicated that for a 2% reduction in k , the solution density must decrease by 7.5%. This would mean the generation of $.075 \times 15000 = 1120$ cc of gas. It takes 1 Kw-sec of energy to produce 2.4 cc of gas, so the energy expended in reducing k 2% is 470 Kw-sec. The fastest period available in the water boiler according to L. King is .02 sec. We can then approximate the time of duration of such a burst:

$$\int_0^T P dt = P_0 \int_0^T e^{t/.02} dt = 470 \text{ Kw-sec}$$

$$t = 0.38 \text{ sec for } P_0 = 100 \text{ mw.}$$

This is the time for the power to reach its peak value. If we can assume the time to drop from this peak back to zero equals the time to get there, the total energy generated during such a burst is approximately 1000 Kw-sec. The instantaneous peak power is near 4 MW. During this burst some of the solution will be expelled from the sphere. This together with the temperature increase (about 15 C°) should prevent any recurrence of the runaway before the safety rod can operate. An energy release of 10^6 watt-sec requires about 3×10^{16} fissions to take place. This generates about 2.4×10^{17} Nev of

B-1

[REDACTED]

prompt gamma rays, assuming 8 Mev of gamma energy per fission.

If we can assume that a 1% increase in k occurs and that the excess k must be compensated for by means of temperature increases, we must expend more energy than in the above case. A 35 C° rise in temperature will reduce k by 1%. This will require 15000 cc x 35 $\frac{\text{Cal}}{\text{cc}}$ x 4.186 $\frac{\text{watt-sec}}{\text{cal}}$ = 2200 Kw-sec.

Again, if time to decay from peak equals time to rise to peak, the energy release is near 4400 Kw-sec. This is nearly a factor of 5 larger than the previous case. 4400 Kw-sec = 1.32×10^{17} fissions. Assuming 8 Mev of γ energy/fission, this releases 10.6×10^{17} Mev of γ energy. This must penetrate (radially) 2' of graphite, 2' of concrete, and 1' of air between graphite and concrete. Energy density on surface of shield is then
$$\frac{10.6 \times 10^{17}}{4\pi(5.5 \times 30.48)^2} e^{-[.075 \times 60 + .09 \times 60]} = 1.63 \times 10^8 \frac{\text{Mev}}{\text{cm}^2}$$

Since gamma radiation attenuates by factor of e^{-ut} where $ut = u_1 t_1 + u_2 t_2$,

u_1 = absorption coef in graphite

u_2 = absorption coef in concrete

t_1 = thickness of graphite (cm)

t_2 = thickness of concrete (cm)

Assuming the absorption coefficient for γ of a man is 0.05, (ref MIT Vol 2) the radiation dosage received by a person leaning against the shield at the time of a runaway would be

$$0.05 \text{ cm}^{-1} \times 1.63 \times 10^8 \frac{\text{Mev}}{\text{cm}^2} \times \frac{1.6 \times 10^{-6} \text{ ergs}}{\text{Mev}} \times \frac{\text{roentgen}}{83 \text{ erg/cc}} = 0.16 \text{ r.}$$

Since there are 1.32×10^{17} fissions during the burst, there will be produced $2.5 \times 1.32 \times 10^{17}$ fast neutrons, of which approximately 34.3% will

42

leak from the sphere, $\left(\frac{k_{\infty} - 1}{k_{\infty}} = \frac{.524}{1.524} = .343 \right)$.

The neutron density on outer surface of shield will be

$$\frac{2.5 \times 1.32 \times 10^{17}}{\pi (11 \times 30.48)^2} \times .343 = 3.2 \times 10^{11} \frac{\text{neut}}{\text{cm}^2} \text{ neglecting attenuation}$$

in graphite and concrete. From NAA-SR-Memo-71, the attenuation in the graphite and shield is 10^{-4} . The number of hydrogen nuclei per cc of tissue is 6.7×10^{22} , the scattering cross-section for hydrogen for 2 Mev neutrons is $2.7 \times 10^{-24} \text{ cm}^2$, and the fractional energy loss per collision is $1/2$. All above numbers are from M-1324. The radiation dosage for a person due to fast neutrons is then

$$3.2 \times 10^{11} \times 10^{-4} \times 2 \frac{\text{Mev}}{\text{Neut}} \times 6.7 \times 10^{22} \times 2.7 \times 10^{-24} \times 1/2$$

$$\times 1.6 \times 10^{-6} \frac{\text{erg}}{\text{Mev}} \times 5 \times \frac{1 \text{ roentgen}}{83 \text{ erg/cc}} = .56\text{r}$$

(The factor of 5 accounts for ratio of biological effect to physical effect.)

The maximum total dosage that a person could receive from such a burst is 0.72 r which is not a very large exposure to receive as the result of such an accident. A person may receive one month's exposure (1.5 r) as a result of an accident provided he receives no more that month and doesn't happen every month.

B-3

WBNS SURVEY

by

R. L. Koontz

Health Physicist

INTRODUCTION

In order to insure the safety of personnel around the Water Boiler Neutron Source, a survey has been made with carefully calibrated instruments for the radiation levels existing. The survey has been made at an operating power of 475 milliwatts which represents the maximum power used in experiments so far. Preliminary considerations of the hazards and descriptions of the instrumentation used to evaluate these hazards have been described in NAA-SR-Memo-289.

Previous surveys at 100 milliwatts have shown that this level of operation emitted radiations through the shield which were below one tenth of the maximum permissible exposure dosage rates, as set by the International Committee of Radiological Protection.

LAYOUT AND DESCRIPTION

Drawings are presented with this report, (Figs. 1, 2, and 3) representing three views of the WBNS shield and indicating various positions that were surveyed. The WBNS has a concrete shield two feet thick surrounding a graphite cylinder five feet in diameter which encases the 12 inch steel sphere holding the uranium solution. On top of the graphite cylinder there is an 6 foot high by 5 foot diameter aluminum cylinder, usually containing D_2O and uranium rods for experimental purposes.

The aluminum exponential assembly is the only shielding in the upward direction and thus this direction presents the greatest hazard. Fortunately no work is done above the WBNS while the power is on. The contents of this exponential assembly also determine to a large extent the radiation hazards above and around the WBNS. At the time of this survey the exponential contained approximately 800 gallons of D_2O and 100 ppm of B_2O_3 in this D_2O — with

[REDACTED]

no uranium lattices inside. Needless to say, removal of this boron and the inclusion of lattices of uranium will have some effect on the measurements reported here.

SURVEY METHODS AND CALIBRATION

The WBNS was designed to preclude the possibility of escape of fission product and decomposition gases. Measurements were made using a commercial Mine Safety Appliance electrostatic sampler and an inexpensive gas collecting survey device described in Fig. 4.

Gamma surveys were made with radium calibrated air wall equivalent instruments. The calibration of one of these instruments is shown in Fig. 5. For comparison the reading of this instrument (G.E. ion chamber) inside the shield of the WBNS is shown as a function of power level on the same graph. At levels below 1.0 mr/hr G-M survey instruments were used. Standard personnel films and dosimeters were also used for surveying.

The fast neutron survey was made using the methane filled proportional counter described in NAA-SR-Memo 289. Some characteristics of this counter are shown in Fig. 6. BF_3 and boron lined counters and indium foils were used to measure slow neutrons. Some surveys were made with a portable slow neutron survey meter using a 6 inch BF_3 counter with the "Pee-Wee" alpha proportional counting survey meter manufactured by the Nuclear Instrument and Chemical Co. All neutron calibrations were made with a standard Po-Be neutron sources.

PERSONNEL MONITORING

All personnel working in or visiting the WBNS during operation receive three types of integrating monitoring devices. These are photographic film, boron lined pencil chamber and gamma ray dosimeters. From these three radiation detectors the total accumulated exposure is evaluated and made a part of the individual's health record. Periodic physical examinations including blood counts and blood chemistry are also a part of the monitoring program.

SURVEY DATA

Most of the data collected in this particular survey are shown in Table 1. The location description is merely a method for fixing the survey instrument in space. All blank spaces in the columns mean that no measurements were made. No radioactive levels above normal background were detected with the electrostatic sampler or gas collecting survey device.

SUMMARY AND CONCLUSION

The radiation levels which exist at 100 milliwatts for 8 hr/day operation meet the required maximum permissible dosage rates of 1/10 the AEC standard dosage rates.

A simple explanation for the required 1/10 of the AEC maximum permissible exposure rate is the simultaneous existence of three so-called tolerance dosage rates and an unknown summative effect of fast neutrons, slow neutrons, and gamma radiation. In addition there are potential exposures from other sources of radiation in the laboratory.

It has been shown that the radiation levels existing are below the AEC permissible rates in working areas for each of the separate types of radiation. No attempt has been made to summate the total exposure.

RECOMMENDATIONS

Most of the recommendations listed here have been carried out since the survey data has been made available to the WBNS personnel.

1. No one should be inside the shield or above the shield in the vicinity of the WBNS during operation at any power level.
2. Use of additional shielding at powers approaching 400 milliwatts in the vicinity of wood ports through the shield.

-
3. Installation of red warning lights to notify personnel of operation of the WBNS.
 4. A permanent monitoring device which will summate the watt-hours of operation.
 - 5 A notification system for counting rooms where low background G.M. tubes are used.
 6. Health Physics notification before and after all target irradiations.
 7. More shielding in the vicinity of the D_2O line as it runs into the shield.

C-4

SURVEY WATER BOILER NEUTRON SOURCE AT 475 MILLIWATTS

LOCATION Symbol	DESCRIPTION Location on Figures	FAST NEUTRON			THERMAL			GAMMA		
		$n/s/cm^2$	FRACTION MPE/ RATE	FRACTION MPE AT 50 WATTS-HRS PER WEEK	$n/s/cm^2$	FRACTION MPE/ RATE	FRACTION MPE AT 50 WATTS-HRS PER WEEK	mr/hr	FRACTION MPE/ RATE	FRACTION MPE AT 50 WATTS-HRS PER WEEK
A ₁	Top and front views	6	0.3	0.08	200	0.13	0.03	1.4	0.224	0.059
A ₂	Top and front views	10	0.5	0.13	300	0.2	0.05	1.5	0.24	0.063
B ₁	Top and end views	12	0.6	0.16	400	0.26	0.06	2.5	0.4	0.105
C ₁	Top and end views (plug in)	55	2.75	0.6	272	0.18	0.056	32	5.1	1.34
C ₁	Plus 2 feet concrete added	1	0.05	0.013	-	-	-	0.8	0.128	0.034
C ₁	Top and end views (plug out)	1400	70.0	18.5	2600	1.7	0.46	58	9.3	2.4
C ₃	Top and end views (source rod)	40	2.0	0.52	-	-	-	-	-	-
C ₄	Top and end views	200	10.0	2.6	1050	0.7	0.183	60	9.6	2.5
D ₁	Top and end views (outside paraffin-Cd shield)	40	2.0	0.52	(1400)	0.93	0.21	16	2.56	0.675
D ₂	Top and end views (inside boiler)	-	-	-	36,000	24	6.3	-	-	-
E ₁	Top and front views	150	7.5	1.95	2,000	1.3	0.3	7	1.12	0.3
E ₂	Top and front views	-	-	-	617	0.41	0.1	12.5	2.0	0.53
H ₁	Top and front views	16	0.8	0.2	319	0.2	0.05	5.5	0.88	0.25
H ₂	Top and front views	100	5.0	1.3	(500)	-	-	-	-	-
H ₂	" "	"	"	"	600	0.4	0.1	60	9.6	2.5
I	Top view 3 feet from floor	-	-	-	-	-	-	2.0	0.32	0.084
I _b	Top view 3 feet from floor	-	-	-	-	-	-	0.4	0.064	0.017
J	Top view 3 feet from floor	-	-	-	-	-	-	6.5	1.04	0.273
K ₂	Top view 5 feet from floor	-	-	-	617	0.41	0.1	-	-	-
M ₂	Front view	-	-	-	6,300	6	1.0	-	-	-
d ₁	Top and end views	-	-	-	200	0.13	0.03	1.6	0.256	0.07
d ₂	Top and end views	-	-	-	200	0.13	0.03	3.5	0.56	0.14
d ₃	Top and end views	-	-	-	200	0.13	0.03	4.5	0.72	0.18
CY ₁	Top and end views	-	-	-	-	-	-	1.0	0.16	0.04
CY ₂	Top and end views	-	-	-	-	-	-	1.0	0.16	0.04
CY ₃	Top and end views	-	-	-	-	-	-	0.5	0.08	0.02
CY ₄	Top and end views	-	-	-	-	-	-	0.5	0.08	0.02
CY ₅	Top and end views	-	-	-	-	-	-	1.0	0.16	0.04
CY ₈	Top and end views	-	-	-	-	-	-	0.8	0.13	0.03
CS1a	Top and end views	-	-	-	-	-	-	0.9	0.15	0.04
CS2a	Top and end views	-	-	-	-	-	-	1.2	0.2	0.05
CS3a	Top and end views	-	-	-	-	-	-	0.25	0.04	0.01
CS1b	Top and end views	-	-	-	-	-	-	0.2	0.03	< 0.01
CS2b	Top and end views	-	-	-	100	-	-	0.2	0.03	< 0.01
CS3b	Top and end views	-	-	-	-	-	-	0.2	0.03	< 0.01
CS1c	Top and end views	-	-	-	-	-	-	0.15	0.02	< 0.01
CS2c	Top and end views	-	-	-	50	-	-	0.15	0.02	< 0.01
CS3c	Top and end views	-	-	-	-	-	-	0.15	0.02	< 0.01
CS1d	Top and end views	-	-	-	-	-	-	0.15	0.02	0.01
CS2d	Top and end views	-	-	-	12	-	-	0.15	0.02	0.01
CS3d	Top and end views	-	-	-	-	-	-	0.15	0.02	0.01
CS1e	Top and end views	-	-	-	-	-	-	0.1	0.015	< 0.01
CS2e	Top and end views	-	-	-	12	-	-	0.08	-	-
R ₁	Front and end views	-	-	-	170	-	-	4.5	0.6	0.17
R ₂	Front and end views	-	-	-	105	-	-	-	-	-
R ₃	Front and end views	-	-	-	65	-	-	1.0	0.16	0.04

(1) 20 n/cm²/sec

(2) 1500 n/cm²/sec

(3) 6.25 mr/hr

49

50

$\alpha(1,2,3)$

TOP VIEW
WBNS HOUSING

FIG. 1

Edwin 3090

51

FRONT VIEW
WBNS HOUSING
FIG. 2

CONTENT OF EXPONENTIAL

1. 800 GALLONS D_2O
2. 100 PPM B as B_2O_3

COARSE ROD - 50
FINE ROD - 36.7

3 FT. SCALE

53

END VIEW
WBNS HOUSING

FIG. 3

54

FIGURE 4
GAS COLLECTING SURVEY

DEVICE

FIGURE 5

RESPONSE CURVE OF
AIR-WALLED IONIZATION
CHAMBER
(POSITION "X")

FIGURE 5

CHARACTERISTICS OF CH₄ COUNTER

○ = 2R/HR OF R_α γ RADIATION
AT SURFACE OF COUNTER

• = 0.06 R/HR AT SURFACE OF COUNTER

⊗ = WBNS 0.06 R/HR - γ
POSITION "H"

X = 78N/S/CM²
0.160N/S/CM²

1000

100

10

2400

2500

2600

2700

2800

2900

3000

(C/MIN @ 6) VOLTAGE

109 48 -