~~SECRET~~

AEC RESEARCH AND DEVELOPMENT REPORT

~~SECRET~~ ~~OSTI~~ ~~INV~~ ~~BP~~ **UNCLASSIFIED**

HW-51856 CH3

COPY No. 243 A

MASTER

IPD PHYSICS PRIMER

CHAPTER 3 - THE PILE STRUCTURE

E. H. LOCKWOOD

MAY 1, 1958

~~S-R D
Classification
Confirmed.
11-3-71.
H. L. Lee~~

IRRADIATION PROCESSING

DO NOT MICROFILM
COVER

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

GENERAL ELECTRIC

~~RESTRICTED DATA~~

~~THIS DOCUMENT CONTAINS RESTRICTED DATA AS DEFINED
IN THE ATOMIC ENERGY ACT OF 1954. THE INFORMATION
RELATES TO THE CIVILIAN APPLICATIONS OF ATOMIC ENERGY.
ITS TRANSMITTAL OR THE DISCLOSURE OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS
PROHIBITED.~~

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

UNCLASSIFIED

~~SECRET~~
1 3847

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.

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.

UNCLASSIFIED

~~CONFIDENTIAL~~
~~G. C. Fuller~~

HW-51856 CH3 ✓

C-42, Reactors - Production
(M-3679, 21st Ed.)

This document consists
of 95 pages. Copy No. 248
of 272 copies. Series A

IPD PHYSICS PRIMER

CHAPTER 3 - THE PILE STRUCTURE

By

E. H. Lockwood

Operational Physics
Research and Engineering Operation

HW--51856-Ch.3

DE90 010042

May 1, 1958

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

Work performed under Contract No. W-31-109-Eng-52 between
the Atomic Energy Commission and General Electric Company

~~CONFIDENTIAL~~

~~This document contains Restricted Data as defined in the Atomic
Energy Act of 1954. Its transmittal or the disclosure of its con-
tents in any manner to an unauthorized person is prohibited.~~

Route To:	P. R. No.	Location	Files Route Date	Signature and Date

Printed in USA. Charge \$1.65. Available from the U. S. Atomic Energy
Commission, Technical Information Service, P. O. Box 1001, Oak Ridge,
Tennessee. Please direct to the same address inquiries covering the
procurement of other ~~CONFIDENTIAL~~ AEC reports.

CLASSIFICATION CANCELLED

BY AUTHORITY OF S. E. Gydesen

BY T. Davis DATE 3-26-90

T. Davis 3-26-90

MASTER

~~SECRET~~

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

pe

TABLE OF CONTENTS

	<u>Page</u>
I. GENERAL DESCRIPTION OF THE PLANT	8
A. Plant Site	8
B. Area Sites	8
C. Typical Reactor Area	10
D. Reactor Building	12
II. DESCRIPTION OF THE REACTOR	15
A. Requirements of a Production Unit	15
B. Lattice Structure	16
C. Reflector	18
D. Cooling Tubes	21
E. Fuel Slugs	23
F. Dummy Slugs	27
G. Thermal Shield	28
H. Biological Shield	30
I. Reactor Atmosphere	34
J. Reactivity Control Systems	35
K. Horizontal Control Rods	36
L. Vertical Safety Rods	41
M. Ball 3X System	43
N. Process Water System	44

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.

TABLE OF CONTENTS (contd.)

	<u>Page</u>
III. INSTRUMENTATION FUNDAMENTALS AND REQUIREMENTS	50
A. Introduction	50
B. Detection of Flux	52
1. Fundamental Methods	52
2. Neutron-Sensitive Chambers	52
3. Flux Range	55
4. Reactor Geometry Effects	60
C. Instrumentation Requirements and Partial Reliance on Procedure	61
1. Reactor Safety Requirements	63
2. Dependence on Operating Procedures	65
3. Summary of Safety Protection Needs and Methods	66
Table I - Operating Conditions Associated with Undesirable Events	66
Table II - Protection Against Undesirable Events	68
IV. EXISTING HANFORD INSTRUMENTATION	69
A. BF ₃ Counter (PC)	69
B. Galvanometer System	70
C. Octant Monitor	71
D. Foil Traverse	73
E. Beckman System	74
F. Panellit System	77
G. Temperature Monitor	78

~~SECRET~~TABLE OF CONTENTS (contd.)

	<u>Page</u>
IV.	
H. Seismoscope	79
I. Safety Circuits	80
J. Response Time	83
K. Annunciator	83
L. Miscellaneous Instrumentation	85
V. INSTRUMENT DEVELOPMENT	86
A. Sub-critical Flux Monitor	87
B. Tube Outlet Temperature	89
C. Octant Monitor	89
D. Rate of Rise Instrumentation	90
E. Miscellaneous	91

~~SECRET~~

UNCLASSIFIED

~~SECRET~~

-5-

HW-51856 CH3

PREFACE TO THE IPD PHYSICS PRIMER

Training of operating personnel is a vital phase of reactor operation here at Hanford; despite all the limits and safeguards which can be imposed, the ultimate responsibility for reactor safety rests with the individual operating the reactor. Because the operation is constantly being changed and improved, the training program must be flexible, varied, and continuous.

Some effects of power level changes and control rod movements are not immediately evident. Therefore, it is necessary that the operator anticipate sensitive control conditions and thoroughly understand all the characteristics of the reactor under various circumstances.

Increased use of electronic equipment, higher power levels, sensitive control, etc., all indicate the urgent need to thoroughly train new personnel, and to upgrade the skill of the present operating group; the degree of skill and know-how of the operating personnel can often mean the difference between safe and unsafe reactor operation.

To aid in this training, the Operational Physics group presents the "IPD Physics Primer". This manual deals generally with the pile physics aspects of the processes used at Hanford for the production of plutonium. The text is primarily descriptive, rather than definitive. Process conditions, such as pressures, temperatures, concentrations, activities, etc., stated in this manual are not firm specifications for these processes. Such specifications are covered by "Process Standards", issued separately. It is intended that this manual be used primarily by the Reactor Specialists to serve as follows:

1. As an aid toward a better understanding of crucial pile conditions.
2. As a training guide for new personnel.
3. As a source of subject matter for group discussion.
4. As a method for establishing closer communication between Reactor Operation and Operational Physics personnel.

UNCLASSIFIED

-6-

HW-51856 CH3

As time permits, it is planned to cover the subjects listed below in the following sequence:

- Chapter I Structure of the Atom
- Chapter II Physical Principles of the Reactor Process
- Chapter III The Pile Structure
- Chapter IV Variations in Pile Reactivity
- Chapter V Control of the Pile Reaction
- Chapter VI Operating Procedures and Standards
- Chapter VII Radiation and Shielding

UNCLASSIFIED

~~SECRET~~

-7-

HW-51856 CH3

IPD PHYSICS PRIMER

CHAPTER 3 - THE PILE STRUCTURE

INTRODUCTION

The preceding chapters have introduced the principles of nuclear reactions involved in the production of plutonium. In this chapter, it is proposed to describe the plant site and to outline the nature of the pile in order to show the specific design and layout requirements for the production of plutonium by nuclear synthesis.

The selection of the plant site involved a number of special considerations. An essential requirement was a large dependable supply of relatively pure water that remains at a fairly low temperature throughout the year. A large source of power was required to circulate the tremendous quantities of water. The potential dangers connected with the high energies of the nuclear reaction and the formation of a large quantity of radioactive by-products required large distances between each operating section of the plant, and between the plant and main rail and highway routes.

The plant site layout and reactor areas are discussed in the first part of the chapter, followed by a functional description of the more essential pile components. The chapter concludes with a discussion of reactor instrumentation.

ACKNOWLEDGMENTS

The field of nuclear physics is so broad and so complex that it would be presumptuous of the author to claim any new or novel ideas in the material presented in the IPD Physics Primer. Since the material was gathered from many sources, it would be impractical to try to give individual recognition in every case, but the use of such material is gratefully acknowledged.

Specifically, I wish to express my appreciation to the members of the Operational Physics Operation for their valuable suggestions and constructive criticisms. I am particularly grateful to R. E. Trumble for the use of certain material and illustrative sketches used in this chapter of the manual.

UNCLASSIFIED

~~SECRET~~

-8-

HW-51856 CH3

I. GENERAL DESCRIPTION OF THE PLANT

A. Plant Site

The Hanford Atomic Products Operation is located in the south-central part of the state of Washington. The site is east of the Cascade Range, in a semi-arid region beside the Columbia River, one of the largest rivers in terms of water flow in the United States, and near the Grand Coulee, McNary, The Dalles, and Bonneville power networks. The surrounding area is sparsely populated - the nearest community of any considerable size is Yakima, about 40 miles to the west. The larger cities of Seattle, Tacoma, Portland, and Spokane lie well outside a 100 mile radius. The locations of the Hanford Site and the BPA main transmission system are shown in Figure 3-1.

The site itself lies largely, and the manufacturing area entirely on the south bank of the Columbia River, which bounds the manufacturing area on the north and northeast. The area owned or controlled through lease amounts to approximately 602 square miles, plus a secondary control zone of 164 square miles. Lying within this controlled area, the manufacturing reservation contains 194 square miles. The remaining property owned is accounted for by the purchase of power and irrigation properties and rights and by the village of Richland. Occupancy in the remaining leased property is restricted and controlled on the basis of safety and security considerations.

B. Area Sites

The manufacturing process is carried out in "100", "200", and "300" Areas. There are five "100" areas (including three dual-reactor areas) where eight nuclear reactors are located, two "200" areas where plutonium is separated from the irradiated uranium, and one "300" area. The "300" area contains supporting activities such as fuel preparation facilities, research and development laboratories, and fabrication shops. The "100" areas contain the nuclear reactors and their supporting

~~SECRET~~

LOCATION OF HANFORD SITE AND BPA MAIN GRID TRANSMISSION SYSTEM

FIGURE 3-1

activities. Each area site lies on a nearly level plain at elevations above the river which range from some 30 to 100 feet. These areas are widely separated from each other, from other operating areas, and from Richland, as shown in Figure 3-2.

The Columbia River furnishes the water for cooling the nuclear reactors. This great river, with its headwaters in British Columbia west of the continental divide, is fed by melting snow. Just north of the plant site, the river drains an area of about 95,000 square miles which is twice the size of Pennsylvania. The average flow of the river at the site is 121,000 cu ft/sec, with an average monthly minimum of 40,000 in February and a maximum of 334,000 in June. The combined rated capacity of the pumps taking water from the river amounts to about 3 per cent of the minimum river flow. The water is exceptionally pure and has an average temperature of 50°F for 8 months of the year and 60°F for the remaining 4 months.

D. Typical Reactor Area

The "100" areas at Hanford contain the nuclear reactors and their supporting activities - principally water pumping, purification, storage, and disposal systems, power generation and distribution, administration, technical services, maintenance, and security. The supply, treatment, distribution and final disposal of the reactor cooling water is perhaps the most important supporting facility on the Hanford plant. Although the Columbia River water is high in purity, some treatment is required to make it conform to standards acceptable for reactor cooling. A river pump house supplies water from the river to storage basins. It is then treated to meet the requirements of the process, which are minimum corrosion and freedom from film formation in the water tubes of the reactor. Following this treatment the water is pumped to the pile building. After passing through the pile, the water is held up in a retention basin to allow decay of certain short-lived radioactive products before it goes back into the river.

HANFORD SITE AND SURROUNDING AREA

FIGURE 3-2

CONFIDENTIAL

-11-

UNCLASSIFIED

HW-51856 CH3

CONFIDENTIAL

UNCLASSIFIED

~~SECRET~~

-12-

HW-51856 CH3

In addition to the cooling water, a mixture of carbon dioxide and helium is also circulated through the pile.

Each reactor area is bounded by about 5 miles of fence enclosing about 700 acres of land on which there are several miles of broad gauge track and blacktop roads. A typical arrangement of dual-reactor area is shown in Figure 3-3.

D. Reactor Building

A typical Hanford reactor building is a concrete and concrete block structure approximately 120 feet by 150 feet and 120 feet high. It houses the reactor and associated spaces. These spaces may be classified functionally as pre-irradiation, post irradiation, and service areas. The pre-irradiation areas are the fuel preparation area and the work area adjacent to the charging face of the reactor. The post-irradiation areas include the discharge area at the rear face of the reactor, the experimental face of the reactor, and the combined storage basin and transfer area. The service areas include the control, monitor, and clothing change rooms and various shops and offices; the fan room which supplies building ventilation, the rod rooms containing the horizontal rod drive mechanisms, and the sampling rooms containing slug rupture detection equipment. A simplified ground floor plan of the reactor building is shown in Figure 3-4.

The storage basin and transfer area is separated from the discharge area by a concrete wall five feet thick. The control room is shielded from the reactor by a concrete wall three feet thick. This shielding is in addition to the thermal and biological shields which surround the reactor.

A positive air pressure of approximately one inch of water is maintained in the inhabited areas of the building. The building ventilation system directs air through the inhabited areas, around the reactor (external to the reactor atmosphere) and into a reinforced concrete chimney stack two hundred feet tall, from which the air is released into the atmosphere. The air at the rear face of the reactor is maintained at less than atmospheric pressure by the exhaust fan drawing air into the chimney stack.

~~SECRET~~

~~CONFIDENTIAL~~

-14-

HW-51856 CH3

FIGURE 3-4

SIMPLIFIED GROUND FLOOR PLAN OF REACTOR BUILDING
C & H REACTORS

II. DESCRIPTION OF THE REACTOR

A. Requirements of a Production Unit

The reactor must first of all furnish an arrangement of parts in which the self-sustaining or chain reaction mentioned in previous chapters can be started and controlled. Then it must be capable of permitting the removal of heat as fast as possible, since the rate of production is directly proportional to the rate of heat generation. It must be capable of practical operation, in a way that permits ultimate semi-isolation of the product, and in a way that is safe.

In order that the chain reaction may take place, it is necessary to have metallic uranium dispersed in a medium that is capable of slowing down the fast neutrons produced in the chain reaction, but which at the same time prevents their loss by leakage or absorption in quantities such that the reaction can not sustain itself. Both theory and experience have shown that one of the most practical methods by which this can be done is to arrange the uranium in the form of cylindrical bars, evenly spaced in a large mass of graphite. The length, diameter and spacing of these fuel rods are all-important. The theory shows that a certain ratio between weight of the graphite and of the uranium must be preserved. It also shows that if the fuel rods are too thick, too many of the neutrons are captured inside them under conditions such that no additional neutrons are formed and the reaction dies off. If the fuel columns are too short, too many neutrons leak out at the ends of the pile; if they are spaced too close, there is a good chance that the escaping neutron will re-enter the metal before it is properly slowed down; if the rods are spaced too far apart, too many neutrons are captured by the moderator.

The most effective arrangement of parts is still further complicated by the necessity of passing a cooling agent over the surface of the metal. In the Hanford reactors this cooling agent is water. The water must be kept out of the graphite and away from the uranium with which it would react. For this reason it becomes necessary to jacket the uranium in a protective coating, and to place it inside water tubes running through the reactor. A survey of the materials from which these jackets and tubes

could be made shows that of the more common metals only aluminum has the necessary combination of good resistance to corrosion and low absorptive power for neutrons.

Because it is necessary to discharge the jacketed uranium pieces at certain intervals as the product builds up in it, special end fittings must be provided through which the metal can be moved and the cooling water brought in and taken away; these end fittings are known as nozzles. A typical front nozzle assembly is shown in Figure 3-5.

B. Lattice Structure

The arrangement finally chosen for the first six reactors was a nearly cubical pile of graphite made up of blocks $4 \frac{3}{16}$ inches square by 48 inches long. The nominal over-all graphite dimensions for the B, C, D, DR, F and H Reactors are:

Front to Rear:	28 feet
Top to Bottom:	36 feet
Side to Side:	36 feet

Four feet must be subtracted from each of the above dimensions to obtain the "active zone" dimensions which do not include the reflector regions.

The reactor rests on a carefully-leveled surface made up of cast-iron blocks, which in turn are laid in grout on top of a massive concrete foundation. In addition to giving a good surface upon which to start to lay graphite, the cast iron serves another purpose that is discussed later.

The graphite blocks are stacked in alternate layers from bottom to top with the long dimensions at right angles to the blocks in the alternate layers. A number of short blocks are used so that the joints are staggered. This crisscross arrangement makes the pile relatively stable to mechanical distortion. Additional protection against shifting is provided in the form of large graphite keys. Alternate columns in alternate layers are pierced for the aluminum tubes, which are thus spaced in a square lattice in which the tubes are $8\frac{3}{8}$ inches apart, giving a total of 2004 process tubes in

FIGURE 3-5

CG-558 Nozzle Assembly

each of the above reactors (K area reactors have 3220 process tubes, 7-1/2 inch lattice spacing). A cutaway view of a typical reactor building is shown in Figure 3-6. Additional openings, not shown in these diagrams, are provided for special irradiations and for monitoring instrumentation.

The arrangement of "tube" and "filler" blocks for the B, D, and F Reactors is shown in Figure 3-7a. The edges of the tube blocks are beveled to provide passage for the circulating "pile atmosphere" which is a mixture of carbon dioxide gas and helium. To allow for potential graphite expansion the tube blocks at the DR Reactor are undercut on top and hollow ground on the sides as shown in Figure 3-7b. At C and H Reactors the blocks are undercut on both sides as well as on top, and are spaced by trunnion blocks placed between the ends of the tube blocks. This arrangement is shown in Figure 3-7c.

The diameter of the holes in the tube blocks at the C and K Reactors is slightly larger than at the other reactors in order to accommodate a larger process tube. In addition the tube blocks are overbored or "cored" near the front and rear faces. This coring consists of varying the graphite bore diameter inversely with expected flux density in order to maintain a more uniform graphite temperature distribution over the entire stack.

C. Reflector

Fission-born neutrons escape from the uranium at high speed and enter the graphite, where they bounce from atom to atom, losing a fraction of their energy at each impact until they have been slowed down to a velocity roughly comparable to that of an atom of gas at the temperature of the reactor. In this state they are called slow or "thermal" neutrons because their kinetic energy is roughly that of the thermal energy of the atoms of the pile. Throughout this process, there is a competition between the various fates of the pile neutrons. A neutron may get back into the uranium and be absorbed while it is still going too fast, leak out through the sides of the pile, be absorbed by the graphite, the aluminum, or the water, or reach the desired final slow velocity at which it is most effective in producing other neutrons when it reacts with uranium.

~~SECRET~~

FIGURE 3-6

Cutaway of Typical Reactor Building

~~SECRET~~

~~SECRET~~

-20-

HW-51856 CH3

NO GAS GAP AS BUILT

.0007" RADIAL GAS GAP AS BUILT

TUBE DIAM. $1.729 \pm .003$
BORE DIAM. $1.744 \pm .003$
RADIAL GAS GAP MAX. .0105
MIN. .0045
NOM. .0075

TUBE RESTS ON BOTTOM OF CHANNEL

FIGURE 31a

.120" GAS GAP AS BUILT

.0007" RADIAL GAS GAP AS BUILT

.040" MAX. GAS GAP AS BUILT

TUBE DIAM. $1.729 \pm .003$
BORE DIAM. $1.744 \pm .003$
- .000
RADIAL GAS GAP MAX. .010
MIN. .0065
NOM. .0075

TUBE RESTS ON BOTTOM OF CHANNEL

FIGURE 31b

.122" GAS GAP AS BUILT

.061" GAS GAP AS BUILT

.0007" RADIAL GAS GAP AS BUILT

TUBE DIAM. $1.729 \pm .003$
BORE DIAM. $1.744 \pm .003$
(TUBE BLOCKS) - .000
BORE DIAM. $1.750 \pm .002$
(TRUNNIONS) - .003

RADIAL GAS GAP MAX. .010
MIN. .0065
NOM. .0075

TUBE RESTS ON BOTTOM OF CHANNEL

FIGURE 31c

FIGURE 3-7

Detail of Graphite Blocks

~~SECRET~~

The most costly of these possibilities is that neutrons will leak out the sides of the pile structure. Leakage of neutrons is reduced by using a "reflector" to send most of them back from the surface into the mass of graphite that contains the uranium. The reflector that is used consists of an additional layer of graphite about two feet thick on all six sides of the reactor. It would appear that if the reflector were thick enough all neutron leakage could be prevented. However, no matter how thick the reflector, some neutrons will escape and some will be absorbed by the atoms of carbon. In fact, the effectiveness of the reflector in turning neutrons back into the interior falls off very rapidly as the thickness of the reflector is increased.

Each cooling tube pierces not only the active portion of the reactor, but also the front and rear sections of the reflector; if the portions of the tube going through the reflector were filled with uranium, its purpose would be defeated. Therefore, it is necessary to properly position the uranium charge in the active zone only and to fill the remaining portions of tube with some shielding element. This is accomplished through the use of a downstream dummy charge of perforated aluminum pieces. The combination of aluminum and water at the downstream end produce enough scattering of gamma rays and absorption of neutrons to protect the effectiveness of the reflector at this point. The water and a cap-supported solid aluminum piece serve the same function at the upstream end of the process tube. Thus, the absorption of neutrons in the front and rear reflectors is not sufficient to greatly reduce their effectiveness.

D. Cooling Tubes

The heat generated by the nuclear process is removed from the Hanford reactors by pumping water once through the reactor, after which the mildly radioactive water is retained for a time and then discarded into the Columbia River. The high heat transfer is accomplished by surrounding the jacketed uranium, which has an outside diameter of 1.440 inches, with an aluminum tube which has an inside diameter of 1.611 inches, thus leaving an annular space for water flow that is 0.086 inch wide (Figure 3-8).

~~SECRET~~

-22-

HW-51856 CH3

FIGURE 3-8

Section Through a Charged Tube in B, D, DR, F, and H Reactors

At C Reactor the slug diameter is unchanged, but the water annulus is increased to 0.102 inches, and the aluminum tube is correspondingly larger.

~~SECRET~~

Because of the rapidity with which local overheating can occur if the water flow is not maintained, the tubes have to be drawn with very close dimensional tolerances, and the uranium is centered within them by means of two ribs running full length of the inside of the aluminum tubing. The pressure drop required to force the water through the tube determines the pressure at the inlet to the tubes, and thus sets a lower limit to the wall thickness. This wall thickness must not be greatly increased for greater resistance to creep and corrosion, or too many neutrons will be absorbed. A reasonable compromise was attained by making the minimum nominal tube wall thickness 0.059 inches. The outside diameter of the aluminum tubing thus becomes 1.729 inches. Much consideration was given to the question of whether the aluminum tube should be larger, slightly thicker, or both, but if it were enlarged too much, the amount of uranium would have to be increased, and if it were merely thickened, the pressure required to force the water through the remaining annulus would be too high. However, the newer reactors are equipped with larger tubes of the same wall thickness which increases the water annulus at C Reactor to 0.102 inches and at the K Reactors to 0.123 inches.

E. Fuel Slugs

The basic reactor fuel is natural uranium which contains 0.712 per cent of uranium-235 and 99.288 per cent uranium-238. The metal is formed into solid right cylindrical "slugs", approximately 8.8 inches long. The slugs are sealed within aluminum jackets which are bonded to the metal. The aluminum jacket serves to contain the radioactive fission products formed within the uranium by neutron bombardment and to prevent chemical reaction between the process water and the uranium metal.

Another type of slug is the I & E fuel element. The I & E slug is fabricated to provide internal (I) cooling in addition to the external (E) cooling. This slug has an open channel (hole) centered radially in the fuel element allowing the cooling water to pass through the center of the fuel piece. The dimensions of an I & E slug are determined by the process tube size. The cross sections of an initial design I & E slug and a solid fuel element for C Pile are shown in Figure 3-9.

FUEL ELEMENT TUBE GEOMETRY C REACTOR

CONFIDENTIAL

SOLID FUEL ELEMENT

I & E FUEL ELEMENT

-24-

HW-51856 CH3

FIGURE 3-9

CONFIDENTIAL

Cylindrical slugs (approximately six inches long) jacketed in aluminum and filled with a neutron absorbent such as lead-cadmium alloy (poison) may also be used in the reactor. To understand the purpose of these slugs it is necessary to picture the distribution of power in a Hanford reactor. Since the active portion of the reactor is a rectangular prism the center tube is the most active one, and the activity falls off like a rounded hill towards the sides and towards the top and bottom, following a cosine curve, modified for reflector buildup effect in each direction as shown in Figure 3-10. It reaches about 25 per cent of the maximum activity in the middle of the sides, and about 10 per cent at the corner tubes. If the curve of activity could be "flattened" to form a high plateau instead of a rounded hill, more tubes would run at or near maximum activity, and the output of the reactor would be increased. This flattening can be accomplished by filling carefully chosen tubes near the middle of the activity peak with the absorbent slugs (poison columns) mentioned above. The resulting distribution of activity, while approaching the ideal high plateau, is actually a hill, the top of which contains a number of depressions corresponding to the absorbent tubes, so that it resembles a pincushion (Figure 3-11). In the flattened pile the neutron activity reaches about 45 per cent of the maximum in the middle of the sides, and about 15 per cent at the corner tubes.

Material loaded for flattening purposes may also produce useful isotopes. Such materials may include lithium for production of tritium, thorium for production of uranium-233, depleted uranium for production of plutonium, and cobalt for use in medicine and research.

At the present time, the maximum power generated in a single process tube in the Hanford reactor is limited by (1) rupture rates at high exposure, (2) potential boiling of process cooling water within the tube, and (3) graphite burnout considerations. In order to spread the neutron distribution within a reactor so as to increase production when the power generated in a single tube must be limited, process tubes near the top, bottom and side fringes of the reactor may be loaded with material containing more than 0.712 per cent of uranium-235. This permits a further increase in the average flux without

Metal Bearing Tubes

FIGURE 3-10

Neutron Density Unflattened Pile

FIGURE 3-11

Neutron Density Flattened Pile

exceeding the central tube limits. The use of this "fringe enrichment" increases the reactivity of the reactor, and the compensating poison columns loaded reduce the relative flux near the center of the reactor.

Aluminum spacers, or "dummy slugs" are used in the downstream end of the process tube to position the fuel slugs properly.

F. Dummy Slugs

As pointed out earlier, it is necessary to fill the portions of the tube that pass through the reflector with a relatively inert material which will serve to properly position the fuel slugs in the active portion of the pile without defeating the purpose of the reflector. Ideally this material would be a reflector of neutrons in itself. For practical purposes, however, it has been found adequate to fill the downstream end of the process tubes with tubular aluminum dummies. These "dummies" have the same outside diameter as the fuel slugs and have an inside diameter slightly under one inch. Their walls are perforated with holes $5/16$ inch in diameter. The perforations allow water to flow inside these tubular dummies as well as in the annular space around them. The pressure drop in the portions of the tube which they fill is accordingly materially reduced. Their walls are sufficiently heavy to transmit the forces required for charging and discharging the tube without buckling or collapsing. The combination of water and aluminum in the downstream dummy pattern produces enough scattering of gamma rays and absorption of neutrons to protect the biological shield, which is discussed later. The absorption of neutrons in the aluminum and water within the reflector is not such as to reduce its effectiveness to a large extent.

To ensure that the fuel slugs are properly positioned in the active portion of the reactor, each uranium charge is "seated" from the front of the process tube with a seating charge of perforated aluminum dummies. The seating charge is removed and the portions of tube upstream of the fuel slugs fill with water, providing an effective medium for neutron scattering. Most of the gamma ray radiation at the front of the tube comes from the upstream slug as the uranium itself is an excellent shielding

material; the remaining gamma radiation is attenuated by the water, the columnar effect being reduced by a solid aluminum piece attached to the front face tube cap.

G. Thermal Shield

That the reactor must be covered with protective outer layers is obvious when it is realized that the total ionizing power of the radiation produced in the pile is equivalent to several hundred tons of radium. Although the reflector turns back most of the neutrons and absorbs most of the gamma rays entering it, the small fraction that still escapes is capable of producing thermal and physiological effects enormous in comparison with any natural source of radioactivity. For this reason the reactor is surrounded on all six sides with a shield approximately five feet thick.

The innermost portion of the shield is a layer of iron about 10-1/2 inches thick called the "thermal" shield. The thermal shield absorbs 97 to 98 per cent of the energy emerging from the reflector; therefore, its cooling system is very effective in removing the bulk of the heat generated within the entire shield. The heat energy generated in the thermal shield is mostly from gamma radiation absorbed in the cast iron; this gamma radiation comes both from the reactor core and from that "born" in the shield in the thermal neutron absorption reaction.

Figure 3-12 indicates the box-like coverage of the stack made by the thermal shield. This layer is built of iron blocks which overlap at the edges to eliminate straight through beams which could result in localized hot spots within the biological shield. Water is circulated through tubes imbedded in the thermal shield in the top, bottom, near and far sides of the reactor for the purpose of removing the heat. The front and rear shields are cooled by the water flowing through the process tubes which pierce these shields. The radiation which emerges from the thermal shield consists of roughly equal numbers of fast neutrons and gamma photons, plus a small amount of thermal neutrons; most of the gamma photons emerging from the thermal shield have been "born" within it.

FIGURE 3-12

Thermal and Biological Shields and
Reactor Atmosphere Circulation

The thermal shield, therefore, acts as a sort of filter which strains out the thermal neutrons and most of the pile gammas, and so prevents overheating of the biological shield.

H. Biological Shield

In order to bring the level of radiation outside the reactor down to a low enough level to permit people to work around its sides, an additional layer several feet thick, called the "biological" shield is constructed. This biological layer must perform several functions: absorb gamma radiation, slow down fast neutrons, and capture slow neutrons. In order to be most effective for performing these functions, the biological shield must contain both high-density and low-density materials - high-density for absorbing gamma radiation, for performing inelastic scattering of fast neutrons to slow them to the intermediate range, and for capturing thermal neutrons; and low-density for efficiently "thermalizing" intermediate energy neutrons by elastic collision so that they can be captured within the shield.

This combination of shielding materials has been supplied in the older reactors by a four foot laminated structure of iron and masonite, alternately in layers respectively 3-3/4 inches and 4-1/2 inches thick. The biological shields in the K Reactors and in the top of C Pile are made of concrete. The iron ore used as the aggregate provides the high density component, whereas water of hydration in the concrete provides the low density material.

Although only a small amount of heat is released in the biological shield, it is enough to be troublesome if cooling is not provided. This is the case at the older reactors where maximum shield temperatures are sufficient to cause masonite deterioration.

At the working faces of the older reactor, the shield is built up of blocks. Each block is a cube about four feet on a side which supports the "gunbarrels" and associated fittings for cooling water tubes. The edges of these blocks are fitted together by tongue-and-groove joints to prevent the direct escape of radiation from the thermal shield to the operating

areas. At the edges and corners of the pile, the laminations form a series of lap joints to block direct escape (See Figure 3-12). The K Pile front and rear gunbarrels were fitted into massive crates approximately five feet high and extending from one side of the reactor to the other. The steel walls of the crates provided the form for pouring of the concrete.

Framework for the side and top shields in the older reactors consisted of giant beams called "T" flange plates placed approximately four feet apart. Masonite and iron layers were simply placed between the stem plates and the iron layers tack welded. The iron plates used came in assorted widths of 1-7/8 inch plate. These plates were tack welded to each other as well as to the stem plates. This construction is illustrated in Figure 3-13.

At the base of the reactor the thermal shield rests directly on the concrete foundation of the reactor structure, so that no biological shield is needed there. The face and side laminated shields extend down into the concrete foundation to form a skirt which prevents leakage of radiation through the concrete. The bottom thermal shield is leveled off to form an accurate base for laying the graphite blocks. The entire biological shield is encased in a welded steel box which serves to confine the reactor gas atmosphere. At the working faces of the pile this box forms the tube sheet. The base of the box is a steel sealing membrane imbedded in the concrete foundation.

The top and side biological shields at the B, D, DR, F, and H reactors are uncooled. The inner surfaces of the top and side biological shields at C Reactor are cooled by circulating water. The K Reactors have complete biological cooling on the sides and top plus foundation cooling. The foundation cooling is provided at the K Reactors in order to prevent excessive temperature differentials in the concrete foundation immediately below the steel membrane. A cross section of the thermal and biological shields is shown in Figure 3-14. The sketch also illustrates the gunbarrel assembly.

SECRET

"T" Flange Plates
(2 1/2" thick Steel)

3 3/4" thick Steel Layers
Made up of two 1 7/8" Steel Plates

4 1/2" thick Masonite
Layers Made up of 1 1/8" Sheet of High Density Masonite

FIGURE 3-13

Iron-Masonite Arrangement of Biological Shield at Older Reactors
(Side and Top Shields)

FIGURE 3-14

Typical Gunbarrel Assembly

I. Reactor Atmosphere

The reactor atmosphere serves two main functions, (1) to provide a heat transfer medium, and (2) to keep the reactor moderator free of undesirable impurities such as water and air. The earth's atmosphere contains, among other things, 78 per cent nitrogen and 21 per cent oxygen. Since nitrogen is an effective absorber of neutrons and oxygen contributes to graphite burnout, all voids inside the reactor are filled with some other gas. Helium and carbon dioxide were chosen because of their chemical inertness, low neutron capture cross sections, and desirable heat transfer characteristics. Helium is completely inert chemically and is a very good conductor of heat, whereas carbon dioxide causes oxidation at high graphite temperatures but is useful at low temperatures because it is a poor heat conductor.

The mixture of helium and carbon dioxide (reactor atmosphere) is sealed in by providing a continuous membrane of welded steel over all surfaces of the reactor, including its biological shielding. Expansion joints are provided at the edges and at the joints between the front and rear membrane and at the gunbarrels that carry the aluminum process tubes. This reactor atmosphere permits a relatively rapid transfer of the heat generated in the graphite across the spaces between blocks and to the process tubes.

The reactor atmosphere is circulated through the pile at a rate of about 2500 cu ft/min by means of turbo-blowers. About half of this volume flows through the channels formed by the champered edges of the graphite blocks of the pile (See insert - Figure 3-12), and the remainder flows through spaces around the side, top and base thermal shields. The continued circulation of the gas atmosphere in the reactor serves to maintain a uniform gas composition, thereby helping to eliminate hot spots that might develop should masses of gas of low thermal conductivity blanket certain energy absorbing portions of the structure. In order to avoid bringing the gas in and out through the biological shield, a large duct enters the reactor through the pile foundation. The gas is distributed along the charging face of the reactor by means of a horizontal manifold, opening into a four inch wide plenum chamber between

the front thermal and biological shield. It passes through the offset spaces of the thermal shield blocks and then through channels in the graphite, or around the pile in contact with the side, top and base thermal shielding, and then through the rear thermal shields into a rear four inch wide plenum. From the rear plenum chamber, the gas flows down into a collecting manifold in the foundation and out through a return duct to the turbo-blowers. The path of the gas through the reactor is shown in Figure 3-12. The gas leaving the reactor is passed through a silica gel tower where excess moisture is removed, then through a filter to remove such impurities as graphite dust, metal particles, and silica gel which could be entrained in the gas stream.

In order to detect leakage of water into the graphite, the moisture content of the gas returning from the reactor is monitored continuously. A special thermal conductivity type of recording gas analyzer is provided for this purpose. To aid in locating the water leak, the current of gas is divided into streams corresponding to certain sections of the reactor. For this purpose the discharge plenum is divided into ten vertical channels, in each of which there are ten gas sampling tubes with their open ends spaced evenly from top to bottom of the reactor.

The graphite temperature at a given power level may be varied by changing the gas composition. The graphite temperatures are adjusted to produce just the right balance between graphite radiation damage which is annealed out at high temperatures and graphite burnout which is speeded up at high temperatures. The change in graphite temperature results in a change in reactivity of the reactor, thus introducing a control variable which may either be an operating problem or another control tool.

J. Reactivity Control Systems

Although such a structure as we have described would serve to carry on the chain reaction and produce plutonium, it would be uncontrolled and if all its parts were not in perfect balance, it would get hotter and hotter and perhaps end in a blaze of self-destruction. Like all other devices for the conversion of energy, such as a steam boiler or an internal combustion

~~SECRET~~

~~SECRET~~

-36-

HW-51856 CH3

engine, a nuclear reactor must have a suitable control system, the purpose of which is to provide smooth and steady operation under the circumstances for which the device was designed. Methods must be available for starting the reactor, for bringing the power output to the desired level, to maintain it at that level, and then to shut down the reactor when necessary. In addition, as with other energy converters, safety devices must be provided to prevent damage in case of an accident.

In order to maintain control of the nuclear reaction it is necessary that neutron absorbing material (poison) be introduced into the reactor in sufficient amounts to compensate for the excess reactivity. Furthermore, the amount of poison in the reactor must be constantly varied in order to adjust for changes in the neutron multiplication factor of the reactor caused by temperature changes, by variations in the amount of fission product poisoning (principally xenon), by uranium-235 burnout, and by the conversion of uranium-238 into plutonium.

At Hanford the following methods are used to control the reactivity of each reactor: (1) horizontal control rods (operating control), (2) vertical safety rods (fast safety control), and (3) the ball 3X system (backup safety control). A fourth method, the PCCF (poison column control facility) provides for the continuous charge and discharge of poison during reactor operation. Two additional systems, the "Poison Spline" system, and a final emergency "Boron Trifluoride Injection" system are being investigated at the present time. Control of the composition of the reactor atmosphere, mentioned in the last section, provides an additional means of varying the reactivity of the reactor at a slow rate.

K. Horizontal Control Rods

For the chain reaction in a pile to keep going, the production of neutrons must equal the leakage plus the absorption of neutrons. If it is desired to control or to change the production of neutrons in a graphite-moderator type pile, there are the two choices of manipulating either the leakage or the absorption. To change the leakage one might mechanically put a hole or a window in the reflector to permit the escape of neutrons or

~~SECRET~~

one might change the moderator level in a liquid moderated reactor. Changing the multiplication factor by absorption is the more practical method in a Hanford pile; control rods containing cadmium, boron or other high neutron cross section materials may be used to absorb neutrons from the reaction. It will be recalled that a multiplication factor k greater than one must be built into the reactor and then some of the reactivity removed by inserting control rods (poison) partially into the reactor to obtain critical operation at the desired operating level.

At Hanford each reactor is provided with horizontal control rods for the control of reactivity (and power level) during normal operation. This is accomplished by pushing into or withdrawing from the reactor a rod containing sintered aluminum and boron-carbide rings. This extruded aluminum rod, which is about 75 feet long, comprises two sections, each approximately one-half the total length of the rod.

Only the front half or tip section of the rod enters the reactor. The essential parts of this section are:

1. The neutron absorbing elements consisting of sintered aluminum and boron-carbide rings. (C Area an exception as illustrated in Figure 3-15.)
2. Tubes through which water is forced at the rate of about 10 gallons per minute in order to carry away the heat generated in the rod.
3. The outer aluminum casing that gives rigidity to the structure.

The rear section is primarily a mechanical linkage between the section of the rod that enters the pile and the drive and water supply. It consists of a continuation of the water tubes and supporting structure and a rack that engages the pinion of the driving mechanism (Figure 3-15).

In order that the reactor may be adequately controlled it is necessary that provision be made to neutralize a considerable amount of excess k . If a single control rod were used to compensate for the entire amount, it would have to be extremely large in diameter, and it would cause severe flux distortion.

SCHEMATIC DIAGRAM OF HORIZONTAL CONTROL ROD & DRIVE MECHANISM - C REACTOR

FIGURE 3-15

CONFIDENTIAL

-38-

HW-51856 CH3

By using nine or more rods instead of one and spacing them as shown in Figure 3-16, more satisfactory reactivity and temperature control may be obtained with much smaller rods. The horizontal control rods are inserted at the left side of each reactor as viewed from the charging face, and are spaced approximately five feet apart on a grid pattern. A special silicone rubber seal at the steel membrane surrounding the shielding prevents the escape of the reactor atmosphere. The aluminum metal in the control rods becomes radioactive when exposed to the pile neutrons. As long as the rods are inside the reactor, the radiation emitted from the activated aluminum is absorbed by the pile components, but when the rods are withdrawn they may emit on the order of 10,000 R/hr (exact figure depends on when withdrawn vs. when shut down, etc.) Shielding from this intense radiation immediately after it is withdrawn from the reactor is obtained through the use of extra thick walls for the room surrounding these rods (inner rod room).

At four of the Hanford reactors (B, D, F, and DR) the operating control consists of nine horizontal control rods, having a total capacity of about 600 inhours of reactivity control for natural uranium loading. Two of the rods are electrically driven and not connected into the emergency shutdown circuit; i. e., the "scram circuit". These rods can be driven either forward or reverse, at either of two speeds: 1.0 inch per second, or 0.01 inch per second. The other seven rods in the system are driven by hydraulic motors. For normal operation the oil pressure is supplied by electric-motor driven pumps, and drives the rods at a speed of about 3.0 inches per second. For emergency operation pressure is supplied by three "hydraulic accumulators", which consist of large weights resting on pistons closing cylinders filled with oil. The weights, falling under the force of gravity, will drive all seven rods into the reactor at a speed of about thirty inches per second. The time for complete emergency insertion would be about 20 seconds.

AEC-GE RICHLAND, WASH.

CONTROL & SAFETY ROD LOCATION C REACTOR

45 SAFETY ROD
OPENINGS

15 CONTROL ROD
OPENINGS

GRAPHITE STACK
FIGURE 3-16

At two of the Hanford reactors, C and H, the operating controls consist of fifteen electrically driven horizontal control rods having a total capacity of about 900 inhours of reactivity control. These rods can be driven into or removed from the reactor at speeds varying continuously from 0.01 inch per second to 8.0 inches per second for normal operation; for emergency operation the rods are driven into the reactor at a speed of about 80 inches per second, requiring about 8 seconds for complete insertion. Standby electric power is supplied by batteries.

The other two reactors at Hanford (KE and KW) are each equipped with twenty electrically driven horizontal control rods having a total capacity of about 900 inhours of reactivity control. These rods can be either driven forward or reverse at speeds varying continuously from 0.1 inch per second to 7.0 inches per second for normal operation. For emergency operation the speed remains at 7.0 inches per second, requiring about 60 seconds for complete insertion. Standby electric power is supplied by batteries.

The horizontal control rod system at each of the reactors is equipped with two or more control rods known as "half-rods". The half-rod, as the name implies, contains poison material in the end or "tip" half section, the near half of the rod being comparatively free of poison material. If the rods normally used for controlling the neutron flux on the far side of the reactor have no poison material on the near end of the rod it should be possible to very nearly balance the equilibrium horizontal temperature distribution with the horizontal control rod system alone. This permits more symmetrical flattening patterns and therefore more symmetrical discharge patterns with resultant production gains.

The number of modified half-rods in each system varies from two in a nine-rod system to as many as five in a fifteen-rod pattern.

L. Vertical Safety Rods

Each reactor is provided with a vertical safety rod system to hold the reactor subcritical during shutdown and to stop the nuclear reaction quickly in emergency conditions.

For the first few minutes following a reactor shutdown from normal operating conditions, extensive poisoning from the rod systems is necessary to offset the reactivity gain which accompanies the reduction of temperature in the uranium metal. After about an hour, reactivity losses due to cooling graphite moderator and fission product poison buildup (xenon) depress the nuclear activity until the reactor would remain subcritical even though all the rods were withdrawn. For approximately twenty-four hours this condition continues, after which time the poisons have decayed sufficiently to again permit the reactor to attain criticality if the rods are withdrawn. From this point on, increasing control is necessary as poisons continue to decay and reactivity improves. To ensure that the reactor remains subcritical, sufficient control must be available to offset these normal shutdown reactivity transients and also the large reactivity gains that would occur in case of complete loss of water and complete poison decay.

The vertical safety rod system is provided primarily to shut down the reactor upon indication of potential threat to coolant continuity or adequacy of control. Continuation of the operation at full level could damage or aggravate damage to the reactor in case of overheating, and reactivity gained from water boilout could lead to a power level excursion with disastrous results. Therefore, arrays of vertical safety rods have been so placed above the reactor that they can be dropped into the pile in 2 to 2-1/2 seconds after the emergency signal has been given. These safety rods contain enough poison material and are spaced in such a manner that they will shut down the reactor quickly and hold it subcritical until remedial action can be taken. The B, D, DR, and F piles have 29 vertical rods, C and H piles have 45, and the K's have 41 with provisions underway to supply six more VSR's at each of the K's.

The vertical safety rods in the four older piles consist of boron steel tubes thirty-five feet long, with radiation shielding plugs in each end. They are suspended above the reactor with the lower end of the rod coinciding with the bottom face of the top thermal shield; the rod can be raised and

lowered without changing the point of effective support of the rod with reference to the opening in the reactor. These tubes fall under the force of gravity into vertical channels provided in the graphite and shielding of the reactor, requiring about 2.5 seconds following mechanical release to fall completely into the reactor. Silicone rubber seals prevent escape of the reactor atmosphere. Automatic control instruments are provided to release the vertical safety rods in the event that (1) the power level exceeds a predetermined level, (2) two seismoscope needles swing beyond predetermined limits, (3) the cooling water pressure in any process channel or in the front riser varies beyond predetermined limits, (4) electric power fails, or (5) failure of critical instrumentation occurs. The safety rods may also be tripped manually from the control room. Dual reactors are interconnected so that scrambling caused by a dual indicating level trip in one reactor also scrams the other.

The locations of the vertical safety rod openings in the graphite are shown in Figure 3-16. The general orientation with respect to other components of the reactor is shown in Figure 3-6.

M. Ball 3X System

There is always a chance the reactor may shift or that other events may take place to prevent the desired number of vertical safety rods from entering the pile at the time of impending water failure. The possible consequences of such failure justify the use of another safeguard which acts even though the reactor has shifted. The ball 3X system is provided at each reactor as a substitute for vertical safety rods should any of them fail to enter the reactor properly, and to supplement the safety rods to a small degree should the reactivity requirements exceed the total capacity of these rods.

A ball 3X hopper is provided for each vertical safety rod, twenty-nine at the older reactors, forty-five and fifty-one respectively at the newer piles. The storage containers (hoppers) are so placed above the safety rod channel that they can feed 3/8 or 7/16 inch diameter boron-steel balls into the graphite, completely filling the channel in about sixteen seconds. The balls fall under the force of gravity when tripped automatically

by process water failure, or manually from the control room. At the older reactors the ball 3X hoppers are located on top of the pile, outside the biological shield; at the newer reactors the hoppers are imbedded in the biological shield as shown in Figure 3-17.

The ball 3X system has a slightly greater total capacity for reactivity control than does the vertical safety rod system when the balls are used in place of the safety rods. Should the vertical safety rods fail to enter the reactor, the ball 3X system will serve to hold the reactor subcritical under all normal conditions and to produce a rapid reduction in the reactivity level when an emergency requires immediate shutdown; however the ball 3X system speed of control is not equivalent to that of the VSR's.

N. Process Water System

About 94 per cent of the heat generated in a Hanford reactor is generated by the fission process within the uranium fuel element. This heat must be transferred by conduction to the surface of the uranium, through the slug jacket and into the cooling water, whence it is removed from the reactor with the water. Both the aluminum process tubes, and the aluminum jackets which isolates the uranium fuel slug from the cooling water are subject to corrosion in the reactor. The rate of corrosion is determined primarily by impurities in the water and by the temperature of the water. The water must have a minimum corrosive action on the aluminum tubes, and must not leave scale nor other deposits on the tubes or jackets which would tend to reduce the extremely high heat transfer rates required. Although the Columbia River water is high in purity, some treatment is required to make it conform to these very stringent requirements. The temperature of the inlet water should also be as low as possible the year around so as to give maximum cooling. This requirement is reasonably well fulfilled since the average temperature of the river water the year around is about 12° C.

SCHEMATIC DIAGRAM OF BALL 3X SYSTEM C-REACTOR

FIGURE 3-17

CONFIDENTIAL

CONFIDENTIAL

The operating capacity of a Hanford reactor is limited by the rate at which the heat developed within the pile can be removed. Consequently, in order to obtain the maximum production rate it is necessary to pass the cooling water through the reactor at the highest permissible rate and at the same time to obtain a maximum temperature rise in the water. The total amount of water available to each reactor is limited only by the water plant pumping capacity; however, a limitation does exist on the amount of water which can be passed through any single process tube. This results from the fact that the rate of flow is directly proportional to the pressure drop across the tube. The maximum sustained pressure in the aluminum process tubes must be limited to eliminate the possibility of slow expansion of the tube.

The amount of heat removed by the water in its passage through a process tube is directly proportional to its temperature change. The inlet temperature is determined by the Columbia River; the limitation on the temperature of the outlet water is necessary to prevent boiling within the process tube and in the effluent piping and to avoid harmful corrosion of the aluminum cooling tubes and the jackets of the fuel slugs.

Corrosion of the cooling tubes is objectionable because such action could eventually cause a tube leak. This would permit water to enter the graphite block with a resultant loss in multiplication factor. Corrosion of the slug jackets to a point where a slug jacket leak occurs would permit the highly radioactive fission products in the metal to enter the water stream. Entrance of water into the jacket would also result in chemical action between the water and the metal. Because the reaction product is of lower density than the metal itself, the slug would expand with consequent harmful effects on the flow rate through the tube and difficulty in removal of the swollen slug.

The supply, treatment, distribution and final disposal of 75,000 to 150,000 gpm of water per reactor requires extensive equipment. That this is a very considerable amount of water may be readily understood by

comparing it with that of a municipal supply of treated water. For example, the year-round average consumption for a city population of 125,000 is about 15,000 gpm. The distribution and control of the flow and pressure to 2,000 or 3,000 individual tubes is in itself a complicated problem, particularly when the importance of keeping the flow and temperature in each tube within definite operating limits is considered. Another complication is added by the fact that the water becomes somewhat radioactive in passing through the reactor, so that the exit water lines must be shielded to protect operating personnel.

The raw water is pumped from the river to a large storage basin where certain chemicals are added, then through a filter plant for chlorination, coagulation, dechlorination, and gravity filtration through sand beds. Another set of large storage tanks receive the water from the clear wells of the filter plant; from these storage tanks the water flows to the process pumps where it is brought up to operating pressure. The lines from the process pumps are connected to each end of two horizontal headers, from the ends of which a riser runs up each side of the charging face of the reactor. Four inch cross-headers pass across the face of the pile between the vertical risers and distribute water to the individual cooling tubes. The cooling tubes in the reactor are connected to the crossheader by means of a flexible pigtail. These lead to special fittings on the ends of the process cooling tubes. (See Figure 3-5.) In addition to fine mesh strainers located at both ends of the crossheaders, a strainer for each tube is provided in the inlet fitting. The fitting is also equipped with a throttling device (venturi-orifice) the size of which may be varied to permit the greater flow of water through the tubes where the greatest heat is generated. The water flows through the annular space between the slug and the process tube at high velocity to the discharge system.

The rear system of pipes which collect the water discharged from the process tubes is quite similar to the inlet piping. Each inlet crossheader has a corresponding crossheader at the same elevation on the discharge face connected to the same row of tubes. The discharge crossheaders are connected

at both ends to a vertical stand-pipe (rear riser) at each side of the reactor. The vertical stand-pipes are connected at the top of the reactor by a horizontal pipe of the same diameter. The discharged water overflows from the horizontal connector into a "downcomer" from which it flows to the retention basins, prior to discharge into the Columbia river. The flow of water through the retention basins is controlled to provide time for the decay of the activity which the water has acquired in its passage through the reactor. A schematic diagram of a representative Hanford reactor cooling system is shown in Figure 3-18.

In addition to supplying water of high quality, it is necessary to ensure a continuous supply to the reactor under all possible emergency conditions. For this reason a network of interconnecting lines, various bypasses, and special standby facilities have been provided at each reactor. Cooling water backup is provided at each reactor by one or more of the following facilities; (1) multiple pumping units with electrical primary power, and steam standby power, (2) multiple storage tanks, some of which are capable of supplying cooling water to the reactors by gravity flow, (3) multiple pipe lines within each reactor, and (4) pipe lines interconnecting the reactor areas. The backup facilities have been designed to supply sufficient water to the reactor to limit the maximum tube outlet temperature to 90°C, which is below the operating limit, and to provide sufficient excess water pressure to suppress boiling within the process tube which might be started by a momentarily inadequate flow.

Any condition which interferes with the continuous supply of water to a reactor requires that the pile be shut down as rapidly as possible. Furthermore, it is necessary to provide an emergency supply of water to remove the heat which continues to be generated after shutdown.

SECRET

SCHEMATIC PROFILE OF C-REACTOR COOLING SYSTEM

FIGURE 3-18

SECRET

III. INSTRUMENTATION FUNDAMENTALS AND REQUIREMENTS

A. Introduction

It is imperative that operation of the Hanford reactors be maintained constantly at the peak of efficiency and safety, in order to produce a maximum amount of product in a minimum of time. For this reason, and the fact that the process requires remote operation, a large amount of instrumentation must be provided.

The Hanford reactor instrumentation may be classified according to function into two general groups: (a) power level measurements and control, and (b) auxiliary measurements and monitoring systems. The most important reason for measuring the power level is to keep it within safe operating limits. In addition, power level measurement is important because the power level is directly proportional to the rate of product formation; therefore, the amount of product in the metal at any time (necessary in scheduling discharge dates) can be calculated from the time-integrated power. The auxiliary measurements and monitoring systems include methods and controls designed to give supplementary information regarding the reactor performance and to ensure that no conditions exist which might damage the reactor or endanger personnel. Examples of this second group are radiation levels and miscellaneous pressure and temperature measurements not directly associated with a limiting condition.

As stated previously, the average neutron lifetime in a Hanford reactor is on the order of a thousandth of a second (0.001 sec) from the time of ejection until it is absorbed. This means that a thousand generations of neutrons could be generated in a reactor within one second. Although the delayed neutron effect changes the average time of a neutron generation from one-thousandth of a second to about one-tenth of a second, any mishap or set of circumstances which would permit an excess of reactivity greater than the delayed neutron effect would cause the reactor level to increase at a rate associated with the one-thousandth second lifetime. Such a fast rate of rise is known as "prompt" critical and is extremely hazardous. An extremely fast rising period, if allowed to continue without control would soon exceed

the rate of heat removal by the cooling water, and melting of the fuel elements could result. Therefore, it is imperative that fast responding instrumentation be provided for maintaining strict control over the nuclear reaction rate at all times.

The neutron flux at any point throughout the reactor is proportional to the local fission rate and hence also to the local power generation rate. Neutron monitoring devices have an almost instantaneous response and are particularly suitable for indicating changing power levels and for operating automatic control and safety mechanisms. Instruments that measure neutron flux can be located at many points throughout the reactor system in order to provide representative readings.

Loss of cooling water to the reactor while at operating levels or within hours after shutting down from operating levels would cause the fuel elements to melt, resulting in the release of radioactive fission products to the surrounding area. The determining factor is the rate of heat removal from the reactor. If the temperature of the reactor is to be maintained within safe operating limits, the heat produced by the fission process must be removed at the same rate as it is being generated. Thus, the primary functions of the instrumentation system at Hanford are to maintain strict control over the nuclear reaction and to shut down the reactor upon indication of insufficient flow of process water.

Each Hanford reactor is equipped with automatic shutdown systems which stop the pile reaction in the event of certain types of abnormal behavior. Any operating circumstance which allows excessive power levels, which does not permit adequate removal of heat, or which endangers the operation of the control system is considered dangerous, and the reactor must be shut down until the condition is corrected.

The mechanisms, instruments, and methods used to maintain both control and adequate cooling will be discussed in this chapter.

B. Detection of Flux

1. Fundamental Methods

There are several ways or means of detecting and measuring the nuclear reaction rates and how they change with time. The most direct method of measuring the power level of a reactor is to determine the quantity of heat transferred to the cooling water. This method has two disadvantages, (1) the information is slow, and (2) at low levels there is no appreciable temperature rise to measure. When any change in the reaction rate becomes great enough, the temperature change of the coolant can be used to calculate the change in power level. But the temperature rise may lag the neutron reactions which caused the heating by several seconds. This would permit an extremely fast rising period before the rate of rise could be calculated. Thus, the requirements of satisfactory reactor control are such that it is necessary to have available a method for controlling the reactor power level which will respond much faster than the several seconds required for coolant measurement.

It is quite evident at this point that the total power coming from the reactor consists of the sum of all the energies generated in the fission reaction. As stated previously, over 90 per cent of the total energy comes from the direct fission process and less than 10 per cent by indirect beta and gamma radiations; therefore, it appears that neutrons from the fission process would provide an excellent means of measuring the nuclear reaction rate. Furthermore, the beta and gamma energy does not directly follow the fission energy, but may come from rather long-lived decay activities. From the above, we can assume that the power level of a reactor is proportional to the number of neutrons present in the active core of the reactor. Under certain circumstances following sudden power level changes, this relationship between neutrons and power may be much more complex, but for most purposes it is essentially correct.

2. Neutron-Sensitive Chambers

The measurement problem then is count the number of neutrons at some point. But the neutrons are difficult to detect because they are electrically neutral and do not signal their presence in any direct way.

However, when neutrons are absorbed in boron, this reaction gives off an electrically charged particle (an alpha particle) which can be used to indicate the neutron density. If the boron is used in a chamber whose center forms one electrode and whose walls form another electrode of an external circuit, this charged particle reaction acts as a rheostat to let current flow through the exterior circuit. Such a device is known as an "ion chamber". An ion chamber contains a volume of gas (generally argon) and two or more electrodes. Inside an ion chamber for measuring neutrons, the electrode surfaces are coated with a boron compound. Neutrons striking the boron are captured and cause alpha particles to be ejected into the gas-filled space between the electrodes. These alpha particles produce a large number of charged gas fragments, called ions, which are attracted to the electrode of opposite charge. The electric current mentioned above is the result. When this current is amplified, it can be recorded and made to control various mechanisms. Thus, by watching a meter which indicates electrical current, the relative neutron population inside the reactor can be accurately monitored.

This type of ion chamber is used at the Hanford reactor in the Beckman, galvanometer, and octant monitor systems. A schematic sketch illustrating the rheostat analogy is shown in Figure 3-19.

During the reactor startup, extremely low reactor power levels must be monitored continuously so that dangerously fast periods may be detected in time for corrective action to take place before high power levels are reached. At low levels a method must be available whereby individual neutrons can be detected and counted in order to determine the rate of rise. This is presently accomplished at Hanford through the use of a BF_3 (boron trifluoride) proportional counter. The counter consists of a metal cylinder about eight inches long with a small diameter electrode suspended centrally within the cylinder. The cylinder is filled with BF_3 gas, which is in turn ionized (charged) by the alpha particle emitted in the reaction $\text{B}^{10}(\text{n}, \alpha)\text{Li}^7$ caused by radiation striking the counter tube. The ionization from the recoil alpha particles is accelerated toward the central electrode by the

Galvanometer - Beckman Analogy

BF_3 Pulse Chamber Analogy

FIGURE 3-19

electric field in the counter tube. The sum total of this ionization collected at the center electrode causes a voltage pulse to appear across a load resistor. The rate at which these pulses appear is proportional to the neutron flux level in which the counter is placed. Thus, the BF_3 counter is capable of emitting an electrical pulse for each neutron or gamma ray that enters it, in much the same manner as the telegraph buzzer sounds each time the key is depressed and closes the circuit. The reactions are such that neutron-induced pulses are considerably larger than those resulting from gamma rays, and amplifiers are so arranged that the larger neutron pulses are accepted and passed on to a scaler while the gamma pulses are rejected.

This type of pulse chamber is used in the proportional counter system at the Hanford reactors.

A schematic sketch illustrating the telegraph key analogy is shown in Figure 3-19.

a. Fission Counter

The fission counter is also a proportional counter chamber, but U-235 is used as the coating material in place of boron, and the more highly charged fission particles cause the ionization which results in electrical pulses in place of alpha particles in the BF_3 chamber. The more energetic pulses make possible a wider discrimination against background events caused by gamma activity and circuit "noise".

3. Flux Range

From the shutdown level to full operating level, there are many factors of ten difference in magnitude; yet it is important that the level of neutron flux be known at all times. Since no instrument can give meaningful indications over such a wide range directly, special tricks have to be employed, such as providing shunts on the electrical circuitry, providing for movement of the chamber into or out of the high flux region, and providing several overlapping instruments to cover the required range.

a. Shutdown Flux

The neutron activity during a reactor outage is called the "background" flux, and is created by gamma radiation from poison products in the fuel elements. The gamma rays react with the natural deuterium in the cooling water resulting in the emission of a photoneutron, which the flux chambers monitor during the reactor shutdown. As the longer-lived fission products decay, the photoneutron counts drop to a more or less stable background flux. Some background flux is always present in a reactor several days after shutdown because of cosmic ray reaction with U-235 or Pu-239. It is this background flux which must be monitored during a startup in order to detect any sustained increase of neutron pulses above the background flux.

It is convenient to refer to flux levels in terms of the rate of heat generated by the fissions taking place. The customary background level at which a Hanford pile goes supercritical is of the order of a few watts, and that in the shutdown reactor with the safety rods all in is of the order of a few tenths of a watt.

b. Low Level Flux

The safe operation of a reactor requires that the neutron flux (or fission rate) be known over a very large range; for example, the flux may vary by a factor of 10^{10} or more between startup and full power level. This means that the full power flux may be 10,000,000,000 times greater than the shutdown flux (Figure 3-20). No single instrument can be used for satisfactory measurement of neutron flux over the whole range from shutdown flux to full power operation. Figure 3-20 indicates the range of neutron flux from shutdown to full power and ranges of instrument system in terms of watts of fission heating rate. The proportional counter system is used to detect the first indication of increase in neutron flux during the approach to critical in the one watt region. Until recently the neutron counts accumulated during each successive thirty-second time interval were recorded and plotted; when several plotted points rose above the normal background counting rate, criticality could be detected and the rising pile period determined. Recently

FIGURE 3-20

Range of Neutron Level Shutdown to Full Power

installed period rate meters now automatically perform the period plotting function. Normal criticality, as indicated in Figure 3-20 is initially observed in the 10 to 100 watt range. The proportional counter system range is limited to less than one-half megawatt; a second BF_3 counter may be located in a less active or more protected area to increase this range.

As mentioned before, the measurement of cooling water temperature to indicate power level is not practical at low power levels. As indicated in the graph, the minimum measure of heat production occurs in the region of 10^6 watts, or one megawatt. At the newer reactors with high cooling water flow rates, one megawatt of power is represented by a small fraction of one degree temperature rise. This minute temperature change, plus the normal lag in temperature instrumentation, prohibits the use of coolant temperature rise as an accurate indicator of power level during startup. For this reason fast-operating neutron-sensitive chambers are used to initiate an automatic reactor shutdown whenever dangerously fast initial periods are encountered during startup.

c. Intermediate Range

For accurate pile period data, the pulse-type BF_3 chamber is limited to a maximum number of counts in the region of 10^3 or 10^4 per second. When the counts reach about 10,000 per second, the neutron flux is large enough to make possible the use of an integrating ionization chamber. Such a chamber will operate satisfactorily when the ion current corresponds to about 10,000 pulses per second at approximately the same point where the pulse chamber ceases to be effective. Since the number of ionizing events in the chamber is still relatively small, the accuracy and steadiness of the current will not at first be great, but both will improve with increasing neutron flux.

After the pile period has been established and the proportional counter range exceeded, the rise to operating level is controlled through the galvanometer system. In the intermediate power range, from about 10^{-3} of full power to the operating level, accuracy and sensitivity of instrumentation is important if the rise to full power is to be controlled. For this reason,

ionization chambers are used, but instead of providing period data, the ion current, after necessary linear amplification, is displayed directly on a galvanometer or microammeter (Beckman); these instrument indications may be calculated for power level during steady operation when temperature indications accurately measure heat generation rates. The power level is allowed to increase at a controlled rate, then the increase is halted and the power maintained at the desired level.

d. High Level Range

At low levels, the importance of instrumentation is in detecting that the level is changing and at what rate. Absolute magnitudes are not so important as warning sensitivity and speed of response sufficient to effect action before limiting conditions are reached.

At high operating levels, however, the problem is somewhat different. Because of strong production incentives to operate near limits, only a slight relative change may cause limits to be exceeded, and this slight change could take place as the result of a drift in level rather than a fast compounding rate. Since limits are associated largely with heat generation rates in individual tubes, the most applicable monitoring indication is that of outlet temperature on each tube.

Tube power limits are, of course, also directly dependent upon the available flow. Therefore, the flow through each tube must be known to be sufficient at all times; this is accomplished in the Hanford reactors by trip limits imposed on the Panellit pressure gauge supplied for each tube. If limits are exceeded sufficiently that tube flow stability is threatened, the gauge of the tube first reaching this condition will trip the safety system.

It is desirable to have full-time automatic protection from both the temperature and pressure monitoring systems. Operating efficiency and instrument development limitations have not permitted this in the case of temperature monitoring in the past, but it is scheduled for future improvement.

4. Reactor Geometry Effects

a. Distortions

The neutron flux distribution in a Hanford reactor is not a constant but varies with time, temperature, and position in the core. In order to determine power level directly by neutron count, it is necessary to measure continuously the average flux over the entire active portion of the reactor. The neutron flux at any point is proportional to the fission rate and to the heat generation rate in the region where the flux is measured. In other words, a single neutron detector placed at a particular point in the reactor indicates only the neutron flux (local power) in its immediate vicinity, but does not necessarily give a good idea of the average power level as a whole. The flux in the immediate region of the detector may be grossly distorted because of rod movement, poison or enrichment columns, water leaks, or reactor cycling.

Measurement of the average neutron flux in a reactor can be accomplished in two ways. First, a number of neutron detectors can be evenly spaced about the reactor core and an average taken of their readings. Second, a single detector might be placed so far from the reactor core that the core may be considered a point source of neutrons and local flux distortions of little significance. The first method is used in the octant monitoring system, the second ideally, but not without distortion effects, in the Beckman system. At the present time, however, each system performs a different function. The octant monitoring system is used primarily for operating control; the Beckman system for neutron flux level trips. Ultimately, however, it would be desirable to have flux trips provided by an octant system also. In both cases, fast acting neutron counters are presently the primary automatic control element, rather than cooling water temperature changes.

b. Instrument Shielding

The problem of measuring a given fixed fraction of reactor neutrons is solved by placing ion chambers a certain distance from the active portion of the reactor so that sensitivity and range of the chambers will provide

accurate data at the desired power levels. The reactor core is then considered a point source of neutrons and local neutron flux is assumed proportional to the entire core flux or power.

Since one of the functions of the pile shielding is the capture of neutrons, the number of neutrons present in the inner portion of the shield adjacent to the active core must be considerably greater than the number of neutrons at the outer or surface portion. The under-pile shielding has a similar effect on neutrons. By moving a PC chamber toward the reactor core, the chamber will count a greater number of pulses; withdrawing the chamber into a low flux region will reduce the number of counts. The relative flux regions encountered as the chambers are positioned in the shield are shown in Figure 3-21. The sketch shows the position of the under-pile chamber at approximately six inches from the outside surface of the shield in a 10^3 region of relative flux. Test hole chambers are shown at three feet, in a field of 10^4 to 10^6 . Three positions are shown for the multiple PC system, one at four feet for greater sensitivity, the other two in lower flux regions for greater range and higher power levels. The subcritical fission chamber, now under development is shown as capable of monitoring the neutron flux from full shutdown to operating levels as it is withdrawn and inserted during changes in level.

The fact that there are so many orders of magnitude of change in flux level through the shield is an advantage in that some workable location may be found for most instruments regardless of their limited sensitivity or range.

C. Instrumentation Requirements and Partial Reliance on Procedure

The previous section dealt largely with methods of monitoring indications of power level and power level changes. This section discusses the ways in which this monitoring information is or could be depended upon, either through procedure or by automatic trips, to ensure safe operation. This section is in three parts - the first discusses reactor safety requirements, the second points out dependence upon operating procedures, and the third portrays by way of charts the various requirements and ways in which they may be met.

~~SECRET~~

-62-

HW-51856 CH3

FIGURE 3-21

Neutron Distribution Through Shield

~~SECRET~~

1. Reactor Safety Requirements

Any large-scale release of radioactive fission products would be considered a major "disaster" on a Hanford plant. Such a reactor disaster can occur only if the fuel elements melt. There are two ways in which slugs may be melted:

- (1) An uncontrolled fast rising period. Without control of a fast rising period, the rate of heat generation would soon exceed the rate of heat removal and the melting of slugs would result.
- (2) If the water supply to the reactor were permanently cut off, the fuel elements would eventually melt. The time interval between loss of water and fuel melting may vary somewhat depending upon the reactivity status of the reactor and its previous operating level, but the end result would be the release of fission products.

Thus, the two most important factors of nuclear safety depend upon the complete control of the nuclear reaction rate at all times and the constant supply of cooling water to the reactor.

A cause and effect type of chart is shown in Table I. As indicated in the table, certain operating conditions are directly related to certain types of phenomena. Three degrees of events pertinent to safe operation are listed under the phenomenon column. The expected effect of each event is noted under the effect column. The magnitude and scope of each event is listed under the connotation column, and at the extreme right side is denoted the operating condition most likely to cause such an event to occur. The key to the operating conditions is shown at the top of the page. Water loss from mechanical failure or sabotage is not included in this discussion as nuclear instrumentation is not involved in its detection.

Table II illustrates the mode of protection recommended to prevent the occurrence of such events, both by operational procedure and by automatic shutdown instrumentation. Most of the protective measures recommended are now in use at Hanford; however, all reactors are not

fully equipped. For instance, subcritical monitoring is still in the prototype stage; all reactors are not equipped with low-level trips; rate of rise trips are non-existent; and neutron level trips are not representative of the whole volume of the reactor. However, these instrumentation systems are now under development and will be discussed later in this chapter.

Under the employed definition of reactor safety as the disaster condition involving fuel element melting, the reactor startup is the most worrisome part of reactor operation since the chance for excessive rates of rise is greatest in this case. Thus, rigid startup standards and procedures must be employed to make the ensuing rise in power within the limitations of the operator's reaction time; the time he has in which to react is increased as monitoring instruments are made more sensitive and faster responding. It is important that procedures also be backed up with automatic protection in case of human failure. For safety protection, an ideal instrumentation system would be capable of the following:

1. The information should be supplied continuously.
2. Monitors should operate on instantaneous flux.
3. There should be effectively no time delay between flux and data.
4. Instruments should cover the complete flux range, from subcritical to full power.
5. Systems should be mechanically simple and relatively trouble free.
6. Exposed components should be capable of withstanding intense radiation, and heat and humidity effects.

Many operating events short of water loss may result in severe damage to fuel elements and therefore may be costly. Protection against events of this severity is often by procedure only. Procedure is, therefore extremely important; its breakdown alone may result in costly damage, or its breakdown simultaneous with breakdown of automatic protection may lead to disastrous consequences.

2. Dependence on Operating Procedures

Existence of a safety system provided with automatic tripping devices implies that reliance on procedure is not important. This is far from the case. In many cases the ability of the safety circuit to perform its designed function is dependent upon procedure. For example, it is physically possible to operate without panellit protection by keeping this system bypassed following startup, although the procedure for taking this system off bypass is respected because the importance, or basis, of this requirement is understood and respected by the operating people.

It may be possible at some time in the future to have sufficiently sensitive instrumentation and enough interlocks to relax the present degree of reliance on procedure. In the meantime, nuclear process standards are based on the following criterion:

The reactor operation shall be carried out in such a manner that the operator has complete control of the reaction at all times.

Of course, procedure can break down, and that is when the safety system must be relied upon. But even the safety system reliability is dependent upon procedure in fabrication, maintenance, hookup, and testing of its components.

As pointed out previously, reactor startup presents the largest possibilities for nuclear accidents of any normal phase of operation. The following paragraphs illustrate the current dependence upon procedure at Hanford.

The first thing that must be known is the reactivity status of the pile. Without subcritical monitoring, this is done by a physicist's calculation (prediction chart) - a procedure. Even if subcritical monitoring is available, procedure must be relied upon for interpretation of the readings.

Rod withdrawal is carried out at a slower rate than is physically possible - again a procedure. Safety circuits have been made up, and trip settings have been made on the appropriate ranges - by procedure.

~~SECRET~~

-66-

HW-51856 CH3

The period has been plotted in the past; even with pile period meters, interpretation must be done by the operator to make sure his rate of rise is satisfactory. The operator must manually scram the pile - procedure - if the period is too fast in the pile not equipped with period trips in the safety circuit.

Range changing of the Beckmans is really a procedure for guarding against excessive rates of rise. Leveling out temporarily is a method of providing operator time for observing and evaluating temperature distributions and individual tube readings.

Operation within limits is entirely dependent upon procedure; trip limits are always somewhat higher than recommended limits. Flux distribution control may be aided considerably by better monitoring instruments, but its effectiveness depends upon the procedures of evaluating the data and of carrying out the proper action.

Tables I and II should be examined critically to determine the extent to which procedure is relied upon in many cases where at first glance one assumes automatic protection.

~~SECRET~~

3. Summary of Safety Protection Needs and MethodsTABLE IOPERATING CONDITIONS ASSOCIATED WITH UNDESIRABLE EVENTSOperating Conditions

1. Extremely fast initial period (fast compounding)
2. Excessive rate of rise in MW region (fast simple rate)
3. Excessive rate of rise in limits region
4. Level drift
5. Distortion or cycling.

Degrees of Events

<u>Phenomenon</u>	<u>Effect</u>	<u>Connotation</u>	<u>Operating Condition</u>
A. Worst Case - Meltdown	Disaster	Nuclear Safety	<ol style="list-style-type: none"> 1. Almost Certainly 2. Almost Certainly 3. Yes 5. Possible Contributor
B. Reasonably Conceivable - Severe Fuel Damage	Costly	Plant Safety	<ol style="list-style-type: none"> 1. Possible, not Necessarily 2. Probable 3. Possible, not Necessarily 4. Possible 5. Probable Contributor
C. Routine Operating Efficiency - Normal Infrequent Overlimits	Reduced Efficiency	Normal	<ol style="list-style-type: none"> 1. Infrequent 2. Occasional 3. Infrequent 4. Infrequent 5. Common

TABLE II
PROTECTION AGAINST UNDESIRABLE EVENTS

<u>Operating Condition</u>	<u>Procedure Protection</u>	<u>Automatic Protection</u>
1. Extremely fast initial period (fast compounding)	1. (a) Withdrawal rates (b) Subcritical monitoring (c) Loading procedures (d) Reactivity predictions	a. Low-level period trips - more sensitive the better. b. Low-range level trip.
2. Excessive rate of rise in MW region (fast simple rate)	2. (a) Enter MW region on slow period (b) Lengthen period by rod movement as level increases.	a. Intermediate-level period trip b. Rate of rise trip c. Substitute: Intermediate- range level trips.
3. Excessive rate of rise in limits region	3. (a) Monitor flux and temperature contin- uously - level out early and increase cautiously.	a. Rate of rise trip b. Flow stability trip *c. Neutron level trip d. Outlet temperature trip.
4. Level drift	4. (a) Practice good control techniques (b) Alarm indicating rod withdrawal	a. Outlet temperature trip b. Flow stability trip *c. Neutron level trip
5. Distortion or cycling	5. (a) Representative monitoring (b) Determine repre- sentative trends (c) Good control techniques	a. Outlet temperature trip b. Flow stability trip *c. Neutron level trip

* If representative

IV. EXISTING HANFORD INSTRUMENTATION

A. BF₃ Counter (PC)

In the absence of an ideal neutron counter system, such as the system previously described, the BF₃ proportional counter (PC) is used at Hanford during reactor startup to detect criticality. The PC chamber is located beneath the reactor in one of the instrument channels. The channels are open ducts which pass beneath the pile from one side to the other. Several vertical risers which pierce the bottom shield of the pile open into the instrument channel, providing a point source of neutrons. Mechanical devices are provided to manually insert or withdraw the chamber from any point in the open duct. By careful adjustment of the chamber position in the vicinity of the vertical riser, the correct sensitivity and range of the chamber can be calibrated to the rest of the counter system for peak performance.

The signal is transmitted from the neutron counter to a pre-amplifier located just outside the subpile duct. The signal is amplified and sent on to the amplifier and scaler in the control room. The scaler is an electrical circuit capable of reducing the number of counts received by some factor, such as 4, 16, 512, etc. This reduction is necessary because the rate of pulse arrival is so high and irregular that a mechanical counting device is not fast enough to count all of the pulses directly. The actual number of particles intercepted by the BF₃ counter is found by multiplying the number of counts recorded by the scaling factor and adding the counts still left in the scaler. The number of counts per unit time is proportional to the neutron density or power level. An alternate method of obtaining the same data involves the use of a pulse rate meter; by means of this electronic device the rate of neutron pulse arrival is directly indicated on a meter or recorder.

The generally higher neutron and gamma flux encountered during a "hot" startup can be accurately monitored through the use of a second BF₃ proportional counter. This second counter chamber is located in a

less sensitive and more protected area than the normal counter used for "cold" startup. By a simple switch arrangement, either the hot or cold chamber may be placed into the electronic proportional counter system.

B. Galvanometer System

After the pile period has been determined and the proportional counter range exceeded, the rise to operating level is controlled through the galvanometer system. Because of the inherent delay in instrumentation that records power level from heat output, it is necessary to use instruments that respond directly to changes in reactor neutron density or flux. One such method is the galvanometer system. It is composed of one to eight neutron sensitive ionization chambers from which the current and hence the neutron flux is indicated on two galvanometers at the main control desk. The ion current from the chamber or chambers is monitored on a total level indicator and on a differential indicator of the light beam galvanometer type mounted on the operating control console.

The No. 1 galvanometer is the level indicator and indicates the total current which is proportional to the neutron flux, or power level. The No. 2 galvanometer is a differential monitor that reads small deviations about a preset or operating range. The No. 2 galvanometer system includes a potentiometer which opposes the signal current through the No. 2 circuit. By adjustment of the potentiometer setting the No. 2 galvanometer spot may be placed at the desired position on the reading scale. This bucking arrangement allows a greater sensitivity than with the No. 1 and makes the No. 2 galvanometer useful as an indicator of small power level deviations. Both galvanometers are equipped with shunts which can be manually positioned to give the desired range for any operating power level. The galvanometer system is the operator's main instrument for controlling the power level after criticality has been established and for fine control while at operating level.

~~SECRET~~

-71-

HW-51856 CH3

The primary current for the galvanometer system at the older reactors is provided from a single neutron ionization chamber usually located in one of the experimental test holes on the far side of the reactor. The galvanometer system at the newer reactors utilizes the multiple current from the "octant monitoring" system discussed next.

C. Octant Monitor

The octant monitor system at the newer reactors measures neutron flux in each of the eight corner regions of the pile (see Figure 3-22). Comparison of the individual readings presents a picture of flux distribution throughout the reactor. Since these readings from the eight ion chambers represent a sample of flux from each section of the reactor, the sum or total signal of the chambers gives an accurate measurement of the over-all neutron flux, or power level. The ion current from each chamber is monitored on individual current meters, then combined and passed through the galvanometer system (discussed above). Each chamber may be adjusted in or out approximately nine inches to provide some control of flux at the chamber location. This variation in the positioning of the individual chambers provides a means of adjusting the signals from the chambers so that they are more or less balanced within the meter ranges. Further control of the meter range is provided by "High" and "Low" sensitivity switches at the individual microammeters. The octant system makes startups safer because readings are less subject to flux distortion and rod shadowing effects than is the case with a single chamber.

The octant system also has definite advantages in temperature distribution control at full level. For a given power level, any change of neutron flux in one region must be balanced by a change in some other region. The deviation recorder, presenting a signal from each chamber at the K piles, provides a clue as to when to take corrective action and what method to use, and it accurately records the success or failure of the action taken.

~~SECRET~~

~~SECRET~~

-72-

HW-51856 CH3

FIGURE 3-22
Octant Chamber Location

AEC-GE RICHLAND, WASH.

~~SECRET~~

D. Foil Traverse

During reactor operation it is desirable from time to time to make direct measurements of the neutron density or flux by nuclear means for calibration and other purposes. This may be done in cases where flux levels are extremely low or it is not possible to provide instruments by exposing thin sheets or foils of certain metals such as gold to neutron bombardment inside the reactor. This treatment causes the foil to become proportionately radioactive; when removed from the reactor the beta activity of the foil is then measured with a Geiger counter. From this information the neutron density, either absolute or relative, can be calculated.

It is standard practice to conduct two or more flux traverses at advantageous times during control rod calibration tests which are run at too low level for tube temperature traverses. Simultaneous front to rear and side to side flux traverses are obtained with numbered gold foils attached to wood strips which are inserted in a dry process tube (front to rear) and into an experimental test hole (near to far). The gold foils are evenly spaced along each of the wood strips according to lattice unit dimensions (7-1/2 or 8-3/8 inches); the wood strips are of sufficient length to extend from reflector to reflector in both directions. Thus, each numbered foil represents an exact pile location within the active core of the reactor. The first traverse is usually run at the start of a rod test with very little control rod in the pile, another may be run at an equilibrium configuration several hours later. A foil irradiation of this type will require about five to ten minutes at a power level of approximately two MW. After each irradiation the wood strips are removed from the reactor; the gold foils are placed in a neutron counter and data taken for several days at specified intervals. From this data, plots are made which show the relative flux distribution front to rear and near to far of the reactor core. The curves obtained are similar in shape to the curves shown in Figures 2-9 and 2-10 of Chapter II of this manual.

Front to rear traverses during equilibrium operation may be similarly obtained, using numbered aluminum dummies or even numbered fuel pieces in place of foils and "weasel" ion chambers to obtain the activation readings in place of Geiger counters.

E. Beckman System

All Hanford reactors are equipped with neutron sensitive ion chambers for monitoring reactor power. These instruments, equipped with Beckman Company microammeters and therefore known as the Beckman system, are designed with trips in the No. 1 Safety Circuit to shut the reactor down automatically whenever the neutron flux or power becomes excessive. A minimum of two Beckmans are required to be unbypassed in the safety circuit at all times, including shutdown, to ensure that when undue increases in neutron flux occur, the safety circuit will shut the reactor down.

Current operation of the older Hanford reactors is extremely dependent upon the "Beckman System". By means of very detailed procedures which take advantage of the range change and trip adjustment features of these instruments, this system currently is depended upon for protection against excessively fast periods, excessively fast rates of rise at intermediate levels, and for power excursions above normal operating level. This system is even counted on for protection against unplanned rod pull during an outage.

Four neutron flux level trip systems, or Beckmans, are supplied at each Hanford reactor to record neutron level and to provide a means to operate the safety circuits. Each system is composed of an ion chamber, a direct current (DC) amplifier, and a controller. The flux level trip system is required to cover a neutron flux range from a normal shutdown condition to full power operation. The direct current amplifier in use at the reactors exclusive of K Area is the Beckman RXG-2. This instrument has basic full range from 10×10^{-13} to 10×10^{-8} amperes. Some of the ranges have been modified to accommodate higher currents from the ion chambers. The least sensitive range available is that for full power operation. The ion chambers of the Beckman system are located under the reactor in the vicinity of vertical risers that pierce the bottom shielding.

During reactor outages flux monitor trips are required to be set at a sensitive level which will operate the safety circuit before reactor power can rise uncontrollably, should critical be attained for any reason during the outage. In addition, the No. 2 Beckman is equipped with a bucking voltage system for use during shutdown. This system is considerably more sensitive than the normal flux monitors and can detect rising power before the other Beckmans could respond. The initiation of a flux trip by the Beckmans while the reactor is operating at full power is very rapid, occurring practically at the time that the actual flux equals the trip setting. This is because the start of a flux rise at full power cannot be an instantaneous jump to a fast period, but must occur over a period of time. The full power flux trips are set quite close, 110 to 120 per cent of the full power, so that in case the reactor gets on a fast period, the flux trips may be exceeded and the reactor shut down before the hottest tube reaches its instability temperature.

The relative effective flux ranges of the nuclear instrumentation for reactor safety and control are shown in Figure 3-23. The sub-critical monitoring to full power, the high level trip, and the rate of rise trip as indicated on the chart indicate additional protection being planned or under development, however, all other data presented in the chart is essentially correct.

The safety circuit controller, which senses the Beckman output and activates relays in the scram safety circuit has a response time of less than 0.1 second. The relay closes a set of contacts and rod motion is started. Even with the slightest of time delays, there is some overshoot of power above the trip level because a certain minimum amount of safety rod must be inserted before the rising power level is turned around. Therefore, it is imperative that the flux monitor trips be correctly set at all times. Each controller consists of a two relay combination arranged so that both must drop out to shut down the reactor, while either one will sound an annunciator alarm. At least two Beckman flux monitors must be set to trip at all times. At the K reactors two Beckman trips are required for a

FIGURE 3-23

Effective Flux Ranges of Nuclear Instrumentation for
Reactor Safety and Control

scram; three Beckmans must therefore be in the safety circuit at all times. This is why the Beckman bypass switches are interlocked so that a reactor scram is automatically initiated if more than two (one at K reactors) of the four Beckman channels are bypassed at any one time.

F. Panellit System

Continuous flow of tremendous quantities of water through the process tubes is necessary; otherwise the generation of heat would soon raise the reactor temperature to dangerous proportions. Each reactor is equipped with numerous instruments to measure and record the pressure, temperature, and flow of cooling water as well as certain devices to automatically shut down the reactor in the event of any interruption in the cooling water supply. The removal of heat from a Hanford reactor becomes complicated because of two reasons. First, the temperature of the exit water from each process tube must be maintained within a definite operating limit. Secondly, the heat load varies from tube to tube, making it impractical to adjust the water flow in every tube to the same outlet temperature. Thus, the distribution and control of the cooling water to 2,000 or more process tubes presents a complicated problem, particularly when the importance of keeping the flow and temperature of each process tube within definite operating limits is considered. Individual tube flow is determined by the size of the venturi throat or the orifice placed inside the nozzle connection to the crossheader system - larger openings are used for central columns than for fringe columns. Flow is not measured directly, but for a given size orifice or venturi the difference in pressure in the front crossheader and that observed at the upstream end of the column can be used to calculate the tube flow.

Each Hanford reactor is equipped with a "Panellit" system which consists of specially designed gauges to give a continuous indication of the inlet water pressure of each process tube just downstream from the orifice, or at the center of the venturi. An abnormal increase or decrease in pressure is evidence of a serious change in the rate of flow through the tube. An increase in the panellit pressure may be due to an obstruction downstream in the annular space in the tube, to boiling "vapor lock", or to the

swelling of a slug. A decrease in pressure may result from a plugging of the front cross header or venturi screens. Any of these conditions represents a potential hazard to the reactor. This type of information, together with data on exit water temperature from the same tube, when properly interpreted, can be used to evaluate abnormal performance of individual tubes. The inlet pressure of each process tube is brought separately into the control room to the Panellit gauge rack. Here each tube inlet pressure is constantly indicated on a specially designed drum-type dial gauge. Adjusted high and low contacts are provided for each gauge so that an electrical circuit is broken in the event of an abnormally high or low pressure. All the contacts in each row are connected in series to a relay, and all relays are also connected in series. Should any Panellit gauge indicate pressure outside of previously set high or low operating limits, the breaking of the electrical circuit will activate the No. 1 Safety Circuit and shut down the reactor.

G. Temperature Monitor

Although the exit water temperature of each process tube is highly important, it is not considered practical with the present instrumentation to constantly monitor the exit temperature of each process tube. Therefore, provision is made for periodic measurement of individual tube temperatures to assure that the temperature of each tube is within the operating limit. Thermocouples located in the outlet nozzle of every tube are connected to a panel in the control room with a jack corresponding to each process tube in the reactor, and arranged in the same pattern. This temperature monitor automatically scans and records the exit temperature of all the tubes in the reactor.

Each temperature monitor is equipped with an automatic flexowriter and a punched tape recorder. The flexowriter is an electronic typewriter that is capable of typing the temperature of every tube in the reactor on the order of 15 minutes. The temperature of each tube is typed on a tube pattern chart known as a "temperature map" which shows the location, number, and exit temperature of every tube in the reactor. The tape recorder is

fully automatic and may be used in conjunction with the temperature map; the paper tape is code punched for IBM use.

In addition to the temperature map and tape recording features, the temperature monitor is especially flexible in the selection of any number of tubes for visual measurement. Two high speed Brown recorders are used for this purpose. Skip, row, omit, and repeat switches operate automatically for quick and accurate row or tube selection. Although fully automatic, the device is flexible, as indicated below.

1. Temperature map and tape recording of all reactor tubes may be taken at the rate of about 200 tubes per minute.
2. Any tube in the reactor may be selected and visually monitored in about three seconds.
3. Any section of any horizontal row can be selected and monitored individually in a matter of seconds.
4. The upper and lower halves of the tube pattern may be monitored simultaneously by two separate recorders.
5. Any selection of horizontal tube rows may be measured, recorded, or typed in repeating sequence, such as every other row, every fifth row, etc.
6. The exit temperature of any two tubes may be continuously measured and recorded.

H. Seismoscope

The Hanford plant is located in an area subject to earth tremors of moderate intensities. There is the possibility that a severe earthquake could so damage the reactor that the moderator and shielding would be displaced in such a manner that it would be impossible to insert the horizontal or vertical safety rods. In such an extremely severe earthquake the process water system might be ruptured at the same time, resulting in a complete loss of water to the reactor, causing a power excursion and possible melt-down of the fuel elements. The character of

earthquake shocks is such that minor shock waves usually precede the heavy or major shock waves. These minor shock waves thus give a warning in time for an emergency shutdown of the reactor before the damaging major shock wave arrives.

For these reasons, it is desirable that the reactors be shut down as soon as possible after a tremor begins. To accomplish this, each reactor is supplied with a seismoscope to detect minor shock waves. The seismoscope contacts are set to trip the safety circuits for any tremor which might cause damage to the reactor (just below the threshold for minor structural damage). The seismoscope system consists of one high sensitivity and two low sensitivity pendulums, each having normally open electrical contacts in individual relay circuits. Closure of the contacts on any of the three pendulums will trip an annunciator; closure of the two low sensitivity pendulums will activate the safety circuits. The high sensitivity pendulum contact spacing is set to provide an annunciator alarm on the less severe shocks; the two low sensitivity pendulum spacings are set to activate the safety circuits for any shock of the fifth magnitude or higher on the Mercalli Intensity Scale.

At the C and K reactors coincident signals from two seismoscopes will trip the Ball 3X system. At the B, D, DR, F, and H reactors the seismoscope trips the No. 1 Safety Circuit. The ease of recovery from ball 3X trips at the C and K reactors permit the use of the automatic ball drop at these plants. The high cost of recovery from inadvertent ball 3X trips at the other reactors is considered adequate justification for relying on process water failure trips of the ball 3X system at those reactors.

I. Safety Circuits

The "safety circuits" of the Hanford reactors are composed of three (3) interrelated safety circuits, the 1X, 2X, and 3X. The 1X circuit consists of relays and contacts which will release the vertical safety rods. The 2X circuit controls the horizontal rods in a like manner. The 3X circuit is a third safety device which releases neutron-poison balls which fall into, and fill, the vertical rod channels to stop the nuclear chain reaction. The

actual safety circuits differ a little from reactor to reactor; however, the description below will give a comparatively accurate representation of any Hanford reactor safety circuit system.

Whenever circumstances appear that present an immediate danger to the reactor or the reactor control system, the No. 1 Safety Circuit will operate and cause all the vertical safety rods to drop and all the horizontal rods to move into the reactor at maximum speed. The No. 3 Safety Circuit (Ball 3X) functions as a fast-acting backup of the No. 1 and No. 2 Safety Circuits in case of certain water loss conditions at all piles or seismoscope indications at the C and K piles; it may be operated manually at any reactor. The major components and their associated functions are described below.

1. Beckmans - Four high flux trips which will cause a No. 1 Safety Circuit scram whenever the neutron flux becomes excessive. Bypass interlocks are provided to ensure that at least two active trips are in the circuit at any one time. Dual area interties initiates an annunciator alarm at the companion area if two or more Beckmans trip.
2. Panellit - Each process tube containing slugs or dummies is provided with a Panellit gauge so adjusted as to activate the No. 1 Safety Circuit and shut down the reactor upon indication of insufficient flow. A high and low pressure system senses the proper flow in each process tube; switches are provided which will trip the No. 1 Safety Circuit in the event of abnormal flow conditions. A ground detector system senses any grounding which might bypass a portion of the system.
3. Water Supply - Two sets of low pressure switches are provided to protect the reactor upon loss of process water pressure in the inlet piping system. One set of switches trips the No. 1 Safety Circuit. The other set of switches operates as a pressure decay system which senses the rate of pressure decrease and trips the No. 3 Safety Circuit (Ball 3X) if the rate of decrease is over a fixed amount. The pressure decay system is equipped with a time delay which bypasses the lower pressure switch and prevents the Ball 3X trip if the pressure

decrease has not decayed within the specified trip settings. Normally, the No. 1 Safety Circuit would be tripped by the Panellit or power failure relays before the low pressure (LP) switches operated, however, the low pressure switch provides a backup in case the other trips fail.

4. Power Failure - The undervoltage system senses the power supply at critical points in the water pumping system and in the reactor building. The No. 1 Safety Circuit will trip under any condition which would cause a pump failure or a loss of power to the control system.
5. Seismoscope (C and K reactors only) - The seismoscope system is set to automatically trip the No. 3 Safety Circuit (Ball 3X) on the coincidence signal from two seismoscopes. All other reactors rely on process water failure or manual push-button trips of the Ball 3X system.
6. Circuit Interties - The intertie of No. 1 Safety Circuit to No. 2 Safety Circuit causes the horizontal control rods to scram in if any No. 1 scram occurs.

The VSR to No. 2 Safety Circuit intertie causes the horizontal control rods to scram in if any vertical safety rod falls into the reactor.

The No. 3 Safety Circuit to No. 2 Safety Circuit intertie causes the horizontal control rods to scram in if any column of 3X balls drops into the reactor.

The No. 2 Safety Circuit can be tripped individually only with the control desk push button.

The No. 1 Safety Circuit system as described above protects the reactor by causing automatic shutdown upon receiving a signal from any one of a number of devices monitoring conditions such as water flow, power supply, or neutron flux. However, in addition to these automatic trip devices, other operating limits are imposed for safe operation and to prevent reactor damage. Whenever a critical limit is exceeded or some abnormal condition develops, it may be desirable to shut down the reactor as quickly as possible. For these reasons, each reactor is provided with a manual push-button trip for the No. 1, No. 2, and No. 3 Safety Circuits.

In the event that any of the automatic monitoring devices fails to function properly or whenever any operating limit is exceeded, the reactor may be shut down by manual trip of any or all of the three main Safety Circuits.

J. Response Time

The response time of the Safety Circuits is shown in bar form in Figure 3-24. The chart shows a typical time sequence for C Area; the principal difference at other reactors is in the length of time required to fully insert the horizontal control rods (about one minute at a K reactor). Time bar A illustrates the time sequence of a scram caused by one of the following trips: low water supply pressure, plugged or ruptured process tube, or a seismoscope fault. Time bar B shows a scram initiated by the Beckman system. The pressure decay system trip and subsequent Ball 3X drop is shown in time bar C; a vertical safety rod drop and horizontal control rod scram should accompany this trip through the action in time bar A. Time bar D shows the action from an undervoltage of critical power. Various time delays are used in connection with the undervoltage trip, depending upon what is considered critical at a particular reactor.

The reliability of the Safety Circuit system is strengthened through the use of dual relays and dual contacts at all critical points; the relay coils are arranged in parallel and the contacts in series. Examples of the dual relays in the system include the IXX and IXXA, the BX and BXA, and HX and HXA. In the event of an electric power failure, energy to insert the horizontal control rods is provided by hydraulic accumulators at the B, D, DR, and F reactors. Similar power is provided by battery banks at the C, H, and K reactors.

K. Annunciator

Whenever the reactor is shut down automatically (scrammed) because of the operation of one of the safety circuits, it is necessary that the reason for the scram be determined as soon as possible so that the faulty condition can be remedied and the reactor started up again. This necessary information is provided by a trouble indicating device called

SECRET

-84-

HW-51856 CH3

FIGURE 3-24

Typical Time Sequence for Safety Circuits
(Data applies to C Reactor)

SECRET

UNCLASSIFIED

~~SECRET~~

-85-

HW-51856 CH3

an "annunciator". This annunciator indicates by means of visible signals and a bell what particular abnormal condition caused the safety circuit to operate. The annunciator panel is conveniently located near the control desk and is equipped with 28 or more clearly labeled windows. Whenever an electrical circuit connected to a unit behind each window is disturbed, a flag or light (as the case may be) becomes visible through the window and a bell or gong gives an audible signal. All occurrences that initiate a scram of the safety circuits are indicated on the annunciator; in addition, several other conditions which do not result in operation of the safety circuits are also monitored by the annunciator to serve as a warning for operator checking. Whenever an annunciator flag drops or a light appears, the bell or gong is sounded. The bell may be turned off immediately but the flag or light cannot be reset until the trouble is corrected. The annunciator is especially useful just prior to reactor startup. At this time, the annunciator will indicate any unusual condition throughout the reactor building that may interfere or delay reactor startup. In other words, an annunciator clear of any flags or lights ensures that all safety circuits are properly made up and that all major conditions relative to startup have been satisfied.

L. Miscellaneous Instrumentation

Because of the complexity of the reactor control system and the fact that the process requires remote operation, a tremendous amount of instrumentation is concentrated in the operating control room. The control room is equipped with thousands of gauges and warning devices dealing with every conceivable phase of reactor operation.

Instruments are provided to supply information pertaining to the reactor gas atmosphere. These deal with the composition, pressure, flow, temperature, radioactivity, purity and moisture content of the gas.

Portable air monitors are provided for miscellaneous air sampling in and around the pile. Permanent monitors are installed at numerous locations surrounding the pile structure and the activity recorded on

UNCLASSIFIED

~~SECRET~~

UNCLASSIFIED

~~SECRET~~

-86-

HW-51856 CH3

Micromax recorders. Building and stack air are continuously monitored and recorded. Continuous measurements are taken of integrated dosage and radiation intensity at several points throughout the pile building and permanently recorded on Micromax recorders.

Multiple instrumentation indicates and records the temperature of hundreds of thermocouples distributed throughout the pile graphite and shielding. Provisions are made to monitor inlet and outlet temperature, pressure, and flow of all auxiliary cooling water to control rods, shielding, motor bearings, etc. The radioactivity of the cooling water from each cross header is continuously monitored for rupture detection; all water leaving the reactor building is also monitored and recorded before entering the river.

In addition to the gauges, some of which are mentioned above, thousands of indicating lights are used throughout the reactor building to determine the exact status of the more important components of the reactor. For example, lights are used to indicate open or closed circuits, valves, gates, etc., empty or full ball hoppers, storage tanks, etc., the position of safety rods, doors, elevators, etc.

This chapter has dealt with only the major instruments of the reactor; a detailed description of the entire instrument system of a reactor building is much too specialized to be covered in this manual.

V. INSTRUMENT DEVELOPMENT

There is a continuing program of improving reactor safety through better instrumentation. Studies and tests are constantly in progress toward providing safer instrumentation at critical points in the process. There are certain regions not completely monitored under the present system such as the subcritical neutron flux, the rising periods at low power levels, and the tube outlet temperatures during the rise to operating level.

As previously stated, the power level of a reactor is proportional to the neutron flux, and instruments that measure flux may be located at many points throughout the reactor system to give a representative reading.

~~SECRET~~

UNCLASSIFIED

UNCLASSIFIED

~~SECRET~~

-87-

HW-51856 CH3

However, because of the intense radiation within the reactor at higher power levels, the pulse-type ion chamber used to detect initial criticality must be positioned in a relatively protected area. Although in a protected area, the effective range of the chamber is soon exceeded and the control of the rising period must be transferred to another system, such as the galvanometers. The range of the system may overlap, but the sensitivity and consequently the rate of rise must be re-established at a critical point of reactor operation. An ideal neutron counter system should cover all ranges from shutdown to full power. Such a system should provide information in the subcritical range for a safe approach to predicted critical; in the intermediate power range after the pile period has been established to maintain a safe rate of rise, and to follow the rate of rise to operating level to provide uniform control of the outlet tube temperatures. Perhaps the first step toward such an ideal system may be indicated in the development of the subcritical flux monitor.

A. Sub-Critical Flux Monitor

The sub-critical flux monitor is a system that is capable of detecting and recording the neutron flux when the reactor is in the full shutdown condition. Unlike the present proportional counter (PC) system, which uses a boron trifluoride tube, the interior of the proposed Hanford sub-critical monitor chamber (or the electrode) is coated with a uranium compound enriched with uranium-235; it is called a "fission chamber". The entry of a slow neutron will cause fission of the uranium compound, and the resulting fragments produce ionization in pulse form which can be amplified and recorded in the same manner as other counter systems. The system is composed of a U-235 fission counter, a remote positioning mechanism, preamplifier, amplifier, logarithmic counting rate meter, period amplifier, and a trip, a four decade recorder, and a positioner control. Through the remote positioning mechanism, the pulse-type fission counter may be inserted into the active portion of the reactor during shutdown to monitor the very low neutron flux. As the reactor attains critical and is brought up to the operating level, the fission counter is withdrawn, in steps, to

~~SECRET~~

UNCLASSIFIED

UNCLASSIFIED

~~SECRET~~

-88-

HW-51856 CH3

a protected position within the pile shielding. This withdrawing action provides the system with a high initial sensitivity and a very wide operating range, and it protects the chamber from burnout and radiation damage. This new system is now in the project design and application stage; the prototype has been in operation at the D pile for a number of months.

The greatest value of the fission counter system is that it can detect the change in background flux in the unlikely event of gross loading errors, and routinely as the vertical safety and the horizontal control rods are being withdrawn during the approach to critical conditions. Such information at this time can be used to confirm or correct the calculated critical condition before the reactor becomes supercritical.

Representative reactivity values cannot be obtained directly from the fission counter, or from neutron flux at one location in the reactor. However, the increased initial sensitivity of the fission counter, the capability of following the power level over a wide operating range, plus the logarithmic rate meter and low level trip represent an important improvement over the present counter equipment. It is expected that approximate but important calibrations may be made of the counting rate as a function of degree of subcriticality.

Another test installation employs three PC chambers in sequence. This system is known as the "triple PC". Three separate proportional counters are positioned in three separate flux regions (in a single test hole) within the pile shielding. One chamber is placed in a high flux area for greater initial sensitivity. Another chamber is located in an intermediate flux region to control the rate of rise following criticality, the third chamber is positioned in a relatively low neutron flux area to monitor the rate of rise to operating levels. As the effective range of each chamber is exceeded, the counter system is switched to the next less sensitive chamber, until the third chamber is in operation. The chambers are not movable during operation and remain in the preset position. The triple PC system is capable of monitoring sub-critical neutron flux, but the preset chambers and cables are subject to radiation damage.

~~SECRET~~

UNCLASSIFIED

UNCLASSIFIED

~~SECRET~~

-89-

HW-51856 CH3

B. Tube Outlet Temperature

Another phase of reactor operation that is not completely covered under the existing safety trip instrumentation is the process tube outlet temperature. A project is underway to include a process tube outlet temperature monitor in the safety circuit trip system at all reactors exclusive of KE and KW; the K reactors already have a tube outlet temperature trip system which is employed during startups. The proposed system will be a zone type of temperature monitor operating on about 200 control tubes evenly spaced about the reactor. Each control tube will then monitor the temperature of a zone or section of about ten process tubes. The design is such that the reactor will be shut down automatically if any zone control tube exceeds a certain preset or operating limit. An approach-to-limit scan control will light an indicating lamp or sound an annunciator alarm for each control tube within a particular range of the actual limit trip; this will allow a short period of time for investigation and corrective action. If the tube temperature continues to rise the actual limit trip will activate a reactor scram.

It is expected that such a system would be particularly effective in monitoring heat shifts that may occur during scram recoveries and during periods of rapid rod motion required to control the reactivity transients following reactor startup. Under equilibrium operating conditions, a flexible approach-to-limit monitor of this type will permit a safe and balanced approach to higher process tube limits.

C. Octant Monitor

In an effort to obtain a representative indication of neutron flux throughout the volume of the reactor, plans are being made to convert the present galvanometer systems at all reactors into octant-type systems wherein eight neutron chambers are installed in corner regions of the reactor block as at the C and K reactors. These reactors are provided with the octant-type galvanometer system whereby the total or sum current from the eight corner octant flux monitors is indicated as the total neutron flux or power on the galvanometer. The conversion of the DR and H reactors

UNCLASSIFIED

~~SECRET~~

UNCLASSIFIED

~~SECRET~~

-90-

HW-51856 CH3

presents no problems since both reactors are equipped with octant facilities into which commercial ion chambers can be placed. The B, F, and D reactors have no such facilities and must be provided with special ion chambers of small enough dimensions to be inserted into the front and rear ends of four corner process tubes. Should this be accomplished, the system may be placed in the safety circuit at all reactors. Flux level trips from each of the ion chambers, or perhaps in sets of two, will activate the safety circuit trip. Under such a system, the flux level trips will be spread about the reactor block rather than beneath the pile as at present. This type of octant monitor flux level trip system may replace the present Beckman system in providing the primary full power flux trips.

D. Rate of Rise Instrumentation

A doubling time of thirty seconds may be perfectly safe near background levels of few watts, but extremely dangerous at power levels in the hundreds of megawatts. Therefore, process standards impose a megawatt per minute limit on the rate of rise; at very low levels even a very fast pile period will not cause an excessive MW/minute rise, but near full level the rate of rise limit will be realized with a very slow period.

The operator has need for an instrument which will give him rate-of-rise information directly. In the past he has had to resort to "feel" - to judge his rate of rise by the speed with which the galvanometer spot traverses the scale, by the timing required in changing Beckman ranges, or by the observed approach of outlet temperatures to limiting conditions. An instrument is now being developed which will show this desired indication directly. A zero deviation reading will indicate constant power level, whereas a positive reading will indicate a certain MW/minute increase rate; this system will begin to function around 1-10 MW, as the top of the useful range of period indication is approached. The prototype for this instrument at the D pile uses the new temperature resistance elements for its signal. This same type of device can theoretically use the signal for the octant monitor system for its signal.

~~SECRET~~

UNCLASSIFIED

UNCLASSIFIED

~~SECRET~~

-91-

HW-51856 CH3

The problems in designing a suitable rate-of-rise meter include:

1. Using a signal that is representative of the entire volume of the reactor.
2. Having sufficiently fast response that excessive rates are detected in time for remedial action.
3. Ensuring that the instrument is not so sensitive in response that sudden small changes in background produced by rod movement do not give misleading indications to the operator.

A substitute for this device at C Pile consists of a high speed recording of the total octant monitor signal; by means of a slope overlay, the MW/minute rate of rise may be quickly estimated.

E. Miscellaneous

Another type of period amplifier system known as the "high level trip" is being developed. This system is composed of a standard gamma compensated neutron sensitive ion chamber, a six decade logarithmic DC amplifier, period amplifier and trip, and recorder combination. This system has been tested at the KE reactor to control the nuclear reaction from the kilowatt range to full operating power, in place of the current practice of range-switching a bypassed Beckman flux trip.

Other instrument developments now in progress include the improvement of such items as the Panellit pressure monitor, the temperature monitor, ion chambers, counter systems, ruptured slug detection, and pile gas system instrumentation. The scope of this chapter, however, covers only those instruments directly related to safe operation which are either in service or whose application is clearly indicated.

This concludes the third chapter of the IPD Physics Primer; a fourth chapter of the series "Variations in Pile Reactivity" will be published as time permits.

UNCLASSIFIED

~~SECRET~~

INTERNAL DISTRIBUTIONCopy Number

1	O. C. Allred
2	P. M. Anderson
3	W. R. Anderson
4	C. W. Anthony
5	J. T. Baker
6	J. W. Baker
7	R. S. Bell
8	A. G. Blasewitz - W. E. Fry
9	B. B. Bon Durant
10	C. E. Bowers
11	C. E. Brown
12	J. H. Brown
13	R. K. Browning
14	R. O. Brugge
15	W. L. Bunch
16	R. J. Bursey
17	L. A. Carter
18	R. D. Carter
19	A. B. Champley
20	J. N. Charlton
21	L. C. Cristman
22	R. C. Christianson
23	E. L. Chubb
24	J. C. Clausing
25	R. G. Clough
26	H. V. Colton
27	R. I. Connor
28	D. C. Couhig
29	D. A. Davis
30	W. DeGooyer
31	G. L. Denny
32	L. E. Denton
33	H. E. DeVoss
34	R. L. Dickeman
35	C. E. Drotts
36	R. M. Drury
37	A. G. Dunbar
38	E. T. Edwards
39	A. W. Fash
40	D. B. Ferguson
41	E. J. Filip
42	C. W. Fishback

DO NOT MICROFILM
THIS PAGE

INTERNAL DISTRIBUTION (contd.)Copy Number

43	J. J. Foster
44	J. M. Fouts
45	F. C. Franklin
46	R. A. Frister
47	G. C. Fullmer
48	G. R. Gallagher
49	W. J. Gartin
50	D. E. Goins
51	K. W. Greager
52	O. H. Greager
53	J. W. Green
54	C. N. Gross
55	T. M. Hall
56	F. J. Hallenbeck
57	R. B. Hamilton
58	L. F. Hannan
59	A. K. Hardin
60	K. O. Hartley
61	R. C. Haynes
62	G. Herman
63	D. T. Houser
64	W. G. Howell
65	E. T. Hubbard
66	I. L. Huffman
67	S. H. Hulett
68	M. E. Jackson
69	R. T. Jessen
70	G. W. Kaas
71	N. S. Kaas
72	J. E. Kaveckis
73	R. H. Kopel
74	C. G. Lewis
75	D. S. Lewis
76	E. H. Lockwood
77	W. N. Lusebrink
78	G. L. Madsen
79	A. R. Maguire
80	D. M. Maxson
81	H. C. Mayer
82	A. McCrindle
83	L. H. McEwen

DO NOT MICROFILM
THIS PAGE

INTERNAL DISTRIBUTION (contd.)Copy Number

84	H. A. Michel
85	J. H. M. Miller
86	R. D. Miller
87	L. M. Mitchell
88	M. R. Moon
89	J. F. Music
90	W. S. Nechodom
91	R. H. Nelson
92	S. L. Nelson
93	R. Nilson
94	O. L. Olsen
95	L. M. Ostby
96	A. M. Ostrom
97	C. L. Owen
98	G. R. Parkos
99	J. R. Pierce
100	C. W. Rausch
101	R. W. Reid
102	R. J. Roach
103	G. E. Robinson
104	M. J. Schemenaur
105	H. J. F. Shirey
106	D. E. Simpson
107	H. C. Sittig
108	W. R. Smit
109	H. C. Smith
110	C. L. Stairer
111	S. R. Stamp
112	P. Thompson
113	R. E. Trumble
114	R. L. Turner
115	A. P. Vinther
116	R. K. Wahlen
117	V. L. Wallace
118	R. G. Warner
119	R. F. Warnick
120	J. A. Webster
121	J. A. Werner
122	R. Wesley
123	R. E. Whiteside
124	J. W. Wickstrom

DO NOT MICROFILM
THIS PAGE

INTERNAL DISTRIBUTION (contd.)Copy Number

125	E. W. Wilson
126	N. E. Wilson
127	D. G. Winston
128	M. R. Wood
129	J. T. Worthington
130 - 179	Extras
180	300 Files
181	Record Center

EXTERNAL DISTRIBUTIONCopy Number

182	ACF Industries, Inc. (Etherington)
183 - 186	Argonne National Laboratory
187	Armed Forces Special Weapons Project, Sandia
188	Armed Forces Special Weapons Project, Washington
189 - 191	Atomic Energy Commission, Washington
192 - 193	Atomics International
194	Battelle Memorial Institute
195 - 196	Bettis Plant (WAPD)
197	Brookhaven National Laboratory
198	Bureau of Ships
199	Chicago Operations Office
200	Chicago Patent Group
201	Division of International Affairs (Pennington)
202	Division of International Affairs (Woodruff)
203 - 206	duPont Company, Aiken
207	duPont Company, Wilmington
208	Fluor Corporation
209	General Nuclear Engineering Corporation
210	Hanford Operations Office
211	Knolls Atomic Power Laboratory
212 - 213	Los Alamos Scientific Laboratory
214	National Advisory Committee for Aeronautics, Cleveland
215	New York Operations Office
216	Nuclear Development Corporation of America (SOO-256)
217	Patent Branch, Washington
218 - 221	Phillips Petroleum Company (NRTS)
222 - 227	Union Carbide Nuclear Company (ORNL)
228	USAF Headquarters
229 - 230	University of California Radiation Laboratory, Berkeley
231 - 232	University of California Radiation Laboratory, Livermore
233 - 272	Technical Information Service Extension

UNCLASSIFIEDDO NOT MICROFILM
THIS PAGE