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HANFORD ATOMIC PRODUCTS OPERATION - RICHLAND, WASHINGTON

May 17, 1964

TITLE

PRELIMINARY ENGINEERING STUDY
INTERMEDIATE RANGE INSTRUMENTATION

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PRELIMINARY ENGINEERING STUDY
INTERMEDIATE RANGE INSTRUMENTATION

By

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May 15, 1964

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PRELIMINARY ENGINEERING STUDY
INTERMEDIATE RANGE INSTRUMENTATION

1.0 INTRODUCTION

Instrumentation studies(10.1 & 10.2) and the Hazards Review(10.3) have demonstrated the need for instrumentation which will scram the reactors if the exponential rate of power increase is excessive. A development program has demonstrated the feasibility of such a system.

2.0 PURPOSE

This document defines the program necessary to provide Intermediate Range exponential rate protection in the safety circuits of five reactors, provides justification for the project, and presents estimates of the cost and schedule required to accomplish the program.

3.0 CONCLUSIONS

- 3.1 Three channels of IRATE (Intermediate Range Automatic Trip Equipment) should be installed in the two K and three small reactors, and incorporated into the Number 1 Safety Circuits.
- 3.2 Each channel should sense the output of its own gamma-compensated ion chamber located in the thermal shield of the reactor.
- 3.3 A two-out-of-three (2/3) channel coincident period trip circuit should be used in the safety circuit.
- 3.4 A three-out-of-three (3/3) coincident period trip circuit should be provided which may be selected above the power level of 10^{-2} times Equilibrium Power Level (EPL). The switch which would be used to select the 3/3 matrix should be ineffective below $10^{-2} \times \text{EPL}$.
- 3.5 A 2/3 level trip matrix, with trip settings at about 2 MW should be used to automatically unbypass the Pressure Monitor and PRAAM (Power Rate Alarm and Monitor) safety circuit contacts.
- 3.6 Fail-safe design should be utilized throughout the system.
- 3.7 GE should manage the program and develop the specifications for the engineered equipment.
- 3.8 Procurement should be by competitive bids to GE's specifications and drawings.
- 3.9 The proposed program is estimated to cost \$520,000.
- 3.10 The proposed program is estimated to be completed 24 months after AEC authorization of the project.

4.0 DISCUSSION

4.1 Statement of Problem

A study by R&EO of the basic considerations for providing reactor and nuclear safety protection by means of instruments that measure power level resulted in HW-72555, "Development and Application of Principles of Nuclear Safety Instrumentation". This document discusses the function of level and rate instrumentation for the protection of Hanford reactors and describes the inter-relation of instrument safety systems, geometric considerations, and time response characteristics.

HW-72591, and HW-74094, Vol. 1, further explore the relationships are requirements of the needed reactor instrument systems. All of these studies show that an adequate safety system must include absolute power level protection, linear power rate protection in the heat generation range of power levels (10^{-2} to 10^0 times Equilibrium Power Level (EPL), and exponential power rate protection in the intermediate range (between initial criticality and the heat generation range, or 10^{-7} to 10^{-2} times EPL).

If power is increasing at an exponential rate, then $P = P_0 e^{k(t-t_0)}$ where P_0 is the power level which existed at time t_0 . The time that is needed for the power level to be multiplied by the quantity $e (=2.718)$ is derived by setting $e = \frac{P}{P_0} = \frac{P_0 e^{k(t-t_0)}}{P_0 e^{k(t_0-t_0)}} = e^{k(t-t_0)}$.

From which we see that $k(t-t_0) = 1$. $(t-t_0)$ is the period required for the power to multiply by e and is usually expressed as τ . Obviously $k = \frac{1}{\tau}$. The magnitude of an exponential rate is usually designated by

giving its period (i.e. if τ is large the rate is slow and if τ is very short the rate is very rapid). Instruments which measure exponential rate usually read in terms of period and are therefore referred to as Period Meters. Throughout the remainder of this document, the term Period will be used instead of Exponential Rate.

At the present time there is no Period Instrument, operating in the 10^{-7} to 10^{-2} times EPL range, utilized in the safety circuit. There is a Period Meter, which is activated by signals derived from the Low Level Neutron Monitor, but it lacks the resolution and stability required of a start-up instrument and is largely ignored by operating personnel. Operating procedures (measuring the slope of the recording of the Lo-Lev. Neut. Monitor) are used to determine the period of the exponential rate and provide the function of period protection. By utilizing improved logarithmic instruments and compensated chambers which have recently been developed, this reliance upon procedural controls can be eliminated as was recommended in references 10.1 and 10.3. Today's technology makes instruments available with the accuracy, stability and reliability required of reactor safety circuit components.

4.2 Background

4.2.1 Present Procedure

At the present time, period protection is obtained by monitoring the recordings from the Low Level Neutron Monitors. There are two of these systems in each reactor - each consisting of an ion chamber mounted on a mechanism by which it can be inserted into or withdrawn from the side of the reactor. Each chamber drives a recorder whose deflection is proportional to the logarithm of the chamber current. The range of the recorders is five decades of chamber current. When a recorder reaches 98% of full scale deflection, contacts are actuated which cause the mechanism to pull the chamber away from the reactor core until the recorder reading drops to 40% of its full scale deflection, at which time contacts are actuated which stop the retraction. The chambers are thus withdrawn step-by-step as the reactor power level increases. The positions of the two chambers are staggered so that when one recorder reaches 98% of full scale deflection the other is at about the middle of its travel, thereby providing continuous readings even though one chamber might be moving and thereby providing erroneous readings.

Control room personnel monitor the recordings to see that the slope of the output-vs-time record does not exceed the limit established by the Process Standards. Of course, a reasonable time - one to three periods - is required for the recorder to draw a trace long enough for the operator to make a relatively accurate determination of the rate of change. This protection covers the range from shutdown to about two decades above criticality. Above this level protection is provided by the procedure for resetting the Beckman High Level Neutron Monitor trip settings.

When power level is changing and the Bulk Outlet Temperature is above 85 C, procedures require the Beckman High Level Trip Settings to be continually readjusted to 110% of the highest individual reading. Only one of the four instruments may be adjusted at a time. This limits the rate at which power can increase because too high a rate would cause the instruments to trip before the instrument man would have time to reset the trip point.

4.2.2 Development History

In order to provide mounting locations for the ion chambers required for an Intermediate Range Instrument system, it was necessary to develop a technique of accurately drilling a stepped hole through the side shield of a reactor. Quite accurate dimensional control is required to prevent damage to the thermal shield cooling tubes, which would necessitate permanent reduction in the local power level near the disabled tube.

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Development work on the drilling technology was started in February of 1960. Three different machines and numerous diamond, carbide, and tool steel cutting heads were investigated during the program. A mockup of the thermal shield was built and testing started in October of 1960. A progress report, HW-70342, was published in July of 1961. Further work was delayed by lack of priority. Work was resumed in May of 1963 and in June 1963, the first hole in the mockup was completed. The cutter was redesigned to produce more manageable chips and a second hole was drilled. Cutter design was further improved and after the third hole was successfully drilled in August 1963, the off-reactor portion of the program was complete.

In December 1963, a hole was successfully drilled in the side of F Reactor in 39 hours. This prototype installation demonstrated that the techniques used can provide the accuracy of hole location and the straightness required to avoid the thermal shield cooling tubes. The experience gained in drilling this hole suggests some minor modifications which will greatly reduce both the time required to drill the hole and the personnel radiation exposure accumulated during the operation. HW-80677, the final development report, provides a more complete history of the drilling development program.

In January of 1960, the Instrument and Electrical Development Operation prepared a specification for an Intermediate Range instrument and requested proposals from suppliers utilizing their closest commercial products. Instruments were obtained from three vendors for evaluation. The last one being received in January of 1961. Concurrently, compensated ion chambers were obtained from three vendors for evaluation. Early evaluation of the instruments disclosed serious deficiencies in each which necessitated modifications by the manufacturers.

Testing of these instruments was completed in February of 1962. While no further instruments were purchased for evaluation, I&EDO was developing improved Fixed Radiation Monitoring instrumentation which required refinement of the same techniques and principles that are applicable to the Intermediate Range equipment. They also participated in the design and evaluation of the N Reactor Intermediate Range Instruments.

In December of 1963, I&EDO purchased a compensated ion chamber which incorporated the most advanced state of the art. This chamber was installed in the hole which was drilled in the side of F Reactor and was connected to one of the three instruments originally obtained for evaluation. The operation of the system has been completely satisfactory since its installation.

As a result of this development program, specifications are now being prepared to describe instruments and chambers which will provide a system capable of meeting the requirements for the Intermediate Range System. Furthermore, the evaluation program has demonstrated that equipment which will meet these specifications is now commercially available.

4.3 Proposed Solution

4.3.1 Physical Description of the Proposed System

Figure 1 is a schematic drawing of the proposed system.

In each reactor three independent channels will monitor the power level and the period in the intermediate range (10^{-7} to 10^{-2} times EPL). The instruments will actually be operable over the range 10^{-7} to 10^0 times EPL. Each channel will use one gamma-compensated ion chamber mounted in a new, stepped hole which will be drilled through the thermal shield on the far (opposite from control rods) side of the reactor. The three chambers will be located close to one another so that they will be measuring essentially the same neutron flux.

The three IRATE instrument chassis will be located in the control room. Each IRATE chassis will have meters to indicate the measured power level and measured period. Each chassis will also have three trip functions, two which actuate at separately adjustable power level trip settings and one which actuates at an adjustable period trip setting.

The lower of the two level trip functions (set at about 2 MW) of each of the three channels will be utilized in a two-out-of-three ($2/3$) logic matrix to actuate relays which will automatically disable the bypass switches in the pressure monitor and linear power rate-of-rise safety circuits. This function is presently provided for the pressure monitors by the Flux Monitor-Pressure Monitor interlocks and contacts on the same interlock relays will be used in the PRAAM (Power Rate Alarm and Monitor) safety circuits when they are installed.

The higher of the two level trips in each channel will be utilized in the Period Trip Logic Matrix to indicate when the power level has exceeded the range in which period protection is required. The set point of these trips will be about 10^{-2} times EPL. Above this intermediate range it is permissible to switch to a $3/3$ period matrix. Switching to a $3/3$ matrix will allow maintenance of the equipment when the reactor is at EPL with less probability of producing a spurious scram. Thus, in the admittedly unlikely - but possible - case that while one IRATE

chassis was removed for maintenance (thus automatically introducing one trip into the matrix) a second trip was caused by failure of one of the remaining channels, the reactor would not be scrammed. Should the power level drop below 10^{-2} x EPL the matrix will automatically revert to 2/3, independent of the position of the Period Trip Matrix Change Switch.

The period trips of the three channels will be used in the Period Trip Logic Matrix to actuate final action relays whose contacts are in the Number 1 safety circuit. The period trips will be set to actuate when the period is shorter than 15 seconds.

Figure 2 is an elementary drawing of the period logic matrix, the IRATE-Pressure Monitor - PRAAM interlock matrix, and the safety circuit connections.

After the system has been installed in all reactors and operating experience has verified that the equipment meets the design reliability requirements, the manually-operated Matrix Change Switch (IS), the IRM & IRMA relays, the 10^{-2} x EPL level trips (1 LH, 2 LH, and 3 LH), and the 3/3 period matrix contacts (IP-2, 2P-2, and 3P-2) will be removed from the Period Trip Logic Matrix. The period trip matrix will then revert to a simple 2/3 logic function.

Three two-pen recorders will be located on a panel in the control room, close to the three IRATE chassis. Each recorder will monitor both the period and level outputs of its respective channel. The pen movements will cover the complete range of each variable without range changing. The chart paper will have alternate segments of length in the time direction printed with the scales for period and level. Each segment will be a light shade of the color of the ink used in the pen for its variable. Figure 3 is an illustration of the chart paper.

Three edgewise period meters will be located in close proximity to similar period meters for the two Low Level Neutron Monitor channels on the reactor operator's console. No remote IRATE level meters will be used. Figure 4 is a full-scale sketch of the console meter configuration.

The Period Trip Matrix Change Switch will be located on the bypass panel, as will the lights signifying when it is possible to switch to the 3/3 matrix.

The relay matrices will be located in the safety circuit relay cabinets in the electrical equipment rooms.

4.3.2 Procurement Plan

The most critical procurement items will be the IRATE instruments and the gamma-compensated chambers. Functional specifications

and outline drawings of these items will be prepared for competitive bids by competent vendors. The first production models will be tested by the Instrument and Electrical Development Operation to verify that they meet the specification requirements before the remainder of the order may be shipped. Source inspection by GE field inspectors and by representatives of I&EDO and Reactor Design during the fabrication of the first production parts shall be required to assure that proper fabrication, assembly, and testing techniques are utilized. After GE approval of the first pieces, no changes will be permitted during the fabrication of the rest of the instruments without the prior written permission of GE Engineering.

The recorders and console meters will be purchased by competitive bids on functional specifications.

4.3.3 Responsibility Plan

Preparation of the specifications and design of the safety circuit modifications will be performed by GE's Design Engineering Operation. Installation design will be provided by the AE under GE's technical direction. Project Engineering Operation will manage the project under the usual project procedures.

5.0 JUSTIFICATION

Studies (10.1 & 10.3) of reactor safety considerations have demonstrated the need for automatic safety circuit action based on the measured exponential rate of power increase in the intermediate power level range (10^{-7} to 10^{-2} times EPL). The reason this protection is required is as follows:

The Hanford reactor safety systems are designed to prevent the release of fission products either to the atmosphere or into the effluent cooling water. The only way that appreciable quantities of fission products can escape from these solid-fueled reactors is for the fuel to melt. Thus, the general requirement for safety is to ensure that the heat removal capacity is compatible with the heat generation rate or, in terms of actual practice, that the heat generation rate does not exceed the capacity of the cooling system. Thus, a maximum power level is determined which is a function of the quantity of cooling flow available and the temperature at which it enters the reactor.

However, a safety circuit trip which would scram the reactor above a fixed power level does not, by itself, provide adequate protection. There are finite time delays in the power sensing equipment and in the response of the safety circuit and the safety system mechanisms. Because of these delays, a reactor which was increasing in power and which had reached the trip level and initiated safety action would continue to rise to some higher power level before the safety action would become effective. If the rate of power increase at the time the level trip action was initiated were great enough, the overshoot could exceed the predetermined specific heat generation limits (above which boiling, fuel element melting, and fission product release would be threatened).

Thus protection must be provided to assure that the linear rate at which the reactor approaches the limiting (trip) power level does not exceed a safe value. This protection will be provided by the Linear Power Rate-of-Rise Instrumentation. However, even the combination of level and linear power rate limits does not provide complete protection.

Nuclear reactors are not, by nature, linear devices but actually exhibit exponential properties. In other words, increasing a reactor's reactivity (by removing some poison or withdrawing a control rod, for example) does not have the effect of establishing a linear rate (such as 10 MW/Min) at which the reactor increases in power, but instead establishes an exponential function of time by which the power level is multiplied. In practical terms, the result is that the amount of the reactivity increase determines the length of time it takes the reactor power level to increase by a factor of e (≈ 2.718). This length of time is referred to as the period of exponential rate. The greater the increase in reactivity, the shorter the resulting period would be. A very small increase in reactivity would produce a very slow, or long period. It can be seen that after a time equal to three "periods" of the exponential rate, the power level would be multiplied by $e^3 = (2.718)^3 = 20$, that after 6 "periods" it would be multiplied by $e^6 = 20^2 = 400$, and that after 9 "periods" by 8000.

Linear power rates of the magnitude of the linear rate trip settings can only be generated in the top 2 decades of the power level operating range so the linear rate systems will be ineffective below power levels of approximately 10^{-2} EPL. Thus, it can be seen that if a reactor's power level is increasing with a very short period, the power level would increase right through the last two decades and above to a level which would cause fission product release during the time delay between initiation and the effective implementation of a scram by the linear power rate trip. Therefore, limitation of the exponential rate of rise for several decades of power level below the range of the linear rate instrumentation is required to provide adequate protection.

This, then, is the reason for this project - to provide automatic limitation of the exponential rate in the four or five decades below the region where automatic linear rate protection will be provided, so that the linear rate trip cannot be approached on so short a period that the overshoot would exceed power limits and cause fission product release.

6.0 ALTERNATIVE SOLUTIONS

6.1 One alternative solution would be to mount the chambers in the C and K Reactors in the existing holes for the octant monitor chambers. However, this would have required extensive cleanup of those facilities and installation of additional equipment to replace the removed octant chambers. Consideration of this alternative showed that it would be more costly and less satisfactory than the one proposed, so it was discarded.

6.2 The alternative of continuing to operate with the present system was discarded because we are committed to provide completely automatic safety system protection as soon as the technology is developed to make it possible.

6.3 A third alternative is still being studied. This alternative is to use the same system proposed in this document but to install all three chambers in the same hole. The close spacing of the shield cooling tubes presents a problem. Preliminary studies indicate that slightly smaller chambers of sufficient sensitivity to provide a viable three-in-one system should be attainable. A development program is being undertaken to demonstrate feasibility. Should it be successful in time, this alternative will be followed and a \$30,000 to \$50,000 cost reduction could result.

7.0 PROPOSED SCHEDULE

The following schedule is in months after receipt of AEC's authorization.

	<u>Start</u>	<u>Finish</u>
Detail Design	1	13
Procurement	3	18
Installation	6	24

8.0 ESTIMATED COST

The project is estimated to cost \$520,000. A detailed breakdown of this estimate is included in the budget study, HW-80453.

9.0 ACKNOWLEDGEMENTS

The assistance of G. L. Erickson, W. D. Hamilton, N. T. Hildreth, and C. A. Simsen in refining the system concepts and editing this document is acknowledged with thanks.

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Reactor Design
FACILITIES ENGINEERING OPERATION

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FIGURE 1

SCHEMATIC DIAGRAM INTERMEDIATE RANGE INSTRUMENTATION SYSTEM

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FIGURE 2 - REACTOR SAFETY CIRCUIT MODIFICATION

FIGURE 3 - CONSOLE METER ARRANGEMENT

FIGURE 4 - RECORDER CHART PAPER

APPROVALS

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