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SUBJECT: HFIR Critical Experiment-2 (HFCE-2)

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ABSTRACT

The experiments associated with HFIR Critical Experiment-2 concern reactor performance and safety. The reactor-performance experiments involve fuel and boron concentrations and distributions, power density distributions, and the reactivity available during a fuel cycle; these experiments emphasize those factors which have a major influence on the average sample exposure during a year of HFIR operation. The reactor-safety experiments concern safety of handling the bare core, reactivity worth of safety plates, and the temperature and void coefficients of reactivity; these experiments are related to the ultimate safety of the HFIR. Measurements will also be made which involve fission chamber response during the fuel cycle as a function of position; these experiments concern the operational safety of the HFIR.

HFIR CRITICAL EXPERIMENT-2 (HFCE-2)

Paul R. Kasten

The over-all purpose of the proposed critical experiment is to insure proper nuclear design of the HFIR; however, it is neither necessary nor practical for such an experiment to be used for extensive parameter studies. Thus, the objectives are to study those parameters which have a primary influence on HFIR performance and on reactor safety, and whose influence cannot be predicted adequately.

The need for such an experiment is based on the present inability to predict the reactivity of a specified HFCE-1 loading within 2% Δk_e; associated with the above have been uncertainities of about 20% in calculated power densities. Power-density distribution and reactivity are related to the maximum island flux, the fuel distribution, and reactivity lifetime of the reactor, and thus influence reactor performance, or more specifically, the island-sample exposure over a period of a year. The reactivity of the core under various conditions (e.g., reactivity worth of voids; reactivity of core placed in water alone) and the reactivity worth of control plates under various conditions, influence reactor safety.

The proposed critical experiments, are to be performed with an HFIR mockup, utilizing HFIR U^{235} and B concentrations and distributions (as determined from calculations). A mockup of the irradiation sample should be in the island, although it will be necessary to reduce the diameter below that of the actual HFIR sample in order to utilize an island-region safety plate for shutdown purposes. The experiments would be run at room temperatures, unless specified otherwise. A cross-sectional schematic of the reactor is given in Figure 1.

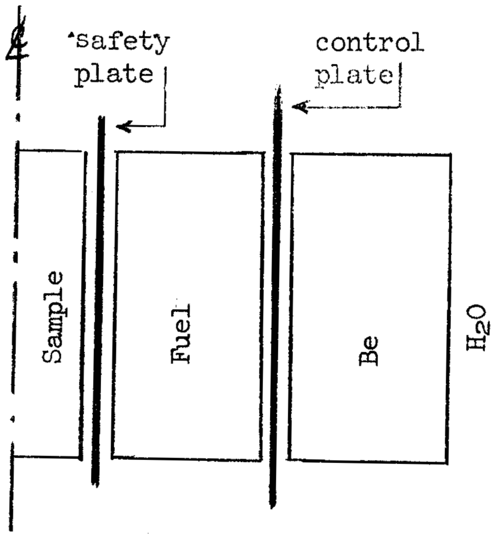
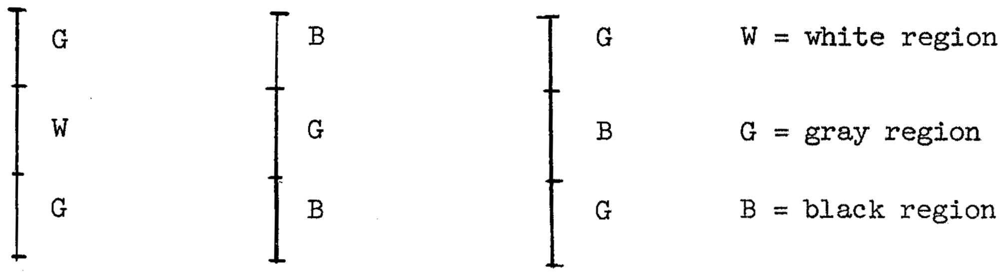


Fig. 1. Schematic diagram of reactor

The control plate would consist of the desired material (gray, white, or black), plus extensions at the ends of the plate of adjacent material (gray, white, or black), as indicated in Fig. 2.



(a) White plate (b) Gray plate (c) Black plate

Fig. 2. Control plate mockups

These plates could be attached to drives and used for criticality control in attaining the desired condition. For example, criticality under desired control-plate conditions would be associated with addition of boric acid solution to the water in the fuel regions; however, for a given boron concentration, criticality could be achieved by movement of the control plates. The extensions should be the same lengths as the fuel-plate length. This will facilitate the running of several of the experiments.

Specific measurements to be made in HFCE-2 are discussed below; these will be associated with reactor performance and reactor safety, and discussed under the appropriate heading.

Reactor Performance

The experiments associated with reactor performance concern fuel and boron concentrations and distributions, power-density distribution, reactivity of loading, and reactivity worth of the "gray" and "white" control plates. The primary information to be obtained from these experiments is the fuel loading and distribution, and the required control-plate cross section. While it is anticipated that the estimated fuel loading and distribution will be sufficiently close to the final desired values so that further experiments on another core will not be required, this may not be the case. If another core is required, fabrication time and present financial conditions dictate that such experiments be deferred to the next fiscal year. The experiments described below assume that the core for HFCE-2 is sufficiently close to the desired design that extrapolation from initial to final nuclear design can be done with confidence. With respect to the control plates, it is anticipated that several plates having different cross sections will be required in these experiments.

Experiment 1-P

Consider the initial loading of the reactor (boron and fuel in inner fuel ring); by adjusting the boric acid concentration in the core water and by movement of the control plate, criticality is attained with the gray control region symmetrically placed around the reactor core. The cross section of the gray plate is then modified until no boron is required in the water of the fuel region. The power distribution is then measured in the fuel region.

Experiment 2-P

The gray extension of the white control plate is inserted into the control region, with boron added to the water in the fuel region. Criticality is achieved by movement of the control plate, and the associated power distribution is measured. This procedure is repeated for several boron concentrations, adjusting the position of the white control plate to attain criticality. The final plate position would be with the core completely surrounded by the white control plate. The power distribution in the fuel region is measured for each criticality condition.

Experiment 3-P

Retaining the final boron concentration associated with experiment 2-P, the gray control plate is inserted. The reactivity change associated with changing from white to gray plates is then measured by pulsed-neutron techniques.

Reactor Safety and Operation

Experiments considered here under reactor safety concern the reactivity of the bare core placed in water, the reactivity worth of the "black" control plates relative to the "gray" and "white" plates, values of the reactivity coefficients, and the value of the prompt neutron lifetime. Experiments associated with reactor operation concern the response of fission chambers as a function of position. The results of these experiments will form the basis for evaluating the ultimate safety of the HFIR, as well as some aspects of its operational safety.

Experiment 1-S

The reactivity of the initial clean core in a pool of water is determined by pulsed-neutron techniques.

Experiment 2-S

The final critical conditions associated with experiment 1-P are first attained. The gray control plate is then replaced by the black plate and the associated reactivity change is determined by pulsed-neutron techniques.

Experiment 3-S

Utilizing the final critical conditions associated with experiment 2-P, the white control plate is replaced by the black plate, and the associated reactivity change is measured by pulsed-neutron techniques.

Experiment 4-S

The final critical conditions associated with experiment 1-P are attained. The water within and surrounding the reactor is then heated, and reactivity as a function of average reactor temperature is obtained. Water temperatures of $\sim$ 140°F may be required.

Experiment 5-S

The final critical conditions of experiment 1-P are again utilized. The void coefficient of reactivity of the fuel and trap regions are measured by insertion of voids, plastic, or other appropriate material. The trap void coefficient should be measured both with and without the sample mockup in position.

Experiment 6-S

The final critical conditions of experiment 2-P are first attained. The white plate is gradually removed, and at the same time the bottom gray extension would be gradually inserted into the reactor control region. As this gray plate is inserted, its reactivity as a function of position is measured by pulsed-neutron techniques.

Experiment 7-S

The final critical conditions of experiment 1-P are utilized. The gray plate is removed and the gray extension of the black plate is inserted into position. The black plate is inserted gradually into the reactor, and its reactivity measured as a function of position by pulsed-neutron techniques.

Experiment 8-S

Experiment 7-S is repeated, replacing the black plate by a "partial" black plate which has a white region over one quarter of its circumference.

Experiment 9-S

This experiment concerns fission chamber measurements as a function of position in the reactor as well as a function of the position of nearby control plates. Provision should be made for measuring fission-chamber response in the region directly above the reactor core and inside the appropriate control plate, as a function of chamber position and control-plate position. Also, provision should be made for measuring fission-chamber response in the radial direction, outside the beryllium reflector.

Discussion

The experiments presented under Performance and Safety are inherently closely associated, and the actual order of the experiments would not be necessarily in the order presented. In fact, several of the experiments listed under Safety would be completed while obtaining the desired conditions for the Performance experiments. However, the above listing does indicate the function of the different experiments.

The information to be obtained from the various experiments will now be discussed. Experiment 1-P will determine the macroscopic cross section required of the control plate under initial reactor conditions, and the associated power distribution. Experiment 2-P in combination with 1-P will indicate the reactivity available during the fuel cycle, and will provide information concerning the power distribution at the end of the fuel cycle. Experiment 2-P will also indicate whether power peaking associated with the "neutron window" effect will be a problem during the fuel cycle. (If counter-current movement of two control plates is as cheap and convenient as the proposed single control plate, then two control plates would be preferable.) Experiment 3-P is a check of the reactivity available during the fuel cycle, or gives information on the prompt-neutron lifetime at the beginning of the cycle.

Experiment 1-S concerns the safety of handling a clean core in water. Experiment 2-S in combination with 1-P determines the reactivity change associated with replacing the gray region with the black region. Experiment 3-S in combination with 2-P gives information on the reactivity change associated with replacing the white region by the black region at the end of the fuel cycle; this reactivity change can be checked against the sums of those obtained in experiments 2-S, 1-P and 2-P, 1-P. Experiment 4-S will measure the reactor over-all temperature coefficient of reactivity, while 5-S will give the individual void coefficients of reactivity of the trap and fuel regions. The results obtained from 4-S and 5-S along with appropriate calculations will also permit evaluation of the temperature coefficients of the trap and fuel regions. Experiments 6-S and 7-S will furnish information on the reactivity of the gray and black plates as a function of position; these experiments would be completed in conjunction with experiments 2-S, 1-P, and 2-P, 1-P. Experiment 8-S will give information on the reactivity worth of the black plate if one of the four HFIR safety-plate sections were not inserted into the reactor. This experiment would be similar to others, but would require a special control plate.

Experiment 9-S is associated with proper design and placement of the HFIR control instruments, so that response during a fuel cycle is satisfactory. The information required could be obtained while running previously-mentioned experiments, but provision for such measurements is necessary.

Other experiments have also been considered, but were considered unnecessary at this time. If measurements indicate their need, they can be performed without requiring any basic changes in the above experimental program. For example, power peaking due to the introduction of a neutron "window" during the fuel cycle may be a problem which requires experimental investigation. If necessary, a control plate could be built which mocks up this window. The power distributions obtained during experiment 2-P will show whether additional experiments are required. (If countercurrent control plates are utilized, the "window" effect will be studied in experiment P-2.) At the present time it is believed that an absolute measurement of the reactivity and power distribution at the beginning of the cycle will permit correct prediction of the power distribution throughout the fuel cycle without resort to additional experiments. Also, additional experiments on reactivity worth of the control and safety plates may be desired as a function of position, on the basis that one section of the 4-section HFIR control-safety plates does not respond. Here again it is believed that measurements associated with experiments 1-P, 2-P, 2-S, 6-S, 7-S, and 8-S will provide sufficient information so that additional reactivity information can be calculated adequately.

One of the significant parameters in these experiments is the cross section of the gray control plates. Provision should be made for the manufacture of gray control plates having different cross sections. The extensions associated with the various control plates should be the same length as the fuel plate (20 inches) so as to facilitate the running of experiments 2-P, 2-S, 6-S, 7-S, 8-S, and 9-S.

Order of Importance

The above presentation and discussion did not indicate the relative importance of the various experiments. Four orders of importance are considered here and presented in Table 1. The relative-importance rating is on the basis of the specific experiment itself, and does not take into consideration whether the associated information will be obtained in running other experiments. This latter situation is noted in the Remarks column of Table 1.

The listing given in Table 1 should serve as a guide in the running of the several experiments, with the most important ones completed first.

Table 1. Relative Order of Importance of the Various Experiments

Order of Importance	Experiment	Information	Remarks
First	1-S	Safety of bare core in water	
	1-P	Requirements of gray region	
Second	5-S	Void coefficient of reactivity	
	4-S	Temperature coefficient of reactivity	
	2-P	Reactivity available during fuel cycle; neutron window effect	
Third	8-S	Reactivity worth of "partial" black plate	
	2-S	Reactivity worth of black plate	
	9-S	Fission chamber response	
Fourth	6-S	Reactivity of gray plate as a function of position	This information will probably be obtained in 2-P.
	7-S	Reactivity of black plate as a function of position	This information will probably be obtained in 2-S.
	3-P	Prompt neutron lifetime	Alternately can be used as a reactivity cross-check measurement.
	3-S	Reactivity change associated with change from white to black plates	Reactivity cross-check measurement.

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