number of center plates removed and a guide tube substituted. The binding occurred between the guide tube and the shim-safety rod.

All of the shim-safety rods in the reactor at the time of the incident had been in the FNR since the reactor went into operation in September, 1957. During that time the reactor operated at 1 Mw for 2200 hr. Preliminary investigation of the damaged rod indicated the presence of hydrogen, oxygen, and nitrogen with no significant helium concentration.

Immediately following this difficulty three new shim-safety rods were installed in the reactor. These rods were identical to the original set except for a cadmium liner for each. After 320 Mw-hr of reactor operation these rods were removed from the reactor and measured. All three indicated expansion and one, when removed from the special fuel element, off-gassed at a plug weld. Analysis of this gas again indicated the presence of a hydrogen, oxygen, and nitrogen mixture with no significant concentration of helium.

The preliminary investigation of the deformed rod has also shown the presence of water within the rod thereby making radiolytic dissociation the most probable cause of the deformations. This is supported by the presence of hydrogen in the shim rods but the possibility of attaining pressures capable of expanding the shim rods is still subject to question.

In order to resolve this and other questions, including the consideration of other possible causes of the deformations, a program of investigation has been initiated at the Phoenix Memorial Laboratory.

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Beta-Gamma Delayed Coincidence Method for Resonance Escape Measurements

Neutron capture in U^{238} produces a series of nuclear reactions according to

$$U^{238} + N \rightarrow U^{239} \xrightarrow[\beta^-, \gamma]{23m} Np^{239} \xrightarrow[\beta^-, \gamma]{54h} Pu^{239} \xrightarrow[\alpha]{2.4 \times 10^4\ y}$$

Assay of that portion of the capture due to neutrons of resonance energy forms the basis of the experimental determination of the resonance escape probability. The first decay of the above chain proceeds with a half-life too short to be of practical importance for this measurement. A unique and presumably distinct property of the Np^{239} to Pu^{239} decay scheme allows identification of this decay on the basis of delayed beta-gamma coincidence measurement, even in the presence of a large background of fission product activity.

A gamma-gamma coincidence technique, which makes use of another fairly distinct property of the same decay, has been proposed by Sher (*1*) and amplified by Weitzberg and Thompson (*2*).

The present method makes use of the fact that about half of the beta decays of Np^{239} feed a gamma-emitting state of 0.193-μsec half-life. It is to be noted that Strominger *et al.* (*3*) list no other known fission product of appreciable abundance having a decay to a metastable state with this order of half-life.

In principle, one makes a beta-gamma coincidence measurement after first delaying the arrival of the beta pulse at the coincidence circuit for a time sufficiently long to reject (1) similar beta-gamma events among the fission products having half-lives shorter than the desired state, (2) prompt beta-gamma events, and (3) false prompt coincidences caused by bremsstrahlung and related events.

The method can be expected to have at least two advantages and one possible disadvantage, when compared with the gamma-gamma technique. First, the measurement is one of small increments in time, which can be measured more precisely than amplitudes. Properly designed equipment for this measurement should be much more stable than the comparable pulse-height-analysis instruments. Second, and more important, the present arrangement allows for the inclusion of a second-order slow coincidence involving a simultaneous pulse-height analysis in either or both channels. This arrangement should give considerable reduction in chance coincidences without a corresponding reduction in efficiency. Pulse-height analysis in this instance need not be so precise as when the entire calibration of the experiment depends upon it. Preliminary experiments, described below, at least partially bear out these conclusions. Finally, there is a possibility that the detection efficiency of this arrangement would be somewhat lower than for the gamma-gamma method, though this is not necessarily the case.

To cause serious difficulties in the time measurement, an (unknown) fission-product activity would have the following properties:

1. The parent state (or its progenitors, assuming a long chain) would have an effective half-life $10h \leqq \tau \leqq 250h$;
2. The daughter (metastable state) would have a half-life 2×10^{-8} Sec $\leqq \tau \leqq 2 \times 10^{-6}$ Sec; and
3. The parent state (or its progenitors) would be produced in more than, say $\frac{1}{2}\%$ of the fissions. No such isotope is known, and its occurrence is extremely unlikely.

Delayed beta-gamma coincidence experiments confirming the above hypotheses have been done. The gamma detector was a 2-in. diameter by 2-in. thick NaI (Tl) crystal. The beta detector was a $1\frac{1}{2}$-in. diameter by 2-mm anthracene crystal. Fourteen-stage photomultipliers were followed by limiters, several stages of distributed amplification, and a fast coincidence circuit. Delays were obtained by insertion of calibrated lengths of coaxial cable. A multichannel pulse-height analyzer was gated by the coincidence signal so that the spectrum of gamma pulse heights giving acceptable coincidences at each delay setting could be obtained. Both depleted and natural foils were used, with good results.

Curves of count rate vs relative delay between the two channels show (1) nothing but chance coincidences when the gamma pulse is delayed, (2) the expected peak due to prompt events, at about zero relative delay, and (3) an exponential decay having an apparently random distribution of errors about the expected 0.193-μsec half-life of the desired state, when the beta pulse was delayed relative to the gamma pulse.

The chance coincidence rate in the "fast" circuit appeared to lie in the range from about one to about ten per-

cent of the true rate, depending on the delay, details of the exposure, and U^{235} content of the foils.

The spectrum of gamma pulses giving acceptable coincidences is that to be expected from the known decay scheme. It consists primarily of a large peak at about 106 kev and successively smaller ones at 224, 283, and 335 kev. A constant spectrum of smaller amplitude then extends at least to energies of $1\frac{1}{2}$ to 2 Mev, due presumably to chance events.

The necessary equipment need be capable only of resolving times of the order 3 to 5×10^{-8} sec. Such equipment can be quite simple, and is well within the present state of the art. Present transistor techniques (*4*) offer promise of excellent stability.

Experiments designed to set an upper limit on usable U^{235} concentrations and to optimize detectors and equipment are continuing.

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Re: "An H_2O–D_2O Moderated Reactor"

A letter to the editor of this journal by Bebbington (*1*) commenting on an article by Klug and myself (*2*) points out that we were in error concerning the cost of separating D_2O from H_2O. While Bebbington's remarks concerning the price of the separation process are presumably correct, I should like to mention two rather important points which Bebbington neglected to consider in his criticism.

1. The statement of Bebbington ". . . if this ratio is to be varied quickly and repeatedly . . ." implies that to effect a significant saving in control rods, short-term reactivity change must be provided by varying the admixture of H_2O and D_2O. This implication is not correct, as a major portion of the control in a nuclear reactor is tied up with long term reactivity changes, the compensation for which does *not* require rapid changes of the H_2O to D_2O ratio. Perhaps Klug and I innocently gave rise to this misconception by pointing out the advantage of operating such a reactor near a maximum in the curve of k_∞ vs H_2O to D_2O ratio. There are several good reasons for doing this which do not require rapid changes of the ratio:

   (a) If burnable poisons are used to help compensate for long-term reactivity changes, cross section mismatch generally produces a reactivity curve which increases early in operating life and later decreases. By operating near a peak in the H_2O/D_2O curve, and by using burnable poisons, shim control could be largely if not entirely eliminated.

   (b) There are large, but fairly slow, reactivity swings in water reactors due to xenon buildup and decay and water density changes in going to and from operating temperature. These could easily be controlled by varying the H_2O/D_2O concentration.

2. A large portion of the expense in D_2O reactors is due to the equipment necessary to prevent contamination with H_2O vapor from the air. This expense could be eliminated in the type of system we propose, as small amounts of D_2O could be added to compensate for the H_2O contamination.

In conclusion, while we appreciate Bebbington's pointing out our error in the cost of preparing D_2O, we feel that a D_2O–H_2O reactor still has many advantages over conventional systems and warrants further study.

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* * *

To clarify some of the points discussed by Messrs. Klug and Zweifel in "An H_2O–D_2O Moderated Reactor" and the subsequent Letter to the Editor by W. P. Bebbington, I would like to point out that for reactivity control of a pressurized water reactor one need not install equipment to produce highly enriched D_2O from ordinary water or approach either significantly low, or high D_2O enrichment limits during reactor plant operation. Hence, D_2O reconcentration plant capital and operating costs can be kept low. In addition, by proper selection of D_2O concentration limits and reactor control philosophy, one can also eliminate the need for the large reconcentration facilities inferred by Mr. Bebbington. These conclusions are based upon over three years of preliminary and detail design of pressurized water reactors which use H_2O–D_2O ratio variation as a means of reactivity control, (B & W calls this the Spectral Shift Control Reactor—SSCR).

To illustrate, the SSCR utilizes H_2O–D_2O ratio for lifetime reactivity control. D_2O is initially purchased at a concentration of 99.75% and then diluted with light water to give the required start of life concentration of about 75% D_2O. This initial volume of H_2O–D_2O mixture is then gradually diluted with light water by a slow "feed and bleed" process over a core lifetime. At the end of core life the D_2O concentration is 2%. The core is then unloaded and the primary system is drained and refilled with H_2O–D_2O at 75% D_2O concentration. For this control method, it is necessary to have a D_2O concentration plant only large enough to reconcentrate the H_2O–D_2O mixture that is gradually withdrawn during core life to 75% D_2O.

The above control procedure has the following pertinent characteristics with respect to D_2O reconcentration:

1. The required D_2O reconcentration range is only 2% to 75% in D_2O or 37.5 fold—not the 6650 fold required to produce D_2O from natural water (0.015% to 99.75%). Over the reconcentration range 2% to 75% we have found con-