TABLE I

CAPTURE PROBABILITIES IN 1:1 H/U MIXTURE (T = 0)

Resonance energy	66.3	103.5 ev	192 ev
Resonance width, Γ	0.050 ev	0.092 ev	0.165 ev
Capture probability			
Numerical, no interference	0.0246	0.0179	0.00797
Numerical, with interference	0.0294	0.0228	0.01077
Variational, no interference	0.0249	0.0183	0.00813
Variational, with interference	0.0301		0.01072
NR, with interference	0.0226	0.0140	0.00597
NRIA or IM	0.0261	0.0219	0.01246
Numerical $\frac{\text{interference}}{\text{no interference}}$	1.20	1.27	1.35

TABLE II

CAPTURE PROBABILITY IN 103.5 EV U^{238} RESONANCE; σ_H = HYDROGEN CROSS SECTION PER URANIUM ATOM, INTEGRATION FROM 73 EV TO 147 EV

σ_H (barns)	Capture probability		
	No interference	With interference	Ratio
0	0.853	0.996	1.17
10	0.0265	0.0358	1.35
20	0.0176	0.0224	1.27
40	0.0116	0.0143	1.21
80	0.00766	0.00883	1.15
200	0.00444	0.00485	1.09
800	0.00197	0.00205	1.04
2000	0.00115	0.00118	1.02

seen that the effect of interference is to increase the absorption by from 20% to 35%. For a $\frac{1}{2}$:1 H/Bi mixture, interference increased absorption in the main Bi resonance (E_n = 784 ev, $\Gamma_\gamma/\Gamma \simeq 0.01$ and $g = 0.55$) by 32%. In Table II, the effect of varying hydrogen dilution is shown for the 103.5 ev U^{238} resonance. Evidently the importance of interference decreases as the uranium is diluted by additional hydrogen. All of these results were obtained at zero temperature. However it can be shown that the effect of interference will be similar at even, say 300°C.

The main physical reason why interference is important for these resonances is as follows: For the resonances in question, the effect of interference is always to increase the scattering for energies above the resonance peak and to decrease it below the resonance peak. Thus the effect is to increase scattering of neutrons into the resonance and to decrease scattering out and interference thus tends to trap the neutrons in the energy region of the resonance. To verify this, we have made one calculation in which the sign of the interference term was changed, thus giving constructive interference for energies below the resonance and destructive interference above. For this case (103.5-ev resonance and σ_h = 20) the capture was only 81% of that with no interference.

Evidently Doppler broadening will tend to decrease the effect of interference. Thus interference will give a contribution to the temperature coefficient which is opposite in sign to the usual Doppler coefficient (*6*).

The numerical integrations were performed with a code written for the IBM 704 by Mrs. J. Rudnick and the variational expressions were evaluated by Mrs. J. Powers.

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FNR Shim-Safety Rod Deformations

In August, 1960, the Ford Nuclear Reactor at the Phoenix Memorial Laboratory of The University of Michigan experienced a deformation of one of the three shim-safety rods installed in the reactor. The incident was discovered when this rod could not be withdrawn by normal procedures during a routine startup operation. Upon investigation it was found that this rod had swelled sufficiently to cause jamming in the special fuel element.

The shim-safety rods used on the FNR are flattened aluminum tubes fitted with appropriate endpieces and filled with boron carbide powder. These shim-safety rods are housed in MTR type fuel elements with an appropriate

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-