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A CAPSULE DESIGN FOR EXPERIMENTAL HIGH-FLUX IRRADIATIONS OF FUEL MATERIALS

by

J. Howard Kittel and P. Tedeschi

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A CAPSULE DESIGN FOR EXPERIMENTAL HIGH-FLUX IRRADIATIONS OF FUEL MATERIALS

J. Howard Kittel and P. Tedeschi

New reactors presently in design or construction stages, as well as revised operating procedures for existing reactors, have shown an increasing emphasis on extending the exposure time of the reactor fuel elements. However, operating experience at Hanford, as at other installations, has demonstrated that as the amount of burn-up in uranium metal is increased an increase is also noted in operational difficulties resulting from the dimensional behavior of the fuel. During reactor irradiation uranium slugs or rods have been observed to change in length and diameter, to warp, and to develop surface roughening.

If the literature is examined to obtain quantitative information on the changes which occur in natural uranium as it is irradiated, it is found to be almost entirely limited to studies of the metal in the form of fuel elements. Because of the size of these elements measurements have usually been confined to gross changes in dimensions, and the cladding on the fuel has made difficult the accurate measurement of surface changes. Measurements, therefore, of changes in physical and mechanical properties resulting from various amounts of burn-up are largely lacking at the present time.

The completion of the MTR, however, with its high available thermal flux, has made feasible an experimental investigation of the progressive effects of burn-up in natural uranium. Such an investigation has been undertaken in the ANL Metallurgy Division.

In order for the experimental irradiations to provide a maximum of useful data it was considered essential that the uranium specimens which are irradiated must be exposed in the reactor in such a manner as to be completely free of physical constraint. The high rate of burn-up which is obtained in the MTR also makes necessary efficient heat transfer between the specimen and the reactor coolant. In order to meet the above requirements the uranium specimens are being irradiated in a capsule which contains, for heat removal, sufficient NaK alloy to cover the specimen.

A useful capsule of this type has been developed which meets the following conditions:

1. Negligible corrosion by both water and NaK.
2. Low cross section for thermal neutrons.

3. Adequate thermal conductivity.

4. Easy inspection for leak-tightness after final closure.

Of the various capsule materials investigated, arc-melted crystal-bar hafnium-free zirconium was found to provide the best combination of desired properties.

The capsule design itself is shown in Figure 1. It is about 3 inches long and is based on the results of a series of tests in which reactor temperature and corrosion conditions were simulated. Referring to the figure, the capsule is assembled as follows:

1. After placing specimen in capsule, screw in bottom plug and weld around bottom of capsule using an argon-shielded arc.

2. Under vacuum add desired amount of NaK.

3. Add helium, if desired for leak detection.

4. Screw top plug in tightly and remove assembly from vacuum system.

5. Remove excess plug length and weld around top of capsule.

The capsule, when completely assembled, is resistant to rupture should high internal pressures occur during irradiation. Shear stresses which might be expected to develop at the welds are largely taken up by the threaded sections. Provision has been made for including a radiation monitor in the capsule by a drilled hole in the bottom plug. The monitor can thus be removed without opening the capsule. Three studs are welded near each end of the capsule to center it in a cooling channel.

A typical capsule, when assembled with a 3/16 inch diameter by 1 inch long uranium specimen, a 1/16 inch NaK annulus, and a capsule wall thickness of 0.094 inch, will contain the following amounts of material:

Zirconium	39. grams
Uranium	8.5 grams
NaK	0.9 grams

For a thermal flux of 3×10^{14} neutrons/cm.^{2}/sec. and a coolant water flow of 30 ft./sec., temperature drops in the capsule assembly have been calculated to be approximately as follows:

Film	16° C.
Zirconium	103°
NaK	80°
Uranium	90°
Total	289° C.

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Thus, if the coolant water temperature were for example 40° C., the maximum uranium temperature would be about 330° C.

In the vacuum chamber shown in Figure 2 eleven capsules can be filled with NaK and closed with the top plugs. The capsules are held in a rotating holder, the shaft of which extends outside through a Wilson seal. After each capsule has been moved under the pipette and filled with NaK, the desired amount of helium is admitted to the vacuum chamber. The top plugs, which are held in Wilson seals in the chamber lid, are then moved down and screwed tightly into the capsules. The auxiliary vacuum and gas purification system is shown in Figure 3.

Various methods have been used to detect possible leaks in the welded capsules. Indications of helium leakage have been observed with a mass spectrometer in some cases, although the test is not always found to be reliable. A simple autoclave test using steam or water at about 200° C. has appeared to be the most satisfactory means of detecting capsules which might fail during reactor exposure. Its chief disadvantage is the length of time required for a reliable test. It was found that a hundred hours of autoclaving were sometimes required to develop conclusive weight changes in faulty capsules. Capsules which failed during autoclaving were found after the test to contain tightly packed uranium, potassium, and sodium oxides. No external dimensional changes were observed. Capsule leaks which were enlarged by autoclaving were located by using a vacuum bubble test with the specimen submerged in kerosene.

In order to determine the reliability of the closure technique described above, 203 capsules and uranium specimens have been assembled and autoclaved for at least 1000 hours. The test caused six of the capsules to fail, as first evidenced by an undue weight increase. No bulging or cracking of failed capsules occurred which might have caused difficulty had the failures resulted during a reactor irradiation. Of the six failed capsules four were found to have failed through defective welds, and the other two failed because of material defects.

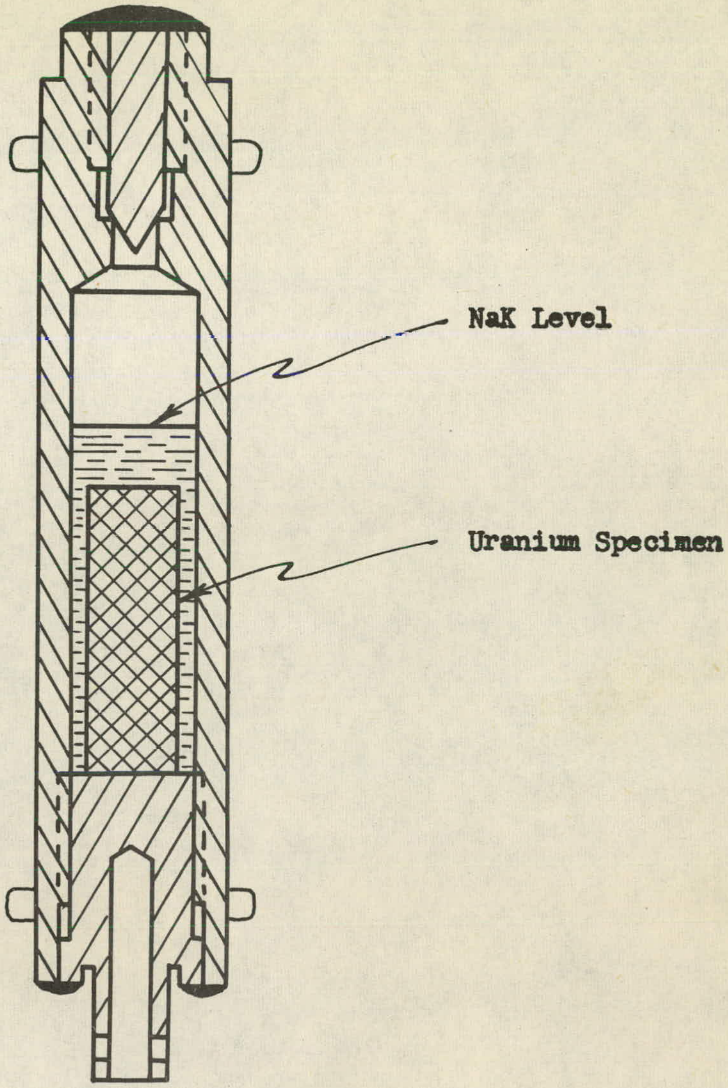

Figure 1. Cross Section of Assembled Irradiation Capsule.
Scale, 1" = 1/2"

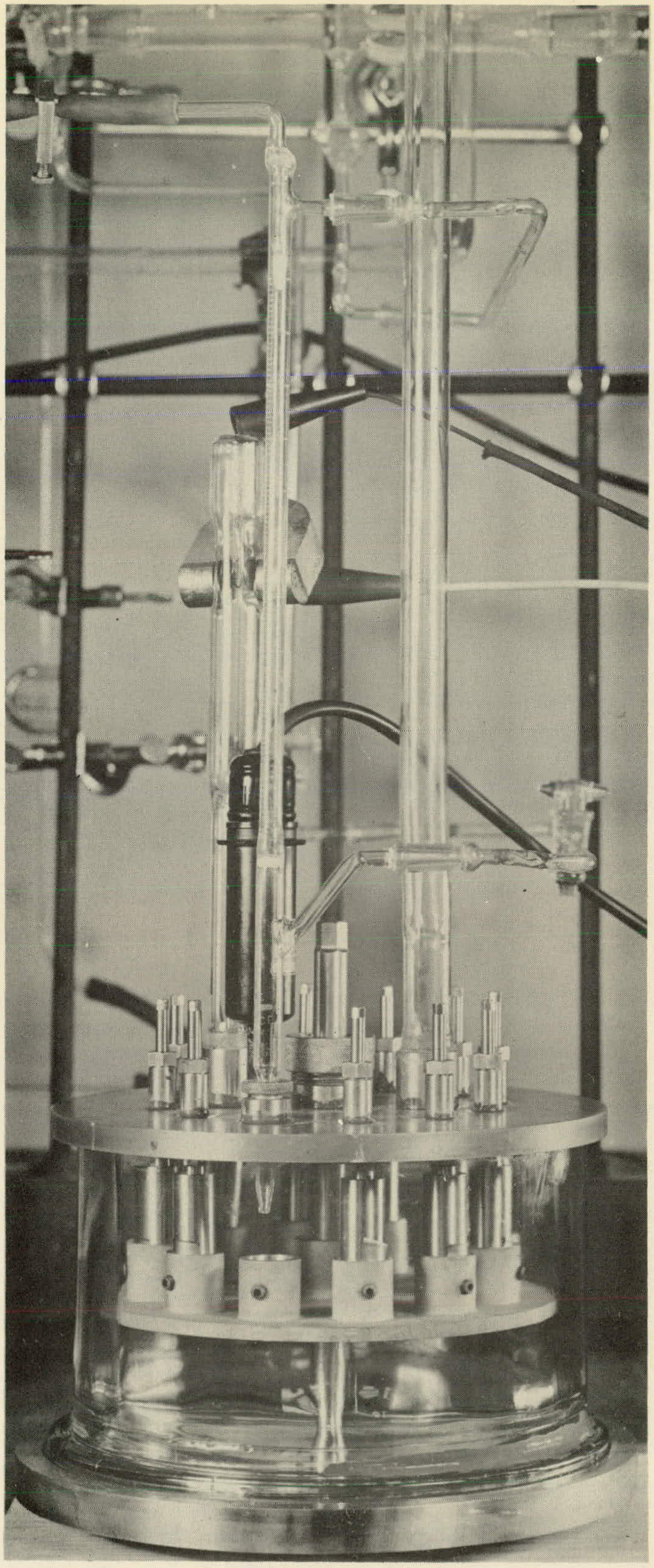

Figure 2. Vacuum Chamber Used for Adding NaK to Irradiated Capsules

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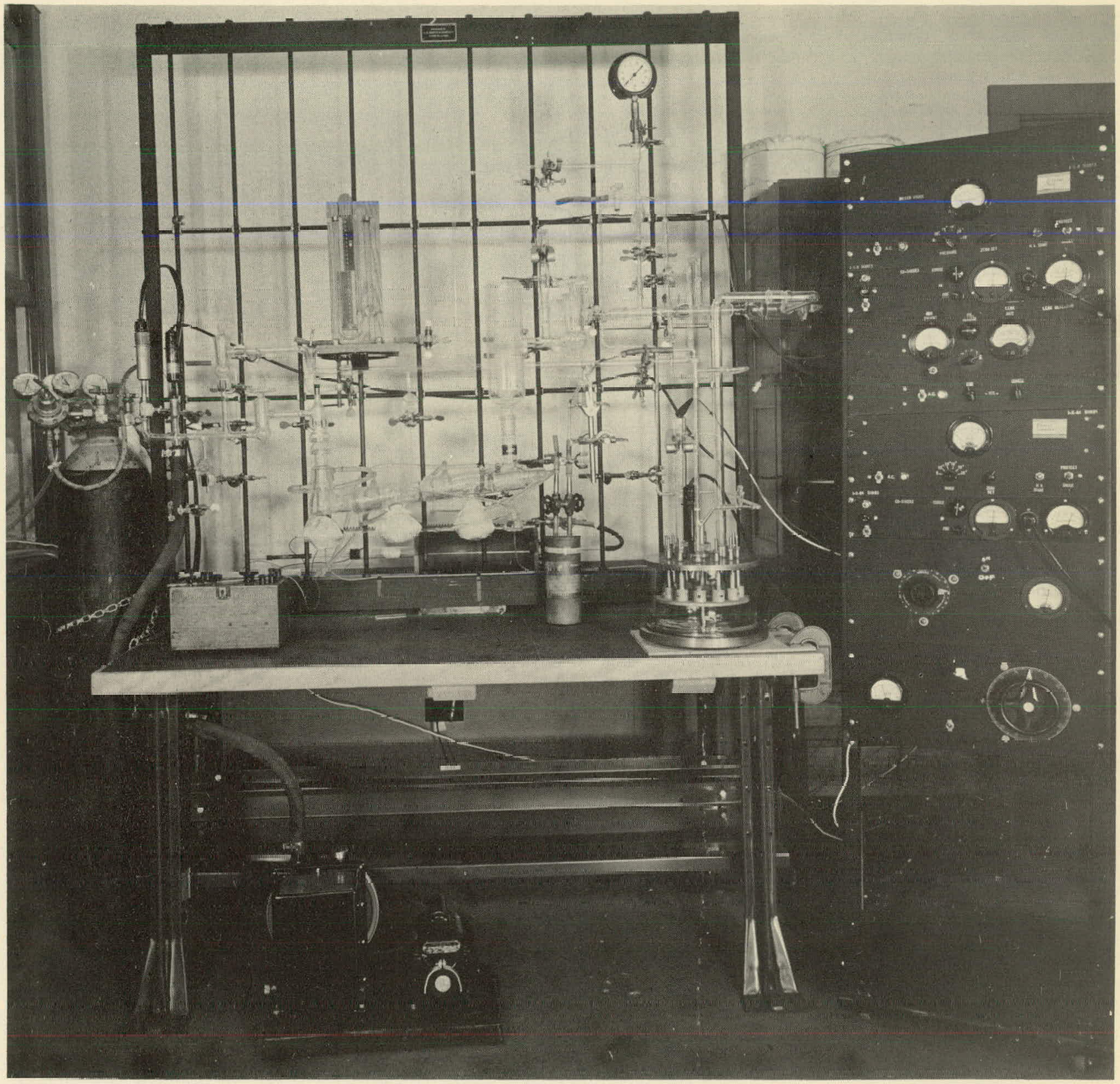

Figure 3. Vacuum and Gas Purification System

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