FACILITIES FOR INVESTIGATION OF POWER PILE MATERIALS IN THE HIGH FLUX PILE

By

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October 27, 1947

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References: 1 - Memo, S. L. Simon to E. B. Ashcraft, August 21, 1947
           2 - Memo, A. Longacre, Research Facilities in the High Flux Pile, September 16, 1947
           3 - Memo, W. C. Saeman to W. L. Sibbitt, September 4, 1947

1 - Purpose: This memorandum is prepared for the purpose of estimating what internal facilities will be required in the high-flux pile for research on materials for power-producing piles and components. Only those facilities which must exist within the outer boundary of the high-flux pile shield have been considered. Facilities for handling irradiated samples during and after removal from the pile must be given consideration in the immediate future. The memorandum is based on studies made by a group consisting of G. A. Anderson, R. O. Brittan, R. Downing, N. Lansing, L. C. Livesay, C. L. Segaser, W. L. Sibbitt, and T. H. Thomas. Details of some of these studies are contained in Appendices A, B, C, D, E and F.

2 - Approach to the Problem: The problem of radiation testing of materials for power-producing piles has been examined. It is evident that the amount of radiation testing required for the building of any given pile is not determinable on purely technical grounds, but may vary from zero to some very large amount, as determined by the design of the contemplated pile, the performance demanded of it, its expected usefulness, the urgency of the over-all program and other intangibles. If, however, the testing of materials is considered as part of a general development of practical power-producing piles, some estimate of the magnitude of the program can be made.

   It has been assumed that the latter approach is the useful one in determining what test facilities should be included in the high-flux pile, and an attempt has been made to anticipate the needs of a general, rather than a specific development program.

3 - Magnitude of the Test Program: An attempt is made in this section to give some indication of the magnitude of the necessary radiation-test program by outlining the tests of materials for certain critical pile applications as they can be foreseen at this early date. If only the solid materials which go into the pile proper (everything within the outer shield surface) are considered, they may be classified according to the following scheme (See Appendix A).

   1 - Active portion of the pile
      a - Permanent structure
      b - Control rods
      c - Fuel elements

   2 - Supporting structures
   3 - Thermal insulations
   4 - Shell inclusions
   5 - Radiation shielding
The limitations of materials in Category number 1 are recognized as possible sources of serious limitation on pile performance, and have been given sufficient thought to make possible some prediction of a test program. Such a program is outlined in Table I. The outline is based upon Reference 1 and Appendices A, B, and C. Inevitably, the outline can be prepared only on the assumption that the needed information is acquired by straightforward test methods. Short cuts in the program that may arise as a better understanding of the fundamental effects of radiation is acquired, or as inter-relations between the variations of the several important material properties are discovered, cannot be predicted. On the other hand, neither can allowance be made for unforeseen experimental difficulties, or for the possibility that very high flux irradiation may produce new effects that lengthen the program. The individual reader will undoubtedly form his own conclusion as to whether the outline is optimistic or pessimistic.

No attempt has been made in Table I to specify the hole sizes needed for the various tests. The irradiation facilities required have been expressed only in square-inch months: the number of square inches of hole cross-section times the number of months of use. The estimates are based on the use of test and irradiation devices similar to those described in the next section. The estimates refer to irradiation time alone; they do not include allowances for pile shut-down, unsuccessful tests, development of test techniques, etc.

Table I indicates that the number of test-holes required for adequate progress on a materials-development program is very large. The table accounts for more than 16,000 square-inch months of irradiation facilities (equivalent to 48 six-inch-hole years), and it does little more than cover an investigation of materials presently available. Since the future development of power piles will depend to a large extent on the development of materials, the need for test facilities may be expected to increase rather than decrease with time. In the face of such large anticipated needs, the conclusion may be drawn that all of the high-flux-pile test facilities are needed for irradiation tests on materials for power-producing piles. Inasmuch as the high-flux pile is intended to be a general research facility, the practical statement of the conclusion is that as many as possible of the facilities should be devoted to the materials work. A satisfactory rate of progress on the materials problem can perhaps be attained when the high-flux-pile facilities are supplemented by a pile built especially for research related to the development of power-producing piles.

4 Types of Tests: The types of tests required are outlined in Table II. The estimates of hole-months of irradiation required to subject a single material to the tests of a given type are supplied for the purpose of estimating the relative importance of the various holes. In estimating the minimum hole sizes required, only increments of two inches on the hole diameter were considered. The size estimates are based on preliminary layouts of typical test facilities. Sketches of some of the proposed facilities are given in Drawings 1, 2 and 3. Drawing 1 is a cross-section of a sample holder for the irradiation of a group of samples at whatever temperature is desired.

The sample holder is designed to accommodate a multiplicity of samples in the axial as well as in the radial direction in order to provide groups of samples of various total exposures from a single test run.
Drawings 2 and 3 show facilities for tensile and compression tests, respectively, during irradiation. Further description of these two facilities is contained in Appendix C. It is evident from the sketches that the design of these facilities is at a very early stage. The hole-size estimates are therefore subject to some uncertainties. There is little doubt, however, that for tests to be made in the high-flux region, 4-inch holes will be of use for simple irradiations, and that 6-inch holes will accommodate most of the tests carried out during irradiation. Some of the tests of the latter type may require an 8-inch hole. Preliminary consideration of set-ups for simulated performance tests of fuel element and permanent structure materials indicates that an 8-inch hole may be necessary. The study of such facilities has not progressed to the point where drawings can be made.

In considering the tests to be made in the lower-flux regions, the availability of the VG-9 hole has been assumed, and its use has been specified. With regard to experiments at the lower radiation intensities, it is estimated that the VG-9 hole will be kept in practically continuous use if it can be modified in accordance with the recommendations of Appendix F.

Types of Test-holes Needed: It is evident from the preceding section that 6-inch holes penetrating to the reactor face are necessary for the tests performed during irradiation. The 8-inch hole will undoubtedly be needed from time to time for tests of the same type. Irradiation of samples for subsequent test can be carried out in 4-inch holes penetrating to the reactor face. Unless the total radiation facilities provided are fairly extensive, use of the facilities will have to be limited almost entirely to radiation of samples for subsequent test. For this reason, consideration of tests to be made during irradiation becomes realistic only if a total of at least two high flux holes is allocated exclusively for the testing of power-pile materials.

Relation of Work to That of Other Groups: The tests and facilities discussed in this memorandum all relate directly to the development of materials and components for power-producing piles. The tests considered may be carried out by groups (such as the metallurgical and solid states groups) outside the Power Pile Division. Insofar as this is true, the memorandum may be considered to apply to such groups. It does not, however, cover facilities for any other types of investigations, such as studies of the fundamental effects of radiation on the structure of matter and tests of materials for other types of piles, to which these groups may devote most of their efforts. Some of the additional facilities required by these groups (e.g., space for low-temperature tests) have already been mentioned at meetings held to consider the research facilities of the high-flux pile (See Reference 2).

Further Work on Test Facilities: Design work, probably supplemented by some experimental construction, should be continued on facilities such as those of drawings 1, 2 and 3 in order to expose at an early date any need for modification of the pile design.

Agreement must be reached with other groups as to the arrangement of the VG-9 facility, after which detailed design of the facility must be completed.

Preliminary design should be begun on facilities for irradiation of samples in the reactor of the pile for the case where the sample holder is to be inserted in the space left vacant by the omission of one of the fuel cells. Although, the
design will present considerable difficulty, a great deal of effort is justifiable in order to make use of the maximum fast flux that exists in the pile. Immediate attention should be given to the problems of removing hot samples from the test holes and of subsequent handling of the samples. In this connection, the design of the hot laboratory should also be given consideration. The possibility of including facilities for the irradiation of organic materials by the radiation from spent fuel elements, as proposed in Reference 3, should be investigated.

8 - Recommendations:

   a. That the facilities allocated for development of materials for power-producing piles be not less than; and, if at all possible, more than:

      1 - One six-inch and one four-inch hole, penetrating to the reactor face, plus

      2 - The VG-9 hole, plus

      3 - Occasional use of the 8-inch beam hole.

   b. That the design of the VG-9 hole be modified in accordance with Appendix F.

   c. That immediate steps be taken to ensure that adequate facilities can be provided for handling of the proposed samples and associated apparatus after irradiation.

   d. That work be begun on the design of apparatus for the irradiation of samples in the active pile lattice itself.
APPENDIX A

Evaluation of Materials for High Temperature Pile Construction

Abstract:

A preliminary outline of an investigation of the physical and mechanical properties of materials which could conceivably be used in a high temperature pile has been formulated.

The possibility of using the test facilities of the hot pile for these investigations has been studied. The time schedule for the first stage of the investigation has been estimated and the second stage of the investigation has been indicated.

Introduction:

A somewhat arbitrary separation is obtained by grouping the materials in one or more of the following categories:

1. Active portion of the pile
   a. Permanent structure
   b. Fuel materials and fuel units
2. Supporting structures
3. Thermal insulations
4. Shell inclosures
5. Radiation shielding

The study of materials in category number one is of paramount importance. Although a pile may not necessarily have a permanent structure within the active portion, the fuel units may contain an inert material in order to retain their integral form or to provide surface area for heat transfer. Only a few materials in category No. 2 operate under severe conditions as compared to those in category No. 1; consequently, they are of secondary importance at this stage of the investigation.

In a relative manner, considerable information is now available on materials which would be included in categories Nos. 3, 4 and 5.

A rational investigation could be made as follows:

Stage 1:

Evaluation of materials in order to find those which could be used as portions of the permanent structure within the active region of the pile.

Stage 2:

a. Development of materials for permanent structures (Contingent upon Stage 1).

b. Evaluation of materials for fuel elements (Guided by Stage 1).
Stage 3:

a. Development of fuel elements. (Contingent upon Stage 2b).

b. Evaluation of supporting structures, thermal insulation, shell enclosures, shielding, etc.

Stage 4:

a. Development and testing of integral components of proposed installations.

Outline of Program for Stage #1

At present, it would appear that the following materials could conceivably be used in high temperature pile construction:

1. Graphite
2. Beryllium oxide
3. Beryllium

Therefore, these materials should be critically evaluated. Of major interest is the effect of fast neutrons and concomitant irradiation at various temperature levels upon the physical stability, and upon the physical and mechanical properties of the materials.

Some information is now available for exposures at moderate flux densities and room temperatures. The major effort should be expended in obtaining data at very high fast flux densities and high temperatures. If suitable specimens are designed for exposures in small water cooled containers placed in the regions of maximum fast flux in the het pile test holes, it is feasible to obtain the following physical properties:

<table>
<thead>
<tr>
<th>Tests for BeO and Graphite</th>
<th>Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Modulus of rupture</td>
<td>A</td>
</tr>
<tr>
<td>2. Crushing strength</td>
<td>B</td>
</tr>
<tr>
<td>3. Elastic modulus</td>
<td>C or D</td>
</tr>
<tr>
<td>4. Dimensional changes</td>
<td>C</td>
</tr>
<tr>
<td>5. Thermal conductivity</td>
<td>C</td>
</tr>
<tr>
<td>6. Temperature coefficient</td>
<td>C</td>
</tr>
<tr>
<td>of linear expansion</td>
<td></td>
</tr>
<tr>
<td>7. Stress vs. strain diagram</td>
<td>A and B</td>
</tr>
</tbody>
</table>

Suitable specimens for obtaining data of reasonable accuracy are as follows:

Sample A 1/2" x 1/5" section on 1/2" dia. x 3" long
Sample B pellets - 1/2" dia. x 1" long
Sample C 3/8" dia. x 3" long
Sample D 1/5" dia. x 3" long

Four samples would be the minimum number required to obtain any one property. The water jacketed aluminum containers would be approximately 13" long and contain 4 complete sets of test specimens. The average fast flux density over the region of the first sample (2.4 x 10^{14}) is approximately 20 times the density over the
last sample. A number of thermocouples are placed at various locations within the container. The filler within the specimen container could be either graphite or beryllium oxide powder. A heater could be provided within the container in order to control the temperature.

<table>
<thead>
<tr>
<th>Test Series</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
<td>Beryllium oxide</td>
<td>Graphite</td>
<td>Beryllium</td>
</tr>
<tr>
<td>Temperature of exposures</td>
<td>500 °F</td>
<td>500 °F</td>
<td>A few samples of Be should be included in the testing of the BeO and graphite (1500°F)</td>
</tr>
<tr>
<td>Length of exposure</td>
<td>1 week</td>
<td>1 week</td>
<td>3 months</td>
</tr>
<tr>
<td></td>
<td>6 months</td>
<td>6 months</td>
<td></td>
</tr>
<tr>
<td>Total time</td>
<td>18 to 28 months</td>
<td>18 to 28 months</td>
<td>6 months</td>
</tr>
</tbody>
</table>

Test series 1, 2 and 3 are to be made at the maximum fast flux density and over the temperature range indicated. Since the present data indicates that beryllium is not appreciably affected by fast flux only a few specimens of beryllium should be included during the tests on the oxide and graphite. However, it is necessary to obtain some stress-rupture data on beryllium since unpredictable processes may occur at high temperatures and high flux densities. It is considered that the maximum time for a pseudo creep experiment is 1000 hours.

Test series 1, 2 and 3 could be carried out in 4", 6" or the 8" holes in the hot pile. The unit could be operated to obtain some data on all three materials during the same test; however, the results would be based on very few samples and therefore they would not be used for reliable design data.

Estimation of the time required to complete Stage #1

| 1 - 4" hole | 4.5 years |
| 1 - 6" hole | 3  4 years |
| 1 - 8" hole | 3   years |

It is not probable that the program can be curtailed by a rational elimination of any one of the above materials since sufficient data are now available to show that each material may eventually be used in high temperature pile construction. The merits of these materials should be plainly indicated by these tests.

It is probable that 8" test holes show no advantages over 6" test holes for the exposure of ordinary test specimens (1/2" dia. x 3" long). However, they may be required in order to provide sufficient space for stress rupture tests since it does not appear feasible to perform this in a 4" hole.
Brief Outline of Program for Stage #2

As previously outlined Stage #2 was given as follows:

a. Development of materials for permanent structure (Contingent upon Stage #1).

b. Evaluation of materials for fuel element units (Guided by Stage #1).

It is obvious that the probable schedule for Stage 2a cannot be estimated; since the ramifications of a development program cannot, in general, be predicted. In any case, the time required (using the same technique as in Stage #1) will be greater than 5 years for any one material with the exception of beryllium.

In the case of beryllium, it would be necessary to perform creep tests (or at least one set of tests) under high fast flux density conditions. If beryllium showed no unusual effects then the tests would be directed more to obtaining information such as:

1. Chemical activity under irradiation (corrosion, reaction with various coolants, etc.).
2. Welding of adjacent units.
3. Limiting temperature under irradiation conditions.

Most of the tests would not require test holes over 4" in diameter. The development tests on beryllium would at present be greatly limited by the meager selection of fabricated metal now being produced. In the case of BeO and graphite, due to the large range in material produced by various methods of manufacture, a period of over 5 years would probably be required to develop either one of the materials. The time required would be much shorter if no appreciable damage occurred at high temperatures but this is a rather remote possibility.

This time could not be appreciably shortened even if a test is perfected which will directly evaluate the performance of the material. This figure of merit test set-up as presently envisioned could not be mounted in a hole smaller than 6" in diameter.

Stage 2b (evaluation of materials for fuel elements) will require a large number of samples for exposures. At present, it is not known that the flux intensity is an important factor. Therefore, some tests must be made in both the low density and high density regions to evaluate this variable. The 4" diameter test holes would be adequate for these experiments. These evaluations could not be reliably performed in less than one year.

The time required for Stage #3 cannot be estimated since it is rigidly dependent on the preceding investigations. The time consumed in such work would, to a certain extent, be controlled by an arbitrary decision. Normally this work continues indefinitely after construction and operation of commercial units.
### Summary

<table>
<thead>
<tr>
<th>Stage</th>
<th>Test Holes Used</th>
<th>Time Required</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4&quot;</td>
<td>4.5 years</td>
</tr>
<tr>
<td></td>
<td>6&quot;</td>
<td>3 years</td>
</tr>
<tr>
<td></td>
<td>8&quot;</td>
<td>3 years</td>
</tr>
<tr>
<td>2</td>
<td>4&quot;, 6&quot; or 8&quot;</td>
<td>5 years (for any one material)</td>
</tr>
</tbody>
</table>

In each case, the creep data probably must be obtained by exposure in a hole greater than 4" in diameter.

These estimates do not allow for development of techniques and are based on 100% use of the test holes.

\[ W. L. Sibbitt \]
APPENDIX B

Radiation Experiments Associated with Fuel Element Development

Complete knowledge of a pertinent property or characteristic of a material to be used in a fuel element for a power pile would require accumulation of sufficient data to develop a family of three-dimensional surfaces. Two classes of variables are involved. (Refer to Figure on page 18). The first class embraces the three dimensions of each surface:

1. Property or characteristic being studied ($F$)
2. Irradiation parameter (flux density-time) ($\lambda_t$)
3. Temperature ($\lambda_t$)

The second class of variables constitutes a material function which becomes the family parameter ($\varphi_m$). Components of this class are:

1. Structure ($\varphi_s$)
2. Fabrication method ($\varphi_s$)
3. Density ($\varphi_d$)
4. Composition ($\varphi_c$)

For most materials being tested, a minimum of 4 tests of a kind are required since results should be evaluated on a statistical basis.

I. Tests for evaluating irradiation damage factor

A. Fundamental Physical Property Tests ($\varphi$)

1. $\sigma$ vs $\epsilon$ (stress-strain relationship to rupture) ($\varphi_s$)
2. $\alpha$ (coefficient of thermal expansion) ($\varphi_s$)
3. $\kappa$ (thermal conductivity) ($\varphi_s$)
4. $\nu$ (Poisson's ratio) ($\varphi_s$)
5. $C_p$ (specific heat) ($\varphi_s$)

B. Overall Tests (Evaluation of thermal rupture resistance factor) ($\varphi_r$)

II. Tests for evaluating canning effectiveness

A. Establishment of standards. A standard (uncanned) sample must be tested for each $\varphi_m$. Characteristics to be determined are:

1. Migration time of fission products from point of fission to coolant boundary (for study of delayed neutron emitters).
2. Rate of fission product release.
B. Specimens must be tested for each type of canning attempted and compared with standard.

1 & 2 - Same as above.

Both A and B are time dependent.

**TEST TYPE I**

To obtain variation of $\gamma$ with $\lambda_1$ and $\lambda_2$ for a single value of $\gamma_m$ requires a minimum of 64 test samples, assuming four samples for each point ($\gamma, \lambda_1, \lambda_2$). The number of values of $\gamma_m$ which must be examined for each material combination varies with type of material. For example, if the basic combination of BeO with UO$_2$ were to be examined:

1. $\gamma_3$ would have a value of 2 for the two types:
   a. Mixture of BeO and UO$_2$.
   b. BeO impregnated with UO$_2$.

2. $\gamma_4$ would equal 4 for the following four fabrication methods.
   a. Hot-pressed
   b. Cold-pressed and fired
   c. Dust-pressed and fired
   d. Extruded

3. $\gamma_5$ would have a value of 3 for the three densities.
   a. Low density
   b. Medium density
   c. Maximum density

4. $\gamma_6$ would be 3 for the three compositions
   a. 100% BeO + 0% UO$_2$
   b. 98% BeO + 2% UO$_2$
   c. 90% BeO + 10% UO$_2$

Hence the number of values of $\gamma_m$ which must be investigated are obtained as follows:
For the values of $y_c$ having $\%\text{UO}_2 = 0$,

\[
(N_{\text{imp}}) = N_k x N_{\text{X}} x N_{\text{U}} x (N_{y_c} = 2)
\]

\[
= 2 \times 4 \times 3 \times 2 = 48
\]

For values of $y_c$ having $\%\text{UO}_2 = 0$

\[
(N_{\text{imp}}) = 1 \times 4 \times 3 \times 1 = 12
\]

Giving $N_{\text{imp}} = 48 + 12 = 60$

For this material combination then, $64 \times 60 = 3840$ tests are required. If, however, $y_c$ were reduced to cases a and d only, the total number of tests would be $3840 \times \frac{2}{4} = 1920$. Such a reduction would be brought about before irradiation effects are considered by judging the merits of certain $\phi_m$'s on the basis of other factors (for example, on the basis of thermal rupture resistance factors obtained for unirradiated material). Obviously, any possible reduction in the number of $y_c$'s by prior tests should be realized. To give a better argument favoring this method of attack, consider again the material used above as an example:

1. ($y_c$) By a few judicious tests, it might be possible to prove superiority of impregnation over mixtures.

hence $N_{y_c}$ would = 1.

2. ($y_c$) Only two out of the four fabrication methods shown here might be capable of rendering some required complex design. Then $N_{y_c}$ drops to 2.

3. ($y_c$) Evaluation of thermal rupture resistance factor for unirradiated material might indicate that only low densities are of interest then $N_{y_c} = 2$

4. ($y_c$) Required values of $\%\text{UO}_2$ might be found to be low and might be accurately known. $N_{y_c}$ would then reduce to 2.

If these things should prove true,

\[
\frac{1 \times 2 \times 2 \times 2 \times 2}{4} = 8
\]

and the total number of test samples would be reduced to $64 \times 8 = 512$ for each property desired.

The types of material combinations are next presented. The three basic types are:

1. $\text{BeO} - \text{UO}_2$

2. $\text{C} + \text{UC}$

3. $\text{Be} + \text{U}$

To these can be added

4. $\text{Be}_2\text{C} + \text{UC}$

5. $\text{BeO} + \text{C} + (\text{UC or UO}_2)$

6. $\text{BeO} + \text{Be} + \text{UO}_2$
Branches of these basic types can be multitudinous if admixtures are considered (for example, where a metallic oxide is added to improve thermal rupture resistance). Some possibilities are

7. BeO + Beryl + UO₂
8. BeO + MgO + UO₂
9. BeO + Al₂O₃ + UO₂

Preliminary studies of high temperature reaction rates are necessary to limit the number of combinations to a minimum.
APPENDIX C

Equipment for High Temperature, High Fast Flux Material Testing

Creep Test:

A creep test program, conducted in a 6" diameter hole that penetrates to the reactor face, may consist of beryllium metal, beryllium-uranium alloy, and control rod materials. A tentative test schedule may be as follows for each material:

I. Stress-Rupture - at 2000 °F. and 1700 °F.

II. 1000 hour creep tests - at 1000 °F, 1500°F., and 1750 °F.

Three stresses per temperature.

This schedule would require approximately 9000 hours per material. A minimum program, based on the assumption that an experimental high temperature reactor will be available, would consist of possibly two or three control rod materials. If no changes were detected from creep tests outside of the pile, this program could obviously be greatly reduced.

A possible structure for conducting creep and stress-rupture tests inside the pile is shown on Dwg. 2. It consists of a 7" O.D. x 6 1/4" I.D. x 14 ft. long steel tube with a 5 1/2" O.D. x 4 3/4" I.D. x 2 ft. long aluminum end which fits into a 8" diameter hole to the beryllium, and 6" diameter to the reactor face.

The conical inner end of the aluminum tube is machined to form a spherical seat for the inner specimen support, which is a steel tube. The test specimen is sealed, in an inert atmosphere, by means of a steel container. Gas pressure is equalized with respect to outside pressure by a relief line which is extended to outside the shielding.

A maximum load of 500 pounds is transmitted by a steel tension tube from outside the pile, through a bellows seal in the seal container, to the test specimen. The tube is supported at each end and connected to the specimen through a ball and socket joint in order to avoid eccentrically loading the test specimen. The problem of holding a constant load for the duration of the test should cause no great complication as it is applied from outside the pile. As long as friction of support member is kept a small percentage of applied load, no serious error is introduced. This can possibly be accomplished by varying the specimen cross-section to suit test conditions.

Means for getting rate of elongation during testing present considerable difficulties, both in the actual measuring device, and in mechanical connection between the specimen and measuring device. Two mechanical connections are being investigated; each of which may introduce a minimum error of 3%. This is based on a temperature variation of ± 5 °F., as specified as an allowable maximum change for the test specimen.

One mechanical connection, shown on Dwg. 2 consists of wires, or rods fastened to the gage points by means of clamp-arms fastened directly to the specimen at gage points. An additional error may be introduced if the clamp-arms either creep or slip.

An alternate scheme is based on changing cross-section in the region of the gage points and taking mechanical connections from the end steel support tubes. Potential errors due to elongation at support points and the indeterminate gage length will probably make this scheme no improvement over that previously mentioned. This problem of mechanical connection requires considerable investigation and test.
Each point (•) represents 4 tests

Each surface (defined by 16 points) represents 64 tests

Each value of φ represents 64 tests.

\( r \) = property or characteristics
\( \lambda_i \) = irradiation (flux density-time)
\( \lambda_t \) = temperature

**Drawing No.**
4764
The general thought that electrical magnification in the detecting instrument rather than some mechanical and some electrical may be more accurate has been reason for avoiding any linkage system. If this proves false, mechanical magnification can be attained without any change in the general arrangement of parts. See Appendix D for discussion of possible measuring devices.

Thermocouple and heater leads enter the hole through the tension tube. Shielding can be accomplished by filling the tube with a spiral steel insert. Shielding between tension tube and structural tube can consist of steel rings fastened alternately to structure and tension tube. See Appendix E for data on cooling and heating requirements.

A total weight of equipment of 2300 pounds can possibly be supported outside the pile. The structure will have a maximum deflection of 0.4", which should cause no trouble as there is a clearance between hole and structure of 1".

A representative method of compression testing is shown in Dwg. 3. This apparatus would be used to expose test specimens, while under compression, to the highest available fast neutron flux at a controlled temperature. No attempt has been made to measure change in length during exposure.

A self-contained unit composed of test specimen, heater coil, and frame fits into an outer shell. This assembly, in turn, fits into a 6" diameter hole. Load is applied by means of a gas force exerted on a moveable piston that bears directly against the test specimen. It is held constant by controlling pressure outside of the pile.

G. A. Anderson
APPENDIX D

Measuring Devices for the Determination of Strain Due to Creep in Test Specimens Inserted in the High Temperature Test Hole of the Proposed Experimental High-Flux Pile

Introduction:

Because of the unusual conditions under which measurements of strain at high temperature must be secured in creep tests conducted under irradiation in the high-flux pile, the following criteria have been established as a guide for the selection of a successful strainometer for this application.

(a) The pick-up element must not have its accuracy or stability affected by irradiation.
(b) It must be capable of detecting and transmitting changes in length due to creep strain only, without transmitting strains due to temperature expansions or contractions.
(c) The data must be obtainable by detecting or recording devices located remotely or outside of the pile shielding.
(d) It must be sufficiently sensitive to measure strains in the order of micro-inches in the specimen.
(e) It must be small, rugged and dependable, and be cheap enough to discard after one usage because of possible excessive induced radioactivity of the strainometer and specimen after exposure.
(f) Attachment to the specimen must be such as not to in any way distort the specimen nor create disturbances in the ambient radiation field, nor should the attachment interfere with heat transfer to the specimen.

Types of Strain Measuring Devices:

Numerous devices based upon widely varying principles have been developed for strain measurements. A few of these devices, with the principle involved and the expected range and sensitivity, are presented in the attached table as typical of commercially available strain gauges.

It is anticipated that the majority of these types will not be suitable for use as strain gauges in the pile because of non-conformity to one or more of the previously listed criteria. For instance, such devices as the Huggenberger Tensometer, Riehle device, etc. would necessitate mechanical linkage at least sixteen feet in length to the recording instrument for convenience in reading. It is obvious that such an arrangement is impractical for reliable and consistent results because of such difficulties as mechanical deflections, thermal expansions, and joint friction losses. Optical methods may also in general be ruled out because of the difficulties involved in transmitting a beam of light from the specimen to the outside of the pile shielding through the small hole allowed for insertion of the apparatus. Other types of devices are based upon such principles as piezo-electrical and sonic phenomenon which depend upon changes in the actual properties of material with strain for functioning. However, it is obvious that in the pile the effects of radiation upon physical properties of material are unpredictable and hence introduce factors of uncertainty which apparently eliminate the use of such devices for precise strain measurements in the pile.
<table>
<thead>
<tr>
<th>Name of Device</th>
<th>Principle</th>
<th>Usual Gage Length (inches)</th>
<th>Approximate Smallest Mean Strain (Micro-inches per inch)</th>
<th>Approximate Range of Strains (Per cent)</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>SR-4 Bonded Electric Strain Gage</td>
<td>Electrical resistance</td>
<td>1 (6 to 1/16&quot; on other types)</td>
<td>0.5</td>
<td>1</td>
<td>Baldwin Locomotive Works Bulletin No. 179</td>
</tr>
<tr>
<td>Tuckerman Strain Gage</td>
<td>Optical Lever</td>
<td>1 or 2</td>
<td>2 on 0.2&quot; losenge</td>
<td>0.25 on 2&quot; g.i.</td>
<td>American Instrument Co., Bulletin No. 179</td>
</tr>
<tr>
<td>Interferometer Types</td>
<td>Light wave interference</td>
<td>*</td>
<td>2</td>
<td>About 1</td>
<td></td>
</tr>
<tr>
<td>Huggenberger Tensometer</td>
<td>Mechanical lever</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>Baldwin Locomotive Works Bulletin No. 139</td>
</tr>
<tr>
<td>General Motors Gage</td>
<td>Grids and Photo-elec. cell</td>
<td>1/64 to 1/4</td>
<td>2</td>
<td></td>
<td>Godd and Van de Grift Trans. A.S.M.E.V. 64 (1942)</td>
</tr>
<tr>
<td>Riehle</td>
<td>Dial Gage</td>
<td>2</td>
<td>100</td>
<td>2.5</td>
<td>American Machine and Metals, Inc. Bulletins</td>
</tr>
<tr>
<td>Photograds &amp; Comparators</td>
<td>Microscope Comparator</td>
<td>0.01 to 0.25</td>
<td>*</td>
<td>About 40</td>
<td>Experimental Stress Analysis, Vol. II, pp. 59-70</td>
</tr>
<tr>
<td>Magnetic Gage</td>
<td>Magnetic</td>
<td>3</td>
<td>5</td>
<td>About 1</td>
<td>Experimental Stress Analysis, Vol. I, pp. 82-89</td>
</tr>
</tbody>
</table>
Therefore, it may be seen that for one or more reasons the majority of the commercially available types of strain gages are not suitable for adaptation in the pile. However, a great amount of research and development work has been done on strain gages based upon electrical methods of mechanical measurement, and these appear to be feasible for use in the pile since they can apparently be made to meet all of the criteria as previously presented. In general, these methods depend upon the measurement of the change in resistance, capacitance or inductance of an electrical circuit induced by the change in length of the specimen to which a portion of the circuit, called the "pick-up element", is attached. An alternate method of electrical measurement based upon principles of micro-wave transmission in a wave-guide is suggested as a possibility.

General Arrangement of Strain-Measuring Equipment:

Drawing shows the general arrangement of equipment for conducting creep tests on materials in the high flux pile. The specimen is shown as a tension member of one-half inch rod approximately five-inches between thread grips. The actual measurement of creep-strain will be made over a gage length of three-inches by attaching collars at these points with knife-edged supports or very sharp pointed set-screws. To these collars will be attached push rods which will serve to transmit relative motion of the measuring points to the pick-up device which is to be located in the annulus of the test-hole away from the pile face. These rods extend through very light bellows in the gas-tight can surrounding the specimen in order to form a leak-proof seal. By thus transmitting the relative strain by mechanical linkage over a comparatively short distance, using small diameter rods and light collars, there will be a minimum of disturbance of the radiation field surrounding the specimen, and the pick-up element will be removed from the region of high-temperature and placed in a field of lower flux.

Since the expected range of strain to be produced in the specimen is to be in the order of one per cent, there will be a total relative movement between gage points of:

\[(0.01)(3) = 0.030\] inches.

The strain gage should, therefore, be capable of measuring total elongation over this range and should be sensitive to increments of change in the order of micro-inches.

Gaging Methods Based on Variations of Resistance:

Several experimenters, but principally the Baldwin Locomotive Works, have developed very sensitive and inexpensive strain gages based upon change of electrical resistance of the gaging element with changes in strain. These devices have as a matter of fact supplanted gaging elements based upon changes of capacitance or inductance for ordinary strain gage applications because of their simplicity.

For use as a strain gage in the pile, however, it must be remembered that actually this type of gage depends upon change in electrical resistance with strain which is a property of material, and this property may be subtly altered by radiation in such manner as to make the measurements unreliable. This objection may be possibly overcome, however, by using an unstressed gaging element mounted side-by-side with the actual gage to serve as a compensating element or comparator. Also, it may be
possible to use this type of element as a ratio-gage in which the strain causes a decrease in resistance in one element of the gage and a corresponding increase in the other element with the actual measurement being one of difference between the two sides. Thus, the effects of radiation on resistance may be made to cancel out since both elements of the gage should experience simultaneously material alterations due to radiation.

Intrinsically, the variable-resistance gaging systems are less sensitive than either the variable-inductance or the variable capacitance systems because of the fact that the percentage change in gage impedance, for equal movements, is smaller. The sensitivity or resistance-sensitive elements, too, depends upon the characteristics of the material of which they are made. Therefore, while the variable-resistance type of gaging element should not be discarded as a possibility for measuring strains in creep specimens, it appears that a strain measuring device based upon one of the other principles may be more feasible for the pile, principally because these devices can be made to depend on changes in position only of the moving element for operation without depending upon changes in material characteristics which may be altered by radiation, and because evidently they can be made more sensitive.

Gaging Methods Based on Micro-Wave Principles:

These methods were suggested by Dr. Lloyd B. Hunter and others as possible strain measurement methods for use in the pile. One of the suggested methods would depend upon the generation of high-frequency micro-waves, conducting these waves through a suitable wave-guide to a movable probe fastened to the creep specimen and then measuring the displacement of the reflected and amplified micro-wave peak on an oscilloscope. However, there is considerable doubt as to the sensitivity of such a device for measurements of displacement in the order of micro-inches, although, theoretically, the principle appears to be feasible. An alternate method suggested as furnishing greater sensitivity, would depend upon the establishment of a resonance-cavity at the end of the wave-guide. This cavity would require ultra-fine finishes in its interior and craftsmanship of the highest order for proper accuracy and stability. As one end of the cavity moves with the gage point, the operator would respond with a change of frequency or other parameter until resonance was re-established, and this change would be calibrated in terms of strain.

However, neither of these methods have apparently been previously developed for measurements of this magnitude, and, hence, they are suggested but not particularly recommended for pile creep-test measurements. Considerable research and development would necessarily be required for adaptation of either of these methods to the pile in order to determine the possible affects of radiation and temperature changes on the wave-length and hence the accuracy and stability of the system.

Gaging Methods Based on Variations of Capacitance:

This method is one of the oldest of the electric gaging methods and has been applied to a wide variety of mechanical measurements. In brief, the method depends upon a variation in capacitance of the element as a result of strain by changing the separation of air gap of the elements, by changing the area, or by changing the specific inductive capacity of a dielectric. For small measurements, the first of these methods is the most applicable since the percentage change in capacity can be the greatest. It is suggested as one method for use in the pile since the device depends only on a change in relative position of one element and not upon a change
in physical material characteristics. Thus, is eliminated one of the principle objections to the use of an electrical resistance strain gage. However, the capacitance type of gaging device has other objections which may be great enough to eliminate it for pile measurement consideration.

The capacitance of a parallel-plate capacitor varies as indicated in the following equation:

\[ C = 0.2248 \frac{KA}{d} \]

where,

- \( C \) = Capacitance in micromicrofarads
- \( K \) = Dielectric constant
- \( A \) = Effective area of the plates in square inches
- \( d \) = Plate separation in inches.

For strain measurements in the pile it is desirable to use a three-element push-pull ratio type of capacitance gaging element in which a difference of capacitance is measured such that any change in dielectric constant due to radiation will be experienced simultaneously by both elements and, hence, will be cancelled. This type of element consists of two fixed plates of given area with a third movable plate mounted between. This third plate is electrically insulated from the other two and is connected to the creep-test specimen by linkages. Thus, as the plates move there is a decrease in capacitance on one side and an increase in capacitance of the other, and this difference is measurable by an external connected bridge-circuit and calibrated in terms of the movement.

For a gage-length of three-inches and a one per cent range there must then be at least 0.030 inches separation between plates plus allowance for insulation, assuming there is no mechanical amplification and the gage element moves directly as the gage point. Therefore, if we assume a capacitance between one of the fixed plates and the movable plate of 100 micromicrofarads at a separation of 0.050 inches, the area of the plates by substitution in the previous formula is,

\[ A = \frac{C}{0.2248K} \]

or

\[ A = \frac{(100)(0.050)}{(0.2248)(1)} = 22.2 \text{ sq. in.} \]

If we assume the plates to be circular, the diameter corresponding to this area is approximately 5-3/8". If square, the length of the sides is 4.7", approximately. These dimensions correspond to the dimensions of the hole in which the apparatus is to be inserted and hence will apparently eliminate the use of this gage for the simple reason of inadequate space.

Also, since a source of high-frequency alternating voltage must be impressed on the condenser plates there may be considerable discharge due to the ionized atmosphere in which the gage must be placed, thus causing difficulty in maintaining a known plate charge and consequent inaccuracy of reading. Finally, the capacitance effect of the cable leads from the condenser is considerable, being of the order of 10 to 15 micromicrofarads per foot which for a cable 20 feet in length would amount to from 200 to 300 micromicrofarads or greater than the gage capacity itself. This
is a serious drawback to the use of a capacitance type of gage using long leads, but, fortunately, methods have been devised whereby the capacitance effect of the leads is minimized, and, hence, this cannot be considered a serious objection to the use of the capacitance-ratio gage in the pile. However, the other objections are very serious (size and plate discharge) and are apparently great enough to seriously limit the consideration of the capacity gage for pile use.

Otherwise, the capacitance type of gaging element has considerable merit since the sensitivity is very high; with such circuits it has been found possible to detect movements of only a few billionths of an inch, and methods are available for constructing capacitors of high stability, or in other words, which will experience little change in value over long periods of time.

Gaging Methods Based on Variation of Inductance:

These methods apparently offer the best solution to the problem of obtaining strain measurements on creep specimens in the pile. In each of the previous methods explained there were objections established by either the inherent design of the mechanism, such as exorbitant size, or due to unknown radiation effects which would prohibit the use of these devices in the pile. However, the inductance methods are based upon magnetic principles which can be assumed as independent of pile radiation (if such effects are present, the use of the inductance ratio-gage should cancel them), it is possible to obtain readings from the gage by remotely located instruments, they can be made to have a sensitivity in the order of five micro-inches per inch, and finally, they can be made small and rugged; one such gage described in the literature for creep-test measurements has a base length of less than one inch and the moving element weighs less than one-fifth ounce.

These gages depend for their operation on change in inductance—either self or mutual—of the gaging element. The pick-ups used in magnetic gaging systems are made in many forms, but for the purpose of selecting such a gage for the pile creep experiments only those working on the push-pull inductance-ratio principle are considered, (in order to eliminate radiation effects) in which the inductance is varied by moving an iron core inside of a center-tapped coil, or by using a form employing two exciting coils connected in series-opposition with a third movable coil connected to the indicating instrument. As already explained in previous sections of this report, the iron-core type may have the permeability of the iron changed by irradiation and therefore impair the sensitiveness and accuracy of the instrument; hence, the second type employing the movable coil may prove to be the more feasible.

In the series-opposition type of inductance-ratio meter three coils are employed, two of which are mechanically connected but electrically wound with opposite polarity, and the third is connected to the gage length and indicating instrument. This third coil experiences the movement to be measured, the movement removing it from the region of no magnetic flux between the two fixed coils into a region in which current will be induced in it as a function of the distance moved. This induced current may then be read by suitably located meters connected to the coil through amplifying devices if necessary.

Manufacturers of such equipment have been contacted and it is anticipated that no trouble will be experienced in adapting their products for use as measuring devices in the pile. However, it may well happen that these products may have to be re-designed in order to substitute alternate materials, such as boryllia, for insulators, etc., such that pile irradiation can be tolerated.
Electric Circuits for Capacitance or Inductance Type Gaging Elements:

The function of an electric circuit associated with an electrical type of gaging element is to convert changes of resistance, capacitance or inductance into corresponding changes in voltage, current or frequency, and to indicate or record these changes. There are two general methods by which this conversion can be accomplished. One method utilizes the capacitance or inductance of the gaging element in an electrically resonant circuit, and the other utilizes the gaging element as a reactance in a bridge circuit.

Several excellent circuits involving both of the above methods are described in the literature, hence, no attempt will be made in this report to describe such circuits. However, there is a strong recommendation for the use of the bridge-type circuit, based upon the fact that in addition to being among the most sensitive circuits developed, this type circuit has proved to be inherently the most accurate of the circuits used with inductance type gages.


Charles L. Segaser
APPENDIX E

Be Creep Test in Bet Pile Temperature Control

Calculations indicate that most of the available space about the test specimen will be needed for insulation if gamma induced heating is utilized as the only source of heat in the experiment. Also, uncontrolled heating of this sort implies controlled cooling which is not desirable. These facts, coupled with the possibility of continuation of the experiment during pile shut-down periods indicate that an external heat source be provided.

With equipment of the sort shown on Fig. 2, thermal equilibrium can be maintained at 2000 °F, specimen temperature with an input of about 800 watts providing a radiant shield surrounds the heater. Cooling is accomplished by flow of water in the annulus around the can. With a velocity in the neighborhood of 2 ft/sec., 15 EW of heat will be dissipated. This includes allowances for the heat induced in the cooling water by radiation. This cooling capacity should be ample since the total possible heat generated in the hole is expected to be of the order of 14 EW. All of this heat will obviously not be released since the overall density of the equipment is less than unity.

T. H. Thomas
APPENDIX F

V. G. 9 Variable Temperature Hole

The V. G. 9 variable temperature hole provides a very useful test facility for the solid materials groups because its large size permits the insertion of considerable test apparatus into the hole along with the specimens. Two minor modifications of this hole are desirable to improve its usefulness.

It is suggested that the present one foot by two foot dimension of the hole be changed to an eighteen inch diameter to accommodate larger test assemblies and simplify the design and fabrication of the twenty foot long exposure tube. It is also suggested that a five inch diameter beam hole be provided thru the beryllium reflector to the V. G. 9 hole. Such a tunnel would provide a source of fast neutrons now available only by conversion of thermal neutrons accompanied by the generation of large quantities of undesirable heat.

The V. G. 9 pile exposure tube is a twenty foot long stepped cylinder 18 inches in diameter at the large end. The upper cap contains a four inch diameter hoisting eye for engagement of the crane hook. Recessed in a yoke below the eye is an electric motor driving a sectional shaft to supply mechanical motion to the test apparatus. Beneath the motor plate are six quick disconnect couplings, four of which are for cooling water, gas and air or vacuum. One connection is to provide electric power for heat and the sixth outlet is for telltale leads to the instrumentation.

The upper part of the tube consists of three, four-foot long, telescoping steel cylinders which make a one-half inch step at each joint. The drive shaft and facility piping are housed within the cylinder and it is finally filled with boron balls and paraffin or other suitable amorphous shielding materials. The lower part of the tube is a fourteen inch diameter graphite cylinder supported by a beryllium frame and carrying retractable aluminum tubes which are housed in the upper section when not in use.

A covered service pit is proposed for the top of the pile to permit an operator access to the facility connections for the exposure tube. A large portable coffin must be provided on the top of the pile to receive the test specimens as they are withdrawn from the pile. Some of the apparatus will be very active upon withdrawal.

Many of the features of this facility are very unattractive and should be seriously considered. The single crane provided to place and remove the test tube in the V. G. 9 hole must also remove the main pile cover during loading and all the numerous plugs filling the large H and O holes which will be kept in a vertical plug storage vault. Much inevitable conflict in loading schedules is to be anticipated in the use of this crane.

The top of the pile is only thirty feet square and in addition to the six and one half foot diameter cover to the main pile has numerous holes for tests and controls which indicate this will be an extremely congested area on occasion and an unsatisfactory location for a service pit or large coffins. The mechanical design and operation of the tube is complicated by its inverted position and the proposed mock up facilities are unsatisfactory.

An alternate method of placing test specimens into the V. G. 9 variable temperature hole on a hydraulic elevator, entering the bottom of the hole from the subpile room, was suggested by the physicists, to provide a larger hole closer to the reactor.
and a detailed study of this facility has shown it to have many attractive advantages over the original design. Representatives of the several groups who will test solid materials in the pile have expressed a decided preference for the hydraulic lift and since it will not cause much change in the basic design of the pile structure, the problem of its installation resolves into one of coordination with the groups having prior claim to the facilities of the sub-pile room. A drawing of the proposed alternate installation is attached (Drawing F-2997).

The lift consists of a twenty-one inch diameter piston housed in a cylinder which extends twenty-seven feet below the bottom of the canal. Resting on the top of the piston is a nine foot long shielding plug consisting of three equal sections, the lowest of which is twenty and a half inches in diameter. Resting in turn on the top of the plug is an eighteen inch diameter graphite cylinder forty-two inches long which forms a reflector plug in the hole and provides a pedestal to support experiments in focus with the beam. The proportions between the graphite pedestal and the shield plug are sufficiently flexible to permit dimensional changes at a later date if future studies indicate the advisability of larger replaceable units to facilitate the reloading of the unit.

The graphite pedestal is assembled around a beryllium frame and contains aluminum tubes for facility piping to the test equipment. It is anticipated that most of the tests will only require replacement of the test element and apparatus resting on the pedestal but provision will be made to remotely disconnect the entire graphite plug and replace it with a new one.

The entire lift retracts into a shielded well leaving only the test element and apparatus exposed in the sub-pile room where it may be observed thru a periscope from the adjoining shuttle room. A remotely controlled crane will disconnect the apparatus and transport it into the canal. Provision will be made to retract extremely active experiments completely into a water-filled well connected to the canal and the transfer made under water.

The portion of the nine foot composition shield above the sub-pile room, which enclosed the V.G. y hole, is divided into alternate fixed and retracting laminated shields nine inches deep. The fixed sections are bored to fit the stopped plug in the extruded position while the movable sections close the hole behind the plug as it returns downward and retract ahead of it as it moves upward into exposure position. By closing the hole with shielding in this manner it is believed possible to use the lift during operation of the pile and provide one test facility which is independent of pile shut-down cycles.

This feature is not adaptable to the upper exposure tube due to the proximity of adjacent facilities which preclude the installation of retractable shields in the upper zone.

The above proposed modification of the V. G. y variable temperature hole will only require a minimum of structural change consistent with the expressed aim of the hot pile design to provide maximum accessibility for experimental work. Some changes in the original plans are to be expected because of the relatively late request for facility requirements from the solid state groups.
To permit the early completion of the pile foundation plans a thirty-inch diameter steel casing may be set into the ground on the center line of the V. G. 9 hole which would extend down twenty-seven feet below the bottom of the canal. The hydraulic lift would then be assembled in this casing at a latter date.

A section of the composite shielding would be omitted in the initial construction thru which the lift would be assembled and into which would be assembled the retracting shield.

Both the upper and lower exposure tubes should be installed as they would provide complementary facilities to insure maximum use of V. G. 9 hole.

G. G. Downing
TABLE I

OUTLINE OF IRRADIATION TESTS OF MATERIALS AND COMPONENTS FOR PILE REACTORS

<table>
<thead>
<tr>
<th>TESTS</th>
<th>TEST SAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Modulus of rupture</td>
<td>A. 1 in. x 1/2 in. section on 1/2 in. diameter x 3 in. long</td>
</tr>
<tr>
<td>2. Crushing strength</td>
<td>B. Bullets - 1/2 in. diameter x 1 in. long</td>
</tr>
<tr>
<td>3. Elastic modulus</td>
<td>C. 1/8 in. diameter x 3 in. long</td>
</tr>
<tr>
<td>4. Dimensional changes</td>
<td>D. 1/5 in. diameter x 3 in. long</td>
</tr>
<tr>
<td>5. Thermal conductivity</td>
<td>E. Hollow cylinder 1 in. x 4 in.</td>
</tr>
<tr>
<td>6. Temperature coefficient of expansion</td>
<td>After irradiation</td>
</tr>
<tr>
<td>7. Stress vs. strain diagram</td>
<td>G. Solid cylinder 1 in. x 4 in.</td>
</tr>
<tr>
<td>8. Specific heat</td>
<td>H. Rod, 6 in. long, up to 1/2 in. diameter</td>
</tr>
<tr>
<td>9. Failure by thermal stress</td>
<td>(See Drawing 3)</td>
</tr>
<tr>
<td>10. Failure by thermal stress</td>
<td>I. Mixtures of materials - to suit tests</td>
</tr>
<tr>
<td>11. Creep</td>
<td>J. Fuel units and special samples</td>
</tr>
<tr>
<td>12. Compression</td>
<td>K. Shapes and sizes as needed to produce thermal-stress failures</td>
</tr>
<tr>
<td>13. Thermal conductivity</td>
<td>L. Welding of adjacent parts</td>
</tr>
<tr>
<td>14. Welding of adjacent parts</td>
<td>M. Chemical activity and evaporation</td>
</tr>
<tr>
<td>15. Migration rate of fission products in fuel element</td>
<td>During irradiation</td>
</tr>
<tr>
<td>16. Leakage rate of fission products through surface</td>
<td></td>
</tr>
<tr>
<td>17. Temperature coefficient of expansion</td>
<td></td>
</tr>
<tr>
<td>18. Leakage rate of fission products through surface</td>
<td></td>
</tr>
<tr>
<td>19. Variation of fission product migration during life</td>
<td></td>
</tr>
<tr>
<td>20. Stress rupture</td>
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<tr>
<td>21. Simulated performance test</td>
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In the remainder of the outline, tests will be referred to by number and samples by letter.

<table>
<thead>
<tr>
<th>TYPE MATERIAL OR FABRICATED COMPONENT</th>
<th>TESTS</th>
<th>SAMPLE</th>
<th>* Square-inch Total Square</th>
<th>Some Possible Total Square</th>
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<tr>
<td>I. Permanent Structure</td>
<td>A. Materials Tests</td>
<td>1</td>
<td>A</td>
<td>B</td>
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<tr>
<td>1. Ceramic-like materials</td>
<td>2, 8</td>
<td>B</td>
<td>C</td>
<td>BaO plus fabrication methods</td>
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<td>3, 4, 5, 6</td>
<td>E</td>
<td>F</td>
<td>Be alloys</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>A x B</td>
<td>Graphite</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>A</td>
<td>1050</td>
<td>Be alloy</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>K</td>
<td>300</td>
<td>Be alloy</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>S</td>
<td>200</td>
<td></td>
<td></td>
</tr>
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<td>12</td>
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<tr>
<td>13</td>
<td>C</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>C</td>
<td>50</td>
<td></td>
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<tr>
<td>15</td>
<td>I</td>
<td>50</td>
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B. Components - Samples of Fabrication Technique 20 | J | 100 | Yields |

II. Control Rods | A. Materials Tests | 1 | A | B | ThO2 |
<table>
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<tr>
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<tr>
<td>1. Ceramic-like materials</td>
<td>2, 8</td>
<td>B</td>
<td>C</td>
<td>ThO2 plus BeO, etc.</td>
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<tr>
<td>3, 4, 5, 6</td>
<td>E</td>
<td>F</td>
<td>Be alloys</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>A x B</td>
<td>Graphite</td>
<td></td>
<td></td>
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<tr>
<td>9</td>
<td>A</td>
<td>1050</td>
<td>Be alloy</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>K</td>
<td>300</td>
<td>Be alloy</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>S</td>
<td>200</td>
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</tr>
<tr>
<td>12</td>
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<td>C</td>
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<tr>
<td>15</td>
<td>I</td>
<td>50</td>
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</tbody>
</table>

B. Components - fabricated assemblies | 20 | Portrait | 150 | 150 | Metal control rod (cooled) |

III. Fuel Elements | A. Material Tests | 1 | A | B | Be elements |
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1. Ceramic-like materials</td>
<td>2, 8</td>
<td>B</td>
<td>C</td>
<td>Be alloy</td>
</tr>
<tr>
<td>3, 4, 5, 6</td>
<td>E</td>
<td>F</td>
<td></td>
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<tr>
<td>7</td>
<td>A x B</td>
<td>Cold pressed</td>
<td></td>
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<tr>
<td>9</td>
<td>A</td>
<td>130</td>
<td>Various</td>
<td></td>
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<tr>
<td>10</td>
<td>K</td>
<td>200</td>
<td>Brazed</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>S</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>C</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>C</td>
<td>50</td>
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<tr>
<td>15</td>
<td>I</td>
<td>50</td>
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</tbody>
</table>

B. Components - Samples of fabrication techniques 16, 17, 18 | 20 | J | 300 | 700 | Complex thin-walled Lattices |

The values of uranium-loaded samples may be reduced in high-flux regions to avoid thermal-stress failures.
<table>
<thead>
<tr>
<th>Type of Test</th>
<th>Typical Tests</th>
<th>Typical Material or Component Under Test</th>
<th>Radiation Required</th>
<th>Minimum Hole Size Required</th>
<th>Notes</th>
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</thead>
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<tr>
<td>A. Tests after irradiation</td>
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<td>Be</td>
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<td>4 inch diameter</td>
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<tr>
<td></td>
<td>Crushing strength</td>
<td>BeO</td>
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<tr>
<td></td>
<td>Elastic Modulus</td>
<td>Graphite</td>
<td></td>
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<td></td>
</tr>
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<td>Steel</td>
<td></td>
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<tr>
<td></td>
<td>Thermal conductivity</td>
<td>Control-rod materials</td>
<td></td>
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<tr>
<td></td>
<td>Temperature coefficient of expansion</td>
<td>Be, BeO, plus graphite, Uranium</td>
<td>Thermal neutron flux $10^{14}$ or higher</td>
<td>4 inch diameter</td>
<td>8 - 16</td>
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<tr>
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<td>Stress-strain diagrams</td>
<td>Fertile materials</td>
<td>Fast and thermal neutron fluxes $10^{13}$</td>
<td>Various</td>
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<tr>
<td></td>
<td>Specific heat</td>
<td>Structural materials, etc.</td>
<td>Thermal and fast neutron fluxes $10^{13}$</td>
<td>Various</td>
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<tr>
<td></td>
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<td>Be</td>
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<td>6 inch diameter</td>
<td>6 - 12</td>
</tr>
<tr>
<td></td>
<td>Crush</td>
<td>Steel, Control-rod materials</td>
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<tr>
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<td><strong>II. Simulated performance tests</strong></td>
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<tr>
<td>A. Tests of non-moving parts and assemblies</td>
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<td>BeO structural unit</td>
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<td></td>
<td></td>
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<td></td>
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<td>Fuel element</td>
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<tr>
<td></td>
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<tr>
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<td>Parts of fuel loading and retaining devices</td>
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<td>V. G. 9</td>
<td>4 - 12</td>
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<tr>
<td></td>
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