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KER LOOP FUEL TESTING PROGRAM AND SCHEDULE -
CY-1962

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KER LOOP FUEL TESTING PROGRAM AND SCHEDULE - CY-1962

INTRODUCTION

The interests of several departments at Hanford are involved in the planning, execution and evaluation of the results of the KER loop testing effort in support of the NPR fuel program. The varied interests and activities of the participating groups must be well-integrated if effective use of our limited testing

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capability is to be made. The purpose of this report is to help achieve this integration by summarizing the current thinking on the goals of the NPR fuel testing program and by presenting the current loop schedule.

I. Testing Objectives

The NPR first load fuel design is firm, the fabrication process is essentially established, and the fuels plant is complete and production has begun. Ideally, our greatest need at present is for knowledge of the behavior of the product of the fuels plant under anticipated NPR operating conditions, in quantities great enough to have statistical significance. Because of the low capacity of the loops, however, statistical performance data cannot be obtained until after N reactor, itself, begins operation. The loop testing effort will only be able to turn up design, material or process deficiencies which are serious enough to be detected by irradiation of small quantities of test elements. Realizable program needs and the scope of test designs to satisfy these needs, are discussed below.

A. Characterization of "First Load" Behavior

The first load fuel design was fixed before any appreciable, directly pertinent testing had been accomplished. The greatest need has been, and will continue to be until reactor startup, for tests which will provide assurance that the first load will be reasonably adequate or that will indicate where changes must be made to assure adequacy. The small capacity of the loops imposes serious limits on our ability to do this and makes it mandatory that considerable care be given to the planning and interpretation of the tests. A list of those elements that constitute characterization of the behavior of the first load follows.

1. Metallurgical Behavior

The behavior of uranium in tubular geometry, irradiated at temperatures from 200-450°C to exposures somewhat in excess of 2000 MWD/T, is not well known but is felt to be the most important single factor in determining the behavior of the NPR fuel element. Information is needed on the magnitude of swelling as a function of temperature and exposure, the dimensional changes that occur to accommodate swelling, the extent to which warp, growth and bumping occur, the nature and severity of the cracking of the uranium and the tendency for cracks to propagate into and through the cladding.

The behavior of the cladding is of concern from the points of view of corrosion, hydrogen pickup, crud deposition and mechanical behavior under creep loading conditions with strain-cycling and irradiation damage superimposed.

In addition, the brazed closure process results in phase transformations in both the uranium and the Zircaloy-2 and in thickening of the clad-to-fuel bond. The effect of the associated metallurgical changes on the fuel element performance should be evaluated. The thermal incompatibility of uranium and zirconium may lead to failure of the cap-to-fuel bond which, if it occurs, may result in cladding failure at the cap-fuel interface. Evidence bearing on the likelihood of this event is required.

2. Design Testing

In addition to the concern over the independent material properties discussed above, the gross, over-all fuel element behavior needs to be determined. The fuel element consists of fuel, cladding, closures, spot-welded supports of two types, one of which has iron covers (shoes), and a fixing device. The behavior of the whole assembly needs a considerable amount of proof-testing. The fuel dimensions have been picked to satisfy, among other things, heat split requirements. Measurement of water channel temperatures will be required to determine whether the heat splits are within the allowable range. Trouble is not expected to arise from any of these problems. The purpose of the testing effort is to demonstrate whether this confidence is justified. It is presumed that if the tests indicate the need for design or process changes that the changes required will be of a minor nature so that they may be made without appreciable disruption of the fuels plant or process.

3. Fuels Plant Quality Monitoring

If the materials of the fuel element behave well and if the design of the element is found to be adequate there is still the very important practical problem of mass-producing the element in a fairly economical manner. While economy is not an important consideration for the first load, every inspection step requires a quantitative criterion of acceptability which, to a large extent now, is determined by judgment based on only limited data. While it is true that this will always be the case, to some degree, the testing effort should continually provide more information on which to base these judgments, although the statistical aspect will be missing.

4. Surface Contamination

Rupture monitor reliability is important in the NPR because of the possible consequences of fuel element failure. Early, positive detection of failures appears now to be essential. Extraneous sources of gamma activity in the primary loop of the reactor will reduce the sensitivity of the rupture monitors, and may also increase personnel exposures significantly. Contamination of the fuel element surface is possible and work on instrumentation to detect surface contamination is in progress. Quantitative information is needed on all aspects of this potential problem - how much contamination is probable, how much can be detected with the existing instrumentation and how much does it take to interfere with the detection of failures.

5. Restraint of Warp

Because of the relative slenderness of the two fuel components, the inner tube is felt to be the more warp-prone. It is held in position inside the outer tube by supports, the crushing strength of which is adjustable to some extent by design. The magnitude of the problems that will arise should the inner tubes warp should be determined by the extent to which the supports and the outer tube are capable of restraining warp. Information on this point is required.

6. Frequency and Severity of Warp

The need for clarifying the consequences of warp of the inner tube was stated above. In addition, we need to know the amount of warp likely to occur. This falls into the category of things that can be determined with confidence only after reactor startup when significant numbers of fuel elements are irradiated. A considerable effort has been expended on study of fuel attributes likely to cause warp during fabrication. Determination of the relation (if any) between warp tendencies during fabrication and warp during irradiation is needed.

7. Cladding and Closure Corrosion

The corrosion rates of Zr-2 and Zr-5 Be have been studied extensively and are believed to be more than adequate for the anticipated service conditions. Although prototype testing has been in progress for six months, the main problems have been assumed to be with the central elements in a process tube and the testing conditions adjusted accordingly. This requires coolant temperatures some 50°C below the NPR outlet temperature. Corrosion is expected to be most rapid in the downstream elements and prototype tests have not yet been conducted under conditions appropriate for corrosion testing.

8. Fuel Element Limits

While the NPR fuel element is currently felt to be adequate for use under the anticipated operating conditions, knowledge of the fuel operating limits is desirable for a number of purposes. Strictly speaking, large scale testing is required for an accurate statement of fuel limits but much of value can be determined from small scale testing - information that should be useful in determining the direction of the fuels development program.

B. Testing of Process and Design Improvements

Characterization of the behavior of the first load of fuel is currently the most important job for the KER test loops. The need for the testing of process and design improvements is beginning to grow and will continue to do so. The level of effort on the development of the first load design and process has been so high as to prevent much attention being paid to process alternates until recently. Some work has been done, however, and the level of work will increase. As promising alternate approaches reach an appropriate stage of development, tests will be scheduled in the loops.

1. Alternate Closures

Several alternate closures have been proposed and two currently look promising after a moderate amount of development work. The mechanical pressure bonded closure is being developed by HLO and the gas-pressure diffusion bonded closure is being developed by FPD. Both are expected to be ready for testing within the next year. Both processes produce a bonded closure without heating the fuel element into the uranium gamma phase, as is done in the current brazing process.

2. Single Tube Fuel Design

Use of a single tube fuel element with an inert flow divider offers economic advantages over the tube-tube design. The swelling rate at the higher temperatures expected in a single tube has been the greatest deterrent to consideration of this geometry. Information is needed on the swelling rate in the 500-600°C temperature region and the nature of the resulting fuel deformation. Some knowledge of the limits of this design are required to further develop the incentive for an extensive testing effort.

3. Fluted Fuel

Shaping of the outer surface of a tubular element, so that only compressive and bending strains occur in the cladding when the fuel swells, has been proposed as a means of extending fuel life if the clad-thinning failure mechanism becomes limiting. Application to the tube-tube element is currently deemed unlikely except, possibly, in association with an attempt to reduce the cladding thickness. Use of the fluted concept in the single tube design seems more likely because the swelling threat is greater in this design.

4. Reduction of Clad Thickness

If, as is predicted, the tube-tube element turns out to be reasonably trouble free, development programs aimed at cost reduction, by chipping away at the conservatism in the design, will be instituted. Elimination of the brazed closure is one possibility, the single tube design is another, and reduction of cladding thickness is still another. The clad thickness of the first load element has been set somewhat arbitrarily and conservatively (we believe). As more information is obtained on fabrication capability, in-reactor fuel performance, and swelling rate reduction possibilities through optimization of composition (see below), a better basis for establishing cladding thickness should emerge.

5. Optimization of Fuel Composition

Small alloying additions to uranium can change the behavior of the metal during coextrusion and the resulting fuel quality (e.g., the Fe-Si additions now being made to NPR fuel). In addition, the swelling rate may be affected by the presence of alloying elements. British experience in particular indicates that Fe-Al additions may lower the swelling rate appreciably. The effects of small alloying additions are, in the case of both fabrication and swelling behavior, expected to be incremental. Thus it appears that large scale testing would be required to allow selection of the optimum composition. Work is in progress now to improve the fabricability by altering the amount of Fe-Si additions and the heat treating schedule. If significant improvement is found, the appropriate process changes will be made and test elements for the KER loops will reflect the changes as soon as possible so that irradiation testing can be started in order to check whether the fuel performance is affected in any way. That is, if slight composition changes will improve the coextruded product, these changes would be made, on the assumption that the swelling rate would not be increased unduly.

The problem of optimization may be approached from the other direction. That is, we could aim to find a fuel composition that would minimize swelling, and then check it later from the fabrication point of view. However, at the present time, swelling does not appear to be a problem, but fabrication does. Thus the effort is being directed mainly toward the other approach.

The single-tube fuel element offers economic gains as a replacement for the double-tube element. Swelling is regarded as the greatest potential problem with this geometry because the maximum fuel temperature will be about 100°C greater. Thus, the establishment of feasibility will involve determination of the swelling rate and the consequences of swelling in single tube elements in the higher temperature domain. If excessive swelling is encountered, then optimization of the composition (for swelling) would, possibly, make use of the single tube element feasible.

The effort to reduce the cladding thickness would be affected beneficially by fuel composition optimization for swelling also because a reduced swelling rate will push the exposure limit for a given cladding thickness out further.

C. Proof Testing of First Load Alternates

Consideration must always be given to alternate materials and processes when the success of a project depends on the satisfactory completion of development work during the course of the project. While no backup to coextrusion appears to be available, there are several backups to other aspects of the fuel element. The extent to which a backup should be proof tested depends on how badly you feel you may need it and on whether loop-space is available for the testing.

1. Backup Closures

The brazed closure has been regarded as one of the critical aspects of the first load element. Our ability to predict the behavior of various end closures has left something to be desired. There is a need for a demonstration test of alternate closures which may be regarded as a backup for the brazed closure presently specified for the first load. The brazed closure has performed well under irradiation in the prototype tests completed to date, so the need for backup testing in the closure area is diminishing but, nevertheless, still is present.

2. Alternate Fuel Material

The use of unalloyed uranium fuel in the NPR has been a matter of some concern because of (1) core corrosion of failed fuel elements (2) swelling and (3) fabrication. The uranium-2% zirconium alloy has been considered as a backup fuel material because it has a lower corrosion rate than uranium and because a better coextruded product can be obtained with it. It appears to have a higher swelling rate but limited data suggests that the cladding uniformity is sufficiently improved to offset this and produce a longer-lived fuel. Irradiation performance data in prototypic geometry would be desirable.

D. Phase II and Phase III Fuel Testing

As time goes on, the emphasis on first load testing will diminish and shift toward testing of improved Phase I elements. At the same time, consideration should be given to the testing of Phase II and Phase III fuel elements. The Phase II element is expected to differ from the Phase I element only slightly so the testing effort will be a minor one. Phase III operation seems to be a long way in the future but the design criteria will be quite different from those for the Phase I element so that a major testing effort will be required. Further, because the goal exposure for the Phase III element will be high, very long term tests will be required if significant information is to be obtained. Although Phase II and Phase III element tests will be minor effort for the near future, the emphasis in this direction eventually will increase.

E. Miscellaneous Tests

1. Water Quality Studies

Zircaloy-2 is a very corrosion-resistant cladding material if the cooling is adequate. Crud deposits will raise the cladding temperature and may, if heavy enough, lead to early failure of the cladding by corrosion. Crud deposition tests with thermocoupled elements performed to date have shown that crud should not be a problem under normal operating conditions. Tests are needed yet to determine whether this is equally true during periods of abnormal operation such as that period immediately following a decontamination.

2. Development of a Crud Monitor

For the reason stated in the preceding paragraph, it has been decided that several crud monitors shall be in the NPR at all times for the first year of operation. This requires that an adequate crud monitor be developed and tested to an extent sufficient to demonstrate a high probability that the crud monitors adopted for NPR usage will operate without failure.

3. Irradiation of Defected Elements

Irradiated elements are needed for the PRTR rupture loop program. At present, the only proven scheme for "push-button" failure of an irradiated element requires that a defected element, with a cover welded over the defect, be irradiated in the KER loops to the desired exposure level and then transported to the PRTR for the rupture test. Thus, space must be made available in the loops for irradiation of defected elements.

Development work is in progress on ways to defect a sound irradiated element. If this work is successful, all elements from KER loop tests would be potential candidates for failure tests and the need for the specially prepared elements would be greatly reduced or eliminated.

4. Service Irradiations for Other Programs

When loop space is available that would otherwise be wasted, irradiations in support of other programs may be carried out.

II. Tests

Generally, a separate test is not required for each of the objectives listed in the previous section. In the water quality tests, for instance, highly specialized tests are called for, but, usually, a given fuel element test will contribute to several of the problem areas. In some cases, (e.g., fuels plant quality monitoring) it is almost impossible to design a test that will provide meaningful data. In other cases (e.g., restraint of warp), it should be possible to devise a good test, but this has not been accomplished yet.

A. Tests in Progress

The tests described below have been developed to provide information bearing on one or more of the problem areas listed in Section I.

1. Prototype Tests

The term "prototype testing", as used in this discussion, refers to the irradiation of N fuel components, or fuel elements reasonably close to them in dimensions, composition, support hardware, et cetera, under temperature, power and exposure conditions typical of those which are expected in the central region of a flattened zone process tube with the reactor operating at a power of 4000 MW and with a goal exposure of 1400 MWD/T. (Peak exposures are: outer tube - 2300 MWD/T, inner tube - 1700 MWD/T, average - 2100 MWD/T). Because of equipment limitations, only the central 5 to 10 feet of the KER loops are charged with fuel. Thus, exposure quotations in the loop tests refer to the peak value rather than to a tube-average value and should be compared to the 2100 MWD/T figure above rather than to 1400 MWD/T.

Prototype testing began in November, 1960, when the irradiation of braze-closed KSE3, NIN1 and NIE1 elements was started. KSE3 elements are thin-walled, large diameter tubes, and as such, are regarded as a stand-in for the actual N outer tube, which cannot now be irradiated in the KER loops. NIN1 elements differ from the actual NPR inner component (NIE1) only in that they contain natural rather than enriched (0.947%) uranium and they do not contain the iron and silicon additions (about 100 and 50 ppm respectively). NIN1 elements produce about the same power in the KER loops as the peak power of the inner component in the NPR. Without the shielding of the outer tube, the NIE1 element produces significantly more power in the KER loops than it will in the NPR and, therefore, fuel temperatures are high in NIE1 tests in the KER loops.

On successful completion of the current KER-2 irradiation, tests of KSE3 and NIN1-NIE1 elements to roughly 1000, 2000 and 3000 MWD/T will have been completed. Prototype testing will shift to KER-3 and KER-4 exclusively on completion of CGI-839 (the loop modification project). Full size, complete N elements, fabricated by the approved process, and intensively characterized, will be irradiated to average exposures of 700, 1400 and 2100 MWD/T. The corresponding peak exposures are 1000, 2000 and 3000 MWD/T. This series of tests will provide information in most of the categories under A (Characterization of "First Load" Behavior).

2. Crud Monitor Development Tests

Crud is not expected to be a problem under normal operating conditions in the NPR. However, a number of transient conditions may lead to crud formation. Crud on the fuel element heat transfer surfaces will induce auto-catalytic cladding corrosion. Therefore it has been decided that crud monitors should be used in the NPR. The current approach is to measure the central temperature of a fuel sample, using the behavior with time to indicate whether anything is happening that would cause the fuel temperatures to increase. Development of a suitable design for the crud monitor is in progress. The first design was found through in-reactor testing to be inadequate so a new design is being studied now with a KER loop test now under way in KER-1. Subsequent tests will be scheduled to an extent sufficient to demonstrate that the design and fabrication process will be adequate for N Reactor usage.

3. Crud Measurement Studies

Study of water chemistry changes and the effect on crud deposition can proceed in parallel with the crud monitor development tests to some degree. The sensitivity requirement for the NPR crud monitor is not as great as desired for study of water chemistry effects so the latter will suffer to some extent. We do not yet know the sensitivity of the present crud monitor design, so the degree of incompatibility of the two objectives cannot be assessed at this time.

Tests proposed for this aspect of the loop program include: a) study of crud deposition after a decontamination, b) measurement of crud deposition at pH values below 10 (to aid in setting operating limits) and c) evaluation of ammonia as a pH control material (instead of lithium hydroxide). When an operating crud monitor is in place, and the sensitivity is determined, KER-1 will be decontaminated and the thermocouple readings taken over a period of several weeks. If no temperature increase is noted and if the thermocouple continues to operate, the pH will be lowered to about 9 and the thermocouple readings followed. If no increase in temperature is noted, the pH will be lowered further, etc, with pH-7 being the lower limit. The primary indicator of crud deposition in these tests will be the temperature behavior with post-irradiation examination as a backup.

4. Tapered End Cap Test

The critical aspects of the braze closure are felt to be: 1) Can it be mass-produced with high yields and in good quality? 2) Will the cap-to-fuel bond stand up under irradiation?

Backup closure designs then fall into two categories - backups for brazing per se and backups to the present brazed closure design. The best backup of the former variety is felt to be a simple welded (unbonded) closure. However, the flat end cap design with a flush end cap has been shown to have a short lifetime (the thermal incompatibility of uranium and zirconium leads to shear failure of the cladding at the cap-fuel juncture) and use of a gap between the cap and fuel appears to be undesirable from the point of view of handling damage. Thus the best welded closure is currently felt to be one in which the

cap and fuel are essentially flush but the contact surface is V-shaped in cross-sectional view. This shape is expected to lead to a reduced failure potential by extension of the length of cladding over which the thermal incompatibility operates. This type of closure has not been tested.

If the brazing process is found to be satisfactory, but a failure problem develops as a result of fracture of the cap-to-core bond followed by cladding failure by the shear mechanism, then it appears that the next best design is a brazed closure with the same shape of cap and fuel discussed above. The effect of the tapered end cap in a brazed closure is to reduce the shear strain on the cap to fuel braze that results from the thermal incompatibility of uranium and zirconium. This type of closure also has not been tested.

A test has been prepared involving ten NIEL elements with tapered end caps, half of the charge being unbonded (with no gap) and half being brazed (with Zr-5 Be). The objectives of the test are to demonstrate the capability of the two backup closures to overcome the potential problems just noted and to provide information on the behavior of end caps of these two designs.

5. Warp Test

The decision to use straightened fuel elements in the NPR is a source of some concern. Our understanding of the causes and mechanisms of warp - during fabrication and also during irradiation - is not well enough developed to provide positive assurance that straightening will not lead to a warp problem. Thus the recent KER-1 test was designed: 1) to provide some information on the propensity of straightened fuel to warp, and 2) to provide some information on the correlation, if any, among straightness, warp during heating, and in-reactor warp. Fuel elements are included in the test which were far beyond what is currently regarded as acceptable for straightening and elements which were acceptable in all respects but came from extrusions which were very crooked. Further warp tests may be scheduled as development studies indicate they are warranted.

B. Tests Currently Under Consideration

The tests listed below are being actively considered for CY-62. They have not been scheduled yet and preparation of the test elements has not yet been started. The need for the tests has essentially been established and the settlement of one or more details of the test design must be established or further development work must be done before work on the test elements can be started.

1. Tests of New Closures

Development work is in progress on several new closure processes. When and if each of these programs reaches the point where reactor grade material can be produced, and the closure in question holds sufficient promise of cost reduction and/or product improvement relative to the present design, tests will be scheduled in the KER loops. It appears now that no tests of new closure designs will be ready until late this calendar year.

2. Alternate Fuel Material Test

It will be some time before we have positive assurance that unalloyed uranium is an adequate fuel from the point of view of failure behavior. Although use of U-2 Zr fuel would increase the cost of separation of plutonium from the irradiated fuel, the corrosion resistance of this alloy makes it an attractive alternate or backup fuel material. It is desirable to irradiate some elements of NIN1 geometry using U-2 Zr fuel during the next year. The objective would be to determine the dimensional behavior and to provide irradiated elements for IRP and PRTR rupture loop tests.

3. Water Quality Tests

In the one successful test with a thermocoupled element to date, no evidence of crud deposition was observed during normal operation (at pH-10, maintained with LiOH additions). The test scheduled next for KER-1 will involve study of crud deposition after a decontamination, in addition to being the first test of the new design for the N reactor crud monitor. There is some concern over potential corrosion problems with LiOH as a pH control additive. Thus it appears desirable to test another approach. The next water quality test after the currently scheduled test probably will be carried out using ammonia as the pH control additive.

4. High Temperature Swelling Data

The swelling data obtained to date indicates that swelling should not be a problem in the first load element. A single tube element would offer economic advantages over the tube-tube element, but extrapolation of the swelling data we have obtained in the prototype tests suggests that it may be severely limited by swelling. It is expected that we will want to explore these limits during the next few years. Tests of actual single tube designs must be carried out in KER3 and KER-4 (because of the process tube size) but these loops will not be available for this purpose for a year or more. In the meantime, our swelling data could be extended nearly to 550°C by irradiation of KSE-3 elements in the smaller loops with the loop outlet temperature set at or near the maximum permitted.

5. Crud Monitor Development Tests

The next crud test will probably determine whether the new design is adequate. If it is not, another design will be tried. After completion of a successful test ("success" will be determined by (a) did the monitor element survive without failure and (b) was the sensitivity found to be adequate) a fabrication process will be devised which will economically produce the required number of monitors (currently estimated at about 20 for the first year). It is deemed necessary at this time to undertake something resembling volume testing of the design selected. Consideration is being given to the best way to accomplish this objective. Use of crud monitors without thermocouple leads as heater elements for later crud tests currently is favored.

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III. Priorities

Stated very broadly, the order of priority for the various testing activities is felt to be as follows:

1. Prototype tests
2. Proof testing of first load alternates
3. Crud monitor development tests
4. Water quality tests
5. Testing of process and design improvements
6. Testing of Phase II and Phase III fuel designs

On an individual test basis, the next crud and crud monitor test is regarded as being of higher priority than the backup closure test (tapered end caps). However, generally speaking, the above list reflects the current feeling on priorities. As an indicator of our current thinking, the following estimate of priorities one year from now is given:

1. Testing of process and design improvements
2. Prototype tests
3. Crud monitor development tests
4. Water quality tests
5. Testing of Phase II and Phase III fuel designs

IV. Schedule

Test loop schedules must be regarded with some degree of skepticism. Past experience has demonstrated our inability to predict precisely when certain tests will be performed or how long they will remain in the reactor. With some reservation, then, a schedule is presented (Figure 1) which represents the course we now feel will offer the best chance of achieving the testing objectives mentioned earlier.

Loop Modification

KER-3 and KER-4 are currently being modified under CGI-839. It is desired that KER-1 and KER-2 be removed from service for modification soon after KER-3 and KER-4 resume operation. It is currently anticipated that KER-3 and KER-4 will be ready for resumption of testing before the middle of March. Thus, it is now planned that KER-1 will be released for modification after the current crud test (mid-April) and KER-2 after completion of the high exposure NIEL test currently in KER-2 (April).

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Figure 1. KER LOOP SCHEDULE

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V. Reconciliation

The KER loop testing objectives and the tests in progress and planned have been discussed and the schedule has been presented. Some discussion of how the particular tests in progress contribute to achieving the stated objectives and whether all the objectives are covered is in order.

The prototype tests with NAEI elements planned for KER-3 and KER-4 cover those parts of IA entitled Metallurgical Behavior, Design Testing and Cladding Corrosion quite well. They cover Fuels Plant Quality Monitoring, Surface Contamination, Frequency and Severity of Warp and Fuel Element Limits as well as we feel we can do now. The item, Restraint of Warp, is essentially ignored.

Alternate Closure Tests will be scheduled when test elements are available. High Temperature Tests of KSE3 elements should provide data of use in assessing the limits of the single tube fuel design, in lieu of tests of actual elements. Fluted Fuel, Reduction of Clad Thickness and Optimization of Fuel Composition are ignored here and must be considered as part of next year's program.

The Tapered End Cap Test constitutes our effort on First Load Alternates, Alternate Fuel Material being ignored. Phase II and Phase III testing has not been included here except insofar as characterization of the first load design and investigation of limits for the first load element bear on assessing the potential of Zr-2 clad, coextruded uranium elements for Phase II and Phase III application.

The Water Quality Studies and Development of a Crud Monitor are covered well by the tests planned although volume testing of the crud monitor is not, as yet. Four irradiated, defected elements are available for PRTR tests and a test is planned for the ETR this spring of the device for defecting irradiated elements in-reactor.

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IRRADIATION PROCESSING DEPARTMENT