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HANFORD ENGINEERING DEVELOPMENT LABORATORY

Richland, Washington
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A Subsidiary of Westinghouse Electric Corporation
for the

United States Atomic Energy Commission Under Contract No. AT(45-1)-2170

USERS' GUIDE FOR THE IRRADIATION
OF EXPERIMENTS IN THE FTR^(a)

D. P. Schively

PRELIMINARY REPORT

(Compiled) June, 1970
(Issued) September, 1970

FIRST UNRESTRICTED
DISTRIBUTION MADE OCT 7 '70

(a) Work initiated by Battelle-Northwest under AEC
Contract No. AT(45-1)-1830 and concluded by WADCO
Corporation under AEC Contract No. AT(45-1)-2170

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Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy \$3.00; Microfiche \$0.65

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ACKNOWLEDGMENT

This document, "Users' Guide for Irradiation of Experiments in the FTR," is deliberately patterned after the content and format of the "Guide for Irradiation Experiments in EBR-II, Revision 3," issued by the Argonne National Laboratory. This similarity is consistent with AEC Division of Reactor Development and Technology policy regarding standardization of methods and procedures. It is expected that the similarity will yield reciprocal benefits to testing programs in both the FTR and EBR-II. Immediate benefits expected from standard procedures for initiating, documenting and performing experiments are:

1. Necessary RDT participation in and approval of planning, funding, and administration of development programs will be facilitated.
2. Improved or corrective procedures may be applied expeditiously at both sites.
3. Experimenter competence developed by activities at one site is transferable, in high degree, to the other site.

The author gratefully acknowledges the technical contributions of Dr. W. W. Little and Dr. E. T. Boulette pertaining to reactor physics, and to D. W. Hayes for his submittal on operational aspects. All of this material appears in the Appendices. Appreciation is also due L. M. Finch for his detailed review of the initial draft.

USERS' GUIDE FOR THE IRRADIATION OF EXPERIMENTS IN THE FTR

I. INTRODUCTION

The primary function of the Fast Flux Test Facility (FFTF) is to provide reliable closed-loop testing of fuels and materials under controlled conditions that are prototypic of fast-reactor environments. An important secondary function is to provide open test positions in the reactor core that are cooled by the reactor sodium coolant. The FFTF is to provide not only fuels and materials irradiation needs, but also to provide experience in the design, fabrication, testing, and operation of sodium systems and their components. In achieving these objectives, the FFTF is to be responsive to all national needs for fast-flux testing of which the Liquid Metal Fast Breeder Reactor Program constitutes the major portion.

The FFTF Project is responsible to the Atomic Energy Commission for the safe operation of the Facility. This responsibility includes apprising experimenters of 1) the capabilities and limitations of the reactor, 2) safety requirements for experiments, and 3) administrative and technical procedures to promote the availability of the FTR for the experiment program. In this regard, future issues of the "Users' Guide" will be serially numbered to facilitate distribution of updated pages as the need arises. The recipient of each copy will be asked to return the Guide to the FFTF Project if he no longer needs his copy. Guides may be transferred by arrangement with the Project. Copies of updated pages will be distributed only to the Project list of Guide recipients.

This preliminary issue of the FFTF "Users' Guide" is intended to outline the requirements to be met by experimenters who intend to utilize the testing capabilities of the FFTF. A description of the testing capabilities of the FFTF is not within the scope of this document, however, several appendices have been added to provide related information. This information is essential to meet the requirements for test submittal and will be useful in visualizing the test environment and in describing the physical limitations thereof. In addition, a recent report⁽¹⁾ describes the test

characteristics of the closed-loops. During the interim, until the final design of the FFTF is completed,* the potential experimenter may develop test plans and preliminary test designs from the material now available. The conceptual drawings shown in Appendix D, for example, may be used for this purpose. A revised version of this Guide will be issued when final design details are available. For the present it is assumed that prospective experimenters have become familiar with the Conceptual Design Descriptions of the FFTF⁽²⁾ and with the FFTF Scope Document.⁽³⁾ It is recommended that experimenters peruse the FFTF Preliminary Safety Analysis Report⁽⁴⁾ in connection with the submittal of safety analyses.

Inquiries pertaining to the use of this Guide or to the irradiation of tests in the FTR should be directed to the cognizant manager within the FFTF Project as appropriate.

II. EXPERIMENT DESIGN REQUIREMENTS

Certain design requirements must be met by experiments proposed for irradiation in the FTR. These requirements result from inherent design features of the reactor and from the importance of identifying and negating hazards to the reactor. The following experiment requirements must be met for an experiment to be approved for insertion into the FTR. Exceptions may be made in certain instances of high-priority experiments where undue hazard to the reactor or operating personnel does not result.

A. FUEL ELEMENT OR CAPSULE DESIGNS

Experimental fuel elements and materials specimens may be irradiated in capsules or, under certain conditions, such experiments may be irradiated without capsules directly in the primary coolant. The external dimensions of unencapsulated fuel elements, or of capsules containing experimental fuel elements or materials, must conform to FFTF Project specifications. These specifications, when completed, will be shown in official Project drawings, copies of which will be provided to experimenters at their request. This requirement ensures that the experimental elements or capsules can be assembled into the standardized ducts that will be provided by the FFTF

* A pictorial representation of the FFTF is shown in Figure 1.

FIGURE 1. Cutaway View Showing the FTR

Project. Appendix D contains preliminary drawings of open and closed-loop unencapsulated fuel element test subassemblies. Capsule designs have not yet been developed. The FFTF Project ordinarily will supply tubing, end fittings, and spacer wire to experimenters for assembly of irradiation capsules. Section VIII lists requirements to be met by experimenters for assuring the quality of capsules and unencapsulated fuel elements submitted for experimental irradiations in the FTR.

B. SUBASSEMBLY DESIGN

The external dimensions of the subassembly comprising the experimental material to be irradiated in open test positions should match those of driver assembly. This requirement ensures that the experimental subassembly can be handled by the In-Vessel Handling Machine which is permanently installed within the reactor vessel for all subassembly handling. Preliminary drawings of experimental subassemblies are shown in Appendix D. Experimenters requiring subassembly designs not shown in Appendix D should contact the FFTF Project for assistance in developing the required designs. The FFTF Project ordinarily will fabricate the subassembly at the FFTF site. Experimental subassemblies that are to be fabricated and assembled by the experimenter will require prior arrangements with the FFTF Project.

C. EXPERIMENT IDENTIFICATION

Each individual capsule or unencapsulated fuel element placed in the FTR must be identified by a legible identification number. The number must include a prefix letter that is assigned by the FFTF Project and that is unique for the site sponsoring the experiment.

D. XENON TAGGING

All unencapsulated and gas-bonded fuel elements are ordinarily required to be tagged with small amounts of an identifying xenon isotopic mixture. Use of xenon tags enables rapid identification, location, and removal of gas-bonded unencapsulated fuel experiments from the reactor that experience cladding failure while under irradiation. The requirements for xenon tagging are described in Section IX.

E. COOLANT ENVIRONMENT

All experimental subassemblies are placed in the primary sodium coolant system of the reactor, or of the closed-loop systems. The surfaces contacting the coolant must therefore be compatible with flowing sodium at the maximum coolant temperatures developed within the subassembly.

F. EXIT COOLANT TEMPERATURE

The exit coolant temperature from an open test position experimental subassembly must not differ more than 100°F from the average exit coolant temperature for driver fuel or blanket subassemblies assumed to be in the core positions surrounding the experimental subassembly. This requirement is based on maximum allowable alternating stresses in the upper structure of the reactor resulting from sodium mixing effects. Appendix C contains a set of curves showing heat absorption rates at various core radii.

G. CRITICALITY CONSIDERATIONS

The subassembly containing the experiment ordinarily must be subcritical when submerged in water. This requirement is based on the fact that the subassembly will be flooded with water during flow testing and also will be exposed to water during postirradiation sodium removal operations.

H. EFFECTIVE FUEL CLADDING THICKNESS

The effective fuel cladding or capsule wall thickness used in stress analyses must not be the preirradiation nominal thickness, but a lower value that makes adequate cumulative allowance for:

- (1) Fabrication tolerances,
- (2) Possible defects in the cladding that are below the limit of detection (normally 10% of the wall thickness),
- (3) Material wastage due to sodium effects at hot channel temperatures over the life of the test, and
- (4) Loss in original unreacted cladding thickness from fuel/cladding reactions.

Item (3), for austenitic stainless steel, is to be calculated from the data of Thorley and Tyzack⁽⁵⁾ unless adequate justification is presented for use of less conservative values. For the convenience of experimenters, a curve of corrosion rates taken from data in Reference 5 is shown in Figure 2.

III. SUMMARY OF PROCEDURES FOR EXPERIMENTAL IRRADIATIONS IN THE FTR

Certain procedures must be followed by experimenters who wish to irradiate materials in the FTR. These procedures are intended to ensure that 1) the experimental space in the reactor is used to the best advantage for the FBR program; and 2) the experiment presents no unacceptable hazard to the reactor. Item (1) above is accomplished by preliminary experiment review by the FFTF Project and by granting of Approval in Principle by AEC-RDT. Item (2) is achieved primarily by the experimenter's safety analysis of his experiment and the subsequent review of his analysis by the FFTF Project.

The following list of sequential actions required on the part of the experimenter summarizes the principal steps that ordinarily must be followed from the first planning of a prospective irradiation in the FTR through the postirradiation examination of the experiment. The listed requirements and procedures are discussed in detail in Sections IV through X of this document. Careful adherence to the procedures, in the order shown, will help avoid wasted effort by the experimenter and the FFTF Project.

A. EXPERIMENT APPROVAL

1. Preliminary discussions should be held with the FFTF Project staff to establish technical feasibility of the proposed experiment and capability of providing the desired out-of-reactor services.
2. Submit to AEC-RDT a request for Approval in Principle, with information copies to the Director, FFTF Project.

FIGURE 2. *Corrosion Rates for Austenitic Stainless Steel to be Assumed by Experimenters for FTR Primary Coolant Conditions*

3. Provide the FFTF Project with a purchase order (or equivalent) to enable disbursement of chargeable costs for implementing the experiment.

B. EXPERIMENT ACCEPTANCE

1. Obtain, from the FFTF Project, assignment of a characteristic prefix letter to be used for identification numbers of all capsule and unencapsulated fuel elements originated by the experimenter.
2. Submit 15 copies of the data package containing Experiment Description, Safety, Analysis, and Quality Assurance Description with 5 information copies to the Director, RDT.
3. Provide 15 copies of as-built experiment data, if not included in the Experiment Description, with 5 information copies to the Director, RDT.
4. Obtain approval from the FFTF Project for shipment.
5. Ship experiment to the FFTF Project with the sample welds required for Quality Assurance.

C. POSTIRRADIATION REPORTING

1. Provide six copies of data from postirradiation examinations that relate to reactor safety or that help to characterize the experimental environment in the FTR.

IV. EXPERIMENT APPROVAL PROCEDURES

Both technical feasibility and administrative program considerations apply in the approval process for experimental irradiations in the FTR. Preliminary technical discussions between the experimenter and appropriate FFTF Project staff are useful not only for establishing technical feasibility of the proposed experiment, but they also enable development of preliminary schedules and cost estimates.

A. TECHNICAL FEASIBILITY

1. Routine Experiments: Technical feasibility for routine experiments can usually be established by the experimenter through contact with the appropriate manager within the FFTF Project. It can then be determined if the experimenter's requirements for irradiation and for out-of-reactor services can be met.

2. Nonroutine Experiments: Typical experiments that are considered to be of a nonroutine nature are those that are first of a kind, or those requiring unusually high coolant temperatures, nonstandard experimental subassemblies, in-core instrumentation, or unusual postirradiation handling or examination. Preliminary technical discussions between the experimenter and the FFTF Project engineering staff are required for such experiments to determine if they are technically feasible. The discussions are ordinarily arranged at the experimenter's or the Project's request.

B. ADMINISTRATIVE APPROVAL (APPROVAL IN PRINCIPLE)

Administrative approval for the proposed experiment is known as "Approval in Principle." It is supplied by the AEC Division of Reactor Development and Technology, along with a priority rating.

Requests for Approval in Principle should be submitted to:

Director
Division of Reactor Development and Technology
U. S. Atomic Energy Commission
Washington, D.C. 20545

Information copies of each request should be sent to:

Asst. Dir. for Engineering Standards, RDT-HQ
Asst. Dir. for Nuclear Safety, RDT-HQ
Asst. Dir. for Plant Engineering, RDT-HQ
Asst. Dir. for Project Management, RDT-HQ
Asst. Dir. for Reactor Engineering, RDT-HQ
Asst. Dir. for Reactor Technology, RDT-HQ
Manager, FFTF Project (2 copies)
Director, LMFBR Program Office - ANL
Manager, AEC-Richland Operations

Typically, a request for Approval in Principle is a document containing on the order of three to six pages. The format shown below has been found satisfactory for most proposed experiments.

1. Scope and Objectives of Experiment: This section should summarize the range of materials, design, and environmental variables that the experimenter intends to study. The objectives of the experiment should be clearly stated. Reference to other related documents such as 189a's and the LMFBR Program Plan may be appropriate.

2. Justification for Use of FFTF: The limited test space in the FTR, and the relatively large amounts of available space in both Commission-owned and privately-owned thermal test reactors, require that experimenters justify their use of FFTF in preference to the other test reactors.

3. Technical Feasibility: The experimenter must provide adequate assurance that his experiment is technically feasible in the FTR. Such assurance is established by prior discussions with the FFTF Project, or, for routine experiments, by reference to similar previous irradiations in EBR-II or the FTR.

4. Relationship to FBR Program: The relevance of the proposed experiment to the FBR program should be summarized.

5. Summary of Prior Irradiation Experience: Relevant prior irradiation experience should be summarized, with identification of areas of uncertainty that the proposed experiment is expected to help resolve.

6. Summary Description of Experiment: A brief description of the experiment should be provided. Schematic drawings of the design features and tabular summaries of the design and environmental variables are usually helpful.

7. Schedule: A brief table should be included showing anticipated calendar dates for beginning and completion of experiment fabrication, shipment of data package and experiment to the FFTF Project, and beginning and completion of postirradiation evaluation.

8. Desired Irradiation Conditions: The experimenter should include in this section the approximate location in the reactor that his experiment requires and the estimated total exposure in reactor megawatt-days. Information should also be provided on desired fuel burnups, fluences, and linear heat ratings.

9. Desired Out-of-Reactor Services: The experimenter must provide adequate assurance that, through prior discussion with the FFTF Project, his requirements can be met for assembly, interim or postirradiation examination, and shipping of the experiment.

C. CHARGES TO EXPERIMENTERS

The following items and services normally will be furnished to experimenters without charge by the FFTF Project:

1. Reactor space and neutrons
2. Experiment safety reviews
3. One full set of capsule and subassembly hardware for each experiment (a few extra pieces of capsule hardware can be furnished for welding practice)
4. NDT inspection and testing of experiments
5. Assembly, flow testing, and disassembly of experimental sub-assemblies
6. Routine interim or postirradiation services including measurements of dimensions and weight, neutron radiography, and gamma scanning. To qualify as "no-charge" items, such services must have been specified previously in the request for Approval in Principle.
7. Interim examinations that may be specified by the FFTF Project in order to assure safety and availability of the reactor.

Items currently not included in the "no-charge" list are:

1. Subassembly hardware requested by the experimenter for welding practice, assembly mockups, etc.
2. Xenon tag gas
3. Special out-of-reactor services, such as unusually costly handling requirements, extensive amounts of interim or postirradiation measurements, and extra large assistance from facilities for shopwork, chemistry, computing, etc.
4. Shipment to or from the FFTF site
5. Services at sites other than FFTF.

The FFTF Project requires a purchase order or equivalent to enable recovery of chargeable costs for implementing the experiment. The purchase order should be provided by the experimenter soon after he has received Approval in Principle.

V. EXPERIMENT ACCEPTANCE PROCEDURES
(DATA PACKAGE REQUIREMENTS)

After an experimental irradiation proposed for the FTR has been determined to be technically feasible, and after the proposed experiment has received Approval in Principle, 20 copies of the "data package" are then provided to the FFTF Project for detailed review. An additional amount of 5 information copies should be mailed to the Director, RDT.

Questions and comments that arise as a result of the Project's review of the data package will be communicated to the experimenter. Depending on the nature of the questions, a response from the experimenter may or not be required before the experiment is approved for insertion in the reactor.

The data package includes three parts: 1) Experiment Description and Requirements, 2) Safety Analysis, and 3) Quality Assurance Descriptions. The items to be included in each part are listed and described in Sections VI through VIII. Each item listed should be acknowledged in the

data package either by supplying the information requested or by noting that the particular item does not apply. Data packages that do not adequately identify and treat the listed items will be returned to the sender for completion.

The experimenter may elect to omit required information from the data package for a given experiment if he can provide adequate references to appropriate sections of previous data packages prepared by his organization that have been accepted by the FFTF Project. Previous data packages, referenced in this manner, shall have been for experiments essentially identical to the given experiment and which were irradiated under conditions at least as severe as those proposed for the given experiment.

With prior approval from the FFTF Project, the experimenter may prepare a single data package to apply to more than one experiment. In such cases, the experiments must be essentially identical and must be fabricated and shipped to the FFTF site at approximately the same time.

VI. EXPERIMENT DESCRIPTION AND REQUIREMENTS

A. PURPOSE AND OBJECTIVES OF EXPERIMENT

This may be the same (or an expansion thereof) as that originally submitted in the request for Approval in Principle.

B. DESIRED IRRADIATION CONDITIONS

The experimenter should specify the desired location for his experiment in the reactor, desired coolant flow rate, the range of acceptable linear heat ratings or flux levels, peak fuel burnup (in percent burnup of uranium plus plutonium atoms) or fluence, and estimated total reactor residence time in megawatt-days. Fuel burnup requirements stated in engineering units (e.g., MWd/T) are not acceptable because of inherent ambiguities in converting from such units to atom percent burnup. The nomenclature for sub-assembly locations in the reactor is shown in Figure 3.

- OPEN TEST ASSEMBLY—WITH PROXIMITY INSTRUMENTATION—1
- OPEN TEST ASSEMBLIES—6 INITIALLY (2 FUTURE)
- CLOSED LOOPS—2 INITIALLY (6 FUTURE)
- SAFETY RODS—3
- IN-CORE SHIM/SCRAM RODS—4
- PERIPHERAL CONTROL RODS—15
- DRIVERS—27 INNER —48 OUTER
- REFLECTORS—111

FIGURE 3. FTR Core Map - Preliminary

C. DESIRED OUT-OF-REACTOR SERVICES

Special requirements for out-of-reactor operations should be described. These should include:

1. Special procedures if necessary during sodium removal from sub-assemblies, including specific action necessary if the experiment contains, or is suspected of containing failed capsules or unencapsulated fuel elements.
2. Special procedures for subassembly handling, cooling, or dismantling, if necessary.
3. Details of postirradiation examinations, including types of tests and measurements, accuracy or precision required, special tools, instruments or fixtures required, and pertinent preirradiation data (if not included elsewhere in the data package).
4. Details of any special requirements for fabrication of the sub-assembly prior to irradiation, or prior to reirradiation following interim examination.
5. Procedures to be followed in shipping the completed experiment from the FFTF Site.

As noted in Section IV-A, the experimenter is required, prior to requesting Approval in Principle, to have obtained concurrence from the FFTF Project that his out-of-reactor requirements can be met.

D. IDENTIFICATION OF CAPSULES AND UNENCAPSULATED FUEL ELEMENTS

Each capsule or unencapsulated fuel element in the experiment must be legibly marked with an identification number. This identification number is not to be used for any other capsule or unencapsulated fuel element shipped to the FFTF by the experimenter, including replacements for capsules or fuel elements found to be unacceptable. Unacceptable capsules or unencapsulated fuel elements returned to an experimenter for repair shall not be assigned a new identification number.

To ensure against possible duplication of identification numbers by different experimenters, the Irradiation Coordinator assigns to each experimenter's site a characteristic prefix letter. Each experimenter is required to use the prefix letter assigned to his site in all identification numbers generated by him, and to continue using the same prefix letter for all future capsules or unencapsulated fuel elements.

The identification marking shall be as large as possible, consistent with the size of the capsule or unencapsulated fuel element. The markings are to be applied with die stamps if at all possible. Engraved markings may be acceptable if carefully done so as to ensure legibility. "Vibratool" marking is not adequate. The marking is to be applied on the lower end fitting of the capsule or unencapsulated fuel element. Wherever possible, the marking should also be applied on the upper end fitting to reduce handling and to provide greater insurance against loss of experiment identity. No marks should be applied to the cladding, particularly over the fuel or gas plenum region.

E. SUBASSEMBLY LOADING DESCRIPTION

The description should specify the preferred location of each capsule or unencapsulated fuel element relative to a corner or side of the subassembly specified to be nearest the center of the reactor core. It is recommended that a tentative core position (see Figure 3) be used for this description.

F. CAPSULE OR UNENCAPSULATED FUEL ELEMENT DESCRIPTION

Two sets of dimensioned full-size (or larger) drawings should be provided of each type of capsule assembly or unencapsulated fuel element. The following as-built information also must be provided for each capsule or unencapsulated fuel element.

1. Capsule or unencapsulated fuel element identification number
2. Fuel chemical composition
3. Fuel isotopic composition

4. Fuel dimensions
5. Fuel weight
6. Fuel smeared density
7. Composition, dimensions, and weight of other items in fuel element such as insulator pellets, spacers, springs, motion restrictors, blanket or reflector sections, etc.
8. Fuel cladding material
9. Fuel cladding OD
10. Fuel cladding thickness
11. Sodium volume and level in sodium-bonded fuel elements
12. Gas used in specimen assembly
13. Volume of specimen gas plenum (as assembled)
14. Sodium volume and level in sodium-bonded capsule assembly
15. Gas used in capsule assembly
16. Volume of capsule gas plenum (as assembled)

G. THERMAL PERFORMANCE OF CAPSULES OR UNENCAPSULATED FUEL ELEMENTS

The anticipated thermal operating characteristics of each capsule or unencapsulated fuel element must be presented. Sample calculations including axial temperature distributions must be provided for the capsule or element with the highest linear heat flux. The thermal effects of any sodium bond discontinuities, as noted in Sections VIII-A-6-c or VIII-B-3-c, shall be described. Appendix C should be used as a guide for fission rates, gamma heating values, etc. Table C-II should be used as a guide for the internal flow distribution in experimental subassemblies, which must be taken into account. The following items should be included for each capsule or unencapsulated fuel element, with assumed flow rate and uncertainty factors defined:

1. Peak linear heat generation in kW/ft
2. Total heat generation

3. Peak fuel centerline temperature
4. Peak fuel surface temperature
5. Peak fuel cladding inner surface temperature
6. Peak fuel cladding outer surface temperature
7. Peak capsule inner surface temperature
8. Peak capsule outer surface temperature
9. Peak local coolant temperature

H. THERMAL PERFORMANCE OF SUBASSEMBLY

When an experimenter has sole use of a subassembly, he shall furnish the following information for the subassembly, in addition to that required for individual capsules or unencapsulated fuel elements in Section VI-G:

- a. total heat generation, and b. mixed mean coolant outlet temperature.

I. STRESS AND STRAIN ANALYSES

The experimenter shall summarize results of his stress and strain analyses for each capsule or unencapsulated fuel element. Sample calculations should be shown for the capsule or unencapsulated fuel element with the highest end-of-test capsule or cladding stress. The summaries should evaluate the integrity of the capsule or unencapsulated fuel element with the greatest capsule or cladding diametral strain. The summaries shall include the following maximum conditions at both the beginning and end of the experiment:

1. Fuel element plenum pressure
2. Fuel cladding pressure stress
3. Fuel cladding thermal stress
4. Total fuel cladding diameter increase, including that due to
 - a. creep, b. fuel expansion, c. internal gas pressure, d. thermal stress, and e. volume changes in the cladding material.

5. Properties of the cladding material, referenced to source, assumed in calculating item 4. above.

For encapsulated experiments, the summaries should also include the following maximum conditions at both the beginning and end of the experiment:

1. Capsule plenum pressure
2. Capsule pressure stress
3. Capsule thermal stress
4. Total capsule diameter increase, including that due to a. creep, b. internal pressure, c. thermal stress and d. volume changes in the capsule material
5. Properties of the capsule material, referenced to source, assumed in calculating item 4. above.

J. EFFECT OF INCREASED DIAMETER OF CAPSULES OR UNENCAPSULATED FUEL ELEMENTS ON COOLANT FLOW

The experimenter shall include results of calculations of the effects of anticipated diameter changes of capsules or unencapsulated fuel elements on conditions in the experimental subassembly. The following items should be included:

1. Axial form of assumed diameter increases in capsules or unencapsulated fuel elements
2. Calculated reduction in subassembly coolant flow
3. Resulting increase in maximum temperatures calculated for Section VI-G
4. Increase in capsule or unencapsulated fuel element diameter resulting from increased temperatures calculated in item 3. above.
5. Calculated effect of capsule or unencapsulated fuel element diameter increases on subassembly dimensions

VII. SAFETY ANALYSIS

The experimenter is required to include in the data package an analysis of the safety of his experiment. The analysis must evaluate potential hazards of the experiment to the reactor for both closed loop and open test experiments including encapsulated tests. An evaluation must be presented for both normal and abnormal operation, failure of the experiment, and inadvertent criticality. Hazards resulting from nuclear effects other than criticality, such as from fuel slumping, will be evaluated by the FFTF Project. Potential personnel hazards should be described, such as those involved in handling plutonium fuel.

A. NORMAL OPERATION

The analysis shall evaluate possible effects on the integrity of fuel elements resulting from normal operation of the experiment at the heat rating and burnup specified by the experimenter. Such effects might typically be fuel movement or restructuring, loss of sodium bond between fuel and cladding because of fission gas release from the fuel surface, changes in cladding density and mechanical properties, reduction in coolant flow because of dimensional changes, stress corrosion of components exposed to the coolant sodium, etc.

B. ABNORMAL REACTOR OPERATION

The analysis of the effects of possible abnormal reactor behavior on the integrity of the experiment should extend to the point at which experiment failure occurs or at which experiment temperature equilibrium is attained, whichever occurs first.

1. Overpower Operation

The analysis shall include the effects on the integrity of the fuel elements of two forms of reactivity transients: 1) a transient that would occur if a control rod were inadvertently driven out of a core that is assumed to be critical but initially at low power, and 2) a transient that would occur if a control rod were inadvertently driven out of a core that is assumed to be initially at normal operating power. The rates of power increase to be assumed in each case are shown in Appendix E.

2. Loss of Coolant Flow

The analysis shall include the effects on the integrity of the fuel elements of an assumed loss of all pumping power for the primary coolant with immediate scram. The rates of the reactor power and coolant flow decay to be assumed in the analysis are shown in Appendix E for closed loop and open test experiments.

C. CLADDING FAILURE

1. Closed Loop Fuel Element -- Cladding Failure

The analysis shall include an evaluation of the following items, assuming complete release into the closed loop of volatile fission products from a fully-irradiated test fuel element at the peak temperature, with all uncertainties, for the full residence time for the element in the reactor:

- a. Total closed loop test section wall stress
- b. Increase in test section diameter (the contribution from creep strain should assume that the fuel pin failed at the start of irradiation)
- c. Effects of test section diameter increase on coolant flow past the section and resultant temperatures in experimental components
- d. Possible contamination of closed loop coolant system and cover gas system with fuel and fission products
- e. Possible consequences of exposure of fuel to the primary coolant
- f. Calculations of the sodium level in the test section, related to the fueled length, as a function of the local coolant pressure
- g. Possible consequences of subjecting the failed element to the normal sodium removal process

2. Open Test Fuel Element -- Cladding Failure

The analysis shall include an evaluation of the following items, assuming complete release from the lower end of the fuel element of all volatile fission products from a fully-irradiated test fuel element:

- a. Possible gas blanketing effects on adjoining fuel elements
- b. Possible solid or liquid debris effects on adjoining fuel elements
- c. Possible contamination of main primary coolant system and cover gas system with fuel and fission products, including possible "washout" effects from the primary coolant moving at normal velocity
- d. Possible consequences of exposure of fuel to the primary coolant
- e. Possible consequences of subjecting the failed fuel element to the normal sodium removal processes

3. Nonfuel Materials -- Test Failure

The analysis shall include an evaluation of the following items, assuming complete entry into the test of primary coolant sodium for the full residence time of the test in the reactor:

- a. Possible contamination of coolant and cover gas system
- b. Possible consequences of subjecting the failed test to the normal sodium removal process

D. CRITICALITY CONSIDERATIONS

For fuel-bearing experiments, the analysis shall ordinarily verify that the assembled experiment is subcritical when flooded and surrounded with an infinite water reflector. The analysis shall include the calculated value of k_{eff} of the flooded subassembly containing the experiment. For flooded experiments in which the calculated value of k_{eff} is greater than 0.60, advance arrangements with the FFTF Project will be required before the experiment is assembled and shipped to the FFTF site.

E. CRITERIA FOR REINSERTION OF EXPERIMENTS

If the experimenter requests interim examinations of his experiment, he shall provide, in quantitative terms and with technical bases, the criteria he proposes for determining whether or not his experiment is safe for reinsertion in the reactor. The same information will be required from the experimenter if the FFTF Project's safety review of the experiment indicates the advisability of interim examinations of the experiment, in addition to those that may be requested by the experimenter. Of particular importance is the extent of cladding diameter increase that can be permitted without unduly high probability of failure of cladding integrity.

VIII. QUALITY ASSURANCE DESCRIPTIONS

Increased emphasis on quality control and assurance procedures and their documentation has been applied throughout the civilian reactor development activities sponsored by the Atomic Energy Commission. The following quality assurance requirements for irradiation experiments submitted for insertion in the FTR are based in large part on guidance and recommendations provided by AEC-RDT. The required information is to be provided by the experimenter as part of his data package.

It is expected that provision by the experimenters of the information requested in this Section will, in the large majority of cases, satisfy FFTF and applicable RDT quality assurance requirements. However, in some instances accessibility by authorized FFTF Project personnel to an experimenter's facilities for fabrication and inspection and to his organization's internal Quality Assurance manuals may be required prior to final decisions regarding the safety of his proposed irradiation experiment.

The experimenter is required to perform and to report the results of certain quality assurance inspections, as defined in Sections VIII-A, B, and C. The same sections also define the inspections that the FFTF Project will perform on individual capsules or unencapsulated elements after they arrive at the FFTF site.

Special inspection and quality assurance arrangements with the FFTF Project, prior to experiment fabrication, will be required for irradiation experiments in which the experimental subassembly is fabricated or assembled either partly or entirely at the experimenter's site. Such arrangements will normally require inspection of experimental components at the experimenters site by appropriate FFTF Project personnel to directly observe subassembly fabrication and assembly operations. Approvals provided by Project personnel at the experimenter's site are to be regarded as preliminary only. Final approval and acceptance of the experiment at the FFTF site will be contingent upon absence of possible damage to the experiment from shipping or other causes.

This Section deals with the three general classes of experimental materials irradiations: unencapsulated fuel elements, encapsulated fuel elements, and encapsulated structural materials.

A. UNENCAPSULATED FUEL ELEMENTS

1. Tubing for Cladding

a. Procurement Specifications: The experimenter shall furnish copies of the applicable specifications (including any waivers or supplementary requirements) used by the experimenter for procurement of the tubing for fuel element cladding. The experimenter shall provide a statement of justification in the event that he accepts tubing that does not entirely conform to his specifications.

If seam-welding tubing is used, the specification should include the requirement that the wall thickness should be reduced during fabrication by a sufficient amount so that in the finished tube the grain size of the weld does not differ from that in the base metal by more than one ASTM grain size number.

b. Inspection and Testing Procedures: The experimenter shall furnish either 1) copies of testing and inspection procedures specified by the experimenter, or 2) detailed descriptions of testing and inspection procedures used by the vendor and by the experimenter to assure that the tubing meets all specifications as described in Section VIII-A-1-a.

c. Reports: The experimenter shall provide 1) chemical analysis data independent of that provided by the vendor to verify that the composition of the tubing material meets his specifications, 2) results of mechanical properties tests, metallographic examinations, and any other pertinent tests, and 3) certifications that the inspection and testing procedures described in Section VIII-A-1-a were followed with satisfactory results.

d. Tubing Samples: The experimenter shall certify that archive samples of the tubing materials will be available to the FFTF Project if requested. (Up to 3 ft of tubing may be requested for chemical analyses, mechanical property tests, etc.)

2. End Fittings and Spacer Wires

a. Procurement Specifications: The experimenter shall furnish copies of the applicable specifications (including any waivers or supplementary requirements) used by the experimenter for procurement of end fittings and spacer wires. The experimenter shall provide a statement of justification in the event that he accepts material that does not entirely conform to his specifications.

b. Inspection and Testing Procedures: The experimenter shall furnish either 1) copies of testing and inspection procedures specified by the experimenter, or 2) detailed descriptions of testing and inspection procedures used by the vendor and by the experimenter to assure that the end fittings and spacer wire meet all specifications as described in Section VIII-A-2-a.

c. Reports: The experimenter shall provide 1) chemical analysis data independent of that provided by the vendor to verify that the composition of the end fitting and spacer wire material meets his specifications, 2) results of mechanical properties tests, metallographic examinations, and any other pertinent tests, and 3) certifications that the inspection and testing procedures described in Section VIII-A-2-a were followed with satisfactory results.

d. Materials Samples: The experimenter shall certify that archive samples of the end fitting and spacer wire materials will be available to the FFTF Project if requested.

3. Welds of End Fittings to Cladding Tube

a. Welding Procedure: The experimenter shall furnish either 1) a copy of the welding procedure used, or 2) a detailed description of the welding procedure. A standard form may be used.

Information shall be included concerning materials to be joined, the type of welding, weld design, welding equipment, atmosphere control, current, voltage, arc gap, position, rotational speed, arc taper and quench, and any other pertinent items.

A copy of the welding procedure qualification and its control shall also be submitted or described in detail. The procedure qualification shall demonstrate that the welding procedure is capable of producing acceptable welds, as verified by radiography and by metallographic examination, and that it meets the weld acceptance criteria described in Section VIII-A-3-b.

b. Weld Acceptance Criteria: All welds shall be free of cracks, laps, seams and surface porosity or inclusions, and shall exhibit good workmanship. Subsurface porosity and inclusions may not exceed 20% of the tube wall thickness. Referring to Figure 4, the minimum land thickness (root-to-toe distance) shall be 125% of the tube wall thickness. The minimum effective weld thickness (root-to-surface distance less any porosity and inclusions) shall be equal to or greater than 80% of the nominal tube wall thickness. The determination of minimum weld thickness will be based on measurements taken from X-rays of finished welds as described in Section VIII-A-3-f. There shall be no lack of weld penetration as evidenced by either radiographic inspection of the experimental fuel element or by metallographic inspection of representative weld samples.

c. Reports: The experimenter shall provide 1) results of mechanical properties tests, metallographic examinations, and any other

FIGURE 4. *Definition of Terms Used in Acceptance Criteria for Tube-to-End Fitting Welds for Unencapsulated Fuel Elements and for Capsules Containing Experimental Fuel Elements or Materials*

pertinent tests, and 2) certification that the welding procedure described in Section VIII-A-3-a was followed and that the welds meet the acceptance criteria of Section VIII-A-3-b.

d. Sample Welds: Four representative sample welds (two each of top and bottom welds for each lot^{*} of cladding used), each with at least 12 in. of tubing and fully identified, shall be provided by the experimenter for examination and testing by the FFTF Project.

e. Weld Repairs: The experimenter shall furnish a description of procedures used to repair or salvage any unacceptable welds on elements submitted to the FFTF Project. The description should include fuel element identification, weld location, repair welding procedure, and inspections following repair.

f. Weld Radiography: A minimum of three radiographs of each closure weld is required. The radiographs shall be made at 0, 60, and 120° rotations of the fuel element, with reference to a specified identification mark on the fuel element. Each radiograph is to show a view through the weld at the tangent of the tube and be exposed for maximum contrast of the weld at this point, with minimum "burnout" at the tube tangent. Duplicate X-ray films shall be exposed and one film shall be furnished to the FFTF Project so that the experimenter and the Project have record films that are essentially identical. Each radiograph shall be identified, using lead numbers and letters, as to fuel element, weld location, orientation, and date.

One radiograph (duplicate film) of each closure weld, top and bottom, is also required, using the technique in ASTM Technical Publication No. 223 (Symposium on Nondestructive Testing in the Field of Nuclear Energy), page 312, Figures 8 and 9. These radiographs made with a "shape correction form" should reveal porosity and inclusions. A penetrometer shall be included to indicate a quality level of at least 2-2T. Very fine

* A lot is defined as tubing of the same dimensions, fabricated from the same heat, drawn consecutively, and annealed in the same furnace charge.

grain or ultrafine grain film should be used with leak intensifying screens to provide high quality radiographs. One film shall be furnished to the FFTF Project so that the experimenter and the Project have record films that are essentially identical. Each radiograph shall be identified, using lead numbers and letters, as to fuel element weld location, orientation, and date.

4. Helium Leak Testing

All closure welds are to be leak tested with helium. The bottom weld shall be helium leak tested prior to final closure.

a. Leak Test System Sensitivity: The method used shall have a system sensitivity of at least $2 \times 10^{-9} \text{ cm}^3/\text{sec}$. Test data shall be furnished to demonstrate that this sensitivity was maintained during testing of all weld closures.

b. Procedure: A copy of the leak test procedure used or a detailed description of the procedure shall be furnished. The material submitted shall include diagrams or photographs of the equipment used. The system shall be capable of detecting leaks in the experimental fuel element as small as $2 \times 10^{-9} \text{ cm}^3/\text{sec}$. The use of a standard helium leak is required. Frequency of spectrometer calibration shall be specified.

c. Certification of Test: The experimenter shall certify that a leak test was performed in accordance with the described procedure on each fuel element to be irradiated, and that the leak test disclosed no detectable leaks in the elements submitted for irradiation.

5. Xenon Tag Insertion (Gas-Bonded Fuel Elements)

The requirements for inserting xenon tags in unencapsulated gas-bonded fuel elements and for verifying that the tag has been properly inserted are described in Section IX.

6. Bond Tests (Sodium-Bonded Fuel Elements)

The sodium bond between the fuel and the cladding shall be tested by the experimenter for continuity.

a. Proof of Method: The experimenter shall furnish information and data to demonstrate the minimum size of bond discontinuity that his method of inspection is capable of detecting.

b. Procedure: The experimenter shall furnish a copy of the bond testing procedure or a detailed description that should include information on the temperature of the fuel elements during the test. The procedure should assure that the elements are preferentially cooled from the bottom to minimize shrinkage voids.

c. Certification of Test: The experimenter shall certify that a bond test was performed in accordance with the described procedure on each fuel element to be irradiated, and shall provide a description of the size and location of all bond discontinuities detected during his inspection.

7. Spacer Wire Attachment

Spacer wires for unencapsulated fuel elements may be attached either by the FFTF Project or the experimenter in accordance with prior agreement. Fuel element weld inspection at the FFTF site is considered more reliable if the elements are received without the spacer wires attached. Descriptions of the experimenter's procedure for wire attachment and method of inspection shall be provided if the spacer wires are attached. The description shall include the procedure for measurement of the effective diameter of each wire-wrapped element (see following section).

8. Dimensional Inspections

Length, diameter, and straightness of each finished element shall be measured to assure that the requirements of the specification have been met. Measurements of the effective diameter of wire-wrapped elements shall be included, in those cases where the experimenter has attached his own spacer wires, to assure that the assembled element bundle can be inserted into the experimental subassembly hex tube without interference.

a. Procedure: The experimenter shall furnish a copy of the dimensional inspection procedures or a detailed description of the procedures. This shall include descriptions of the gages used and the requirements for gage calibration.

b. Reports: As-built dimensional data shall be furnished as specified above and in Section VI-F.

9. Fuel Element Weights

The finished fuel elements shall be weighed to ± 0.1 gram by the experimenter.

a. Procedure: The equipment used and the requirements for calibration shall be described.

b. Reports: The weight of each as-built element shall be furnished as specified in Section VI-F. The FFTF Project will reweigh the elements if the elements are wire-wrapped by the Project.

10. Fuel Element Assembly Radiographs

a. By the Experimenter: A complete radiograph of each assembled and finished fuel element shall be made by the experimenter, preferably just prior to shipment, showing the arrangement and condition of internal parts. This radiograph shall show also the sodium level (in the case of sodium-bonded elements). Duplicate X-ray films shall be exposed and one film shall be furnished to the FFTF Project so that the experimenter and the Project have record films that are essentially identical. Each radiograph shall be identified using lead numbers and letters with the fuel element number and date.

b. By the FFTF Project: A complete radiograph of each element will be made upon receipt to verify that internal arrangement and condition are satisfactory after shipping. Duplicate record films will be exposed and one film will be furnished to the experimenter. Both the experimenter and the Project shall review and compare the as-received and the as-shipped radiographs to verify the satisfactory internal condition of each element.

B. ENCAPSULATED FUEL ELEMENTS

Experiments in this category include capsules that 1) contain fissile materials, 2) are intentionally pressurized during assembly, 3) contain control materials, 4) contain nonfissile materials that may

generate significant quantities of gas during irradiation, and 5) contain nonfissile materials that are not known to be compatible with the primary coolant.

The following quality assurance requirements apply for encapsulated experiments in which the capsule hardware is supplied by the FFTF Project. If the experimenter elects to provide his own capsule materials, additional requirements comparable to those listed in Section VIII-A shall apply.

1. Welds of End Fittings to Capsule Tube

a. Welding Procedure: The experimenter shall furnish either 1) a copy of the welding procedure used, or 2) a detailed description of the welding procedure. A standard form may be used. Information shall be included on the type of welding, weld design, welding equipment, atmosphere control, current, voltage, arc gap, position, rotational speed, arc taper and quench, and any other pertinent items.

A copy of the welding procedure qualification and its control also shall be submitted or described in detail. The procedure qualification shall demonstrate that the welding procedure is capable of producing acceptable welds, as verified by radiography and by metallographic examination, and that it meets the weld acceptance criteria described in Section VIII-B-1-b.

b. Weld Acceptance Criteria: All welds shall be free of cracks, laps, seams, and surface porosity or inclusions, and shall exhibit good workmanship. Subsurface porosity and inclusions shall not exceed 20% of the tube wall thickness. Referring to Figure 4, the minimum land thickness (root-to-toe distance) shall be 125% of the tube wall thickness. The minimum effective weld thickness (root-to-surface distance less any porosity and inclusions) shall be equal to or greater than 80% of the nominal tube wall thickness. The determination of minimum weld thickness will be based on measurements taken from X-rays of finished welds as described in Section VIII-B-1-f. There shall be no lack of weld penetration as evidenced by either radiographic inspection or by metallographic inspection of representative weld samples.

c. Reports: The experimenter shall provide 1) results of mechanical properties tests, metallographic examinations, and any other pertinent tests, and 2) certification that the welding procedure described in Section VIII-B-1-a was followed and that the welds meet the acceptance criteria described in Section VIII-B-1-b.

d. Sample Welds: Four representative sample welds (two each of top and bottom welds), each with at least 12 in. of capsule tubing, shall be provided by the experimenter for examination and testing by the FFTF Project.

e. Weld Repairs: The experimenter shall furnish a description of procedures used to repair or salvage any unacceptable welds on capsules submitted to the FFTF Project. The description should include capsule identification, weld location, repair welding procedure, and inspections following repair.

f. Weld Radiography: A minimum of three radiographs of each closure weld is required. The radiographs shall be made at 0, 60, and 120° rotations of the capsule, with reference to a specified identification mark on the capsule. Each radiograph is to show a view through the weld at the tangent of the tube and be exposed for maximum contrast of the weld at this point, with minimum "burnout" at the tube tangent. Duplicate X-ray films shall be exposed and one film shall be furnished to the FFTF Project so that the experimenter and the Project have record films that are essentially identical. Each radiograph shall be identified, using lead numbers and letters, as to capsule, weld location, orientation, and date.

One radiograph (duplicate film) of each closure weld is also required, using the technique described in ASTM Technical Publication No. 223 (Symposium on Nondestructive Testing in the Field of Nuclear Energy), page 312, Figures 8 and 9. These radiographs made with a "shape correction form" should reveal porosity and inclusions. A penetrameter shall be included to indicate a quality level of at least 2-2T. Very fine grain or ultrafine grain film should be used with lead intensifying screens to provide high quality radiographs. One film shall be furnished to the FFTF Project so

that the experimenter and the Project have record films that are essentially identical. Each radiograph shall be identified, using lead numbers and letters, as to fuel element weld location, orientation, and date.

2. Helium Leak Testing

All closure welds are to be leak tested with helium. The bottom weld shall be helium leak tested prior to final closure.

a. Leak Test System Sensitivity: The method used shall have a system sensitivity of at least $2 \times 10^{-9} \text{ cm}^3/\text{sec}$. Test data shall be furnished to demonstrate that this sensitivity was maintained during testing of all weld closures.

b. Procedure: A copy of the leak test procedure used or a detailed description of the procedure shall be furnished. The material submitted shall include diagrams or photographs of the equipment used. The system shall be capable of detecting leaks in the experimental capsule as small as $2 \times 10^{-9} \text{ cm}^3/\text{sec}$. The use of a standard helium leak is required. Frequency of spectrometer calibration shall be specified.

c. Certification of Test: The experimenter shall certify that a leak test was performed in accordance with the described procedure on each capsule to be irradiated, and the leak test disclosed no detectable leaks in the capsules submitted for irradiation.

3. Bond Tests

The sodium bond between the capsule and the experimental fuel element shall be tested by the experimenter for continuity.

a. Proof of Method: The experimenter shall furnish information and data to demonstrate the minimum size of bond discontinuity that his method of inspection is capable of detecting.

b. Procedure: The experimenter shall furnish a copy of the bond testing procedure or a detailed description that should include information on the temperature of the capsules during the test. The procedure should assure that the capsules are preferentially cooled from the bottom to minimize shrinkage voids.

c. Certification of Test: The experimenter shall certify that a bond test was performed in accordance with the described procedure on each capsule to be irradiated and shall provide a description of the size and location of all bond discontinuities detected during his inspection.

4. Dimensional Inspections

The length, diameter, and straightness of each finished capsule shall be measured to assure that the requirements of the specification (capsule assembly drawing) have been met. As-built dimensional information shall be furnished as specified in Section VI-F.

5. Capsule Weights

The finished capsules shall be weighed to ± 0.1 gram by the experimenter. The FFTF Project will reweigh the capsules if the capsules are wire-wrapped by the Project.

a. Procedure: The equipment used and the requirements for calibration shall be described.

b. Reports: The as-built weight of each capsule shall be furnished as specified in Section VI-F.

6. Capsule Assembly Radiographs

a. By the Experimenter: A complete radiograph of each assembled and finished capsule shall be made by the experimenter, preferably just prior to shipment, showing the arrangement and condition of internal parts. This radiograph shall also show the sodium level (in the case of sodium-bonded elements). Duplicate X-ray films shall be exposed and one film shall be furnished to the FFTF Project so that the experimenter and the Project have record films that are essentially identical. Each radiograph shall be identified using lead numbers and letters with the capsule number and date.

b. By the FFTF Project: A complete radiograph of each capsule will be made upon receipt to verify that internal arrangement and condition are satisfactory after shipping. Duplicate record films will be exposed and one film will be furnished to the experimenter. Both the experimenter and

the Project shall review and compare the as-received and the as-shipped radiographs to verify the satisfactory internal condition of each capsule.

C. ENCAPSULATED STRUCTURAL MATERIALS

Experiments in this category include capsules that are not intentionally pressurized prior to irradiation and that contain materials that 1) are known to be compatible with the primary coolant, and 2) do not generate significant quantities of gas under irradiation. They also include "weeper" capsules which allow intentional ingress of primary coolant sodium into the capsule. The quality assurance requirements for other types of encapsulated structural materials are described in Section VIII-B.

1. Welds of End Fittings to Capsule Tube

a. Welding Procedure: The experimenter shall furnish either 1) a copy of the welding procedure used by the experimenter, or 2) a description of his welding procedure. A standard form may be used. Information shall be included on the type of welding, weld design, welding equipment, atmosphere control, current, voltage, arc gap, position, rotational speed, arc taper and quench, and any other pertinent items.

A copy of the welding procedure qualification and its control shall also be submitted or described in detail. The procedure qualification shall demonstrate that the welding procedure is capable of producing acceptable welds, as verified by radiography and by metallographic examination, and that it meets the weld acceptance criteria described in Section VIII-C-1-b.

b. Weld Acceptance Criteria: All welds shall be free of cracks, laps, and seams. Porosity and inclusions may not exceed 50% of the tube wall thickness. Referring to Figure 4, the minimum land thickness (root-to-toe thickness) shall be 100% of the tube wall thickness. The minimum effective weld thickness (root-to-surface distance less any porosity or inclusions) shall be equal to or greater than 50% of the nominal tube wall thickness. The determination of minimum weld thickness will be based on measurements taken from X-rays of finished welds as described in Section VIII-C-1-e.

c. Reports: The experimenter shall provide 1) results of mechanical properties tests, metallographic examinations, and any other pertinent tests, and 2) certification that the welding procedure described in Section VIII-C-1-a was followed and that the welds meet the acceptance criteria described in Section VIII-C-1-b.

d. Weld Repairs: The experimental shall furnish a description of procedures used to repair or salvage any unacceptable welds on capsules submitted to the FFTF Project. The description should include capsule identification, weld location, repair welding procedure, and inspections following repair.

e. Weld Radiography: A minimum of three radiographs of each closure weld is required. The radiographs shall be made at 0, 60, and 120° rotations of the capsule, with reference to a specified identification mark on the capsule. Each radiograph is to show a review through the weld at the tangent of the tube and be exposed for maximum contrast of the weld at this point, with minimum "burnout" at the tube tangent. Duplicate X-ray films shall be exposed and one film shall be furnished to the FFTF Project so that the experimenter and the Project have record films that are essentially identical. Each radiograph shall be identified, using lead numbers and letters, as to capsule, weld location, orientation, and date.

One radiograph (duplicate film) of each closure weld is also required, using the technique described in ASTM Technical Publication No. 223 (Symposium on Nondestructive Testing in the Field of Nuclear Energy), page 312, Figures 8 and 9. These radiographs made with a "shape correction form" should reveal porosity and inclusions. A penetrameter shall be included to indicate a quality level of at least 2-2T. Very fine grain or ultrafine grain film should be used with lead intensifying screens to provide high quality radiographs. One film shall be furnished to the FFTF Project so that the experimenter and the Project have record films that are essentially identical. Each radiograph shall be identified, using lead numbers and letters, as to capsule weld location, orientation, and date.

2. Dimensional Inspection

The length, diameter, and straightness of each finished capsule shall be measured to assure that the requirements of the specification (capsule assembly drawing) have been met. As-built dimensional information shall be furnished as specified in Section VI-F.

3. Capsule Weights

The finished capsules shall be weighed to ± 0.1 gram by the experimenter. The as-built weight of each capsule shall be furnished as specified in Section VI-F.

4. Capsule Assembly Radiographs

a. By the Experimenter: A complete radiograph of each assembled and finished capsule shall be made by the experimenter, preferably just prior to shipment, showing the arrangement and condition of internal parts. Duplicate X-ray films shall be exposed and one film shall be furnished to the FFTF Project so that the experimenter and the Project have record films that are essentially identical. Each radiograph shall be identified using lead numbers and letters with the capsule number and date.

b. By the FFTF Project: A complete radiograph of each capsule will be made upon receipt to verify that internal arrangement and condition are satisfactory after shipping. Duplicate record films will be exposed and one film will be furnished to the experimenter. Both the experimenter and the Project shall review and compare the as-received and the as-shipped radiographs to verify the satisfactory internal condition of each capsule.

5. Certification of "Weeper" Capsule Contents

The experimenter shall provide certification that the contents of any "weeper" capsules (those which allow intentional ingress of coolant sodium into the capsule) are as specified in the Experiment Description. Such certification should include chemical analysis data independent from that provided by the vendor of the specimen material.

IX. XENON TAGGING PROCEDURES AND REQUIREMENTS

A. PROCEDURES

The term "xenon tagging" designates a procedure that is intended to enable the rapid identification, location, and removal of gas-bonded unencapsulated fuel elements from the reactor that experience cladding failure during irradiation. The ultimate technique for identifying a failed or defective fuel element in the FTR requires a trial and error process, described in Appendix B, in which suspect subassemblies are transferred from the core to in-vessel storage. The reactor is then returned to power to determine if the suspect element was faulty. This procedure is not only costly, time consuming, and decreases the reactor plant factor, but also causes needless handling of unfailed experiment. Also involved are potential safety problems associated with operation of the reactor while fission products are being released to the coolant.

With the xenon tag procedure, each experimental subassembly containing gas-bonded unencapsulated fuel elements is given its own identifying tag by adding a small amount of a unique xenon isotopic mixture to each fuel element within the subassembly. Any subsequent failure of a tagged element during irradiation will normally release a portion of the xenon mixture with gaseous fission products into the reactor cover gas system. Following detection of fission products in the cover gas system, the cover gas is sampled and the xenon analyzed for its isotopic composition in order to identify the subassembly containing the defective fuel element. The subassembly releasing fission products can then be removed and the reactor returned to power without additional delay or risk to further operation.

Because there is little doubt that tag gas will be released following cladding failure of a gas-bonded fuel element, xenon tagging is required for all unencapsulated gas-bonded fuel elements. Exclusion from this requirement can be permitted only if adequate written justification is supplied. Other applications of xenon tagging are being evaluated and may be added to the requirements if justification becomes evident. Methods of tagging bond

sodium are being studied, for example, and a combination of xenon tagging and sodium-soluble tagging may be required later for sodium-bonded fuel experiments.

The experimenter must obtain prior approval from the Irradiation Coordinator for his proposed procedures and equipment to be used for tagging. Because of the physical nature of the xenon tags, it is not possible to determine by current nondestructive methods whether or not a fuel element has been properly tagged once the element has been seal-welded. An FFTF Project observer must therefore be permitted to witness each experimenter's initial tagging operation and verify that the operation has been performed satisfactorily. An FFTF Project observer also should be permitted to witness tagging operations thereafter, if requested by the Project. All xenon tag gas mixtures are supplied to experimenters at cost by the FFTF Project.

Immediately before tagging the first fuel element of a particular subassembly, and immediately after tagging the last fuel element, the experimenter is required to tag a dummy element. This consists of a length of tubing approximating the size of gas plenums of the elements being tagged. The same procedures used in tagging and sealing the actual fuel element are to be followed for the dummy element. The two dummy elements are to be sent to the FFTF Project where they are analyzed with the same mass spectrometer that would be used in the event of xenon tag release into the primary coolant. Results of the analysis will be used as part of the experiment acceptance considerations, and will be kept on file at FFTF to provide a readily accessible "fingerprint" for each tagged subassembly.

B. SUMMARY OF REQUIREMENTS

1. The xenon tag requirement applies only to unencapsulated gas-bonded fuel elements to be irradiated in the FTR.

2. Responsibility for tagging fuel elements and selection of techniques to be used is borne by the experimenters. The Irradiation Coordinator will provide, on request, any available information on tagging equipment and procedures.

3. At least one month prior to the tagging operation, the experimenter must submit his proposed xenon tagging procedures to the Irradiation Coordinator for review and approval.

4. A FFTF Project observer must be permitted to witness each experimenter's initial tagging operation and to verify that the operation has been performed according to the procedure previously approved by the Irradiation Coordinator. A FFTF Project observer also should be permitted to witness tagging operations thereafter, if requested by the FFTF Project.

5. Two tagged dummy elements must be provided by the experimenter for each subassembly. One dummy element should be filled just prior to tagging the experimental fuel elements; the other should be filled just following the tagging operation.

6. The cost of the tag gas must be borne by the experimenter; the tag gas will be supplied at cost by the FFTF Project.

7. The amount of tag gas to be added to each element of the subassembly before final weld closure should be 1.0 ± 0.25 ml (STP).

8. The xenon tagging procedure must yield at least 0.75 ml (STP) of xenon in the completed element, as indicated by sampling of a dummy element tagged and sealed by the same procedure.

9. The experimenters must take adequate measures to insure that specific tag gas mixtures cannot become contaminated with other tag mixtures.

10. Unused tag gas and containers should be returned to the Irradiation Coordinator.

X. SHIPMENT OF EXPERIMENTS TO THE FFTF

No shipments of experiments to the FFTF site are to be made without prior approval. Approval may be provided following written request from the experimenter. Such approval is not given until after the data package containing the Experiment Description, Safety Analysis, and Quality Assurance Description has been received and has had preliminary review.

The experimenter's letter requesting permission to ship shall include the following items:

1. Number of units (capsules or unencapsulated fuel elements) to be shipped
2. Weight of fissionable isotopes in each identified unit
3. Form of fuel, i.e., oxide, carbide, metal, nitride, etc.
4. Physical description of shipping container, i.e., outside dimensions, materials of construction
5. U.S. Department of Transportation permit number (or equivalent ICC special permit number) for shipping container
6. Terminal dates that the above approval is effective
7. Criticality limits on the maximum number of units of the type proposed for shipment that could be shipped in the approved container
8. Certification that any external surface contamination on his experimental materials does not exceed the following limits:

Smearable alpha activity: 220 dpm/100 cm²

Smearable beta-gamma activity: 2200 dpm/100 cm²

After receiving permission to ship, the following considerations apply to the actual shipment:

1. All items in the shipment shall be clearly identified. (Specifications for marking capsules and unencapsulated fuel elements are described in Section VI-D.)
2. All fuel-bearing materials shall be enclosed in an individual, sealed, secondary container. The functions of the secondary container are to protect the capsule or fuel element during the shipment, and to confine contamination in the event that a breach of cladding should occur. Examples of acceptable secondary containers are sealed heavy-duty polyethylene, capped pipe, and fiber tube.

3. After loading the capsules or unencapsulated fuel elements into the shipping container, temporary external markings identifying capsule or fuel element therein should be affixed to the container for their ready external identification.

4. All shipping containers shall be clearly marked for delivery to the FFTF address specified in the approval and also shall show the identification and address of shipper.

XI. REPORTING OF POSTIRRADIATION RESULTS

Experimenters using the FTR as an irradiation facility are required to provide the FFTF Project with early and continuing reports of certain types of observations obtained during postirradiation examination. These observations are primarily those which could assist in 1) safety evaluations of continuing or new irradiations in the FTR, and 2) characterizing the experimental environment in the FTR. Timely provision of such information is thereby of considerable value to all experimenters.

The following list summarizes the types of information that are to be communicated promptly to the FFTF Project.

A. POSTIRRADIATION OBSERVATIONS PERTAINING TO REACTOR SAFETY

1. Cladding or capsule failure
2. Cladding or capsule diameter changes
3. Reactions of fuel with sodium, cladding, or capsule
4. Effects of sodium environment on cladding and capsule
5. Microstructural changes in fuel, cladding, and capsule material
6. Irradiation-induced changes in mechanical properties of cladding and capsule material
7. Extent of gas release from fuel material

B. POSTIRRADIATION OBSERVATIONS PERTAINING TO EXPERIMENTAL ENVIRONMENT

1. Fuel burnup measurements, including spatial variations. The method of measurement and assumed values, such as fission yields, should be specified.

2. Measurements of neutron flux and fluence, including energy distributions and spatial variations. The method of measurement should be described as well as assumed values such as reaction cross sections, damage functions, etc.
3. Gamma heating value. The method of measurement also should be described.
4. Coolant characteristics that may be deduced from experimental observations, such as outlet temperature, impurity effects, velocity effects, etc.

Six copies of postirradiation information which the experimenter obtains, of the type specified above, should be forwarded promptly to the FFTF Project. Experimenters are assured that all preliminary reports of postirradiation observations provided to the FFTF Project will be for official use by Project personnel only. Such reports will not be referenced or quoted without written consent from the appropriate experimenter.

XII. REFERENCES

1. R. E. Keyes. FFTF Closed-Loop Test Characteristics, BNWL-1251, Battelle-Northwest, Richland, Washington, May 1970.
2. FFTF Conceptual Design Descriptions, BNWL-500 (24 Volumes), Battelle-Northwest, Richland, Washington
3. FFTF Scope Document, B3-060001 (3 Volumes), Battelle-Northwest, Bechtel Corporation (Compiler), Westinghouse Advanced Reactors Division
4. FFTF Preliminary Safety Analysis Report, (2 Volumes), Battelle-Northwest, To Be Issued
5. A. W. Thorley and C. Tyzack. "Corrosion Behavior of Steels and Nickel Alloys in High Temperature Sodium," IAEA Symposium on Alkali Metal Coolants, Paper SM-85/18, Vienna, 1967.

APPENDIX A

PLANT SCHEDULING CONSIDERATIONS
FOR EXPERIMENTAL IRRADIATIONS

APPENDIX A

PLANT SCHEDULING CONSIDERATIONS FOR EXPERIMENTAL IRRADIATIONS

The anticipated run length for the FFTF is a nominal 40,000 MWd. The calendar days needed to complete a run in its entirety would normally include:

- 15 days for fuel handling in preparation for the run
- 15 days for replacement of reflectors and control or safety rods
- 2 days for startup preparations, critical measurements and approach to power
- 100 days of full power operation
- 3 days for miscellaneous shutdowns

Thus, for planning purposes, the total run length at power rating of 400 MW may be considered to be 135 days. Long term experiments should also factor into their irradiation schedule an anticipated 30 day shutdown of the reactor at the start of each calendar year for major maintenance or modification items including containment vessel leak rate testing.

Prior to insertion of experiments in the FFTF, from four to six weeks are required for operations that are performed on experiments at the FFTF site. These operations may include such items as assembly, inspection and testing of the experimental components as well as the total subassembly.

Experimental subassemblies are normally installed at the beginning of a scheduled run and remain in the reactor for the number of full runs necessary to meet the experimenters irradiation requirements.

The experimental subassemblies installed in an open test loop position are removed from the reactor, following irradiation to an in-vessel storage position as described in Appendix B. Fueled experiments are held in in-vessel storage until their fission product heat generation is within the cooling capability of the Combined Loop Ex-Vessel Machine (CLEM). For low

power experiments this could be less than 30 days after reactor shutdown. Higher power experiments would be treated the same as driver subassemblies and would not be removed from in-vessel storage until the next reactor shutdown. The experimental subassemblies are then transferred to the Fuel Examination Facility for disassembly or transferred to Interim Decay Storage (IDS) for further decay. Nonfueled experimental subassemblies do not require storage time in in-vessel storage before transfer.

An experimental subassembly installed in one of the closed loop positions will be removed from the reactor as an unit with its in-reactor coolant thimble to the Assembly and Disassembly Cell (A&D) as described in Appendix B. Again, adequate decay time must be allowed so the required cooling is within the capability of the CLEM. At the A&D cell the experimental subassembly is removed from its coolant thimble and installed in a standard finned coolant pot. The instrument stalk is then removed and the experimental subassembly is transferred to the Fuel Examination Facility for inspection and disassembly. If desired, the experimental subassembly and its coolant thimble can be transferred from the reactor to a test assembly decay tank in the IDS rather than directly to the A&D cell.

APPENDIX B

PLANT HANDLING PROCEDURES
FOR EXPERIMENTAL SUBASSEMBLIES

APPENDIX B
PLANT HANDLING PROCEDURES
FOR EXPERIMENTAL SUBASSEMBLIES

1. Initial Assembly

There are several ways an experiment can be received from the experimenter including:

- a. Completely assembled with instrument stalk attached. In this case the experiment must be capable of being handled and shipped horizontally.
- b. Assembled but with the instrument stalk not attached. Generally this would be the case where the experiment must be maintained in the vertical position.
- c. Fuel pins or material test specimens only supplied by the experimenter. The hardware to be furnished and assembly are done at PNL.

In all cases the material would first be received at the Fuel Fabrication Facility. Each experiment would be assembled under rigid standards with each component or subassembly subject to the necessary tests and examinations to insure high integrity.

The completed assemblies would be radiographed, checked for straightness, measured and the dimensions checked for proper clearances, etc. Also, a final check of the instrumentation would be made. If the experiment was shipped assembled, the shipping accelerometer would be checked to assure allowable stresses were not exceeded.

In those cases where the experiment must be maintained in a vertical position, the instrument stalk will be welded to the subassembly using equipment to be installed in the FFTF containment vessel. The total assembly would then be tensile and straightness tested, the weld leak checked and the instrumentation retested. The assembly would then be placed in a Test Assembly Interim Storage Position (TAIS) within Interim Decay Storage (IDS).

Following final tests and examinations the subassembly would be given a final cleaning with acetone followed by alcohol.

Prior to shipping a experimental subassembly from the Fuel Fabrication Facility to FFTF it would be flow tested.

2. Loading Procedure

a. Closed Loop Experiments

The experimental subassembly is preheated in the TAIS. Preheating of those subassemblies with sodium bonded capsules is programmed so the sodium melting begins at the top end where the plenum space provides room for expansion. The subassembly is transferred from the TAIS to the Combined Loop Ex-Vessel Machine (CLEM) where the preheat temperature is maintained by circulation of heated gas. It is then lowered into an in-vessel coolant thimble which contains molten sodium at the proper temperature. The subassembly and thimble are then transferred as a unit, via the CLEM, to the reactor core position. A Loop Preparation Cask is used to make the necessary interface connections at the top of the primary vessel.

b. Open Loop Experiments

The open loop experimental subassemblies are handled in the same manner as the closed loop experiments except the thimble is not used.

Detailed consideration is given to the fuel handling procedure for experimental subassemblies to assure that the final orientation of each subassembly in the reactor is as requested by the experimenter.

3. Unloading Procedure

Experimental subassemblies are normally transferred from the reactor to decay storage during scheduled shutdowns for driver fuel change. The subassemblies remain in storage for the cooling period requested by the experimenter or for the period that is determined to be necessary by the FFTF Project.

a. Closed Loop Experiments

The instrument leads are disconnected and the Loop Preparation Cask is used to prepare the in-vessel coolant thimble, and the experimental subassembly it contains, for removal from the reactor core. The CLEM is then used to transfer the thimble and subassembly as a unit from the reactor to IDS. Cooling is provided in the CLEM by gas circulation.

After the necessary decay period the thimble and subassembly are transferred, via the CLEM, to the Assembly Disassembly Cell (A&D). The assembly is lowered into a double-walled, long, finned pot containing molten sodium at the proper temperature. The pot is cooled by drawing gas from the cell through the bottom, up between the double walls to the top of the pot and to the suction of a gas blower.

A test assembly adapter is installed on the grapple and the CLEM is again used to remove the experimental subassembly from the thimble. It is raised through a special manifold and is without cooling a short time until the manifold can be clamped to the bottom of the subassembly and gas flow established from the cell down through the fuel pins and into the manifold to the blower suction. After cooling is established and the subassembly is properly clamped the instrument stalk is cut and removed from the test assembly. The subassembly is then installed into a standard finned pot with equipment in the A&D cell. The finned pot with test subassembly can then be transferred to a shipping cask for transfer to the Fuel Examination Facility or back into IDS for further cooling.

b. Open Loop Experiments

The instrument leads are disconnected and again the Loop Preparation Cask is used to make the necessary disconnects at the top of the primary vessel. An adapter is used to twist the

instrument stalk so that special cutters are engaged to cut the stalk near the top of the subassembly. The CLEM is then used to remove the instrument stalk from the primary vessel.

The open loop experimental subassembly is then handled in the same manner as a driver fuel. It is removed from the core using the In-Vessel Fuel Handling Machine (IVHM) to an in-vessel storage position for decay. The subassembly is transferred from in-vessel storage, using the CLEM, to either a shipping cask for transfer to the Fuel Examination Facility or to IDS for further decay storage.

4. Reactor Operations and Experiment Handling When Fission Product Releases Occur into the Coolant

The reactor will be provided with three on-line fuel element cladding failure detector systems as follows:

a. Fuel Element Rupture Detector

This system senses the delayed neutrons emitted from the fission products that may be released to the coolant from a failed fuel element. One detector is on each of the three primary loops.

b. Fission Gas Monitor

This system senses the shorter lived cesium and rubidium daughters of the gaseous fission products when they are released to the cover gas system over the primary coolant. The "charged wire" technique will be used.

c. Reactor Cover Gas Monitor

This system senses the gaseous fission products krypton and xenon when they are released to the primary vessel cover gas. A NaI crystal photomultiplier tube, and a multi-channel gamma energy analyzer will be used to detect the specific energy peaks of the fission product isotopes.

In addition to the on-line detection systems, samples of the primary cover gas and sodium will be routinely analyzed as an aid in detecting fission product releases.

Although all of the fission product detection system, singly and in combination, are highly sensitive to minute fuel cladding failures, none of the system will be capable of identifying the failed subassembly.

The reactor ordinarily will be shut down when a fission product release to the coolant occurs that indicates a possible cladding failure of an experiment or driver fuel. However, continued reactor operation will be permitted if indications are that a direct fission product gas release has occurred from a driver subassembly and that the magnitude of this release is less than a factor of five above normal background.

When failure of an open loop experiment is indicated, with no detectable concurrent release of a xenon tag mixture, the most suspect experimental subassembly will be removed from the reactor and placed in an in-vessel storage position. A known subassembly will be installed in the open core position. The reactor will then be operated to determine if the source of the fission product release has been removed. If the source of the fission product release is not the first experiment then a second one will be removed and the above operation repeated.

The failed experimental subassembly is allowed to cool in the in-vessel storage position and then shipped to Fuel Examination Facility as described in the preceding section. In the closed cover gas, detectors will sense the gaseous fission products and their daughter elements. Initially, vented fuel elements will not be accepted for the closed loop systems. Accordingly, in case of a cladding failure, the reactor will be shut down and the closed loop experiment removed.

APPENDIX C

NUCLEAR PARAMETERS FOR THE FAST TEST REACTOR (FTR)

APPENDIX C

NUCLEAR PARAMETERS FOR THE FAST TEST REACTOR (FTR)

This appendix gives a brief description of the neutronics characteristics of the FTR conceptual design. Parametric studies also are included to show the effects of possible design changes.

It should be understood that the values given in this appendix merely reflect the current FTR reference design. This is particularly true for those items that are sensitive to design changes, such as Na and Doppler coefficients.

All neutronics calculations were performed using an extensively modified version of the Russian 26-group data compilation. The 1-D and 2-D computations were performed using the 1DX and 2DB diffusion codes, respectively. Since the FTR consists of hexagonal tubes, essentially all reference reactor calculations were performed in hexagonal geometry using the 2DB code.

1. Geometric Model

A schematic cross section of the 2-zoned FTR core and reflector is given in Figure C-1. The initial core consists of 91 in-core lattice positions. A breakdown of these in-core positions into their specific function is given in Table C-I. In addition to the 6 shim rods in the core, there are 15 shim rods in the first row of the reflector.

TABLE C-I. *Initial In-Core Positions*

Driver Assemblies	73
Closed Loops	2
Open Loops	7
Safety Rods	3
Shim Rods	6

Most design calculations are based on a two-dimensional, hexagonal simulation of the cross section shown in Figure C-1. The component dimensions on which the neutronics analyses are based are given in Table C-II. The resulting volume fractions and loadings are listed in Tables C-III and C-IV, respectively.

FIGURE C-1. *Conceptual Core Arrangement*

TABLE C-II. *Component Dimensions*

<u>Parameter</u>	<u>English Units</u>	<u>CGS Units</u>
No. Pins/Assembly	217	217
Pin Length	3 feet	91.4 cm
Pin OD	230 mils	0.584 cm
Clad Thickness	15 mils	0.0381 cm
Wrapper Wire Diameter	56 mils	0.142 cm
Shroud Thickness	140 mils	0.356 cm
Shroud Clearance	15 mils	0.0381 cm
Shroud Gap	100 mils	0.254 cm
Cell Flat-to-Flat	4.72 inches	11.98 cm

TABLE C-III. *Reactor Composition*

<u>Region</u>	<u>Volume (liters)</u>	<u>Material</u>	<u>V/O</u>
Inner Driver (28 Assemblies)	317.8	PuO ₂	5.96
		UO ₂	25.14
		Void	3.9
		316 SS	26.0
		Na	39.0
Outer Driver (45 Assemblies)	544.9	PuO ₂	7.45
		UO ₂	23.65
		Void	3.9
		316 SS	26.0
		Na	39.0
Radial Reflector Assembly	11.35	Void	0.0
		316 SS	0.0
		Ni	65.0
		Na	35.0
Control Assembly	11.35	Void	0.0
		B ₄ C	39.4
		316 SS	30.3
		Na	30.3
Control Follower	11.35	Void	0.0
		316 SS	37.0
		Ni	28.0
		Na	35.0

TABLE C-III. *Reactor Composition (Cont)*

<u>Region</u>	<u>Volume (liters)</u>	<u>Material</u>	<u>V/O</u>
Open Loop Assembly	11.35	PuO ₂	4.3
		UO ₂	19.1
		Void	3.6
		316 SS	40.0
		Na	33.0
Closed Loop Assembly	11.35	PuO ₂	1.1
		UO ₂	4.2
		Void	0.7
		316 SS	46.0
		Na	48.0
Axial Reflector	(T=45 cm)	Void	10.0
		316 SS	35.0
		Ni	11.0
		Na	44.0

TABLE C-IV. *Assembly Loadings (kg)*

<u>Isotope</u>	<u>Inner-Zone Driver</u>	<u>Outer-Zone Driver</u>	<u>Open Loop Test</u>	<u>Closed Loop Test</u>	<u>Control Rod</u>
Pu-239	6.02	7.53	4.35	1.15	0.0
Pu-240	0.82	1.03	0.60	0.16	0.0
U-235	0.20	0.19	0.15	0.03	0.0
U-238	27.40	25.79	20.77	4.54	0.0
O	4.66	4.67	3.47	0.79	0.0
Na	3.86	3.86	3.31	4.74	3.0
Fe	15.68	15.68	24.48	28.21	18.55
Cr	3.92	3.92	6.12	7.05	4.64
Ni	2.67	2.67	4.32	4.98	3.26
Mo	0.69	0.69	1.08	1.24	0.82
B-10	0.0	0.0	0.0	0.0	1.60

2. Principal Neutronics Parameters

The significant neutronics parameters for the FTR conceptual design are listed in Table C-V. Needless to say, many of the items given in this table are subject to appreciable uncertainty. An extensive critical experiment program is underway to reduce these uncertainties.

In addition to these calculational uncertainties, a significant error probably can be ascribed to inadequate definition of the core configuration and composition. For example, it is difficult to predict at this early stage the precise composition of each test loop. Thus, the parameters listed herein give a consistent, but not necessarily final, core description.

3. Flux and Power Profiles

Two-dimensional power and flux profiles have been computed in both hexagonal and R-Z geometry. All hexagonal computations were performed using 2DB with 4 energy groups and all R-Z computations were performed using 2DB with 13 energy groups. The axial leakage in the hexagonal calculations was simulated by a group and zone independent buckling of $6.04 \times 10^{-4} \text{ cm}^{-2}$. The core composition in the R-Z calculations were obtained by volume weighting all test loops, control follower assemblies, and driver loops.

Figures C-2 and C-3 show the average power density and flux, respectively, in selected hexagonal assemblies. The numbers in these figures are based on a core configuration in which all core rods were withdrawn. The peripheral rods, however, were all at half B^{10} density.

Figures C-4 and C-5 give the axial and radial profiles for power density and flux with all values being normalized to unity at the core center. The figures are based on R-Z calculations in which all control rods were withdrawn. It should be noticed that, in both the axial and radial direction, the power profile near the core-reflector interface has a smaller gradient than the flux profile. This difference, of course, is caused by spectrum softening.

TABLE C-V. *Parameters for Initial 2-Zone Core*

<u>Parameter</u>	<u>Units</u>	<u>Value</u>
Power (Including all loops)	MWt	400
Core Height	cm	91.4
Equivalent Radius	cm	60.6
Total Core Volume	liters	1033
Total Pu ²³⁹ Mass	kg	540
Pu ²³⁹ Mass in Driver	kg	507
Delay Fraction	--	0.003
Neutron Generation Time	sec	5.0×10^{-7}
Peak Power Density	MW/l	0.77
Peak Linear Power Density	KW/cm	0.44
Radial Peak-to-Average Power	--	1.35
Axial Peak-to-Average Power	--	1.24
Neutron Flux (At core center)		
Peak	n-cm ⁻² -sec ⁻¹	7.5×10^{15}
% > 0.1 MeV	--	65
% > 1.0 MeV	--	12
Fuel Composition		
% 239 in Pu	--	88
% 240 in Pu	--	12
U ²³⁸ /Pu ²³⁹ (Zone 1)	--	4.56
U ²³⁸ /Pu ²³⁹ (Zone 2)	--	3.42
Fuel Burnup		
Breeding Ratio	--	0.53
Reactivity Cycle	days	100
Reactivity Loss/Cycle	δk	0.02
Average Burnup/Cycle	MWd/kg	11
Average Total Burnup	MWd/kg	45

TABLE C-V. *Parameters for Initial 2-Zone Core (Cont)*

<u>Parameter</u>	<u>Units</u>	<u>Value</u>
Reactivity Requirements		
Safety	δk	.048
Fuel Burnup	δk	.026
Cold to Hot	δk	.008
Shutdown Margin	δk	.010
Test Compensations	δk	.020
Miscellaneous	δk	.016
Control Elements		
Number of Safety Rods	--	3
Number of In-Core Shim Rods	--	6
Number of Peripheral Shim Rods	--	15
Worth of Safety Rods	δk	0.070
Worth of In-Core Shim Rods	δk	0.074
Worth of Peripheral Shim Rods	δk	0.044
Reactivity Coefficients		
Doppler (Reflector Shims Inserted)	$T\delta k/\delta T$	-.005
Clad Axial Expansion	$\delta k/(\delta L/L)$	-0.30
Central Channel Pu ²³⁹ Worth	$\delta k/kg$	$+1.97 \times 10^{-3}$
Central Pu ²³⁹ Worth	$\delta k/kg$	$+2.87 \times 10^{-3}$
Core Averaged Na Worth	$\delta k/kg$	-8.5×10^{-6}
Central Channel Na Worth	$\delta k/kg$	-5.1×10^{-5}
Central Na Worth	$\delta k/kg$	-13.0×10^{-5}

TABLE C-V. *Parameters for Initial 2-Zone Core (Cont)*

<u>Parameter</u>	<u>Units</u>	<u>Value</u>
Temperature and Power Coefficients (At P = 400 MWt)		
Doppler	$\delta k / \delta T \ (\bar{T}_f \cong 1000^\circ\text{C})$	-3.2×10^{-6}
Clad Axial Expansion	$\delta k / \delta T \ (\bar{T}_{ss} \cong 425^\circ\text{C})$	-5.4×10^{-6}
Na Expansion	$\delta k / \delta T \ (\bar{T}_{Na} \cong 400^\circ\text{C})$	$+0.8 \times 10^{-6}$
Doppler	$\delta k / (\delta P / P)$	-22.0×10^{-4}
Clad Axial Expansion	$\delta k / (\delta P / P)$	-6.0×10^{-4}
Na Expansion	$\delta k / (\delta P / P)$	$+0.7 \times 10^{-4}$

FIGURE C-2. Axial Average Power Density (MW/1)
for a Total Power of 400 MW

FIGURE C-3. Axial Average Flux Profile ($n/cm^2\text{-sec} \times 10^{-15}$)
for a Total Power of 400 MW

FIGURE C-4. *Normalized Axial Power Density and Flux Profiles at Radial Center*

FIGURE C-5. *Normalized Radial Power Density and Flux Profiles at the Axial Midplane*

4. Flux Spectra and Reaction Rates

The central flux spectrum and integrated flux spectrum are shown in Figures C-6 and C-7, respectively. The corresponding specific powers and spectrum averaged cross sections are given in Table C-VI. Since there is little spectrum variation in the core, these central values are essentially equal to the core averaged values.

Observe that the fraction of flux above 1 MeV is about 12%, and the fraction above 0.1 MeV is approximately 65%. These percentages are slightly higher at the interface between the 2 core zones, and slightly lower at the core periphery.

FIGURE C-6. *Central Flux Spectrum*

FIGURE C-7. *Central Integrated Flux Spectrum*

TABLE C-VI. *Specific Power and Spectrum Averaged
Cross Sections in Central Zone*

<u>Isotope</u>	<u>Specific Power (Watts/gm) for $\phi = 5 \times 10^{15}$</u>	<u>σ_f (barns)</u>	<u>σ_a (barns)</u>
Pu-239	782	1.89	2.31
Pu-240	158	0.38	0.84
Pu-241	1026	2.50	2.86
U-235	842	2.00	2.57
U-238	19	0.046	0.347
Na	0.0	0.0	0.0016
O	0.0	0.0	0.0014
Fe	0.0	0.0	0.0103
Cr	0.0	0.0	0.0077
Ni	0.0	0.0	0.0243
B-10	0.0	0.0	2.40

5. Gamma Heat

Figure C-8 depicts radial distributions of the gamma heat absorption in the FTR. Calculations were made with a discrete ordinate transport theory code using a 10-group S_8P_3 approximation. The energy absorption mass attenuation coefficients were extracted from ANL-5800. Calculations were made for a high Z material (uranium) and a low Z material (sodium). Distribution for intermediate Z materials will fall between these two curves.

In Figure C-9 are shown relative axial distributions of gamma heat absorption at two radial positions from the FTR core centerline. These distributions are based on experimental thermoluminescent dosimeter data obtained in a critical facility simulation of the FTR system.

FIGURE C-8. *Gamma Heating at Reactor Midplane*

FIGURE C-9. *Relative Axial Distributions of Gamma Heat Absorption*

APPENDIX D

TEST SECTION DRAWINGS

SCALE 0 1 2 3 4 5 6 INCHES

CONCEPTUAL

Closed Loop In-Reactor Assembly (SK-20303)

NEXT USED ON	
DATE	BY
REFERENCE DRAWINGS	
NO.	DATE
DRAWING TITLE OR NUMBER

Closed Loop Test and Lower Section (SK-20327)

SPACER PAD-3 EQUALLY
SPACED PADS (WELD BUILD-UP) AT
EACH ELEVATION, STAGGERED IN
INCREMENTS OF 10 INCHES

APPENDIX E

ABNORMAL REACTOR OPERATING CONDITIONS TO BE ASSUMED
FOR EXPERIMENT SAFETY ANALYSES

APPENDIX E

ABNORMAL REACTOR OPERATING CONDITIONS TO BE ASSUMED FOR EXPERIMENT SAFETY ANALYSES

The subject matter discussed in this Appendix has been grouped into two categories. In the first section, two nuclear excursions are assumed in which reactivity is added to the reactor by uncontrolled motion of a single control rod. In the second section, an operational abnormality is assumed in which all primary system pumping power is lost, with immediate reactor scram.

1. Nuclear Excursion

- a. Case 1: Assume that the reactor is at delayed critical and low power conditions (1 watt, 600°F, and no coolant flow), and that a single safety rod is driven out of the reactor in an uncontrolled manner at 9 in. per minute. Figure E-1 shows the rate of power increase calculated for such an incident.
- b. Case 2: Assume that the reactor is at normal operating power, with full coolant flow, and that a single control rod is driven out of the reactor in an uncontrolled manner at 9 in. per minute. Figure E-2 shows the rate of power increase calculated for such an incident.

2. Loss of Pumping Power

Reactor scram is assumed to follow immediately (< 0.2 sec) after cessation of pumping power. The coolant flow rate decays initially in accordance with the momentum and flow resistance characteristics of the main heat transport or closed loop primary system. Thus, the flow decreases at a progressively slower rate as momentum is dissipated. However, since the system is designed to cool the reactor (at very low power) by natural convection, momentum is gradually replaced as a source of driving force by a thermal head effected in the flow system downstream from the core. Figure E-3 shows the decay in reactor power. Figure E-4 shows the decay in

coolant flow rate to be used in evaluation of a closed loop test. Figure E-5 gives the decay in coolant flow rate of the main heat transport primary system to be used in evaluating an open test.

FIGURE E-1. *Power Increase Following Accidental Withdrawal During Startup*

FIGURE E-2. *Power Increase Following Accidental Rod Withdrawal from Full Power*

FIGURE E-3. *Reactor Power Versus Time After Scram*

9-E

FIGURE E-4. *Closed Loop Flow Versus Time in Response to Loss of All Pumping Power*

FIGURE E-5. *Primary Coolant Flow Versus Time in Response to Loss of All Pumping Power*

APPENDIX F

OUT-OF-REACTOR SERVICES

APPENDIX F

OUT-OF-REACTOR SERVICES

All arrangements for out-of-reactor services to experimenters at the FFTF site are to be made well in advance. Such services typically include fabrication and flow testing of experimental subassemblies, interim and final postirradiation examinations, and shipping arrangements.

1. Postirradiation Examinations

As specified previously in this Guide, experimenters are required to contact the FFTF Project prior to seeking Approval in Principle for a given experiment to verify that the Project can obtain the necessary out-of-reactor services. To allow for final planning and scheduling, detailed information on interim and final postirradiation examinations should be sent to the FFTF Project several months in advance of the time that the experimental subassembly is scheduled for removal from the reactor. Observations of the postirradiation operations by the experimenter are usually possible by prior arrangement. Upon completion of the requested examinations, the data, photographs, etc., will be transmitted to the experimenter.

2. Postirradiation Shipping Arrangements

Previous communications concerning discharge, disassembly, handling, and examination of an experimental subassembly should have also established the disposition of the irradiated equipment. Experimental materials are normally returned to the experimenter, although they can be delivered to other sites if arrangements are made by the experimenter.

Preparation of experiments for shipment normally includes fabrication of a suitable container to protect the experimental materials in transit. Shipments of irradiated experiments from the FFTF fall into two general categories:

- a. Shipments to a point within the confines of Hanford Works
- b. Shipments to a point beyond the boundaries of the Hanford Works, generally utilizing a contract carrier

Shipments under category a. can generally be handled most efficiently by use of the FFTF casks and transport equipment.

Normally, for shipping casks that cannot be loaded with the specialized FFTF equipment, arrangements will be made for the transfer of the experimenter's specimens to nearby hot cell facilities at Hanford. The experimenter then makes the final shipping arrangements directly with initial assistance from the FFTF Project in establishing that contact if required.

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