DOE/ET-0032/1

The Fusion Reactor Materials Program Plan

Section I

Alloy Development for Irradiation Performance

July 1978

U.S. Department of Energy
Assistant Secretary for Energy Technology
Task Group on Alloy Development for Irradiation Performance

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Materials is the queen technology of any advanced technical system. The economics eventually depend upon the materials, the reliability depends upon the materials, and safety depends upon the materials. I assure you that before we are through with fusion, the physicists will give way to the materials engineers as being the leading lights of fusion.

E. E. Kintner
Introductory Remarks to International Conference on Radiation Effects and Tritium Technology for Fusion Reactors.
Gatlinburg, October 1–3, 1975

FOREWORD

The research and development activities of the Reactor Materials Program of the Office of Fusion Energy, DOE, consist of four major elements or task areas — *Alloy Development for Irradiation Performance (ADIP)*, *Damage Analysis and Fundamental Studies (DAFS)*, *Plasma-Materials Interaction (PMI)*, and *Special Purpose Materials (SPM)*. Program Plans for each element have been prepared by technical Task Groups composed of personnel from the various laboratories and contractors that contribute to the magnetic fusion program. Each Task Group of 6-10 principal investigators and/or consultants worked under the guidance of a Chairman drawn from a National Laboratory and his Counterpart, a staff member of the Materials and Radiation Effects Branch of the Office of Fusion Energy. For preparation of the Program Plans, these have been:

Task Group	Chairman	Counterpart
ADIP	J. O. Stiegler, ORNL	T. C. Reuther
DAFS	D. G. Doran, HEDL	T. C. Reuther
PMI	W. Bauer, Sandia	C. R. Finfgeld
SPM	J. L. Scott, ORNL	M. M. Cohen

The distribution of the Task Group members from among national laboratories, universities, industrial concerns and other Government organizations is given in the following table:

Type of Laboratory	Number of Laboratories	Individual Participants
National	8	19
Industrial	6	7
University	2	3
Other Government	2	2
TOTALS	18	31
Office of Fusion Energy Staff		3
		34

Each group operated through a number of Subtask Groups, which were *ad hoc* groups charged with problem definition and program planning in specific technical areas. Including membership on Subtask Groups, a total of over 100 individuals were involved in various stages of preparation of the Plans.

The assumptions inherent in the planning process were the construction of an experimental power producing reactor about 1990 and a Demonstration Plant by the end of the century. Beyond those assumptions, the Plans deal with the generic materials work that needs to be done, irrespective of magnetic confinement system. To the extent that such generic problems apply to hybrid reactors and laser fusion reactors, the Plans are applicable to them as well. However, they do not include tasks that are specific to hybrids (fuels, for example) or laser fusion (optical materials and ultra high frequency pulsing or ramp rates, for example).

The emphasis in the planning process was to examine the potential problems and to create a summary of materials-related work that needs to be undertaken for the successful development of fusion reactors. The wide representation of national laboratories, universities, and industry was encouraged to remove institutional bias to the greatest extent possible.

Each Task Group adopted a common format so that each Plan contains the same type of information. The format includes the following chapters:

Chapter 1, "*Executive Summary*"

Chapter 2, "*Introduction*"

In addition to introducing the subject matter, the Introduction contains a complete listing of Task Group members, Subtask Group members, and consultants.

Chapter 3, "*Problem Definition and Analysis*"

A discussion of materials-related problems and an analysis of such problems is given for each major topical area.

Chapter 4, "*Program Strategy and Major Milestones*"

This chapter is the most important one in each of the Plans. It describes the strategy that will be used to solve the materials problems described in Chapter 3. As part of this program strategy, a series of major milestones (Level 1) is identified that extends over the next 20 years. Chapter 4 is meant to be a *stand alone* section which succinctly summarizes the strategy to be employed in solving the problems. It is generally quite brief and is recommended to the reader who would like to get an overview of the approach that has been developed for solving the problems.

Chapter 5, *"Task Definition"*

This chapter contains detailed task descriptions for the next five years leading to the achievement of the major milestones listed in Chapter 4. Each task is described on a separate page (or task sheet) which includes the task number, task title, objective, scope, and the major milestones addressed by the task. Secondary milestones (Level 2) within a given task or subtask are defined, together with a priority assignment and an estimate of man-years to accomplish the work. Each Plan is organized along major topics which parallel the Subtask organization of the Task Group responsible for the Plan. In outline form, these major topics are given a letter designation, as follows:

Plan I: *Alloy Development for Irradiation Performance*

- A. Analysis and Evaluation
- B. Mechanical Behavior
- C. In-Reactor Deformation

Plan II: *Damage Analysis and Fundamental Studies*

- A. Environment Characterization
- B. Damage Production
- C. Damage Microstructure Evolution and Mechanical Behavior

Plan III: *Plasma-Materials Interaction*

- A. Plasma Device Characterization: Wall Interaction
- B. H, D, and T Recycling
- C. Impurity Introduction
- D. Near-Surface Wall Modification

Plan IV: *Special Purpose Materials*

- A. Breeding Materials
- B. Coolants
- C. Materials for Tritium Service
- D. Graphite and Silicon Carbide
- E. Ceramics

F. Heat Sink Materials

G. Magnet Materials

Major milestones are designated by Roman numerals (for each Plan) and serially by Arabic numbers. Tasks and subtasks are identified by a decimal system with corresponding secondary milestones designated in lower case letters. Priority ratings are assigned on the basis of a letter *H*, *M*, or *D* indicating the priority and a number *1*, *2*, or *3* indicating the timeframe.

Major Milestones

III.1

III. Plan III (Plasma-Materials Interaction)

1. Major Milestone (Level 1)

Major Topics, Tasks, Subtasks, and Subtask Milestones

III.A.1.1.a

III. Plan III (Plasma-Materials Interaction)

A. Major topic (letter) within Plan (Topic A in Plan III: Plasma Device Characterization)

1. Task number

1. Subtask number

a. Milestone (Level 2) within subtask

Priorities

H: Highest priority data needed to achieve Level 1 milestone either because the data are urgently needed or because the work is on a critical path for the accomplishment of other important milestones

M: Important data needed to complete a milestone but on a less time-restricted basis than H

D: Data required for a more complete understanding of important effects, desirable but not essential at this time

1: Near-term impact, defined as extending through TFTR

2: Intermediate-term impact, defined as affecting EPR and DEMO

3: Long-range impact, defined as affecting commercial reactors

The Program Workshop held in January 1978 showed that approximately one-third of the tasks in Plans I, II, and III are adequately funded in FY 1978 (where adequate funding is defined as the application of 50 percent of the required manpower postulated for the task). Another one-third of the needed tasks is receiving some support in FY 1978, while work in the remaining tasks needs to be initiated. The number of tasks funded in Plan IV, *"Special Purpose Materials"* is very small, since these materials are primarily needed outboard of the first wall, and such work is conducted on a longer timeframe. It is estimated that full funding (in terms of 50 percent of the required man-years) of all tasks would require resources three to four times those available in FY 1978 ($7.8M).

It is important to realize that the Plans describe problem areas and the approach to solutions as seen today, and that these will have to be updated periodically. Furthermore, the Plans should be regarded as outlining the major avenues to be explored rather than as a detailed road map. Although a task structure has been outlined, the detailed approach to the solution of specific problems will be proposed by individual investigators.

In conclusion, I would like to thank the many individuals who participated in the planning process during the past 18 months. Special appreciation is due to the four Task Group Chairmen, their respective laboratories for support, and their respective secretaries who suffered through several drafts. Special thanks are also due to my colleagues in the Materials and Radiation Effects Branch, ETM, who served as Counterparts to the Task Group Chairmen.

Klaus M. Zwilsky
Klaus M. Zwilsky, Chief
Materials and Radiation
Effects Branch
Office of Fusion Energy

ALLOY DEVELOPMENT FOR IRRADIATION PERFORMANCE PROGRAM PLAN

Table of Contents

1. EXECUTIVE SUMMARY

The Alloy Development for Irradiation Performance Program has as its objective the development of structural materials to withstand the hostile environment of the first wall of a fusion reactor. The goal of the program is a material that will survive an exposure of 40 MW-y/m^2 at a temperature of at least 600°C. Although the ultimate aim of the program is development of materials for commercial reactors by the end of this century, activities are organized to provide materials data for the relatively low performance interim machines that will precede commercial reactors.

This is certainly the most ambitious materials development program ever undertaken because the reactor environment and operating conditions create a host of materials problems that can cause or lead to failure including

- Crack growth
- Fatigue
- Creep-fatigue interaction
- Creep-rupture
- Elastic instability
- Loss of strength
- Swelling
- Irradiation creep
- Phase stability

Design or operating conditions can be envisioned for which any one of these could limit performance, so the Alloy Development Program must be sufficiently broad to encompass all these properties or characteristics. Development efforts are needed to improve all of them simultaneously, and performance targets are required to concentrate resources in the areas where the largest gaps exist.

Nearly all of the properties listed above are, under conditions of interest to fusion reactor design, sensitive to the metallurgical condition of the material being considered. This means that in any alloy system, improvements in properties are possible through careful control of composition and microstructure. If this were not so, broad searches for alloy systems having the full range of desired properties would be required. As it is, promising systems can be identified and then optimized in terms of details of composition and microstructure.

There is today no single class of candidate materials that clearly will be able to meet the requirements of a commercial reactor. The program must in its early stages be broad in the range of materials that it includes. Premature selection or rejection of a structural material could severely limit design options later. Initial studies suggest that the stainless steels, higher strength Fe-Ni-Cr alloys and the refractory or reactive metal alloys all offer attractive properties for fusion reactor applications. The Alloy Development Program will follow a parallel path approach including

- Austenitic alloys
- Higher strength Fe-Ni-Cr alloys
- Refractory/reactive alloys
- Innovative concepts

The latter path is included in the program in recognition that the conventional concepts of alloy development may not be adequate for fusion reactor applications. This path might include novel approaches such as graded materials, fiber structures, composites, structural ceramics, ordered alloys, low activation materials, unique material processes and other imaginative ideas that offer the possibility of reduction to engineering practice.

The broad scope of materials and properties to be considered in this program requires participation by experts representing most of the disciplines of physical metallurgy, as well as representatives of the design community. The Office of Fusion Energy has approached this problem by forming a Task Group to coordinate and oversee the activities involved in the program. Subtask groups having expertise in (1) Mechanical Behavior and (2) Point Defect Behavior (In-Reactor Deformation) have been established to guide alloy development work in these areas. They will be supported by an Analysis and Evaluation Subtask Group that will establish appropriate test matrices, evaluate reactor concepts in terms of materials performance and serve generally as a bridge between the materials and reactor design communities. Additional Subtask Groups on Environmental Effects and Fabrication Development will be established as the program grows. Close coordination of activities with the Damage Analysis and Fundamental Studies Task Group will be established and maintained through a representative common to both task groups.

The range of problems, irradiation conditions and possible solutions in terms of composition and microstructure is so vast that the conventional trial and error or Edisonian approach to alloy development is unlikely to lead to anything other than confusion. An approach in which the effects of important material and irradiation variables are understood, at least in qualitative terms, and applied to the design of alloys is essential to meeting the schedules and requirements of this program.

The exposure goal of 40 MW-y/m^2 makes irradiation effects the dominant element in the program. There is no way to estimate the properties of materials irradiated to such high levels from the properties of unirradiated materials. Final decisions on alloy choices will be based on extensive measurement of irradiated materials, including the evaluation of properties during irradiation. The program will not be directed exclusively at irradiation performance, however, and much of the early identification of promising alloy systems will be based on measurement of properties outside the irradiation environment.

The ideal test environment has a fusion neutron spectrum, a flux high enough to allow accelerated testing and an experimental volume on the order of several liters. Such a source is not currently available or authorized, but the plan assumes that one will become available around 1990. During the intervening time the program must rely on less-than-ideal sources (principally fission reactors), simulation techniques, and, of necessity, a strong understanding of the physical processes that occur during irradiation. The Damage Analysis and Fundamental Studies Task Group and the d-Li Neutron Source are essential elements of this part of the strategy, for they will allow us to relate fission reactor behavior to the fusion reactor environment.

This plan describes the steps for producing an optimized alloy on each of the four parallel paths. This is not intended to imply that all four paths will be followed to completion. As the program develops, the less promising approaches will be eliminated, and attention will be concentrated along the more productive lines. This will be possible only if the program is initiated now. During the first five or six years the program is designed to fill two needs: first, an optimized stainless steel will be identified and a partial data base will be developed to guide design of interim machines; and second, scoping work will be completed to identify promising alloy development approaches on the other paths. At that time the reactor design concepts should become better defined as a result of plasma physics experiments now under construction, and the alloy development effort can then be focused to meet those needs. If we wait until the time to begin work in a major way, intensive development efforts will be required on all the paths if the overall objectives and schedule of the fusion program are to be met. This approach will be both more costly and inefficient. If resources do not permit this, some of the options of the parallel path approach may be closed and design options may be compromised.

MAJOR RECOMMENDATIONS

1. Obtain and maintain a dedicated mixed spectrum fission reactor that can be adequately instrumented.
2. Obtain an instrumented test position in the Fast Test Reactor (FTR) for use as soon as the reactor becomes available.
3. Obtain authorization and funding for a high energy-high flux-large volume neutron source, preferably d-Li.
4. Develop plans for a large volume, high flux Fusion Reactor Test Facility to become operational about 1990. See Appendix A for a discussion of options.
5. Establish a working relationship and information exchange with the companion alloy development program supported by the LMFBR Program.
6. Support an effort, probably in the Damage Analyses and Fundamental Studies Task Group, to develop innovative testing methods which reduce the size and number of specimens required.

2. INTRODUCTION

2.1 Program Goals

The Alloy Development for Irradiation Performance Program is focused on meeting the materials requirements for commercial fusion reactor systems. As such it has the ambitious goal of developing the materials to withstand the hostile reactor environment for a time integrated exposure of 40 megawatt years per square meter (MW-y/m^2). Although the program is aimed at developing alloys for commercial reactors, it also is organized to provide materials and design data for lower performance intermediate fusion systems.

Long term goals can be stated only in the most general terms at the present time because fusion reactor design options are still not well defined. A choice of an exposure goal can be derived from estimates of wall loadings from fusion reactor point designs, from economic considerations based on plant availability, and from an assessment of available test facilities. These factors are discussed in many of the current systems studies and are summarized in Fusion Materials Program Bulletin 2. The exposure goal of 40 MW/y-m^2 derived from such studies results in a 20 year first wall life for a reactor operating at 2 MW/m^2 or a 10 year life for one at 4 MW/m^2. This is an extremely ambitious goal that is well beyond our present capabilities. For stainless steel this corresponds to a damage level of about 460 displacements per atom and a helium content of 5600 atomic parts per million. Corresponding goals for the Breeder Reactor alloy development program are 90 to 180 dpa and about 100 parts per million of helium.

Temperature goals depend on the heat conversion system that is available for use. For current liquid metal/H_2O systems a maximum alloy temperature of about 600°C is desired. This defines a temperature goal for all alloys in the program. We suppose that by the end of the century advanced conversion systems will become available that can accept heat at higher temperatures. Alloys will be included in the program that can operate at temperatures up to 730°C for a He/H_2O system and up to 900°C for a direct helium turbine system.

The Magnetic Fusion Energy Program has as its objective the development of a commercially viable reactor system early in the 21st century. The Alloy Development for Irradiation Performance Program is an integral part of this effort. Its goal is development and qualification of a first wall/blanket structural material within that time frame.

2.2 The Alloy Development for Irradiation Performance Task Group

The Office of Fusion Energy has approached the task of meeting these goals by organizing a Task Group to develop the long range alloy development program plan contained in this document and to coordinate the alloy development activities funded by the Office.

The Task Group organization is based on recognition that successful development of an alloy will require the closely coordinated activities of several disciplines. The Task Group accordingly is organized around these disciplines to insure that each will contribute to decision making processes (see Fig. 2.1 and Table 2.1).

An Analysis and Evaluation Subtask Group has been established to provide a bridge between the materials community, represented by two Materials Performance Subtask Groups, and reactor designers. It will analyze reactor performance in terms of relevant experimental data to identify areas of materials problems. It will assess data continually with respect both to types of data and to range of variables. Its objective is to ensure that all necessary materials performance data are obtained and are considered by reactor designers. At the same time it will keep the Materials Performance Subtask Groups advised of design requirements. In concert with the Materials Performance Subtask Groups it will establish specific materials performance goals.

Materials Performance Subtasks have been established for In-Reactor Deformation (Swelling and Irradiation Creep) and for Mechanical Behavior. These subtask groups are responsible for developing a strategy for achieving the performance goals, for formulating detailed plans, especially for irradiation experiments, and for implementing the plans. As results become available the group members will review, interpret, and evaluate the experimental data and eventually develop a data base suitable for fusion reactor design in the form of a materials performance handbook.

Fig. 2.1 Task Group Relationships

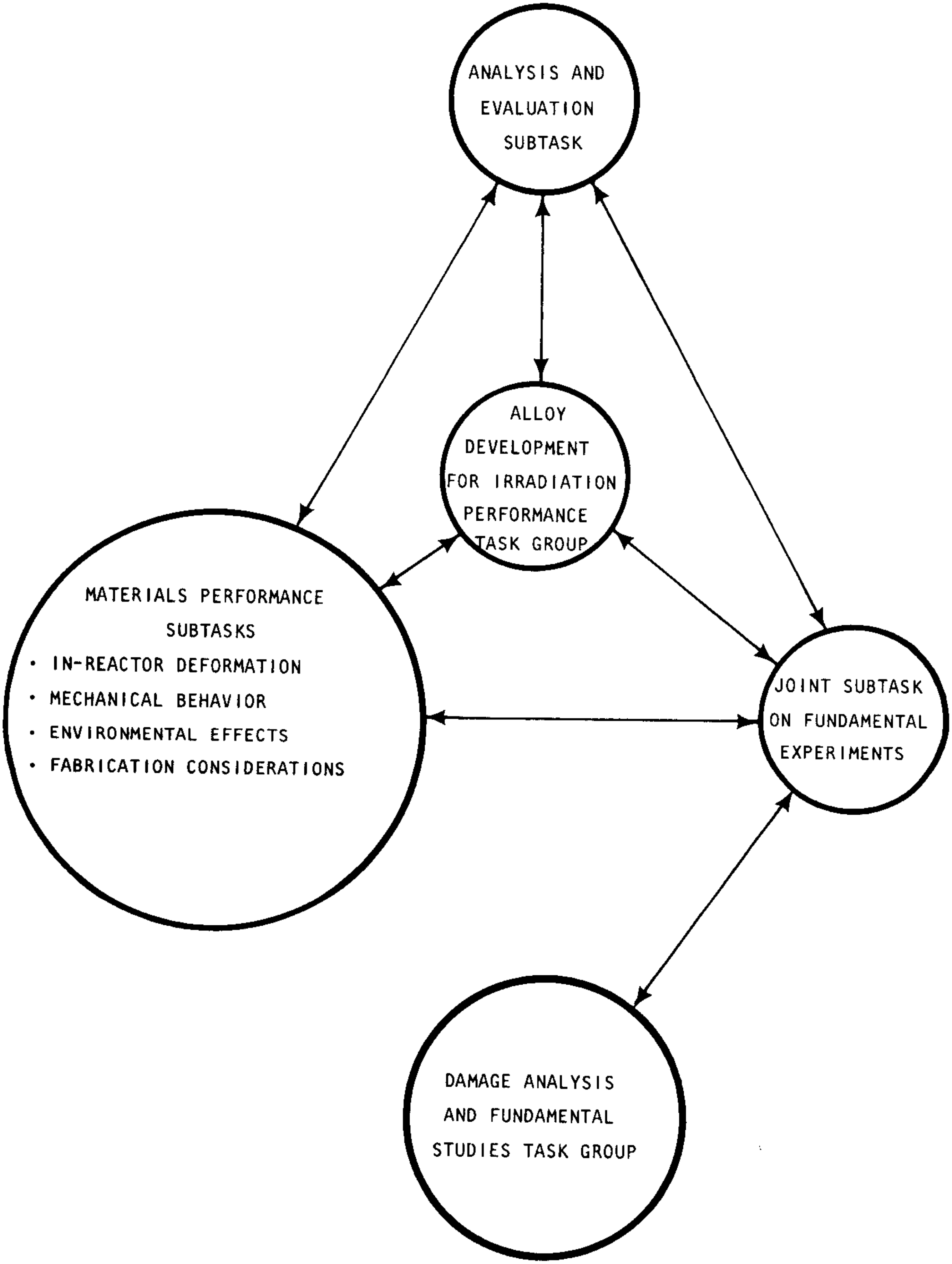

Table 2.1. Alloy Development for Irradiation Performance

TASK GROUP MEMBERS	
E. E. Bloom	ORNL (Chairman, October 1, 1977 –)
E.N.C. Dalder	DOE-ETM
R. E. Gold	Westinghouse Research Laboratory
J. J. Holmes	HEDL
D. L. Kummer	McDonnell Douglas Astronautics Company - East
F. V. Nolfi	ANL
T. C. Reuther	DOE-ETM
J. O. Stiegler	ORNL (Chairman, October 1, 1976 – September 30, 1977)
F. W. Wiffen	ORNL
MECHANICAL BEHAVIOR SUBTASK	
J. J. Holmes, Chairman	HEDL
D. R. Diercks	ANL
M. L. Grossbeck	ORNL
R. H. Jones	PNL
B. A. Cramer*	McDonnell Douglas
L. A. James*	HEDL
J. L. Straalsund*	HEDL
IN-REACTOR DEFORMATION SUBTASK	
F. W. Wiffen, Chairman	ORNL
E. R. Gilbert	HEDL
P. R. Okamoto	ANL
J. A. Spitznagel	Westinghouse Research Laboratory
ANALYSIS AND EVALUATION SUBTASK	
D. L. Kummer, Chairman	McDonnell Douglas
B. A. Cramer*	McDonnell Douglas
E.N.C. Dalder	DOE-ETM
R. E. Gold	Westinghouse Research Laboratory
J. A. Delessandro	General Atomic
J. H. DeVan*	ORNL
S. D. Harkness*	ANL
K. C. Liu*	ORNL
V. A. Maroni	ANL
D. L. Smith*	ANL
JOINT SUBTASK ON FUNDAMENTAL EXPERIMENTS	
F. V. Nolfi, Chairman	ANL
C. Y. Li	Cornell University
F. A. Smidt	NRL

*Consultants

As the program develops, additional Materials Performance Subtasks in the areas of Environmental Effects and Fabrication Development will be activated. The Environmental Effects Subtask will be concerned with evaluating and assessing the influence on materials performance of the coolant and plasma environments. This will include compatibility and corrosion considerations as well as effects of gases on materials performance. A major function of this subtask will be recommendation of testing environments to the In-Reactor Deformation and Mechanical Behavior Subtask Groups. The Fabrication Development Subtask Group will be established to develop suitable fabrication and joining techniques for the alloys considered in the program. This is likely to become more involved than what is usually thought of as fabrication development (e.g., development of techniques for fabricating tubing), because microstructural control will probably be a key element in alloy design. Fabrication procedures will be required to produce a specified microstructure as well as a particular shape. Furthermore, materials performance will certainly be sensitive to composition, which must be carefully controlled both on a macroscale in bulk pieces and on a microscale in weldments.

As was mentioned earlier, the Environmental Effects and Fabrication Development Subtasks will not be activated during the initial phases of the program. Individuals having experience in these areas will be members of the Analysis and Evaluation Subtask where they will serve in an advisory capacity. As program needs in these areas become more clearly defined, the subtask groups will be activated.

Since the activities of the Alloy Development for Irradiation Performance and the Damage Analysis and Fundamental Studies Task Groups are closely related, a Joint Subtask group has been formed to coordinate common activities, including research materials, irradiation experiments, and testing procedures and facilities. Its purpose is to ensure that critical questions are most effectively addressed by the programs included in the charters of the two Task Groups.

The Task Group proper acts to coordinate the activities of the various Subtask Groups. It is responsible for establishing general goals and strategy and for developing a comprehensive overall program plan. It establishes schedules, especially for major irradiation experiments in which several subtask groups may participate, and recommends priorities to the ETM Materials and Radiation Effects Branch to meet goals and schedules of the Magnetic Fusion Energy Program.

Establishment of criteria and rationale for the selection of alloys to be included in the alloy development program is the responsibility of the full Task Group. Materials and alloys suggested to the group are submitted to all of the Subtask Groups for review and comment before acceptance to ensure that alloys having fatal qualities in one area are not investigated extensively in another. The Task Group also is responsible for seeing that all appropriate measurements are made on alloys included in the program.

Since the individuals participating in the program are widely dispersed both by geography and by discipline, communication is essential to the success of the program. Within the Subtask Group direct interaction between members occurs during periodic meetings. Additional participants, consultants or members of other Task Groups, are expected to attend from time to time. Annual Program Meetings including all Subtask Groups will be held once the program is established. Coordination of activities between Task Groups will also be accomplished through regular meetings of Task Group chairmen and their DOE counterparts and through the Fusion Materials Coordination Committee. Technical results will be summarized and published periodically in a joint report that includes contributions from all participating laboratories.

2.3 Program Assumptions

The plan presented in this document is designed to develop a material to meet the exposure and temperature goals for a commercial reactor system early in the 21st century. It is consistent with schedules and milestones given in the Program Plan for Fusion Power by Magnetic Confinement (ERDA-76/110). In addition to providing materials for commercial reactors, the plan is organized to produce near and mid-term materials information for design of an Experimental Power Reactor (EPR) in the 1980s and a Demonstration Power Reactor (DEMO) in the 1990s.

The program is not tied to any particular reactor concept but is arranged to provide a broad data base with choices for optimizing properties for reactor designs that emerge ultimately from the studies now being undertaken. The program recognizes that no single alloy condition is likely to be optimum for all reactor applications; small changes in design may change the property that limits useful service life. The program must, therefore, be broad in its early stages. It is designed to provide a general description of materials behavior in a fusion reactor environment by the early 1980s. At that time, the results of major plasma physics experiments now under construction should be available to narrow the range of reactor design options. The alloy development program will be in a position then to focus its actions on the more specific needs of the program. It is necessary that the broad, scoping studies be conducted in the intervening period to provide the basis for the more concentrated development that will follow.

The program will be paced and perhaps limited by irradiation experiments, which are both costly and time consuming. It is the judgment of the Task Group that an alloy for commercial fusion power can be developed by the early 21st century if the schedule given in the plan is followed. Delays will reduce the number of iterations possible and certainly result in compromises in properties.

The lack of a fusion reactor test facility dictates that fission reactors be the major irradiation vehicle during the early years of the program. The d-Li neutron source is also needed to provide guidance on the extrapolation of fission reactor properties to the fusion reactor environment. The plan assumes that the d-Li source will become operational sometime before 1985 and that a high flux-large volume fusion reactor test facility will become available by about 1990.

3. PROBLEM DEFINITION AND ANALYSIS

Our concepts of commercial fusion reactors and our knowledge of the performance of materials in a fusion environment are embryonic. The number of potential problems and the number of possible solutions appear limitless. An effective alloy development program must choose between these alternatives to focus efforts on choices that satisfy the long term objective of the program — commercial fusion power. In order to devise a strategy to meet this need, the Subtask Groups were asked to analyze the crucial and generic problems in their areas. This chapter is a brief summary of these findings. A complete, fully referenced version can be obtained from the Task Group Chairman.

3.1 Analysis and Evaluation

To be effective, alloy development tasks must be closely related to reactor design activities; this allows critical properties to be identified and quantitative performance goals to be defined for them. Without this interaction, resources are unlikely to be directed at the most critical problems, and alloys that emerge from the program may severely restrict design options. A successful reactor will be the result of an iterative effort between reactor designers and materials engineers in which both design and materials development techniques are applied to critical problems. Design solutions may ease the performance characteristics of materials, and materials developments may reduce design restrictions.

3.1.1 Definition of Material Property Requirements and Structural Life Predictions

Performance goals must be translated into material property requirements to guide the alloy development process. This is a difficult task, for there are many potential sources of stress in fusion reactors that can lead to a large number of failure mechanisms. Some of the more prominent possibilities are listed in Table 3.1. Design changes or relatively slight improvements in a property may change the failure

Table 3.1. Components of Structural Life Predictions

Sources of stress	Failure mechanisms
● Dead weight	● Creep-rupture
● Thermal gradients	● Fatigue
● Swelling	● Creep-fatigue interaction
● Coolant pressure	● Crack growth
● Magnetic forces	● Elastic instability
	● Embrittlement

process. As a consequency property goals for all the failure mechanisms must be defined that are consistent with the life and temperature goals of the program. This will identify areas in which the alloy development activities should be concentrated. It also will locate areas in which design solutions may be required.

Structural analysis tools and techniques are available. Material property data and details of reactor design and operation are needed to improve the analyses. This activity will identify gaps in these areas. It will include sensitivity analyses to show the effect on structural life of changes in materials properties or operating conditions. Systems analysis will relate reactor operating parameters, structural life, and material costs to the reactor capital costs and to the cost of electricity. Structural and systems analyses will be continuing activities since material properties as well as reactor designs and operating conditions will be continually changing. This activity is needed to focus alloy development efforts on the most critical needs and to provide communication between materials engineers and the reactor design community.

3.1.2 Definition of Test Matrices and Procedures

If all interesting properties were to be measured on all potentially useful materials, the resultant testing program would exceed by at least an order of magnitude the resources available to the program. Reactor space is probably the most limiting factor, but time, personnel and dollars are also significant items. The total matrix must be reduced to a manageable size in a way that does not compromise materials judgments or design considerations.

Three categories of tests will be required:

1. Scoping tests will be used to make relative judgments between materials and metallurgical conditions and to identify critical properties. Such tests, which will be used where large numbers of variables are involved, must be rapid, simple, and decisive.

2. Developmental tests will be used for optimization of the Prime Candidate Alloys. They will be broader in scope and more extensive than the scoping tests. In-reactor testing will be an important part of this work.

3. Engineering property tests will be devised to provide the broad data base needed for reactor design.

In addition to defining test matrices, it is necessary to devise special tests to take into account interactions between properties. For example, the complicated situation resulting from temperature and stress cycling in the reactor environment is difficult, if not impossible, to model from simpler tests. Miniaturization of tests to use reactor space more efficiently must be considered too.

3.1.3 Chemical and Metallurgical Compatibility

There are many examples in power plant operation where the service life of structural components is limited by interaction with the coolant. Corrosion, erosion, and mass transfer are processes that may degrade properties or present maintenance and safety problems. In a fusion reactor the plasma also presents an environmental problem since deuterium and tritium may enter and diffuse through the first wall structure. Reversible uptake and release of fuel can affect post-burn evacuation, plasma startup, and regulation of fueling. Tritium holdup, potential embrittlement at shutdown, and maintenance complications are additional concerns. Design to accommodate these and other compatibility problems may restrict plant efficiency or reliability.

Reactor concepts presently being considered include a wide variety of structural material/coolant options. Compatibility questions must be considered early since they may reduce options or define more restricted temperature ranges, both of which could reduce the scope of the alloy development effort. Compatibility analyses are also needed to provide guidelines to aid the alloy development effort. Limited testing will be required to define compatible systems. Later as the alloy development program becomes better defined environmental effects must be factored into the testing program to evaluate compatibility/property interactions. Since compatibility considerations impact design options, they must be communicated to the design community. This includes not only structural material/coolant/temperature options but also mass transfer of radioactive species, which may influence plant design.

3.1.4 Fabrication

The need to fabricate the large and complex shapes required for fusion reactors must be considered as part of the alloy development program. The use of microstructure to produce desirable properties places an added burden on fabrication effects; the part must have not only a specific size and shape but a uniform and controlled internal structure as well.

There are three areas where fabrication considerations impact alloy design:

1. Alloys must be fabricable to the desired shapes and sizes. In many cases it may be necessary that some fabrication operations be performed at the reactor site. Welding will probably be a primary fabrication technique. Alloys must be weldable, and welding techniques must be developed that produce welds that can survive in the fusion reactor irradiation environment.

2. It must be possible to obtain uniform and controlled microstructures or, more likely, microstructures that have uniform and controlled properties. This is an especially difficult problem in welding where the melting action may introduce impurities, residual stresses, and a variable microstructure.

3. Remote maintenance and repair of components after irradiation is a possibility that must be considered. Welding of irradiated materials is a totally unknown factor.

With the exception of developing weldments that have acceptable irradiation performance the austenitic stainless steels present no serious fabrication problems. The higher strength Fe-Ni-Cr alloys may present some welding problems, especially low weld-metal ductility and cracking in the heat-affected zone. Post-welding heat treatments may be required to produce precipitate structures. These factors must be evaluated before development efforts on these alloys become very advanced.

Reactive and refractory metal alloys present more difficult fabrication problems. For Group V alloys, the detrimental effect of interstitial (O, C, N) pickup during welding requires that welding be performed in vacuum or in very pure inert gas environments. This complicates field assembly by welding but has little effect on welding in a factory. For molybdenum alloys, the low temperature brittleness that results from the recrystallization and grain growth inherent in heating stress-relieved microstructures above the melting point during fusion welding is a serious problem.

For all these materials a fabrication effort is required that will satisfy the MFE design community that no serious fabrication related questions remain unanswered and that will satisfy applicable code or regulatory body requirements. These needs must be factored into the appropriate testing and development efforts.

3.2 Mechanical Behavior

Mechanical properties of materials change continuously during irradiation, usually in a detrimental way. Once the most critical problems resulting from these changes have been identified, the

Mechanical Behavior Subtask Group is responsible for investigating the problems in more detail, for understanding how the properties are degraded, for determining how the changes are affected by alloying, and for identifying areas in which alloy development or design techniques can be used to relieve the problems. Areas in which property changes are not possible must also be identified so that design solutions can be investigated. A brief discussion of the key problems identified by the Analysis and Evaluation Subtask Group follows.

3.2.1 Fatigue Crack Growth

Engineering structures often contain flaws or defects which, if present with an appropriate size, orientation and location, may propagate under cyclic stress fluctuations. Even if such defects are not present, they may be formed during service. Crack growth rates are usually expressed as a function of a stress-intensity factor, which is dependent on the size, shape and location of the crack or flaw, and on the cyclic stress amplitude. Below some critical stress-intensity factor crack growth rates are vanishingly small. Metallurgical variables such as composition, microstructure, and even heat-to-heat variations affect the point at which cracks begin to grow for a given set of temperature, stress, and environmental conditions. At higher stress-intensity factors, crack growth rates are proportional to some power of that factor. In this range the rates are sensitive to external conditions such as temperature, environment, stress ratio, frequency and loading pattern (hold time) but are not very sensitive to metallurgical variables. At still higher stress-intensity factors, crack growth rates accelerate as the onset of instability is approached. This latter condition is related to the fracture toughness of the material, and tougher materials will delay the onset of unstable growth.

Radiation effects are largely unknown. Limited studies in LMFBR and LWR neutron spectra have shown little effect on crack growth in the power law regime, but no data are available describing the crack growth threshold.

Work is needed to define the effects of the fusion reactor environment (especially high dpa and helium content) on crack growth behavior with emphasis on the crack growth threshold and on fracture toughness. The metallurgical variables approach should be used to develop alloys with improved properties.

3.2.2 Stress or Strain Controlled Fatigue

Fatigue resulting from the repeated thermal cycling of first wall components may limit reactor design options. Fusion reactor fatigue problems lie between the low cycle region (about 10^5 cycles to failure) where plastic yielding occurs each cycle and the high cycle region (about 10^7 cycles to failure) where loading is nominally elastic. Hold times introduce complications into the situation by allowing some relaxation each cycle. For given testing conditions, fast neutron irradiation tends to reduce the number of cycles to failure, although exceptions have been noted. Reductions appear to be larger in the low cycle region for post-irradiation tests.

Within an alloy class, low cycle fatigue properties are insensitive to composition and microstructure. In the medium to high cycle region of interest to fusion reactors, metallurgical condition may have a significant effect on fatigue life. This is especially true where effects of hold times are included.

Because of the large number of parameters that may describe fatigue conditions, an extensive testing program to evaluate the effects of these parameters is needed. This may be reduced some by applying empirical relationships between tensile and creep properties and fatigue behavior, but these must be verified for fusion reactor conditions. Some in-reactor testing to evaluate the relaxation effects of irradiation creep must be included.

3.2.3 Tensile Properties

Tensile properties describe the response of a material to uniaxial loading by defining the points at which yielding and fracture will occur, two important criteria in materials selection and reactor design.

Tensile properties can also be related to other types of mechanical behavior (e.g., strain controlled fatigue). Tensile properties are extremely sensitive to composition and structure, and wide variations can occur in a single material from thermal and mechanical treatments. Irradiation also has a strong influence on tensile properties. The complex defect configurations, voids, loops, dislocation lines, and precipitate particles tend to harden materials while the precipitation reactions that remove strengthening elements from solution tend to weaken them. The net result depends on the irradiation temperature, fluence, and the initial composition and microstructure. At lower irradiation temperatures (400°C for stainless steels) the defect strengthening wins out and yield strengths approach ultimate strengths. This results in a reduced work hardening capability and a decrease in ductility. At higher irradiation temperatures softening often occurs, but ductilities are still reduced because of the onset of grain boundary fracture. Both transmutation-produced helium and segregation of solutes to grain boundaries via a defect drag mechanism may contribute to the reduced ductility.

Additional problems may be introduced in body-centered cubic materials where ductile-brittle transition temperatures may be raised above the irradiation temperature and where a total loss of work hardening ability may introduce an unstable deformation mode.

Since tensile properties are so sensitive to composition and microstructure, considerable improvements can be expected through manipulation of metallurgical variables. Tensile tests are relatively easy to conduct and interpret, so they should be used extensively in scoping studies. The ability to relate the results to other properties (e.g., fatigue) and to interpret them in terms of microstructure makes them especially useful.

3.2.4 Thermal Creep and Creep Rupture

At elevated temperatures, slow deformation and fracture with low uniform strain may occur at stresses below the yield strength of the material. Irradiation may decrease or increase the deformation rate by hardening or softening the lattice as described in the previous section, but ductility is invariably reduced. At lower temperatures, displacement damage and matrix hardening appear to be responsible for the loss. In the stainless steels and higher strength Fe-Ni-Cr alloys irradiated and tested at high temperatures, the ductility loss is often associated with intergranular fracture. The segregation of helium as well as solute atoms to the grain boundaries is thought to be responsible.

Both deformation rates and ductilities are sensitive to composition and microstructure, usually more so than tensile properties are. Small amounts of titanium have been shown to be especially effective in reducing the tendency for grain boundary fracture in stainless steels. As with tensile properties, significant improvements can be expected through a systematic investigation of effects of composition and microstructure.

3.3 In-Reactor Deformation

In-reactor deformation includes all those direct effects of microstructural rearrangement that occur in structural materials under irradiation. This dynamic rearrangement of the microstructure results from the displacement of atoms by collisions with energetic neutrons and from the introduction of additional chemical species via transmutation reactions; these processes may result in changes in the volume and/or shape of reactor components, a phenomenon we term in-reactor deformation. These changes in shape and volume are important in themselves as they may generate or relieve stresses or otherwise directly affect component lifetime or reactor operation. The changes in microstructure are also the source of the changes in mechanical behavior discussed in the preceding section. Understanding and controlling them is essential to design of alloys having improved mechanical performance.

In-reactor deformation processes will occur in fusion reactor structural components. Since they are unavoidable, the goal of the In-Reactor Deformation Subtask Group is to understand these processes on an atomic level so that alloys can be developed where the in-reactor deformation is limited and calculable.

3.3.1 Microstructural and Phase Stabilities

Most engineering alloys are produced in a metastable condition, and during service at elevated temperatures they tend to progress toward an equilibrium state. Changes in volume and shape as well as in other physical and mechanical properties frequently result from the atomic rearrangements that occur. Neutron irradiation tends to accelerate many of these changes and to introduce additional ones.

Four basic effects of irradiation on phase stability have been recognized or proposed.

1. Diffusional processes are enhanced by the excess point defects produced by the irradiation. This may accelerate processes that occur slowly in the absence of irradiation.

2. Free energies of phases may be changed relative to one another because of the presence of irradiation-produced defects. This may result in the appearance of phases that do not occur in the absence of irradiation.

3. Solute segregation or de-mixing of solid solutions may occur if certain constituents are bound to point defects. As defects flow to sinks, they carry solutes with them. This results in concentration gradients and in some cases precipitation reactions that do not occur otherwise.

4. Dissolution or disordering of small precipitate particles may occur when collision cascades or climbing dislocations interact with them. Reprecipitation may then occur, but possibly on another scale.

Phase stability is significant in the sense that it may change important engineering properties. Density, strength, ductility, and corrosion resistance are obvious possibilities. Phase stability is included with the in-reactor deformation topics because, like swelling and irradiation creep, it involves microstructural and point defect considerations. Phase stability studies must be an integral part of the program, for design of alloys requires that they be stable enough during irradiation that their properties do not change in undesirable or in unpredictable ways. Such studies can define regions in composition space in which stable, well behaved alloys can be developed. They can also guide alloy optimization work by identifying elements responsible for undesirable traits. A rational (i.e., non-trial and error) approach to alloy development requires at least a description of phase and solute distributions during irradiation. Without it, one can only guess at solutions to problems.

3.3.2 Swelling From Cavity Formation

Significant swelling occurs during irradiation when vacancies survive annihilation and precipate as cavities; the corresponding interstitials create new lattice sites by precipitation at dislocations. Transmutation-produced gases may accelerate the nucleation and growth of the cavities, and in extreme cases the pressure of the gas within the cavities may equal or exceed the surface tension restraint. Gas production rates will be high enough in fusion reactors that some cavity formation is inevitable. If the cavities contain excess vacancies, swelling may pose a serious problem. Stresses and distortion of components from non-uniform swelling, changes in strength and ductility that accompany the swelling, and the formation of paths for easy propagation of cracks are other consequences of swelling.

Helium tends to enhance swelling by promoting the nucleation of both voids and dislocation loops. Because helium may drive cavity growth at higher temperatures, the temperature dependence of swelling for the fusion reactor case where helium contents are high may differ significantly from the fast reactor case where they are relatively low. Hydrogen is expected to be less important because of its high solubility and diffusivity at temperatures of interest. It may, however, undergo chemical reactions that produce species that influence swelling (e.g., with carbon to form methane). Its behavior in the presence of structural imperfections is unknown. Applied stresses may also affect swelling, so this must be included as a variable in the alloy development effort.

Both nucleation and growth of voids are extremely sensitive to composition and microstructure. Very small changes in minor alloying elements such as Si, Ti, Zr, and O can produce order of magnitude changes in swelling behavior. Large variations also occur with systematic changes in major alloy constituents. Dislocations may either hinder or accelerate swelling depending on the material and on the dislocation density and configuration. Finely dispersed precipitate particles may either increase or decrease swelling directly by serving as sites for void nucleation or indirectly by depleting the matrix of solute elements.

3.3.3 Shape Changes from Irradiation Creep

Under irradiation, materials may deform slowly at temperatures and stresses that are below those at which thermal creep is important. The irradiation creep rate is proportional to the displacement rate and to the applied stress. In contrast to thermal creep, it is only weakly dependent on temperature. Swelling often accompanies irradiation creep but it is not a necessary prerequisite. The increased creep rate is thought to arise either from the preferential absorption of self-interstitials at dislocations favorably oriented to the stress system or from a combination of enhanced climb and glide of slip dislocations. At higher temperatures and stresses, the irradiation creep is overwhelmed by thermal creep, but the thermal creep rate may be reduced because of dynamic hardening or from the accumulation of displacement damage.

At least in the austenitic stainless steels and in the higher strength iron-nickel-chromium alloys, the irradiation creep rate is sensitive to composition. It is also sensitive to microstructure, including both dislocations and precipitates, but less so than is thermal creep.

3.4 Summary

Several key property changes that could limit the lives of reactor components have been identified. In all cases properties under the conditions of interest to fusion reactor design have been shown to be sensitive to the metallurgical condition of the material. This indicates that the alloy development effort should be focused on investigations of the effects of composition and microstructure on these properties.

Since so many properties must be considered, choices of optimized alloys will certainly involve compromises. This requires that the same metallurgical variables be investigated on all properties and that they be investigated in enough detail to allow reasoned judgments to be made in identifying alloys that are optimized for irradiation performance. In addition, microstructural choices must be consistent with fabrication requirements.

Because of the large number of materials variables and properties to be considered, scientific design of experiments will be required. Overall performance goals must be defined for all the interesting properties to assure that the program is focused on the most critical problems and is not directed at improving properties that exceed requirements. A strategy for implementing these points is described in the following chapter.

4. PROGRAM STRATEGY AND MAJOR MILESTONES

4.1 Basis of Strategy

1. The program goal of an alloy qualified for commercial fusion reactor service by the year 2000 requires that the program focused on that goal be initiated immediately. At first glance the justification for this statement may not be obvious, but a detailed study of the strategy to be presented later in this chapter will show that all of the available time will be required for the numerous iterations required to reach an optimized alloy. Delay, especially in the early stages, will either postpone completion of the plan or force compromises that will limit the chances of arriving at the best choice of structural material.

2. The exposure goal of 40 MW-y/m^2 makes irradiation effects the dominant element in the program. There is no way to estimate the properties of materials irradiated to such high levels on the basis of unirradiated properties. Final decisions on alloy choices will be based on extensive measurement of properties of irradiated materials, several of which must be measured during irradiation. The program will not be directed exclusively at properties of irradiated materials, however, and much of the early identification of promising alloy systems for development will be based on measurement of properties outside of the irradiation environment.

3. A large volume irradiation test facility having a reasonably high flux of fusion spectrum neutrons is unlikely to be available before 1990. Since materials development is such a long term activity involving many time consuming iterations to achieve an optimum condition, the program cannot be delayed until an ideal neutron source is available. This means that in the next few years the program must rely on less-than-ideal sources, simulation techniques, and, of necessity, a strong understanding of the physical processes that occur during irradiation.

4. No single property is limiting the performance of fusion reactor structural materials. That is, there are several performance factors or failure mechanisms that could limit the useful life of structural

components. Slight design alterations could change both the location and cause of failure or otherwise limit life. As a consequence, a broad program aimed at defining and improving several properties concurrently is necessary.

5. There is today no single class of candidate materials that clearly will be able to meet the requirements of a commercial reactor. This means that the program must be broad in terms of the range of materials that it includes. Premature selection or rejection of a structural material could severely limit design and performance options later. Performance criteria must be established early in the program, and the number of materials considered must be reduced rapidly, on the basis of properties of unirradiated materials wherever possible.

6. The exposure goal also requires that neutron sources having fluxes capable of meeting the goal exposures be available to the program. Properties change continuously during irradiation, and changes or trends deduced from low fluence irradiations may not be indicative of higher fluence behavior. The ideal source has a fusion neutron spectrum, a flux high enough to allow accelerated testing, and an experimental volume on the order of a few liters. Such a source is not currently available or authorized, but the plan assumes that one will become available around 1990.

4.2 The Parallel Path Approach

Systems studies indicate that reactor operating conditions dictated by the performance of materials will have a significant impact on the cost of electricity. Initial surveys suggest that stainless steels, nickel base alloys, and refractory or reactive metal alloys all offer attractive properties for fusion reactor applications. Our present knowledge does not allow us to identify one of these as the most promising and to concentrate our efforts on it. The program must be broad enough in its early stages to encompass the wide range of potential candidates. A parallel path approach is needed to accomplish this. The four paths included in the program represent materials which have not only different basic characteristics in terms of probable fusion reactor performance but also different levels of technology development and different degrees of risk or potential for performance and success. The four paths are identified and described in the following paragraphs.

Path A: Austenitic Alloys

Path A is directed toward the development of austenitic alloys. These represent the most established technology, including both fabrication and irradiation experience. The present development of austenitic alloys is such that program activities can move immediately in the direction of optimization of composition and microstructure for use in the fusion environment. It must be stressed that austenitic alloys show promise for early fusion power systems, but it is uncertain whether or not they will have either the temperature capability or radiation resistance to meet the requirements for commercial fusion power.

The fusion program must add to the existing data base for austenitic alloys an understanding of those factors unique to the fusion environment. The most important of these is the production of high concentrations of helium, which can be studied in fission reactors where the helium to displacement ratios of the fusion environment can be closely approximated at real time or accelerated rates. Other factors that need to be explored are the special effects of high energy neutrons, compatibility effects, surface damage effects and an extension of mechanical property data to representative fusion reactor operating conditions, including stress state, cyclic loading, and temperature.

In addition to the direct utility of austenitic alloys, compositions in this alloy class will serve as model materials for comparison studies between damage produced by fission and fusion environments and will lead to the understanding necessary for extrapolation from one to the other.

Path B: Higher Strength Fe-Ni-Cr Alloys

Path B is aimed at the optimization of the higher strength-higher temperature capability Fe-Ni-Cr superalloys. The irradiation performance of a large range of nickel base alloys has indicated a possibility for a significant reduction of void swelling, and the higher strength levels of this alloy class suggest superior fatigue properties. However, lower ductility, restricted fabrication, and relatively poor liquid metal compatibility are sometimes identified with this alloy class.

Initial activities to be undertaken will consist of basic alloy studies leading to the selection of a limited number of Prime Candidate Alloys for testing and optimization. Since nickel is one of the major constituents, these alloys may be tested in mixed spectrum reactors at the appropriate rate of helium generation.

It is not clear what the ultimate potential of this alloy path will be. It may be similar to austenitic alloys in irradiation performance but permit operation at higher temperatures and stresses.

Path C: Reactive and Refractory Metals and Alloys

Path C will address the reactive and refractory metals option. We recognize that the reactive and refractory metal alloy systems are markedly different in character. They are both included in Path C because the schedules for their development are similar. These alloys must be considered as the most promising candidates for reaching the long range materials goals for economic fusion power. Preliminary estimates indicate that it may be possible to obtain irradiation resistance greater than 20 $MW\text{-}y/m^2$. Vanadium alloys appear particularly attractive at present because of their relative resistance to degradation of properties by irradiation and because of their low activation.

The principal advantages of the refractory metal alloys are high temperature strength and the possibility of reasonable irradiation resistance. Alloys in this class may also offer significant advantages relative to cyclic thermal loading because of relatively high thermal conductivity and low thermal expansion. Fabrication and joining problems as well as sensitivity to oxidation and interstitial pickup are major concerns associated with many of the refractory metal alloys and to a lesser extent with the reactive metal alloys.

The initial phase of this alloy development path will consist of basic studies and broad scoping of material potential through the use of fission reactors, high energy neutron sources, and charged particle irradiations to identify those approaches on which large scale alloy development and optimization should be focused. The properties of unirradiated materials will be an important consideration in identifying alloy systems for development.

Path D: Innovative Concepts

Path D will address innovative and composite material options. This path is included in the program in recognition that the conventional concepts of metallurgical development that are implicit in Paths A, B, and C may not be adequate for fusion reactor applications. These alternative concepts will be examined to overcome the performance limits imposed by more conventional materials engineering. This path might include novel concepts such as graded materials, fiber structures composites, structural ceramics, ordered alloys, unique materials processes, and other imaginative ideas that offer the possibility of reduction of engineering practice. It will also include ultra-low activation concepts.

The objective of this development path is to solicit, evaluate, and, when justified, develop new ideas and innovative and imaginative concepts in materials development and application that are designed to withstand the specifics of the fusion environment for a long period of time. Path D is a departure from conventional concepts of alloy development and applications. The direction of this option will be established by open solicitation for innovative concepts.

This plan includes tasks that will allow identification and full qualification of at least one alloy on each path by about the end of the century. This is not to imply that all four paths will be followed to completion. It is likely that early activities will result in deemphasis or elimination of less promising paths. The intent of the parallel path approach is that no potentially useful alloy class be arbitrarily or prematurely excluded from the program.

4.3 Philosophy of Alloy Development

The materials engineer has at his command two approaches for improving the properties of materials: control of composition and control of microstructure. Composition includes not only the major alloying elements but minor constituents as well, which often exert an influence out of proportion to their concentrations because of segregation to structural imperfections. Microstructure includes all features that disrupt the crystal lattice such as dislocations, precipitate particles, and grain boundaries. Alloy development through control of composition and microstructure is the basis of the metallurgical variables approach described in this Plan.

An alloy development program based on a metallurgical variables approach for the full range of potential structural materials is beyond the capability or resources of the program. Alloy development decisions must be guided by an understanding of the physical processes that are involved. Optimized alloys will undoubtedly represent compromises; judgments as to which is the best choice for a particular application will require an understanding and appreciation of important physical processes.

The necessity of this approach is evident when one considers the magnitude of the task of sorting through the complex multi-dimensional composition — microstructure — property* space appropriate to this application. The scope of the problem is illustrated by the variables shown in Fig. 4.1. It is clearly impossible to investigate all the interesting materials. The philosophy of the program presented here is one of using scientific principles and understanding to sort through the maze of possibilities to arrive at optimized alloys.

All of the alloy development paths contain five common activities:

(1) At some point we will identify what we designate as Prime Candidate Alloys (or materials). On the basis of limited irradiation testing and a thorough evaluation of unirradiated properties, these are alloy compositions that are judged to have the highest potential for optimization for fusion reactor conditions using the metallurgical variables approach. Several may be identified for each path. When they are identified we begin

(2) Metallurgical Variables Study Phase I — Scoping Studies. These are limited irradiation tests directed at identifying for the Prime Candidate Alloys those metallurgical variables that are particularly important in determining properties. In this phase the work is broad and fairly qualitative. A few key tests are used to judge effects of a large number of metallurgical variables. Emphasis is on principles governing materials behavior. These results lead to

(3) Metallurgical Variables Study Phase II — Developmental Studies. The results of the Phase I study identify the important variables for development. In Phase II these key variables are investigated more intensively, quantitatively, and systematically to arrive at

(4) Identification of Optimized Alloys. These are compositions and microstructures that are judged to be optimum for fusion applications for each alloy path. More than one may be selected.

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*In addition properties must be defined as functions of irradiation temperature and exposure.

Fig. 4.1 Variables to be Considered in the Alloy Development Program

Development of Alloys for Fusion Reactor First Wall Applications Requires a Thorough Evaluation of the Effects of

ENVIRONMENT	Neutron Flux and Spectrum Temperature Mechanical Chemical
on	
MECHANICAL AND PHYSICAL PROPERTIES	Swelling Irradiation Creep Phase Stability Strength Ductility Crack Growth
of	
MATERIALS	Austenitic Alloys (Path A) Higher Strength Fe-Ni-Cr Alloys (Path B) Reactive/Refractory Alloys (Path C) Innovative Concepts (Path D)
via	
TEST VEHICLES	Fission Reactors High Energy Neutron Sources Charged Particle Irradiations Environmental Simulations Control (non-irradiated) Tests
using	

TESTING AND ANALYSIS	Theory
	Modeling
	Mechanism Studies
	  Fundamental
	  Phenomenological
	Design Interactions
	Applications

They are designated OPT-XY where X designates the path and Y the number or version of an optimized alloy for that path. For example, OPT-C2 is the second optimized alloy for Path C.

(5) Once the optimum alloys are identified the final task is generation of a detailed engineering data base and establishment of performance limits. These are the end products of this program, the quantitative information on materials properties to be used for the design of commercial fusion reactors.

Although steps (1) through (5) are common to all paths, we are not at present in equal positions in our ability to begin development on the different paths. The differences between the paths and the predevelopment activities are discussed in the following section.

4.4 Major Milestones and Schedules

Major or Level 1 Milestones designate decision points where alloys for scoping or developmental studies will be identified or where engineering data bases will become available for optimized alloys. These milestones, arranged by path, are listed in Table 4.1. The parallel path approach and the relationships in time between the paths can be seen from the milestone schedule shown in Fig. 4.2. As stated earlier our present depth of experience in the irradiation behavior and technology of austenitic alloys allows us to identify *Prime Candidate Alloys* for Path A at the present time. On Path B our understanding of radiation effects is more limited, and we begin by working on a series of *Base Research Alloys* that survey a wide range of compositions. Evaluation of their performance will lead to the identification of Path B *Prime Candidate Alloys* and to a development program that is parallel to, but offset from, the one on Path A.

We are at an even less well defined stage in our knowledge of performance of Path C Alloys, both within and without the irradiation environment. On this path we begin with *Scoping Studies* aimed at identifying alloys having favorable characteristics. This is necessarily a much broader approach than is taken on Paths A and B because of our

Table 4.1. Alloy Development for Irradiation Performance

Level 1 Milestones

I-1.	Select Path A Prime Candidate Alloys	1978
I-2.	Identify OPT-A1 (optimum Path A alloy — first optimization)	1983
I-3.	Establish Engineering Data Base and Performance Limits for OPT-A1 (optimum Path A alloy — second optimization)	1991
I-4.	Identify OPT-A2	1992
I-5.	Establish Engineering Data Base and Performance Limits for OPT-A2	1999
I-6.	Select Path B Base Research Alloys	1978
I-7.	Select Path B Prime Candidate Alloys	1983
I-8.	Identify OPT-B (optimum Path B alloy)	1992
I-9.	Establish Engineering Data Base and Performance Limits for OPT-B	2000
I-10.	Select Path C Alloys for Scoping Studies	1978
I-11.	Select Path C Base Research Alloys	1981
I-12.	Select Path C Prime Candidate Alloys	1986
I-13.	Identify OPT-C (optimum Path C alloys — may be more than one)	
I-14.	Establish Engineering Data Base and Performance Limits for OPT-C Alloys	2002
I-15.	Issue Request for Proposals for Identification of Promising Path D Materials	1978
I-16.	Select Promising Path D Concepts for Scoping Studies	1980
I-17.	Select Path D Base Research Materials	1983
I-18.	Select Path D Prime Candidate Materials	1988
I-19.	Identify OPT-D (optimum Path D materials — may be more than one)	1996
I-20.	Establish Engineering Data Base and Performance Limits for OPT-D Materials	2004

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FIG. 4.2 COMPARISON OF LEVEL 1 MILESTONES ON DIFFERENT ALLOY DEVELOPMENT PATHS

YEAR	PATH A	PATH B	PATH C	PATH D
1978	SELECT PATH A PRIME CANDI– DATE ALLOYS (I–1)	SELECT PATH B BASE RESEARCH ALLOYS (I–6)	SELECT PATH C ALLOYS FOR SCOPING STUDIES (I–10)	ISSUE REQUEST FOR PRO– POSALS FOR IDENTIFICATION OF PROMISING PATH D MATERIALS (I–15)
1979				
1980				SELECT PROMISING PATH D CONCEPTS FOR SCOPING STUDIES (I–16)
1981			SELECT PATH C BASE RESEARCH ALLOYS (I–11)	
1982				
1983	IDENTIFY OPT-A1 (I–2)	SELECT PATH B PRIME CANDI– DATE ALLOYS (I–7)		SELECT PATH D BASE RESEARCH MATERIALS (I–17)
1984				
1985				
1986			SELECT PATH C PRIME CANDIDATE ALLOYS (I–12)	
1987				
1988				SELECT PATH D PRIME CANDIDATE MATERIALS (I–18)
1989				
1990				
1991	ESTABLISH ENGINEERING DATA BASE AND PERFORMANCE LIMITS FOR OPT-AI (I–3)			
1992	IDENTIFY OPT-A2 (I–4)	IDENTIFY OPT-B (I–8)		
1993				
1994			IDENTIFY OPT-C (I–13)	
1995				
1996				IDENTIFY OPT-D (I–19)
1997				
1998				
1999	ESTABLISH ENGINEERING DATA BASE AND PERFORMANCE LIMITS FOR OPT-A2 (I–5)			
2000		ESTABLISH ENGINEERING DATA BASE AND PERFORMANCE LIMITS FOR OBT-B (I–9)		
2001				
2002			ESTABLISH ENGINEERING DATA BASE AND PERFORM– ANCE LIMITS FOR OPT-C (I–14)	
2003				
2004				ESTABLISH ENGINEERING DATA BASE AND PERFORM– ANCE LIMITS FOR OPT-D (I–20)

rather modest experience with the irradiation and compatibility characteristics of these materials. A major part of the effort on this Path will involve evaluation of properties of unirradiated materials. This will allow a larger range of materials to be considered and will reduce the amount of expensive and time-consuming irradiation testing. The scoping studies culminate in the identification of *Base Research Alloys*, and a development schedule follows that is equivalent to that on Path B.

We plan to examine an even wider range of options on Path D and will solicit proposals from the general materials community for concepts to be considered in scoping and developmental efforts. In Table 4.1 we indicate that this activity will be concluded in 1980 to be followed by a developmental program. We expect to continue to receive and evaluate proposals, but ones obtained much later than this cannot be developed in time for the first generation of commercial reactors.

Diagrams depicting the stages in alloy development for the four paths are given in Figs. 4.3–4.6. In addition to the alloy development schedule the program will provide an engineering data base for reference materials or for the leading Prime Candidate Alloys (unoptimized). Because of this, a limited data base for 316 stainless steel can be available in 1983, one for the leading Path B Alloy by 1992 and one for the leading Path C Alloy by 1996. The latter two activities will provide an alternative to the use of stainless steel in a demonstration power reactor to be constructed in the late 1990s.

4.5 Technical Approach

The technical approach is dictated by the need to test and evaluate the development concepts to establish performance in the fusion environment at goal reactor exposures. The lack of a large volume irradiation facility having appropriate neutron spectrum and flux characteristics forces the program to rely on a variety of approaches that to some extent approximate the fusion environment. None is sufficient in itself, and as a consequence fission reactors, high energy neutron sources, ion bombardment, and theoretical modeling all will be employed to guide alloy development decisions.

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FIG. 4.3

ALLOY DEVELOPMENT STRATEGY:
PATH A – AUSTENITIC ALLOYS

A. **INITIAL ALLOY OPTIMIZATION**
   1. SELECT PATH A PRIME CANDIDATE ALLOYS (I–1)
   2. SCOPING STUDIES – IDENTIFY IMPORTANT PROPERTIES AND KEY METALLURGICAL VARIABLES (LIMITED TEST MATRIX ON CANDIDATE ALLOYS).
   3. DEVELOPMENTAL STUDIES – INVESTIGATE THOROUGHLY THE EFFECTS OF COMPOSITION AND MICROSTRUCTURE ON THE BEHAVIOR OF CANDIDATE ALLOYS.
   4. IDENTIFY OPT-A1 (I–2)

B. **ENGINEERING PROPERTIES**
   1. SCOPING STUDIES – IDENTIFY KEY PROPERTIES. ESTABLISH DATA BASE ON REFERENCE MATERIAL.
   2. CONDUCT EXTENSIVE INVESTIGATION OF ENGINEERING PROPERTIES OF OPT-A1.
   3. ESTABLISH ENGINEERING DATA BASE AND PERFORMANCE LIMITS FOR OPT-A1 (I–3).

C. **ADVANCED ALLOY OPTIMIZATION (IF JUSTIFIED BY PERFORMANCE POTENTIAL)**
   1. INVESTIGATE METALLURGICAL VARIABLES.
   2. IDENTIFY OPT-A2 (I–4).
   3. CONDUCT EXTENSIVE INVESTIGATION OF ENGINEERING PROPERTIES OF OPT-A2.
   4. ESTABLISH ENGINEERING DATA BASE AND PERFORMANCE LIMITS FOR OPT-A2 (I–5).

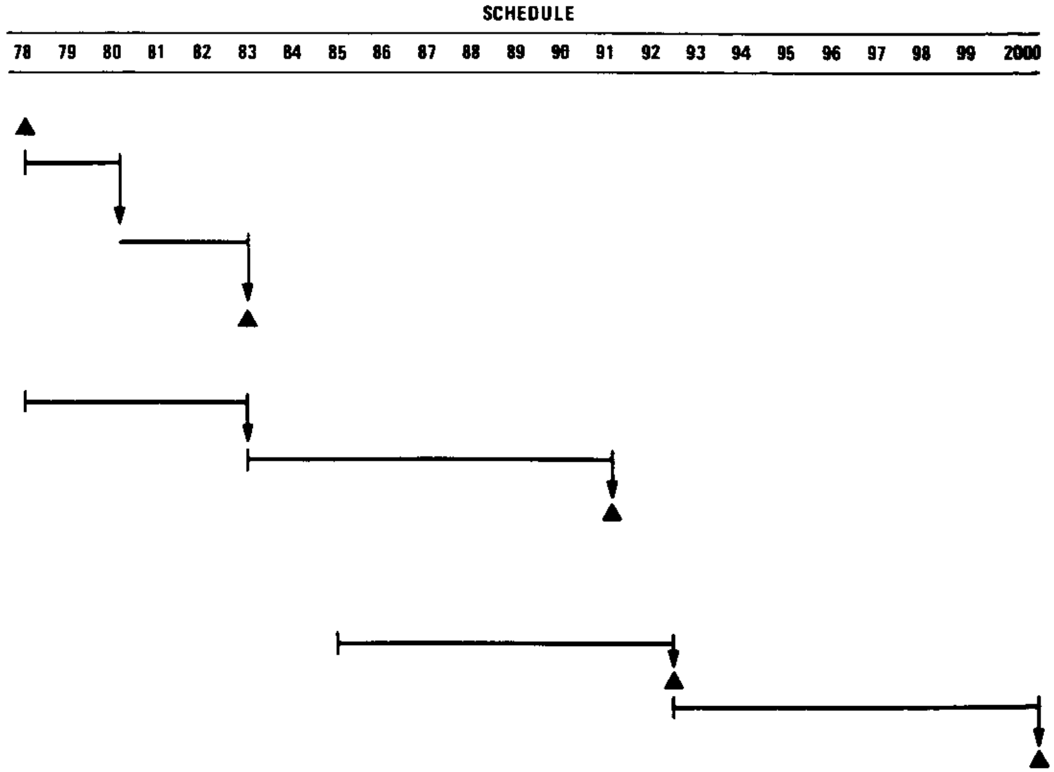

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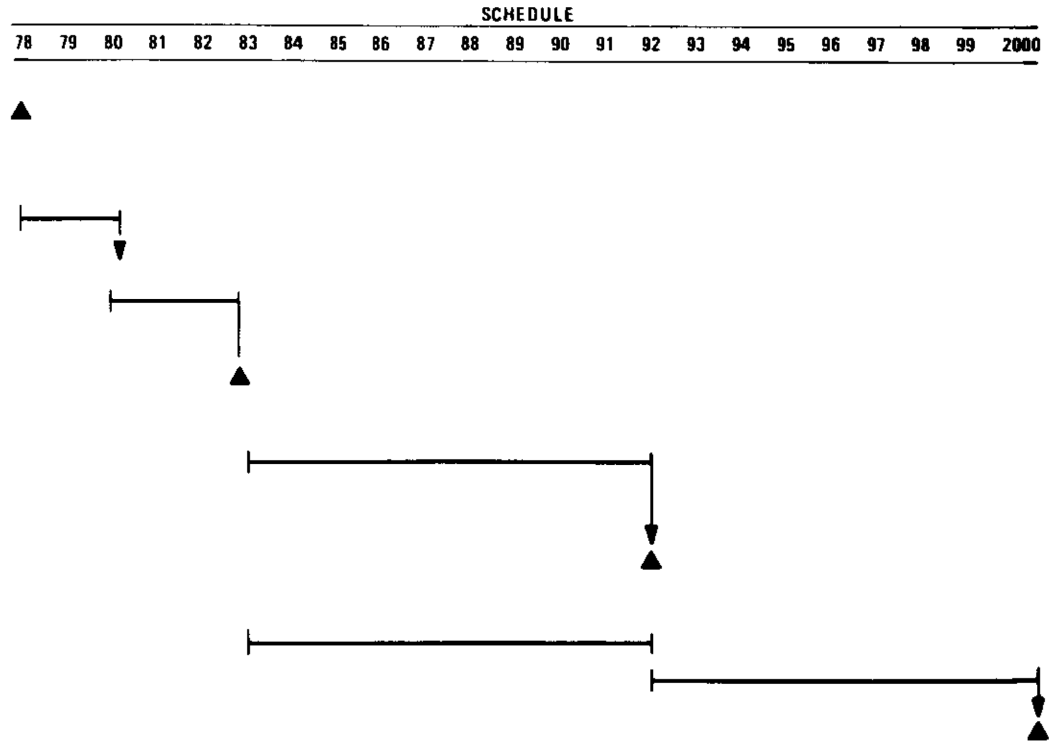
FIG. 4.4

ALLOY DEVELOPMENT STRATEGY:
PATH B: HIGH STRENGTH Fe-Ni-Cr ALLOYS



A. **ALLOY SELECTION**
   1. SELECT PATH B BASE RESEARCH ALLOYS (I–6). FOUR TO SIX ALLOYS SHOULD BE REPRESENTATIVE OF THE DIFFERENT COMMERCIAL ALLOYS IN THIS CLASS; COMPOSITIONS BASED ON DESIRABLE ALLOY TRAITS AND LMFBR EXPERIENCE.
   2. SCOPING STUDIES – IDENTIFY KEY PROPERTIES AND IMPORTANT MICROSTRUCTURAL AND COMPOSITIONAL VARIABLES IN BASE RESEARCH ALLOYS.
   3. DEVELOPMENTAL STUDIES – MORE DETAILED INVESTIGATION OF EFFECTS OF COMPOSITION AND MICROSTRUCTURE ON PROPERTIES OF THE MORE PROMISING CANDIDATES.
   4. SELECT PATH B PRIME CANDIDATE ALLOYS (I–7).

B. **OPTIMIZATION OF CANDIDATE ALLOYS**
   1. DEVELOPMENTAL STUDIES – USE METALLURGICAL VARIABLES APPROACH TO INVESTIGATE THOROUGHLY EFFECTS OF COMPOSITION AND MICROSTRUCTURE ON THE BEHAVIOR OF CANDIDATE ALLOYS.
   2. IDENTIFY OPT-B (I–8).

C. **ENGINEERING PROPERTIES**
   1. DEVELOP FULL DATA BASE FOR LEADING ALLOY (IF REQUIRED)
   2. CONDUCT EXTENSIVE INVESTIGATION OF ENGINEERING PROPERTIES OF OPT-B.
   3. ESTABLISH ENGINEERING DATA BASE AND PERFORMANCE LIMITS OF OPT-B (I–9).

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FIG. 4.5

ALLOY DEVELOPMENT STRATEGY
PATH C: REACTIVE/REFRACTORY METAL ALLOYS

A. ALLOY SELECTION
1. SELECT PATH C ALLOYS FOR SCOPING STUDIES (I-10).
2. EVALUATE SCOPING ALLOYS THROUGH EXISTING IRRADIATION EFFECTS DATA, SIMULATION TESTING AND THOROUGH ASSESSMENT OF UNIRRADIATE MECHANICAL AND PHYSICAL PROPERTIES TO IDENTIFY BASE RESEARCH ALLOY REPRESENTATIVE OF THIS CLASS THAT HAVE POTENTIAL FOR FUSION APPLICATIONS. CONDUCT LIMITED TESTING TO FILL DATA GAPS.
3. SELECT PATH C BASE RESEARCH ALLOYS (I-11).
4. SCOPING STUDIES – IDENTIFY KEY PROPERTIES AND IMPORTANT COMPOSITIONAL AND MICROSTRUCTURAL VARIABLES IN BASE RESEARCH ALLOYS.
5. DEVELOPMENTAL STUDIES – DETAILED INVESTIGATION OF EFFECTS OF COMPOSITION AND MICROSTRUCTURE ON PROPERTIES OF THE MORE PROMISING CANDIDATES
6. SELECT PATH C PRIME CANDIDATE ALLOYS (I-12).

B. OPTIMIZATION OF CANDIDATE ALLOYS
1. DEVELOPMENTAL STUDIES – USE METALLURGICAL VARIABLES APPROACH TO INVESTIGATE THOROUGHLY EFFECTS OF COMPOSITION AND MICROSTRUCTURE ON THE BEHAVIOR OF CANDIDATE ALLOYS.
2. IDENTIFY OPT-C (I-13).

C. ENGINEERING PROPERTIES
1. DEVELOP FULL DATA BASE FOR LEADING CANDIDATE ALLOYS (IF REQUIRED).
2. CONDUCT EXTENSIVE INVESTIGATION OF ENGINEERING PROPERTIES OF OPT-C.
3. ESTABLISH ENGINEERING DATA BASE AND PERFORMANCE LIMITS OF OPT-C (I-14).

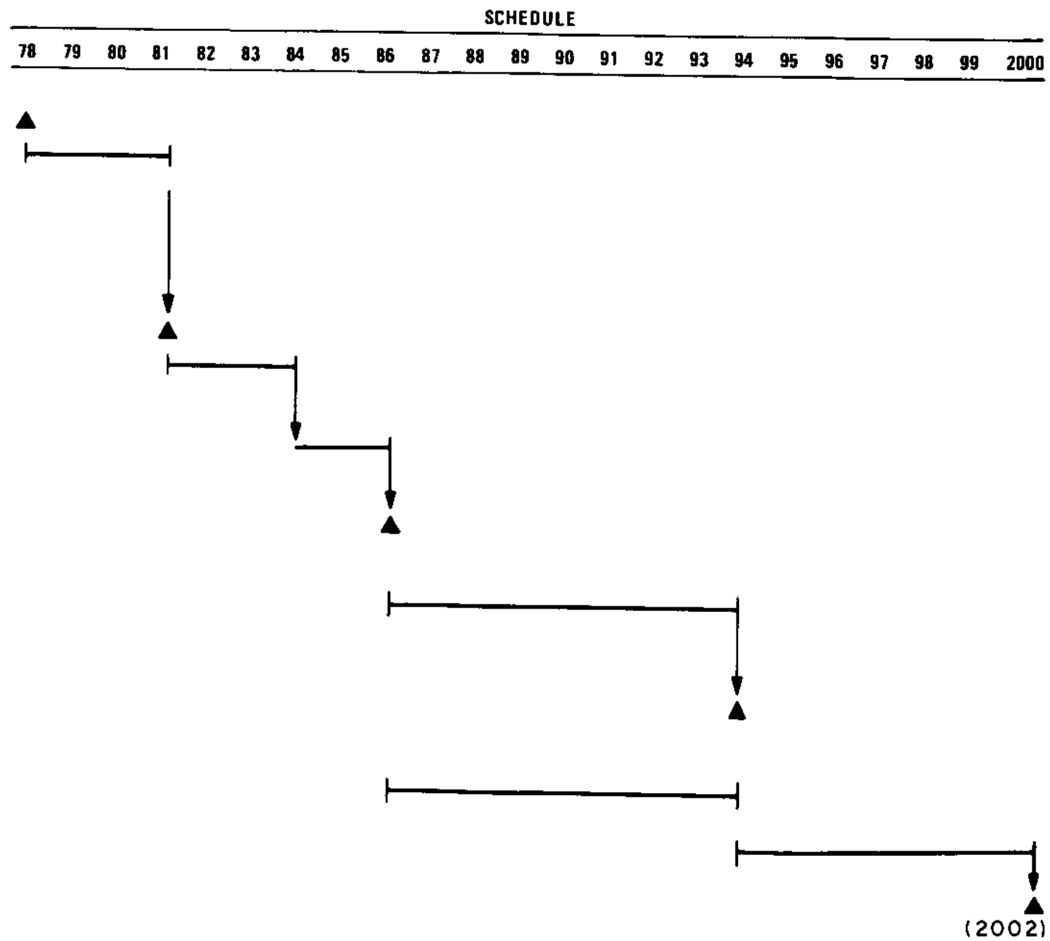

FIG. 4.6

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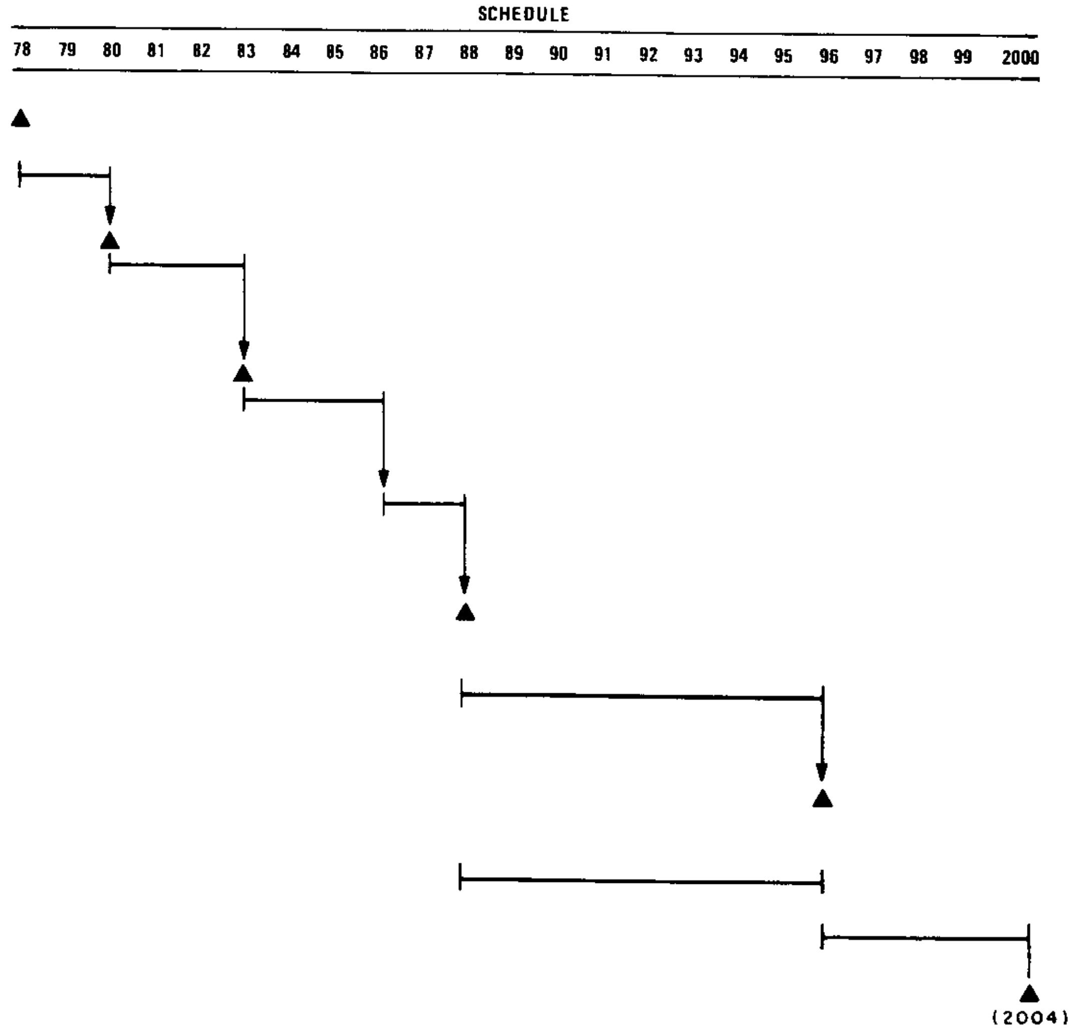
ALLOY DEVELOPMENT STRATEGY
PATH D: INNOVATIVE MATERIALS CONCEPTS



A. MATERIALS SELECTION

1. ISSUE REQUEST FOR PROPOSALS FOR IDENTIFICATION OF PROMISING PATH D MATERIALS (I–15).
2. PERFORM LIMITED STUDIES TO EVALUATE PROPOSALS.
3. SELECT PROMISING PATH D CONCEPTS FOR SCOPING STUDIES (I–16).
4. EVALUATE PROMISING CONCEPTS USING LIMITED IRRADIATION TESTING, SIMULATION STUDIES AND THOROUGH EVALUATION OF MECHANICAL AND PHYSICAL PROPERTIES OF UNIRRADIATED MATERIALS.
5. SELECT PATH D BASE RESEARCH MATERIALS (I–17).
6. SCOPING STUDIES – IDENTIFY KEY PROPERTIES AND IMPORTANT COMPOSITIONAL AND MICROSTRUCTURAL VARIABLES (INCLUDING EFFECTS OF FABRICATION PROCESSES) IN BASE RESEARCH MATERIALS.
7. DEVELOPMENTAL STUDIES – DETAILED INVESTIGATION OF COMPOSITION, MICROSTRUCTURES, AND PROCESSING VARIABLES ON THE PROPERTIES OF THE MORE PROMISING MATERIALS.
8. SELECTED PATH D PRIME CANDIDATE MATERIALS (I–18).

B. OPTIMIZATION OF CANDIDATE MATERIALS

1. DEVELOPMENTAL STUDIES – INVESTIGATE THOROUGHLY EFFECTS OF COMPOSITIONAL, MICROSTRUCTURAL AND PROCESSING VARIABLES ON BEHAVIOR OF CANDIDATE MATERIALS.
2. IDENTIFY OPT-D (I–19).

C. ENGINEERING PROPERTIES

1. DEVELOP FULL DATA BASE FOR LEADING CANDIDATE MATERIALS (IF REQUIRED).
2. CONDUCT EXTENSIVE INVESTIGATION OF ENGINEERING PROPERTIES OF OPT-D.
3. ESTABLISH ENGINEERING DATA BASE AND PERFORMANCE LIMITS OF OPT-D (I–20).

The key attributes of an irradiation source are a flux high enough to permit accelerated damage production, an experimental volume large enough to accommodate hundreds or perhaps thousands of specimens ($\sim$10 liters), and a neutron spectrum that produces an appropriate approximation of the primary knock-on spectrum and transmutation rates. The flux and volume criteria are essential, for without them no meaningful mechanical properties data can be obtained. The spectrum requirement is less severe; the approximation to the fusion environment is, of course, less good as it is relaxed. Total displacements and helium production are generally felt to be the most critical parameters. The distribution of defects in the displacement cascades and the production of other transmutation products, such as hydrogen, have effects but appear to be less significant.

Fission reactors are the only type of neutron source than can meet the flux-volume requirement, and consequently they must serve as the major test vehicles, at least until a suitable fusion test facility becomes available.

Fast reactors are capable of displacing atoms at rates equal to or exceeding those in anticipated fusion reactors but are able to generate transmutation products, especially helium, at rates that are orders of magnitude lower. Properties measured from such irradiations are likely to overestimate performance in a fusion environment. Nevertheless, such facilities are useful in identifying alloys that have potential for development.

Mixed spectrum reactors (those having high fluxes of both fast and thermal neutrons) provide an improved approximation of the fusion environment for materials containing nickel. Fast neutrons generate displacements and thermal neutrons produce helium via the two step reaction sequence

$$^{58}Ni + n \longrightarrow {}^{59}Ni$$

$$^{59}Ni + n \longrightarrow {}^{56}Fe + {}^{4}He$$

By controlling the fast and thermal fluxes it is possible to match very closely the ratio of helium to displacements in alloys containing nickel. Since all the Path A and B alloys contain nickel, a fairly good approximation of their behavior in a fusion environment can be obtained.

The situation for alloys on Paths C and D is less satisfactory. Fission reactors again will provide the main test vehicle, but because of their spectral characteristics, transmutation rates will be much below fusion reactor requirements. This limitation will be overcome to some extent by injecting helium and hydrogen into the specimens prior to neutron irradiation or by doping the specimens with isotopes that have acceptable cross sections for (n,p) and (n,α) reactions. This approach will probably not be useful for generating an engineering data base, but it will provide guidance for alloy development decisions. If such alloys are identified for commercial fusion reactors, a large volume, high flux fusion test facility will be required. Alloy development on these paths will also be aided by ion bombardment studies in which heavy ions produce displacements while light ions (H and He) are simultaneously injected at rates appropriate to their generation in a fusion environment. Because of our relatively meager knowledge of these materials in the absence of irradiation, much of the guidance in the development of alloys will come from studies of the physical and mechanical metallurgy of unirradiated materials. This will greatly reduce the number of materials to be subjected to irradiation testing.

The principal objective of the Damage Analysis and Fundamental Studies Task Group is to assess how good the fission reactor irradiations are or, more properly, to relate or extrapolate observations to fusion reactor conditions. The d-Li high energy neutron source is an essential element in this strategy, for it will provide data to permit damage analysis techniques to be used to accomplish this. Until this is done uncertainties will exist in the use of fission reactor data to design fusion reactors. The d-Li facility will also guide decisions on an advanced testing facility to become operational in the 1990s. In order to meet the program schedules an operational d-Li source will be required no later than about 1985.

Initial reactor irradiations will emphasize postirradiation testing and examination. The capability for performing in-reactor experiments in which temperature, stress, and strain are measured and varied in a controlled way will be developed as rapidly as possible. Because of the large number of materials and conditions to be considered, a major early effort will be devoted to miniaturization of test specimens. Attention will be concentrated on mechanical properties measurements. Microstructural observations will be used as an interpretive tool rather than as a primary experimental objective.

Fission reactors will provide the primary irradiation test facilities during the early years of the program, but both light and heavy ion bombardments will be used as well. Light ions can be used to irradiate thin specimens for mechanical properties measurements, and heavy ions can be used to study microstructural effects at very high displacement levels, with hydrogen and helium simultaneously injected to simulate transmutation reactions.

Reactor irradiations will be organized to accommodate the needs of the entire program. A general schedule of reactor experiments designed to meet the major program objectives will be developed early in the program. These experiments will be scheduled to discharge specimens at specific times to provide input to decisions called for by the Level 1 Milestones and to allow the necessary iterations to identify the optimized alloys. All the subtasks will contribute to these experiments so that the full range of property measurements will be available for a material for common irradiation conditions.

Although this section has emphasized irradiation facilities, the program is not limited to an investigation of irradiation effects. Final decisions on identification of optimized alloys will be based on irradiation performance, but much of the preliminary selection will involve other considerations such as compatibility, fabricability, and various physical and mechanical properties. Conventional facilities and data banks already in place will be used for these activities whenever possible.

4.6 Approach to Decisions

All program activities are organized to provide input into selection and identification of the various alloy groups given in the Level 1 Milestones. The results of this program can not be reduced to a collection of numbers that will allow these choices and decisions to be made. Difficult decisions balancing the often conflicting materials properties will be a frequent requirement of the program.

The full Task Group is the decision making body. It will direct the Subtask Groups to provide the necessary data bases to arrive at the decisions. The views of the Subtasks will be fully represented by their chairmen who are members of the full Task Group. These decisions are unlikely to be simple or straight forward since many properties are under consideration and it is unlikely that one alloy (or condition) will excel in all of them. Through thorough debate and discussion the Task Group will arrive at a consensus. In the event of a serious disagreement or technical uncertainty multiple alloys will be carried until a clear distinction can be made. The Analysis and Evaluation Subtask Group will develop criteria for alloy selection and will carry out additional analyses if necessary to resolve disputes.

The initial milestone on each path, selection of the materials to be developed or investigated, represents a particularly difficult decision point since only very limited information is available. The depth of the decision making on the different paths reflects differences in the state of our understanding of behavior of materials on the different paths. We believe that alloy compositions for optimization can be identified for Path A. For Path B we are in a position to select Base Research Alloys that include the useful compositional and microstructural variations, and for Path C we now are able to choose only Scoping Alloys to identify promising approaches. Position papers stating the rationale for selection of these alloys will be completed during the first quarter of FY 1978. These will provide the basis for the deliberations that will identify materials for study and will establish the details of the initial direction of the program.

At the present time this plan is very broad in order to encompass all promising materials options. In this sense it is a very conservative approach that is designed to give a high probability for success. The plan as developed here describes the approach if all paths were to be followed to completion. This would result eventually in an intolerably large effort, so large that it could be justified only if success on all paths were to remain uncertain. As the program develops, a continuing effort will be required to focus it along the most productive lines. The Task Group will have the additional responsibility of eliminating approaches that fail to live up to their potential. Little of this activity is likely during the early years of the program; materials will be dropped from consideration only if basic physical processes, properties, or phenomena limit the performance potential to unreasonably low levels. Later, as data accumulate, the merits of one material relative to others in its class or in other classes will allow rational and informed choices to be made. In this way the very broad approach described here will be narrowed gradually as we move closer to commercial fusion power.

In view of this eventual need to reduce the breadth of the program, a deliberate effort will be made to avoid identifying an individual laboratory with a single material or path. This will avoid massive dislocations caused by decisions to eliminate materials and will allow more objective debate of the merits of a material.

This strategy is designed to lead to the development of materials data bases for the design of commercial fusion reactors. It is general in the sense that it outlines the schedules and approach required to accomplish this. The detailed way in which this strategy is implemented is subject to change as reactor designs become better defined and as we learn more about the behavior of materials in the fusion environment. The basic strategy is more permanent. Chapter 5 contains the Task Descriptions or tactics that are viewed necessary at the present time to accomplish the objectives of this strategy.

5. TASK DESCRIPTIONS

Charts defining the tasks required to implement the program strategy are given in this chapter. Points at which the tasks provide input to the Level 1 Milestones are identified. The full list of milestones can be found in Section 4.4. The priority designations are discussed in the Foreword. In brief, the terms may be defined as follows:

- H Highest priority items needed to achieve Level 1 Milestones either because the data are urgently needed or because the work is on a critical path for the accomplishment of other important milestones.
- M Important items needed to complete a milestone but on a less restricted basis than H.
- D Items required for obtaining a more complete understanding of important effects, desirable but not essential at this time.
  1. Near-term impact, defined as extending through TFTR.
  2. Intermediate-term impact, defined as affecting EPR and DEMO.
  3. Long-range impact, defined as affecting commercial reactors.

A priority of H-2 indicates that the task is of the highest priority for meeting a Level 1 Milestone that impacts EPR or DEMO.

An attempt has been made to estimate man-year requirements for the period FY 78–82. During this period an optimized Path A alloy will be developed, a limited data base for design of EPR will be obtained, and scoping work for identifying promising approaches for Paths B, C, and D will be completed. The plan is developed in less detail for the period beyond 1982, but points at which information is required to meet the Level 1 Milestones are identified. We expect that the scope of the program will be reduced at that time as reactor designs become better defined and as our understanding of the performance limits of our alloys increases. The plan shows how an optimized alloy could be developed on each of the paths; it should not be inferred that all four paths will be followed to completion.

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OBJECTIVE: TO DEFINE CRITICAL MATERIAL PROPERTIES AND QUANTIFY THEIR RELATIVE IMPORTANCE TO GUIDE ALLOY SELECTION AND DEVELOPMENT.

SCOPE: STRUCTURAL ANALYSES WILL BE PERFORMED TO DETERMINE MATERIAL FAILURE MODE AND TO MAKE LIFE PREDICTIONS. SENSITIVITY ANALYSIS WILL RELATE MATERIAL PROPERTIES, REACTOR DESIGN/OPERATING PARAMETERS AND FIRST WALL/BLANKET STRUCTURE LIFE AND FAILURE MODE. SYSTEMS ANALYSIS WILL RELATE THESE TO THE CAPITAL AND ELECTRICITY COSTS SO THAT OPTIMUM TRADES CAN BE MADE BETWEEN MATERIAL COST, COMPONENT LIFE AND DESIGN/OPERATING PARAMETERS.

TASK NUMBER: I.A.1

TASK TITLE: DEFINE MATERIAL PROPERTY REQUIREMENTS AND MAKE STRUCTURAL LIFE PREDICTIONS

INPUT TO MAJOR MILESTONES:
I-1 THROUGH I-19

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82	78	79	80	81	82	83	84	85	86	87	88	89	90	91-95	96-2000
I.A.1.1	SELECT INITIAL REPRESENTATIVE DESIGNS, OBTAIN PROPERTY DATA, ESTABLISH ANALYSIS PROCEDURES AND COMPLETE INITIAL ANALYSIS	H-2	7	a														
I.A.1.2	ITERATE ANALYSIS TO INCORPORATE CHANGES IN DESIGN, UPDATED MATERIAL PROPERTIES AND NEWLY DEVELOPED ALLOYS	H-2	12				b		c,d,e		f			g			h,i	j

MILESTONES

I.A.1.a INPUT TO SUBTASK I.A.1.2 AND TO SELECTION OF PATH A PRIME CANDIDATE ALLOY (I-1), PATH B BASE RESEARCH ALLOYS (I-6) AND PATH C SCOPING ALLOYS (I-10).

I.A.1.b INPUT TO SELECTION OF PATH C BASE RESEARCH ALLOYS (I-11).

I.A.1.c INPUT TO IDENTIFICATION OF OPT-A1 (I-2).

I.A.1.d INPUT TO SELECTION OF PATH B PRIME CANDIDATE ALLOYS (I-7)

I.A.1.e INPUT TO SELECTION OF PATH D BASE RESEARCH MATERIALS (I-17)

I.A.1.f INPUT TO SELECTION OF PATH C PRIME CANDIDATE ALLOYS (I-12).

I.A.1.g INPUT TO SELECTION OF PATH D PRIME CANDIDATE MATERIALS (I-18).

I.A.1.h INPUT TO IDENTIFICATION OF OPT-B (I-8).

I.A.1.i INPUT TO IDENTIFICATION OF OPT-C (I-13).

I.A.1.j INPUT TO IDENTIFICATION OF OPT-D (I-19).

ORNL–DWG 78-14758

OBJECTIVE: TO DEFINE MATERIAL PROPERTY TEST MATRICES AND TEST PROCEDURES THAT WILL PROVIDE EFFICIENT DEVELOPMENT OF LONG LIFE AND RELIABLE ALLOYS CONSIDERING TIME, COST AND TEST FACILITY CONTRAINTS.

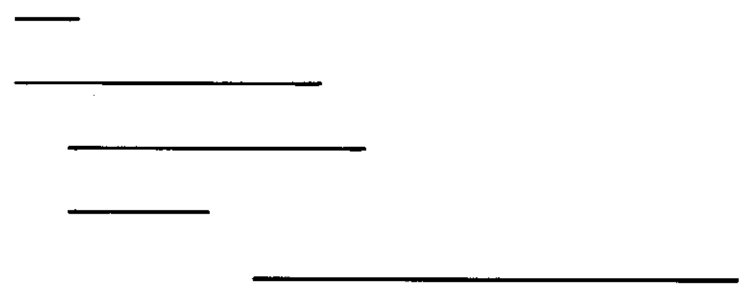
SCOPE: TESTING REQUIRED TO ACCOMPLISH EXPLORATORY ALLOY DEVELOPMENT, CRITICAL MATERIAL PROPERTY AND MATERIAL CHARACTERIZATION WILL BE ADDRESSED SEPARATELY. BECAUSE OF COST, TIME, AND SPACE LIMITATIONS ASSOCIATED WITH IRRADIATION TEST FACILITIES, CONSIDERABLE EFFORT WILL BE DEVOTED TO MINIMIZING AND SIMPLIFYING THE TESTING YET ASSURING THAT THE RESULTANT DATA COVERS THE DESIRED RANGE OF VARIABLES (TEMPERATURES, STRESS, etc.) AND ARE APPLICABLE TO THE DEVELOPMENT OF CONSTITUTIVE EQUATIONS NEEDED FOR COMPONENT STRUCTURAL DESIGNS.

TASK NUMBER: I.A.2

TASK TITLE: DEFINE TEST MATRICES AND TEST PROCEDURES

INPUT TO MAJOR MILESTONES:
NO DIRECT INPUT. SUBTASKS DEFINE TEST PROCEDURES THAT LEAD TO IDENTIFICATION OF OPTIMIZED ALLOYS AND ESTABLISHMENT OF ENGINEERING DATA BASES

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82	78	79	80	81	82	83	84	85	86	87	88	89	90	91-95	96-2000
I.A.2.1	DEFINE MATERIAL PROPERTY MEASUREMENT CAPABILITY OF IRRADIATION TEST FACILITIES	H-2	1															
I.A.2.2	DEVELOP SPECIMEN CONFIGURATIONS AND TEST MATRICES FOR EXPLORATORY ALLOY DEVELOPMENT	H-2	7															
I.A.2.3	DEVELOP TEST APPROACHES AND TEST MATRICES FOR OBTAINING CRITICAL PROPERTY DATA	H-2	5															
I.A.2.4	DEVELOP TEST APPROACHES AND MATRICES FOR MATERIAL PROPERTY CHARACTERIZATION (DESIGN PROPERTY DATA BASE)	H-2	6															
I.A.2.5	ITERATE TEST APPROACHES, MATRICES AND SPECIMEN CONFIGURATIONS BASED ON REACTOR DESIGN CHANGES, FAILURE MODE CHANGES AND TEST RESULTS	H-2	–															



OBJECTIVE: TO ESTABLISH GENERAL AND SPECIFIC GUIDELINES RELATING COMPATIBILITY AND CORROSION PHENOMENA TO ALLOY DEVELOPMENT ACTIVITIES. TO PERFORM CORROSION TESTING OF OPTIMIZED ALLOYS

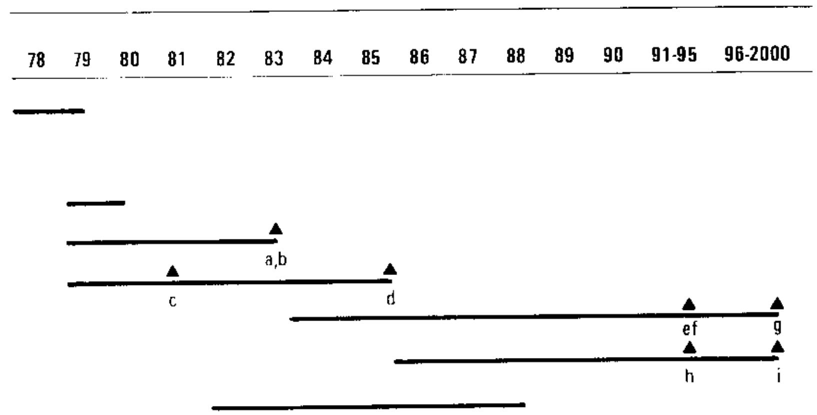
SCOPE: DETAILED COMPILATION OF KNOWN CORROSION BEHAVIOR WILL BE PERFORMED INITIALLY TO GUIDE ALLOY DEVELOPMENT AND AVOID DUPLICATION OF PAST WORK. LIMITED CORROSION TESTING WILL BE PERFORMED DURING THE INITIAL ALLOY DEVELOPMENT ACTIVITIES AS NECESSARY TO RESOLVE DATA GAPS. EXTENSIVE CORROSION TESTING WILL BE PERFORMED DURING THE ALLOY OPTIMIZATION PHASES.

TASK NUMBER: I.A.3

TASK TITLE: PERFORM CHEMICAL AND METALLURGICAL COMPATIBILITY ANALYSES

INPUT TO MAJOR MILESTONES: I-2, 3, 7, 11, 12, 13, 14

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.A.3.1	PERFORM DETAILED COMPILATION OF KNOWN CORROSION BEHAVIOR OF CANDIDATE ALLOY SYSTEMS IN COOLANTS AND WORKING FLUIDS OF INTEREST.	H-2	2
I.A.3.2	DEFINE PROGRAM EXPERIMENTAL REQUIREMENTS	H-2	2
I.A.3.3	PERFORM EXPLORATORY CORROSION TESTING OF A, B. ALLOYS	M-2	12
I.A.3.4	PERFORM EXPLORATORY CORROSION TESTING OF PATH C ALLOYS	H-2	12
I.A.3.5	PERFORM DETAILED CORROSION TESTING OF PATH A, B ALLOYS	M-2	10
I.A.3.6	PERFORM DETAILED CORROSION TESTING OF PATH C ALLOYS	H-2	8
I.A.3.7	PERFORM EXPLORATORY CORROSION TESTING OF PATH D MATERIALS	M-3	6



MILESTONES

I.A.3.a	INPUT TO IDENTIFICATION OF OPT A (I-2)
I.A.3.b	INPUT TO SELECTION OF PATH B BASE RESEARCH ALLOYS (I-7)
I.A.3.c	INPUT TO SELECTION OF PATH C SCOPING ALLOYS (I-11)
I.A.3.d	INPUT TO SELECTION OF PATH C BASE RESEARCH ALLOYS (I-12)
I.A.3.e	INPUT TO ENGINEERING DATA BASE FOR OPT-A (I-3)
I.A.3.f	INPUT TO SELECTION OF OPT-B
I.A.3.g	INPUT TO ENGINEERING DATA BASE FOR OPT-B (I-9)
I.A.3.h	INPUT TO SELECTION OF OPT-C (I-13)
I.A.3.i	INPUT TO ENGINEERING DATA BASE FOR OPT-C (I-14)

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OBJECTIVE: TO EVALUATE STRUCTURAL IMPACTS OF HYDROGEN ISOTOPE (H, D, T) DISSOLUTION AND MIGRATION IN PATH A, B, AND C ALLOYS. TO IDENTIFY CRITICAL PERMEATION MECHANISMS AND DEVELOP COST-EFFECTIVE PERMEATION BARRIER METHODS.

SCOPE: STUDIES OF H, D, T DISSOLUTION AND PERMEATION WILL BE PERFORMED ON REPRESENTATIVE PATH A, B, AND C ALLOYS. PERMEATION BARRIER METHODS WILL BE DEVELOPED ON SMALL-SCALE APPARATUS AND THEN TESTED IN A LARGER FACILITY UNDER REALISTIC FUSION REACTOR CONDITIONS.

TASK NUMBER: I.A.4

TASK TITLE: HYDROGEN DISSOLUTION AND PERMEATION EFFECTS; PERMEATION BARRIER DEVELOPMENT

INPUT TO MAJOR MILESTONES: I-1 THROUGH I-20

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82	78	79	80	81	82	83	84	85	86	87	88	89	90	91-95	96-2000
I.A.4	ESTABLISH DISSOLUTION/PERMEATION DATA BASE	H-1	3		a		b											
I.A.4	DEVELOP PERMEATION BARRIERS FOR PATH A ALLOYS	H-1	2						c								cd	d
I.A.4	DEVELOP PERMEATION BARRIERS FOR PATH B ALLOYS	D-2	2														c	d
I.A.4	DEVELOP PERMEATION BARRIERS FOR PATH C ALLOYS	D-2	1														c	d
I.A.4	ESTABLISH BARRIER TEST FACILITIES	M-2	1															

MILESTONES

I.A.a COMPLETE DEVELOPMENT OF PERTINENT DATA BASE FOR REPRESENTATIVE PATH A AND B ALLOYS.

I.A.b COMPLETE DEVELOPMENT OF PERTINENT DATA BASE FOR PATH C SCOPING ALLOYS.

I.A.c COMPLETE IDENTIFICATION OF TRACTIBLE BARRIER METHOD. PROVIDE INPUT INTO SELECTION OF OPT ALLOYS.

I.A.d COMPLETE *IN-SITU* VERIFICATION TEST OF BARRIER PERFORMANCE IN TRITIUM-INTENSIVE ENVIRONMENT. ESTABLISH ENGINEERING DATA BASE AND PERFORMANCE LIMITS.

OBJECTIVE: TO ESTABLISH GENERAL AND SPECIFIC GUIDELINES FOR THE FABRICATION OF CANDIDATE ALLOYS AND FOR THE EFFECTS OF FABRICATION PROCESSES ON THE ALLOYS. TO DEVELOP FABRICATION PROCESSES AND STUDY SPECIAL FABRICATION PROCESSES.

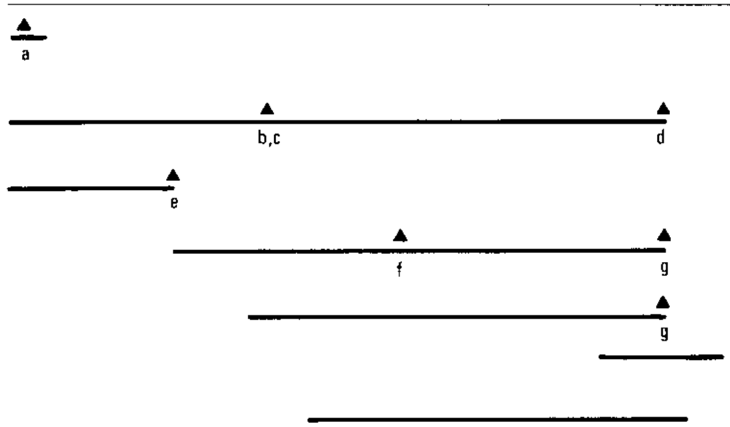
TASK NUMBER: I.A.5

TASK TITLE: PERFORM FABRICATION ANALYSES

INPUT TO MAJOR MILESTONES:
I-1 THROUGH I-13

SCOPE: SINCE MICROSTRUCTURAL CONTROL IS AN IMPORTANT PART OF THE ALLOY DEVELOPMENT EFFORT, FABRICATION PROCEDURES ARE REQUIRED THAT WILL YIELD DESIRED PRODUCT FORMS HAVING SPECIFIED MICROSTRUCTURES. EMPHASIS WILL BE ON WELDING AND BRAZING PROCESSES BECAUSE OF THEIR IMPORTANCE IN REACTOR ASSEMBLY. WELDING OF HELIUM-CONTAINING MATERIALS FOR POSSIBLE REPAIR APPLICATIONS WILL BE INCLUDED. SUPPLIERS OF THE ALLOYS WILL BE INVOLVED IN THE ALLOY PROCESSING DEVELOPMENT ACTIVITIES; THEIR ROLE WILL INCREASE AS THE FINAL ALLOYS ARE MORE CLEARLY DEFINED.

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.A.5.1	PERFORM DETAILED COMPILATION OF FABRICATION CHARACTERISTICS OF CANDIDATE ALLOY SYSTEMS AND THE EFFECTS OF FABRICATION PROCESSES ON THE ALLOYS	H-2	2
I.A.5.2	PERFORM FABRICATION PROCESS DEVELOPMENT DURING PATH A AND B ALLOY DEVELOPMENT	H-2	10
I.A.5.3	PERFORM FABRICATION PROCESS DEVELOPMENT DURING PRELIMINARY PATH C SCOPING/EXPLORATORY WORK	H-2	6
I.A.5.4	PERFORM FABRICATION PROCESS DEVELOPMENT DURING PATH C ALLOY DEVELOPMENT	H-2	6
I.A.5.5	PERFORM FIELD WELDING DEVELOPMENT PATH C ALLOYS	H-2	
I.A.5.6	PERFORM FABRICATION PROCESS DEVELOPMENT DURING ALLOY OPTIMIZATION, PATH C ALLOYS	H-2	
I.A.5.7	PERFORM SPECIAL FABRICATION PROCESS DEVELOPMENT ON IRRADIATED MATERIAL	H-2	



78 79 80 81 82 83 84 85 86 87 88 89 90 91-95 96-2000

MILESTONES

I.A.5.a INPUT TO SELECTION OF PATH A PRIME CANDIDATE ALLOY (I-1), PATH B BASE RESEARCH ALLOYS (I-6) AND PATH C SCOPING ALLOYS (I-10)

I.A.5.b INPUT TO IDENTIFICATION OF OPT-A (I-2)

I.A.5.c INPUT TO SELECTION OF PATH B PRIME CANDIDATE ALLOYS (I-7)

I.A.5.d INPUT TO IDENTIFICATION OF OPT-B (I-8)

I.A.5.e INPUT TO SELECTION OF PATH C BASE RESEARCH ALLOYS (I-11)

I.A.5.f INPUT TO SELECTION OF PATH C PRIME CANDIDATE ALLOYS (I-12)

I.A.5.g INPUT TO IDENTIFICATION OF OPT-C (I-13)

ORNL–DWG 78-14731

OBJECTIVE: TO PROVIDE THE BASIC UNDERSTANDING NEEDED TO DESIGN PATH A ALLOYS FOR FATIGUE CRACK RESISTANCE AND TO PROVIDE BASIC ENGINEERING DATA FOR MFR DESIGN USING PATH A MATERIALS.

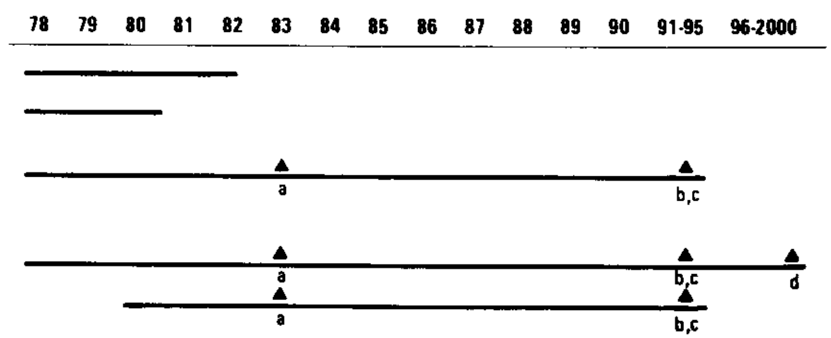
SCOPE: IRRADIATIONS WILL BE PERFORMED ON CRACK GROWTH SPECIMENS OPTIMIZED FOR MFR STUDIES IN ORR AND FFTF ON PROGRAM AND RELATED TASK MATERIALS. TESTING WILL BE PERFORMED IN-PILE OR EX-REACTOR AS REQUIRED TO REVEAL ALLOY RESPONSE.

TASK NUMBER: I.B.1

TASK TITLE: FATIGUE CRACK GROWTH IN AUSTENITIC ALLOYS (PATH A).

INPUT TO MAJOR MILESTONES:
I-2 TO I-5

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.B.1.1	DEVELOP SPECIMENS AND TEST METHODS	H-2	15
I.B.1.2	DETERMINE SENSITIVITY OF FATIGUE CRACK PROPAGATION (FCP) TO MFR FIRST WALL ENVIRONMENT FOR BASE ALLOY	H-2	3
I.B.1.3	DETERMINE SENSITIVITY OF FCP TO ALLOY COMPOSITION AND HEAT TREATMENT, AND REVEAL CONTROLLING MECHANISMS USING BASE ALLOY MODIFICATIONS.	H-2	5
I.B.1.4	EVALUATE ENGINEERING LEVEL FCP PROPERTIES OF BASE ALLOY.	H-2	5
I.B.1.5	IF I.B.1.3 SHOWS THAT FCP IS SENSITIVE TO ALLOY COMPOSITION OR TREATMENT, PURSUE LIMITED METALLURGICAL VARIABLES TESTS AT HIGH FLUENCE ON ADVANCED ALLOYS.	H-2	3



MILESTONES

I.B.1.a INPUT TO SELECTION OF OPT-A (I-2).

I.B.1.b ESTABLISH FATIGUE CRACK GROWTH DATA BASE AND PERFORMANCE LIMITS OF OPT-AI (I-3).

I.B.1.c INPUT TO SELECTION OF OPT-A2 (I-4).

I.B.1.d ESTABLISH FATIGUE CRACK GROWTH DATA BASE AND PERFORMANCE LIMITS BY OPT-A2 (I-5).

ORNL–DWG 78-14727

OBJECTIVE: TO PROVIDE THE BASIC UNDERSTANDING NEEDED TO DESIGN PATH B ALLOYS FOR FATIGUE CRACK PROPAGATION RESISTANCE AND DEVELOP DESIGN DATA BASE ON THESE ALLOYS.

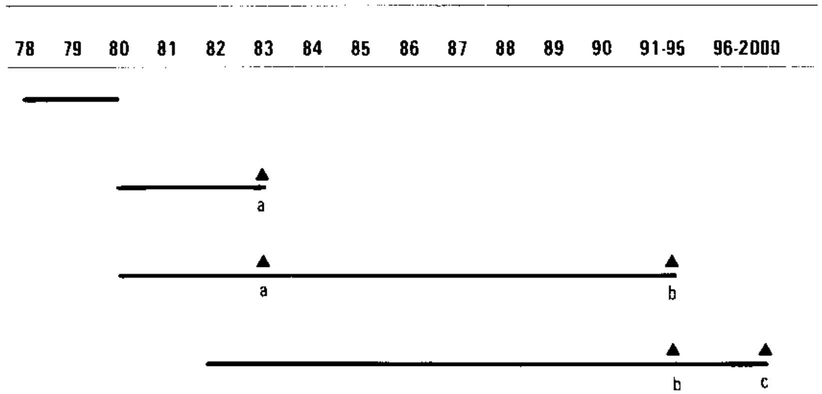
SCOPE: IRRADIATION WILL BE PERFORMED IN ORR AND FFTF ON PATH B MATERIALS; TESTING WILL BE ON A POSTIRRADIATION OR IN-REACTOR BASIS AS REQUIRED. SPECIMENS OPTIMIZED FOR MFR EXPERIMENTATION WILL BE UTILIZED WHERE REQUIRED, BUT PATH A METHODS WILL BE UTILIZED WHEN APPROPRIATE.

TASK NUMBER: I.B.2

TASK TITLE: FATIGUE CRACK GROWTH IN HIGH STRENGTH/HIGH TEMPERATURE Fe-Ni-Cr ALLOYS (PATH B)

INPUT TO MAJOR MILESTONES: I.7 TO I.9

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.B.2.1	EVALUATE SCOPING RESPONSE OF SELECTED PATH B AND RELATED ALLOYS TO SIMULATED MFR ENVIRONMENTS USING ORR (LIMITED MATRIX).	H-2	3
I.B.2.2	IF I.B.2.1 SHOWS MFR ENVIRONMENT SENSITIVITY, DETERMINE EFFECTS OF METALLURGICAL VARIABLES ON FCP IN ORR ON RESEARCH ALLOYS.	H-2	6
I.B.2.3	DETERMINE UNDERLYING MECHANISTIC PRINCIPLES CONTROLLING ALLOY/TREATMENT EFFECTS ON FCP AS BASIS FOR IDENTIFICATION OF PRIME CANDIDATE ALLOYS.	H-2	6
I.B.2.4	GENERATE HIGH FLUENCE ENGINEERING DATA ON PRIME CANDIDATE ALLOYS AND ON OPT-B.	H-3	0



MILESTONES

- **I.B.2.a** INPUT TO SELECTION OF PATH B PRIME CANDIDATE ALLOYS (I-7).
- **I.B.2.b** INPUT TO SELECTION OF OPT-B (I-8).
- **I.B.2.c** ESTABLISH FATIGUE CRACK GROWTH ENGINEERING DATA BASE AND PERFORMANCE LIMITS FOR OPT-B (I-9).

ORNL–DWG 78-14732

OBJECTIVE: TO PROVIDE BASIC UNDERSTANDING NEEDED TO DESIGN PATH C ALLOYS FOR FATIGUE CRACK PROPAGATION (FPC) RESISTANCE AND TO DEVELOP THE DESIGN DATA BASE ON THE IMPROVED ALLOYS.

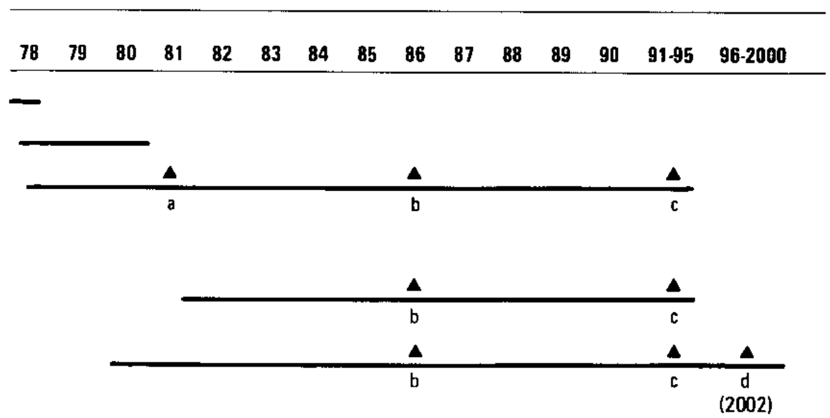
SCOPE: LITERATURE SEARCH AND ANALYSIS WILL BE PERFORMED TO IDENTIFY FCP RESISTANT PATH C ALLOYS AND TO ASSESS NEEDS FOR FURTHER TESTING TO FILL DATA GAPS. SUBSEQUENTLY, IRRADIATIONS WILL BE PERFORMED IN ORR, EBR-II AND FFTF TO FILL GAPS. SPECIAL TECHNIQUES NEEDED FOR PATH C TESTING, SUCH AS HELIUM IMPLANTATION, WILL BE DEVELOPED.

TASK NUMBER: I.B.3

TASK TITLE: FATIGUE CRACK GROWTH IN REACTIVE/REFRACTORY ALLOYS (PATH C)

INPUT TO MAJOR MILESTONES: I-11 TO I-14

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.B.3.1	LITERATURE SEARCH AND ANALYSIS	M-3	0.5
I.B.3.2	TEST METHODS DEVELOPMENT	M-3	8
I.B.3.3	SUPPLEMENTAL DATA GENERATION ON PROTOTYPIC Ti, Nb, V ALLOYS TO DETERMINE IF SIMULATED MFR ENVIRONMENT AFFECTS FCP USING ORR, EBR-II AND FFTF IN ADDITION TO TESTING UNIRRADIATED MATERIALS	M-3	8
I.B.3.4	EVALUATION OF GROSS METALLURGICAL VARIATION EFFECTS ON BASE RESEARCH AND ADVANCED ALLOYS	M-3	3
I.B.3.5	EVALUATION OF ENGINEERING PROPERTIES OF ADVANCED ALLOYS	M-3	3



MILESTONES

I.B.3.a INPUT TO SELECTION OF PATH C BASE RESEARCH ALLOYS (I-11).

I.B.3.b INPUT TO SELECTION OF PATH C PRIME CANDIDATE ALLOYS (I-12).

I.B.3.c INPUT TO IDENTIFICATION OF OPT-C (I-13).

I.B.3.d ESTABLISH FATIGUE CRACK GROWTH DATA BASE AND PERFORMANCE LIMITS OF OPT-C (I-14).

ORNL–DWG 78-14733

OBJECTIVE: TO DETERMINE THE MECHANISMS CONTROLLING THE FATIGUE CRACK GROWTH OF PATH D MATERIALS AS A FUNCTION OF MATERIAL AND IRRADIATION PARAMETERS.

SCOPE: AFTER MATERIALS AND/OR CONCEPTS TO BE EVALUATED ARE SELECTED, IRRADIATION AND TEST MATRICES WILL BE DEVELOPED TO ESTABLISH THE UNDERSTANDING OF FATIGUE CRACK GROWTH PROCESSES IN THESE MATERIALS. IMPROVED ALLOYS WILL THEN BE DEVELOPED AND TESTED.

TASK NUMBER: I.B.4

TASK TITLE: FATIGUE CRACK GROWTH IN SPECIAL AND INNOVATIVE MATERIALS (PATH D)

INPUT TO MAJOR MILESTONES: I-17 TO I-20

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82	78	79	80	81	82	83	84	85	86	87	88	89	90	91-95	96-2000
	INITIATE FATIGUE CRACK GROWTH STUDIES WHEN MATERIALS AND/OR CONCEPTS ARE SELECTED. SUBTASKS WILL INCLUDE:	M-3	(UNKNOWN)			▲ a												
I. B. 4.1	SCOPE IRRADIATION VARIABLE EFFECTS.																	
I.B.4.2	SCOPE MATERIALS VARIABLE EFFECTS.					{ BUDGET, SCHEDULE, AND MILESTONES CANNOT BE DEVELOPED UNTIL MATERIALS ARE SELECTED. }												
I.B.4.3	DEVELOP ADVANCED CANDIDATES.																	
I.B.4.4	EVALUATE ADVANCED CANDIDATES TO ESTABLISH DATA BASE AND PERFORMANCE LIMITS.																	
	MILESTONES																	
I.B.4.a	INITIATE SCOPING STUDIES ON PROMISING PATH D CONCEPTS (I-16).																	

ORNL–DWG 78-14734

OBJECTIVE: TO PROVIDE MECHANISTIC UNDERSTANDING OF STRESS/STRAIN CONTROLLED FATIGUE (SSCF) NEEDED TO DESIGN THE OPTIMIZED ALLOYS AND TO PROVIDE BASIC ENGINEERING DESIGN DATA.

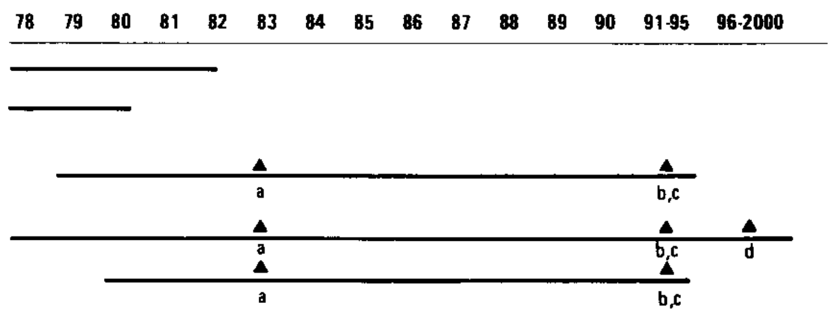
SCOPE: IRRADIATIONS WILL BE CONDUCTED IN ORR AND FFTF ON PROGRAM AND RELATED TEST MATERIALS. EARLY EMPHASIS WILL BE ON ORR TESTS. MATERIALS EVALUATION WILL BE PERFORMED ON SPECIMENS OPTIMIZED FOR MFR APPLICATIONS AND WILL BE PERFORMED EX-REACTOR AND IN-REACTOR AS REQUIRED.

TASK NUMBER: I.B.5

TASK TITLE: STRESS/STRAIN CONTROLLED FATIGUE OF AUSTENITIC ALLOYS (PATH A)

INPUT TO MAJOR MILESTONES: I-2 TO I-5

SUBTASK NO.	ACTIVITIES	PRIORITIES	MAN YEARS FY 78-82
I.B.5.1	DEVELOP SPECIMENS AND TEST METHODS	H-2	5
I.B.5.2	DETERMINE SENSITIVITY OF SSCF TO MFR ENVIRONMENT USING BASE ALLOY	H-2	3
I.B.5.3	DETERMINE SENSITIVITY OF SSCF TO ALLOY COMPOSITION AND CLARIFY CONTROLLING MECHANISMS	H-2	5
I.B.5.4	EVALUATE ENGINEERING LEVEL SSCF PROPERTIES ON BASE ALLOY	H-2	5
I.B.5.5	IF I.B.5.3 SHOWS ALLOY EFFECTS, CONDUCT LIMITED METALLURGICAL VARIABLES ANALYSIS	H-2	3



MILESTONES

I.B.5.a INPUT TO SELECTION OF OPT-AI (I-2).

I.B.5.b ESTABLISH FATIGUE DATA BASE AND PERFORMANCE LIMITS OF OPT-AI (I-3).

I.B.5.c INPUT TO SELECTION OF OPT-A2 (I-4).

I.B.5.d ESTABLISH FATIGUE DATA BASE AND PERFORMANCE LIMITS OF OPT-A2 (I-5).

ORNL—DWG 78-14736

OBJECTIVE: TO PROVIDE THE BASIC UNDERSTANDING NEEDED TO DESIGN PATH B ALLOYS FOR RESISTANCE TO STRESS/STRAIN CONTROLLED FATIGUE (SSCF) AND TO DEVELOP A DESIGN DATA BASE ON THESE ALLOYS.

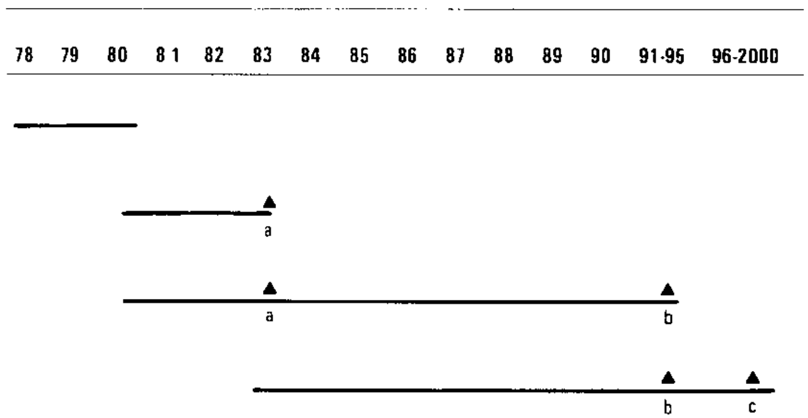
SCOPE: IRRADIATIONS WILL BE PERFORMED IN ORR AND FFTF ON PATH B AND RELATED MATERIALS; TESTING WILL BE ON AN IN-REACTOR OR POSTIRRADIATION BASIS AS REQUIRED. TEST METHODS DEVELOPED ON PATH A WILL BE UTILIZED EXCEPT WHERE ADDITIONAL DEVELOPMENT MAY BE REQUIRED.

TASK NUMBER: I.B.6

TASK TITLE: STRESS/STRAIN CONTROLLED FATIGUE IN HIGH STRENGTH/HIGH TEMPERATURE Fe-Ni-Cr ALLOYS (PATH B)

INPUT TO MAJOR MILESTONES: I-7 TO I-9

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.B.6.1	EVALUATE SCOPING RESPONSE OF SELECTED PATH B AND RELATED ALLOYS TO SIMULATED MFR ENVIRONMENTS USING ORR (LIMITED MATRIX)	H-2	3
I.B.6.2	IF I.B.6.1 SHOWS SENSITIVITY TO MFR ENVIRONMENT, DETERMINE EFFECTS OF METALLURGICAL VARIABLES ON SSCF IN ORR ON RESEARCH ALLOYS	H-2	3
I.B.6.3	DETERMINE UNDERLYING MECHANISTIC PRINCIPLES CONTROLLING ALLOY/TREATMENT EFFECTS ON SSCF AS BASIS FOR IDENTIFICATION OF PRIME CANDIDATE ALLOYS	H-2	3
I.B.6.4	IRRADIATE TO HIGH FLUENCES TO GENERATE ENGINEERING DATA ON FATIGUE OF PRIME CANDIDATE ALLOYS AND ON ALLOY OPT-B	H-3	0



MILESTONES

I.B.6.a INPUT TO SELECTION OF PATH B PRIME CANDIDATE ALLOYS (I-7).

I.B.6.b INPUT TO SELECTION OF OPT-B (I-8).

I.B.6.c ESTABLISH FATIGUE DATA BASE AND PERFORMANCE LIMITS FOR OPT-B (I-9).

ORNL–DWG 78-14738

OBJECTIVE: TO PROVIDE THE BASIC UNDERSTANDING NEEDED TO DESIGN PATH C ALLOYS FOR STRESS/STRAIN CONTROLLED FATIGUE SSCF RESISTANCE. TO GENERATE THE DESIGN DATA BASE ON THE OPTIMIZED ALLOYS.

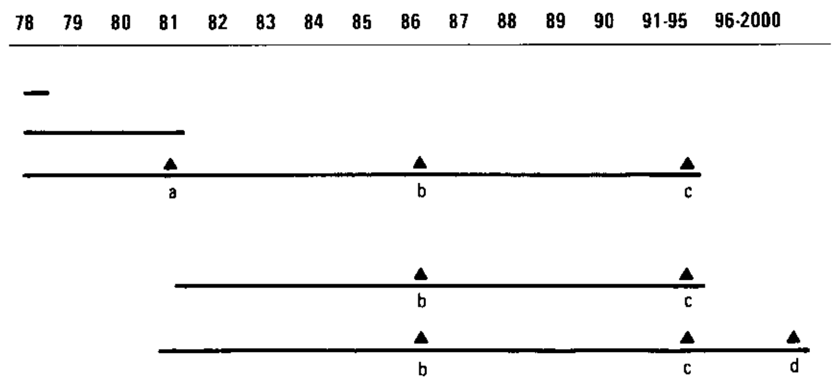
SCOPE: A LITERATURE SEARCH AND ANALYSIS WILL BE PERFORMED TO IDENTIFY SSCF RESISTANT ALLOYS AND TO ASSESS NEEDS FOR ADDITIONAL TESTING; SUBSEQUENTLY, IRRADIATION AND EX-REACTOR TESTS WILL BE PERFORMED TO FILL IN GAPS IN UNDERSTANDING. SPECIAL TECHNIQUES, SUCH AS HELIUM IMPLANATION TECHNOLOGY NEEDED FOR PATH C TESTING, WILL BE PART OF THE TASK.

TASK NUMBER: I.B.7

TASK TITLE: STRESS/STRAIN CONTROLLED FATIGUE OF REACTIVE/REFRACTORY ALLOYS (PATH C)

INPUT TO MAJOR MILESTONES: I-11 TO I-14

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.B.7.1	LITERATURE SEARCH AND ANALYSIS	M-3	0.5
I.B.7.2	TEST METHODS DEVELOPMENT	M-3	8
I.B.7.3	SUPPLEMENTAL DATA GENERATION ON PROTOTYPIC Ti, Nb, V ALLOYS TO DETERMINE IF SIMULATED MFR ENVIRONMENT AFFECTS SSCF USING ORR, EBR-II AND FFTF IN ADDITION TO TESTING UNIRRADIATED MATERIALS	M-3	8
I.B.7.4	EVALUATION OF GROSS METALLURGICAL VARIATION EFFECTS ON BASE RESEARCH AND ADVANCED ALLOYS	M-3	3
I.B.7.5	EVALUATION OF ENGINEERING PROPERTIES OF ADVANCED ALLOYS	M-3	3



MILESTONES

I.B.7.a INPUT TO SELECTION OF PATH C BASE RESEARCH ALLOYS (I-11).

I.B.7.b INPUT TO SELECTION OF PATH C PRIME CANDIDATE ALLOYS (I-12).

I.B.7.c INPUT TO IDENTIFICATION OF OPT-C (I-13).

I.B.7.d ESTABLISH FATIGUE DATA BASE AND PERFORMANCE LIMITS OF OPT-C (I-14).

ORNL–DWG 78-14737

OBJECTIVE: TO DETERMINE THE FATIGUE PROPERTIES OF PATH D MATERIALS AS A FUNCTION OF MATERIAL AND IRRADIATION PARAMETERS.

SCOPE: WHEN MATERIALS AND/OR CONCEPTS ARE SELECTED, IRRADIATION AND TEST MATRICES WILL BE DEVELOPED TO YIELD AN UNDERSTANDING OF FATIGUE PROPERTIES IN THESE MATERIALS. ADVANCED MATERIALS WILL BE DEVELOPED FROM THIS INFORMATION AND QUALIFIED FOR REACTOR DESIGN.

TASK NUMBER: I.B.8

TASK TITLE: STRESS/STRAIN CONTROLLED FATIGUE OF SPECIAL AND INNOVATIVE MATERIALS (PATH D)

INPUT TO MAJOR MILESTONES:
I-17 TO I-20

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82	78	79	80	81	82	83	84	85	86	87	88	89	90	91-95	96-2000
	INITIATE FATIGUE STUDIES WHEN MATERIALS AND/OR CONCEPTS ARE IDENTIFIED. SUBTASKS ARE:	M3	(UNKNOWN)			▲ a												
I.B.8.1	SCOPE IRRADIATION VARIABLE EFFECTS																	
I.B.8.2	SCOPE MATERIAL VARIABLE EFFECTS																	
I.B.8.3	DEVELOP ADVANCED CANDIDATES																	
I.B.8.4	EVALUATE ADVANCED CANDIDATES TO ESTABLISH DATA BASE AND PERFORMANCE LIMITS																	

{BUDGET, SCHEDULE AND MILESTONES CANNOT BE DEVELOPED UNTIL MATERIALS ARE SELECTED.}

MILESTONES

I.B.8.a INITIATE SCOPING STUDIES ON PROMISING PATH D CONCEPTS (I-16).

OBJECTIVE: TO PROVIDE THE BASIC UNDERSTANDING NEEDED TO DESIGN PATH A ALLOYS FOR STRESS-RUPTURE (SR) RESISTANCE AND TO PROVIDE ENGINEERING DESIGN DATA CORRELATIONS.

SCOPE: IRRADIATIONS WILL BE PERFORMED ON STRESS-RUPTURE SPECIMENS UTILIZING LMFBR METHODOLOGY. IN-REACTOR TESTING IN ORR AND FFTF WILL BE UTILIZED FOR DATA DEVELOPMENT.

TASK NUMBER: I.B.9

TASK TITLE: STRESS-RUPTURE PROPERTIES OF AUSTENITIC ALLOYS (PATH A)

INPUT TO MAJOR MILESTONES:
I-2 TO I-5

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82	78	79	80	81	82	83	84	85	86	87	88	89	90	91-95	96-2000
I.B.9.1	DETERMINE SENSITIVITY OF SR TO MFR FIRST WALL ENVIRONMENT FOR BASE ALLOY	H-2	3	—	—	—												
I.B.9.2	DETERMINE SENSITIVITY OF SRR TO ALLOY COMPOSITION AND HEAT TREATMENT, AND REVEAL CONTROLLING MECHANISMS USING BASE ALLOY MODIFICATIONS	H-2	5	—	—	—	—	—	▲ a	—	—	—	—	—	—	—	▲ b,c	
I.B.9.3	EVALUATE ENGINEERING LEVEL SR PROPERTIES OF BASE ALLOY	H-2	5	—	—	—	—	—	▲ a	—	—	—	—	—	—	—	▲ b	▲
I.B.9.4	IF I.B.3.2 SHOWS THAT SR IS SENSITIVE TO ALLOY COMPOSITION OR TREATMENT, PURSUE LIMITED METALLURGICAL VARIABLE TESTS AT HIGH FLUENCE	H-2	3			—	—	—	▲ a	—	—	—	—	—	—	—	▲ b,c	

MILESTONES

I.B.9.a INPUT TO SELECTION OF OPT-AI (I-2).

I.B.9.b ESTABLISH STRESS-RUPTURE DATA BASE AND PERFORMANCE LIMITS OF OPT-AI (I-3).

I.B.9.c INPUT TO SELECTION OF OPT-A2 (I-4).

I.B.9.d ESTABLISH STRESS-RUPTURE DATA BASE AND PERFORMANCE LIMITS OF OPT-A2 (I-5).

ORNL—DWG 78-14740

OBJECTIVE: TO PROVIDE THE BASIC UNDERSTANDING NEEDED TO DESIGN PATH B ALLOYS FOR STRESS-RUPTURE (SR) RESISTANCE, AND TO GENERATE ENGINEERING INFORMATION ON THE OPTIMIZED ALLOYS.

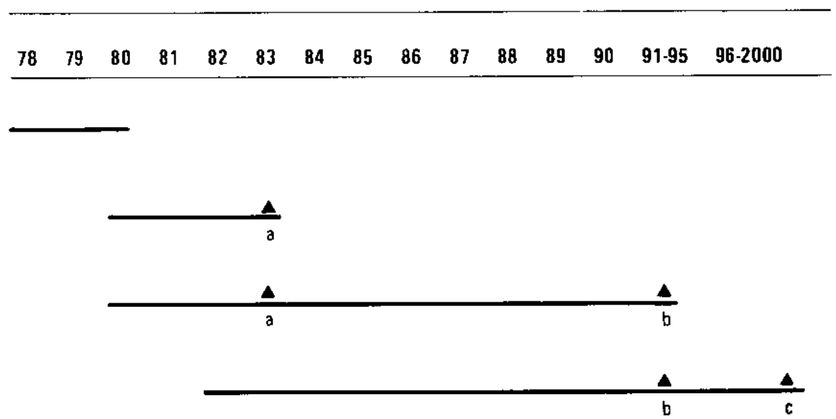
SCOPE: IRRADIATIONS WILL BE PERFORMED IN ORR, EBR-II AND FFTF ON PATH B MATERIALS. TESTING WILL FOLLOW LMFBR METHODS AND WILL BE ON AN IN-REACTOR BASIS. SPECIAL EMPHASIS WILL BE PLACED ON UNDERSTANDING HELIUM/MATRIX/PRECIPITATE EFFECTS.

TASK NUMBER: I.B.10

TASK TITLE: STRESS-RUPTURE PROPERTIES OF HIGH STRENGTH-HIGH TEMPERATURE Fe-Ni-Cr ALLOYS (PATH B)

INPUT TO MAJOR MILESTONES: I-7 TO I-9

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.B.10.1	EVALUATE SCOPING RESPONSE OF SELECTED PATH B AND RELATED ALLOYS TO SIMULATED MFR ENVIRONMENTS USING ORR (LIMITED MATRIX)	H-2	3
I.B.10.2	IF I.B.10.1 SHOWS SENSITIVITY TO THE MFR ENVIRONMENT, DETERMINE EFFECTS OF METALLURGICAL VARIABLES ON SR IN ORR ON RESEARCH ALLOYS	H-2	3
I.B.10.3	DETERMINE UNDERLYING MECHANISTIC PRINCIPLES CONTROLLING ALLOY/TREATMENT EFFECTS ON SR AS BASIS FOR IDENTIFICATION OF PRIME CANDIDATE ALLOYS	H-2	3
I.B.10.4	CONDUCT HIGH FLUENCE IRRADIATIONS TO GENERATE THE ENGINEERING DATA BASE ON STRESS RUPTURE BEHAVIOR OF PRIME CANDIDATE ALLOYS AND ON ALLOY OPT-B	H-3	0



MILESTONES

I.B.10.a INPUT TO SELECTION OF PATH B PRIME CANDIDATE ALLOYS (I-7).

I.B.10.b INPUT TO SELECTION OF OPT-B (I-8).

I.B.10.c ESTABLISH STRESS RUPTURE DATA BASE AND PERFORMANCE LIMITS ON OPT-B (I-9).

ORNL—DWG 78-14741

OBJECTIVE: TO PROVIDE THE BASIC MECHANISTIC AND PHENOMENOLOGICAL UNDERSTANDING TO DESIGN PATH C ALLOYS FOR STRESS-RUPTURE (SR) RESISTANCE. TO GENERATE THE DESIGN DATA BASE ON THE OPTIMIZED ALLOYS.

TASK NUMBER: I.B.II

TASK TITLE: STRESS-RUPTURE PROPERTIES OF REACTIVE/REFRACTORY METALS (PATH C)

INPUT TO MAJOR MILESTONES: I-11 TO I-14

SCOPE: A LITERATURE SEARCH AND ANALYSIS WILL BE PERFORMED TO IDENTIFY STRESS RUPTURE RESISTANT ALLOYS AND TO ASSESS THE NEED FOR ADDITIONAL TESTING TO FILL IN DATA GAPS. SUBSEQUENTLY, IRRADIATION WILL BE PERFORMED IN ORR, EBR-II AND FFTF TO IDENTIFY PATH C ALLOY SYSTEMS WITH HIGH STRESS-RUPTURE RESISTANCE DURING IRRADIATION. DEVELOPMENT OF SPECIAL TECHNIQUES FOR TESTING, SUCH AS HELIUM IMPLANTATION, IS INCLUDED.

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82	78	79	80	81	82	83	84	85	86	87	88	89	90	91-95	96-2000
I.B.11.1	LITERATURE SEARCH AND ANALYSIS	M-3	0.5															
I.B.11.2	TEST METHODS DEVELOPMENT	M-3	5															
I.B.11.3	GENERATE SUPPLEMENTAL DATA ON PROTOTYPIC Ti, Nb, V ALLOYS TO DETERMINE IF SIMULATED MFR ENVIRONMENT AFFECTS SR USING ORR, EBR-II AND FFTF IN ADDITION TO TESTING UNIRRADIATED MATERIALS	M3	8				a					b					c	
I.B.11.4	EVALUATION OF GROSS METALLURGICAL VARIATION EFFECTS ON BASE RESEARCH AND ADVANCED ALLOYS	M-3	3									b					c	
I.B.11.5	EVALUATION OF ENGINEERING PROPERTIES OF ADVANCED ALLOYS	M-3	3									b					c	d

MILESTONES

I.B.11.a INPUT TO SELECTION OF PATH C BASE RESEARCH ALLOYS (I-11).

I.B.11.b INPUT TO SELECTION OF PATH C PRIME CANDIDATE ALLOYS (I-12).

I.B.11.c INPUT TO IDENTIFICATION OF OPT-C (I-13).

I.B.11.d ESTABLISH STRESS-RUPTURE DATA BASE AND PERFORMANCE LIMITS OF OPT-C (I-14).

ORNL–DWG 78-14742

OBJECTIVE: TO DETERMINE THE STRESS-RUPTURE PROPERTIES OF PATH D MATERIALS AS A FUNCTION OF MATERIAL AND IRRADIATION PARAMETERS.

SCOPE: WHEN MATERIALS AND/OR CONCEPTS ARE SELECTED FOR EVALUATION, MATRICES WILL BE DEVELOPED TO ESTABLISH AN UNDERSTANDING OF THE IRRADIATION AND MATERIAL PARAMETER EFFECTS ON THE STRESS-RUPTURE PROPERTIES. ADVANCED MATERIALS WILL BE DEVELOPED FROM THIS INFORMATION AND QUALIFIED FOR REACTOR DESIGN.

TASK NUMBER: I.B.12

TASK TITLE: STRESS-RUPTURE PROPERTIES OF SPECIAL AND INNOVATIVE MATERIALS (PATH D)

INPUT TO MAJOR MILESTONES: I-17 TO I-20

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82	78	79	80	81	82	83	84	85	86	87	88	89	90	91-95	96-2000
	INITIATE STRESS-RUPTURE STUDIES WHEN MATERIALS AND/OR CONCEPTS ARE IDENTIFIED. SUBTASKS ARE:	M-3	(UNKNOWN)			▲ a												
I.B.12.1	SCOPE IRRADIATION VARIABLE EFFECTS							BUDGET, SCHEDULE AND MILESTONES CANNOT BE DEVELOPED UNTIL MATERIALS ARE SELECTED.										
I.B.12.2	SCOPE MATERIALS VARIABLE EFFECTS																	
I.B.12.3	DEVELOP ADVANCED CANDIDATES																	
I.B.12.4	EVALUATE ADVANCED CANDIDATES TO ESTABLISH DATA BASE AND PERFORMANCE LIMITS																	

MILESTONES

I.B.12.a INITIATE SCOPING STUDIES ON PROMISING PATH D CONCEPTS (I-16).

ORNL–DWG 78-14743

OBJECTIVE: TO PROVIDE THE BASIC UNDERSTANDING NEEDED TO DESIGN PATH A ALLOYS WITH IMPROVED TENSILE PROPERTIES (TP) AND TO PROVIDE BASIC ENGINEERING DATA FOR MFR DESIGN OF PATH A ALLOYS.

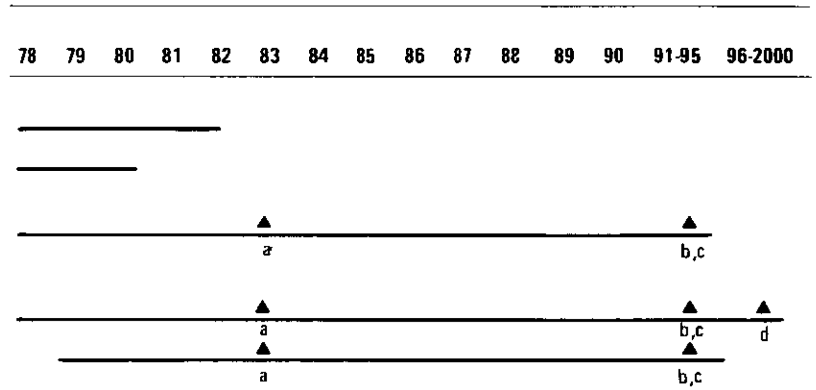
SCOPE: IRRADIATIONS WILL BE PERFORMED IN ORR AND FFTF ON PROGRAM AND RELATED PATH A ALLOYS. TESTING WILL BE PERFORMED ON AN OUT-OF-REACTOR BASIS. SPECIMEN SHAPE AND TEST METHODS WILL BE BASED ON LMFBR EXPERIENCE BUT WILL BE MODIFIED SLIGHTLY FOR MFR RESEARCH ACTIVITIES.

TASK NUMBER: I.B.13

TASK TITLE: TENSILE PROPERTIES OF AUSTENITIC ALLOYS (PATH A)

INPUT TO MAJOR MILESTONES:
I.2 TO I.5

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.B.13.1	SPECIMEN AND TEST METHOD DEVELOPMENT	H-2	1
I.B.13.2	DETERMINE SENSITIVITY OF TP TO MFR FIRST WALL ENVIRONMENT FOR BASE ALLOY	H-2	3
I.B.13.3	DETERMINE SENSITIVITY OF TP TO ALLOY COMPOSITION AND HEAT TREATMENT, AND REVEAL CONTROLLING MECHANISMS USING BASE ALLOY MODIFICATIONS	H-2	5
I.B.13.4	EVALUATE ENGINEERING LEVEL TP OF BASE ALLOY	H-1	5
I.B.13.5	IF I.B.13.3 SHOWS THAT TP ARE SENSITIVE TO ALLOY COMPOSITION OR TREATMENT PURSUE LIMITED METALLURGICAL VARIABLE TESTS AT HIGH FLUENCE	H-2	3



MILESTONES

I.B.13.a INPUT TO SELECTION OF OPT-AI (I-2).

I.B.13.b ESTABLISH TENSILE PROPERTY DATA BASE AND PERFORMANCE LIMITS OF OPT-AI (I-3).

I.B.13.c INPUT TO SELECTION OF OPT-A2 (I-4).

I.B.13.d ESTABLISH TENSILE PROPERTY DATA BASE AND PERFORMANCE LIMITS OF OPT-A2 (I-5).

ORNL--DWG 78-14744

TASK NUMBER: I.B.14

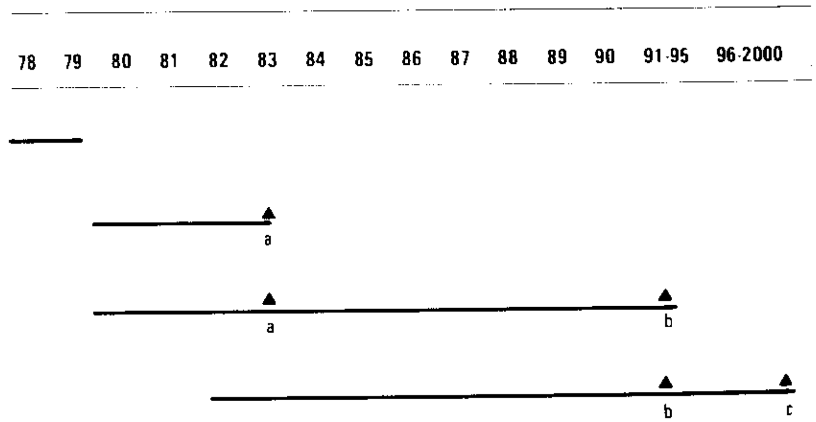
TASK TITLE: TENSILE PROPERTIES OF HIGH STRENGTH-HIGH TEMPERATURE Fe-Ni-Cr ALLOYS (PATH B)

INPUT TO MAJOR MILESTONES: I-7 TO I-9

OBJECTIVE: TO PROVIDE THE BASIC UNDERSTANDING NEEDED TO DESIGN PATH B ALLOYS WITH IMPROVED TENSILE PROPERTIES (TP) AND TO GENERATE THE DESIGN DATA BASE ON THESE ALLOYS.

SCOPE: IRRADIATIONS WILL BE PERFORMED IN EBR-II AND FFTF USING PATH A TEST METHODS. TESTS WILL BE PERFORMED ON A POSTIRRADIATION BASIS ONLY. SIGNIFICANT EMPHASIS WILL BE PLACED ON DEVELOPMENT OF THE UNDERSTANDING OF HELIUM/MATRIX-STRENGTH/PRECIPITATION EFFECTS.

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.B.14.1	EVALUATE SCOPING RESPONSE OF SELECTED PATH B AND RELATED ALLOYS TO SIMULATED MFR ENVIRONMENTS USING ORR (LIMITED MATRIX)	H-2	1
I.B.14.2	IF I.B.14.1 SHOWS SENSITIVITY TO THE MFR ENVIRONMENT, DETERMINE EFFECTS OF METALLURGICAL VARIABLES ON TP IN ORR ON RESEARCH ALLOYS	H-2	2
I.B.14.3	DETERMINE UNDERLYING MECHANISTIC PRINCIPLES CONTROLLING ALLOY/TREATMENT EFFECTS ON TP AS BASIS FOR IDENTIFICATION OF PRIME CANDIDATE ALLOYS	H-2	2
I.B.14.4	ESTABLISH THE EFFECT OF HIGH FLUENCE IRRADIATION ON THE TENSILE PROPERTIES OF PRIME CANDIDATE ALLOYS AND ALLOY OPT-B	H-3	0



MILESTONES

I.B.14.a INPUT TO SELECTION OF PATH B PRIME CANDIDATE ALLOYS (I-7)

I.B.14.b INPUT TO SELECTION OF OPT-B (I-8).

I.B.14.c ESTABLISH TENSILE PROPERTIES DATA BASE AND PERFORMANCE LIMITS ON OPT-B (I-9).

ORNL–DWG 78-14745

OBJECTIVE: TO PROVIDE THE BASIC MECHANISTIC AND PHENOMENOLOGICAL UNDERSTANDING NEEDED TO DESIGN PATH C ALLOYS WITH IMPROVED TENSILE STRENGTH AND DUCTILITY. DEVELOP THE ENGINEERING DATA BASE ON THE IMPROVED ALLOYS.

SCOPE: A LITERATURE SEARCH AND ANALYSIS WILL BE PERFORMED TO IDENTIFY ALLOYS WITH PROMISING TENSILE PROPERTIES AND TO ASSESS THE NEED FOR ADDITIONAL DATA. SUBSEQUENTLY, IRRADIATIONS WILL BE PERFORMED IN ORR, EBR-II AND FFTF TO IDENTIFY PROMISING PATH C ALLOY SYSTEMS. DEVELOPMENT OF SPECIAL IRRADIATION TECHNIQUES, SUCH AS HELIUM IMPLANTATION, IS INCLUDED.

TASK NUMBER: I.B.15

TASK TITLE: TENSILE PROPERTIES OF REACTIVE /REFRACTORY ALLOYS (PATH C)

INPUT TO MAJOR MILESTONES: I-11 TO I-14

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82	78	79	80	81	82	83	84	85	86	87	88	89	90	91-95	96-2000
I.B.15.1	LITERATURE SEARCH AND ANALYSIS	M-3	0.5															
I.B.15.2	TEST METHODS DEVELOPMENT	M-3	2															
I.B.15.3	GENERATE SUPPLEMENTAL DATA ON PROTOTYPIC Ti, Nb, V ALLOYS TO DETERMINE IF SIMULATED MFR ENVIRONMENT AFFECTS TENSILE PROPERTIES USING ORR, EBR-II AND FFTS IN ADDITION TO TESTING UNIRRADIATED MATERIALS	M-3	2				▲ a					▲ b					▲ c	
I.B.15.4	EVALUATE EFFECTS OF GROSS METALLURGICAL VARIABLES ON BASE RESEARCH AND ADVANCED ALLOYS	M-3	1									▲ b					▲ c	
I.B.15.5	EVALUATE ENGINEERING PROPERTIES OF ADVANCED ALLOYS	M-3	1									▲ b					▲ c	▲ d

MILESTONES

I.B.15.a	INPUT TO SELECTION OF PATH C BASE RESEARCH ALLOYS (I-11)
I.B.15.b	INPUT TO SELECTION OF PATH C PRIME CANDIDATE ALLOYS (I-12)
I.B.15.c	INPUT TO IDENTIFICATION OF OPT-C (I-13)
I.B.15.d	ESTABLISH TENSILE PROPERTIES DATA BASE AND PERFORMANCE LIMITS OF OPT-C (I-14)

ORNL–DWG 78-14746

OBJECTIVE: TO DETERMINE THE MECHANISMS CONTROLLING THE TENSILE PROPERTIES OF PATH D MATERIALS AS A FUNCTION OF MATERIAL AND IRRADIATION PARAMETERS.

SCOPE: AFTER MATERIALS AND/OR CONCEPTS TO BE EVALUATED ARE SELECTED, IRRADIATION AND TEST MATRICES WILL BE DEVELOPED TO ESTABLISH THE UNDERSTANDING OF TENSILE PROPERTIES IN IRRADIATED PATH D MATERIALS. IMPROVED MATERIALS WILL THEN BE DEVELOPED AND TESTED.

TASK NUMBER: I.B.16

TASK TITLE: TENSILE PROPERTIES OF SPECIAL AND INNOVATIVE MATERIALS (PATH D)

INPUT TO MAJOR MILESTONES: I-17 TO I-20

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82	78	79	80	81	82	83	84	85	86	87	88	89	90	91-95	96-2000
	INITIATE TENSILE PROPERTY STUDIES WHEN MATERIALS AND/OR CONCEPTS ARE SELECTED. SUBTASKS WILL INCLUDE:	M-3	(UNKNOWN)			▲ a												
I.B.16.1	SCOPE IRRADIATION VARIABLE EFFECTS																	
I.B.16.2	SCOPE MATERIAL VARIABLE EFFECTS								BUDGET, SCHEDULE AND MILESTONES CANNOT BE DEVELOPED UNTIL MATERIALS ARE SELECTED.									
I.B.16.3	DEVELOP ADVANCED CANDIDATES																	
I.B.16.4	EVALUATE ADVANCED CANDIDATES TO ESTABLISH A DATA BASE AND PERFORMANCE LIMITS																	
	MILESTONES																	
I.B.16.a	INITIATE SCOPING STUDIES ON PROMISING PATH D CONCEPTS (I-16)																	

ORNL–DWG 78-14747

OBJECTIVE: TO ESTABLISH AN UNDERSTANDING OF THE FACTORS CONTROLLING THE MICROSTRUCTURAL STABILITY OF ALLOYS DURING IRRADIATION AND TO APPLY THESE PRINCIPLES TO THE DEVELOPMENT OF ALLOYS STABLE IN THE FUSION REACTOR ENVIRONMENT.

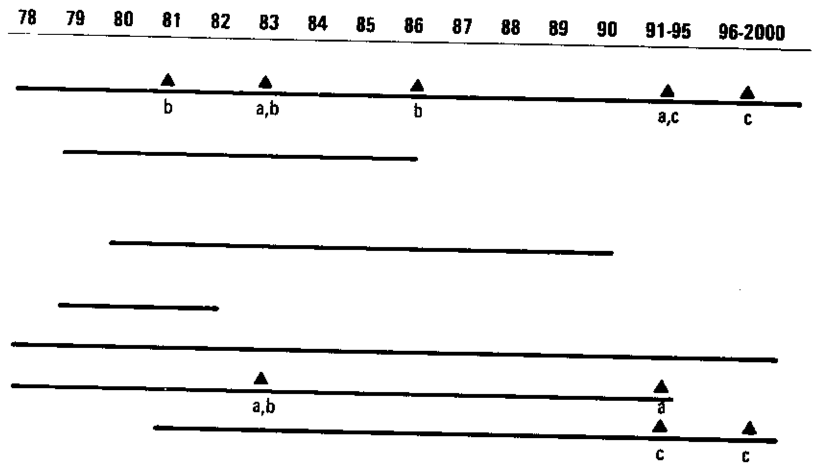
TASK NUMBER: I.C.1

TASK TITLE: MICROSTRUCTURAL STABILITY

INPUT TO MAJOR MILESTONES:
I-2 TO I-20

SCOPE: ALL ALLOYS AND A RANGE OF IRRADIATION CONDITIONS WILL BE INCLUDED TO DETERMINE STRUCTURAL STABILITY. THERMOMECHANICALLY TREATED STRUCTURES WILL BE EXAMINED AFTER IRRADIATION FOR STABILITY OF DISLOCATION AND PRECIPITATE STRUCTURES. THE FORMATION OF NEW PHASES OR PARTITION OF ALLOY CONSTITUENTS WILL BE DETERMINED. FUNDAMENTAL PRINCIPLES OF STABILITY WILL BE DETERMINED IN MODEL SYSTEMS AND IRRADIATIONS. A STRONG ALLOY THEORY EFFORT MUST SUPPORT THIS WORK.

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.C.1.1	STUDY THE STABILITY OF BASE AND DEVELOPMENTAL ALLOYS – ALL PATHS, CONDUCT REPRESENTATIVE NEUTRON IRRADIATIONS	H-2	7
I.C.1.2	INVESTIGATE THE INFLUENCE OF EXTRINSIC SINKS ON INSTABILITIES AND ALLOY PARTITIONING. (GRAIN BOUNDARY AND FREE SURFACE EFFECTS)	H-2	8
I.C.1.3	CORRELATE GRAIN BOUNDARY SEGREGATION WITH FRACTURE MODE/DUCTILITY RESULTS	H-2	2
I.C.1.4	EVALUATE DAMAGE RATE AND DUTY CYCLE EFFECTS	H-2	5
I.C.1.5	CONDUCT ALLOY THEORY AND MODELING STUDIES	H-2	8
I.C.1.6	CORRELATE DATA FOR DEVELOPMENT OF IMPROVED ALLOYS	H-2	1
I.C.1.7	MONITOR AND INVESTIGATE STABILITY OF OPTIMIZED ALLOYS UNDER LONG-EXPOSURES	H-3	1



MILESTONES

I.C.1.a INPUT TO SELECTION OF OPTIMUM ALLOYS, VARIOUS PATHS (I-2, 4, 8, 13, 19)

I.C.1.b INPUT TO SELECTION OF VARIOUS BASE RESEARCH OR PRIME CANDIDATE ALLOYS (I-7, 11, 12, 17, 18)

I.C.1.c INPUT TO DEVELOPMENT OF ENGINEERING DATA BASE AND PERFORMANCE LIMITS FOR VARIOUS OPTIMUM ALLOYS (I-3, 5, 9, 14, 20)

ORNL–DWG 78-14748

TASK NUMBER: I.C.2

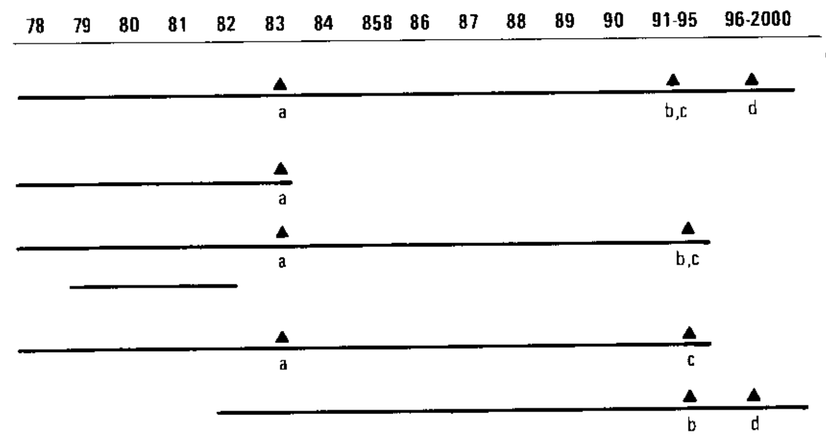
TASK TITLE: MICROSTRUCTURES AND SWELLING IN AUSTENITIC ALLOYS (PATH A)

INPUT TO MAJOR MILESTONES: I-2 TO I-5

OBJECTIVE: TO ESTABLISH MICROSTRUCTURAL RESPONSE AND TO IDENTIFY THE MECHANISMS THAT CONTROL PATH A ALLOY SWELLING; TO IDENTIFY THE IMPORTANT METALLURGICAL AND IRRADIATION VARIABLES THAT GOVERN SWELLING AND TO ESTABLISH THE FUNCTIONAL DEPENDENCE OF SWELLING. TO APPLY THESE TO THE DEVELOPMENT OF OPTIMIZED PATH A ALLOYS AND TO GENERATE DESIGN DATA FOR THEIR UTILIZATION.

SCOPE: DETERMINE THE SWELLING OF A MATRIX INCLUDING BASE COMPOSITIONS, ALLOYS DEVELOPED FOR CLASS SCOPING STUDIES, AND CANDIDATE DEVELOPMENTAL ALLOYS. INCLUDE COMPOSITIONAL AND MICROSTRUCTURAL VARIATIONS, AND WELDMENTS OF THE SAME ALLOYS. EFFECTS OF COMPOSITION, MICROSTRUCTURE, TEMPERATURE, FLUENCE, STRESS STATE, AND THE GRADIENTS IMPOSED BY CYCLIC OPERATION WILL BE STUDIED.

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.C.2.1	EVALUATE REFERENCE MATERIAL (20% CW 316) TO PROVIDE A BROAD DATA BASE AND TO QUALIFY THE ALLOY FOR POSSIBLE USE IN NEAR-TERM REACTORS	H-2	7
I.C.2.2	EVALUATE EFFECTS OF IRRADIATION VARIABLES ON REFERENCE MATERIAL AND PRIME CANDIDATE ALLOY	H-2	4
I.C.2.3	INVESTIGATE METALLURGICAL VARIABLES EFFECTS	H-2	12
I.C.2.4	EVALUATE EFFECTS OF UNIQUE IRRADIATION PARAMETERS, INCLUDING PULSED FLUX, TEMPERATURE, AND STRESS	H-2	6
I.C.2.5	CORRELATE DATA AND APPLY TO DEVELOPMENT OF IMPROVED ALLOYS	H-2	2
I.C.2.6	GENERATE ENGINEERING DATA FOR OPTIMIZED ALLOYS	H-2	4



MILESTONES

I.C.2.a INPUT TO SELECTION OF OPT-A1 (I-2)

I.C.2.b ESTABLISH SWELLING DATA BASE AND PERFORMANCE LIMITS OF OPT-A1 (I-3)

I.C.2.c INPUT TO SELECTION OF OPT-A2 (I-4)

I.C.2.d ESTABLISH SWELLING DATA BASE AND PERFORMANCE LIMITS OF OPT-A2 (I-5)

OBJECTIVE: TO ESTABLISH THE MICROSTRUCTURAL RESPONSE AND THE MECHANISMS CONTROLLING THE SWELLING OF PATH B ALLOYS OVER RANGE OF IRRADIATION PARAMETERS, COMPOSITIONAL AND MICROSTRUCTURAL CONDITIONS. TO USE THIS TO DEVELOP OPTIMIZED ALLOYS AND GENERATE THE DESIGN DATA BASE.

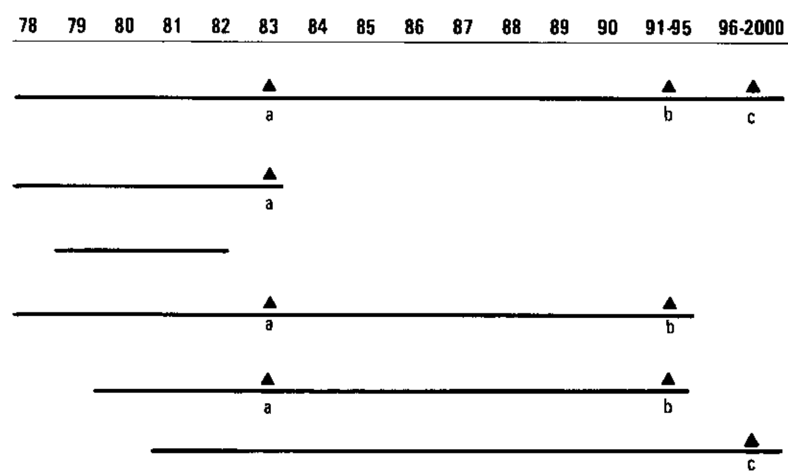
TASK NUMBER: I.C.3

TASK TITLE: MICROSTRUCTURES AND SWELLING IN HIGH STRENGTH/HIGH TEMPERATURE Fe-Ni-Cr ALLOYS (PATH B)

SCOPE: IRRADIATE REFERENCE ALLOYS, AND METALLURGICAL AND STRUCTURAL VARIABLE ALLOYS, TO ESTABLISH MECHANISMS AND FUNCTIONAL DEPENDENCE OF SWELLING OVER A WIDE RANGE OF IRRADIATION PARAMETERS. COMBINE GENERATED INFORMATION WITH OTHER EXPERIMENTAL INFORMATION TO DEVELOP IMPROVED ALLOYS. GENERATE DESIGN DATA ON OPTIMIZED ALLOYS. SWELLING WILL BE DETERMINED BY GEOMETRY, DENSITY, AND TEM.

INPUT TO MAJOR MILESTONES: I-7 TO I-9

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.C.3.1	EVALUATE REFERENCE MATERIAL TO PROVIDE A BROAD DATA BASE AND TO QUALIFY A BACK-UP MATERIAL FOR NEAR-TERM REACTORS.	H-2	7
I.C.3.2	EVALUATE EFFECTS OF IRRADIATION VARIABLES IN REFERENCE MATERIAL AND BASE RESEARCH ALLOYS	H-2	4
I.C.3.3	EVALUATE METALLURGICAL VARIABLES EFFECTS IN BASE RESEARCH AND PRIME CANDIDATE ALLOYS	H-2	15
I.C.3.4	STUDY EFFECTS OF IRRADIATION VARIABLES UNIQUE TO FUSION (PULSING)	M-2	5
I.C.3.5	CORRELATE DATA AND APPLY TO DEVELOPMENT OF IMPROVED ALLOYS	H-3	1
I.C.3.6	GENERATE ENGINEERING DATA FOR OPTIMIZED ALLOYS	H-3	0.5



MILESTONES

I.C.3.a	INPUT TO SELECTION OF PATH B PRIME CANDIDATE ALLOYS (I-7)
I.C.3.b	INPUT TO SELECTION OF OPT-B (I-8)
I.C.3.c	ESTABLISH SWELLING DATA BASE AND PERFORMANCE LIMITS FOR OPT-B (I-9)

OBJECTIVE: TO ESTABLISH MICROSTRUCTURAL RESPONSE AND PROVIDE A DATA BASE ON THE SWELLING OF PATH C ALLOYS LEADING TO AN UNDERSTANDING OF THE MATERIAL AND IRRADIATION VARIABLES CONTROLLING SWELLING. TO IDENTIFY PROMISING SYSTEMS AND DEVELOP OPTIMIZED ALLOYS.

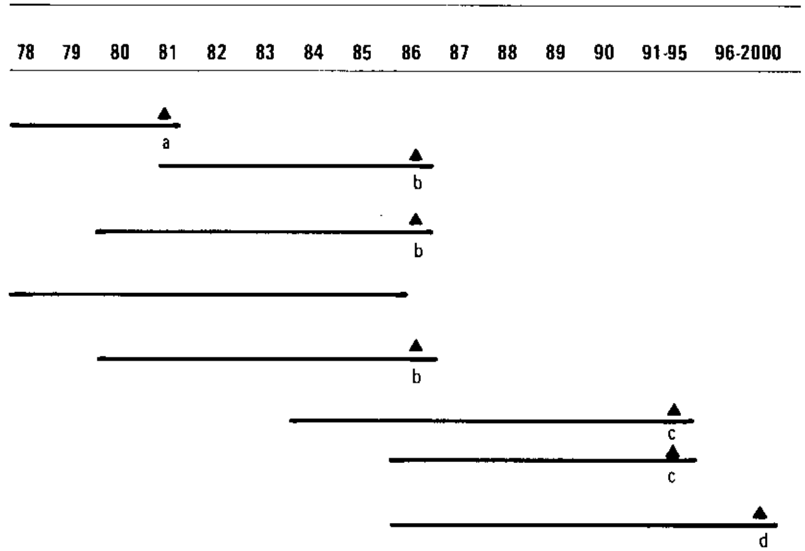
SCOPE: IRRADIATE A SET OF SCOPING ALLOYS TO IDENTIFY KEY IRRADIATION AND METALLURGICAL VARIABLES. WITH THIS INPUT, IDENTIFY AND EVALUATE EFFECTS OF METALLURGICAL VARIABLES ON THE BASE RESEARCH ALLOYS, SELECT THE MOST PROMISING FOR OPTIMIZATION AND IN-DEPTH TESTING. SAMPLES IRRADIATED IN FAST REACTORS AND BY ION BOMBARDMENT WILL BE EVALUATED BY GEOMETRY, DENSITY, AND TEM.

TASK NUMBER: I.C.4

TASK TITLE: MICROSTRUCTURES AND SWELLING IN REACTIVE/REFRACTORY ALLOYS (PATH C)

INPUT TO MAJOR MILESTONES: I-11 TO I-14

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.C.4.1	INVESTIGATE SWELLING BEHAVIOR IN SCOPING ALLOYS	M-3	6
I.C.4.2	CONDUCT HIGH FLUENCE SWELLING EXPERIMENTS ON BASE RESEARCH ALLOYS	M-3	3
I.C.4.3	EVALUATE EFFECTS OF IRRADIATION VARIABLES IN BASE RESEARCH ALLOYS	M-3	1
I.C.4.4	EVALUATE EFFECTS OF METALLURGICAL VARIABLES ON SWELLING OF BASE RESEARCH ALLOYS	M-3	5
I.C.4.5	INVESTIGATE THE ROLE OF HELIUM IN SWELLING OF SCOPING AND BASE RESEARCH ALLOYS	M-3	1
I.C.4.6	CORRELATE DATA AND SELECT PRIME CANDIDATE ALLOYS	M-3	0
I.C.4.7	INVESTIGATE EFFECTS OF METALLURGICAL VARIABLES ON PRIME CANDIDATE ALLOYS	M-3	0
I.C.4.8	DETERMINE HIGH FLUENCE SWELLING OF PRIME CANDIDATE ALLOYS AND OPT-C	M-3	0



MILESTONES

I.C.4.a	INPUT TO SELECTION OF PATH C BASE RESEARCH ALLOYS (I-11)
I.C.4.b	INPUT TO SELECTION OF PATH C PRIME CANDIDATE ALLOYS (I-12)
I.C.4.c	INPUT TO IDENTIFICATION OF OPT-C (I-13)
I.C.4.d	ESTABLISH SWELLING FOR ENGINEERING DATA BASE AND PERFORMANCE LIMIT EVALUATION OF OPT-C (I-14)

ORNL–DWG 78-14751

OBJECTIVE: TO IDENTIFY THE MECHANISMS CONTROLLING THE MICROSTRUCTURAL RESPONSE AND SWELLING OF CANDIDATE PATH D MATERIALS AS A FUNCTION OF MATERIAL AND IRRADIATION PARAMETERS.

SCOPE: WHEN MATERIALS OR CONCEPTS TO BE EVALUATED ARE CHOSEN, THE SWELLING RESPONSE OF CANDIDATE MATERIALS WILL BE EVALUATED. IRRADIATION TEST MATRICES WILL BE DEVELOPED USING THE MIX OF FACILITIES APPROPRIATE TO THE CHOSEN MATERIAL AND THE IRRADIATION PARAMETERS APPROPRIATE TO THE POTENTIAL APPLICATION.

TASK NUMBER: I.C.5

TASK TITLE: MICROSTRUCTURES AND SWELLING IN SPECIAL AND INNOVATIVE MATERIALS (PATH D)

INPUT TO MAJOR MILESTONES: I-17 TO I-20

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82	78	79	80	81	82	83	84	85	86	87	88	89	90	91-95	96-2000
	INITIATE SWELLING STUDIES WHEN CANDIDATE MATERIALS AND/OR CONCEPTS ARE DEVELOPED. SUBTASKS ARE:	M-3	(UNKNOWN)			▲ a												
I.C.5.1	SCOPE IRRADIATION VARIABLES EFFECTS																	
I.C.5.2	SCOPE MATERIAL VARIABLE EFFECTS			BUDGET, SCHEDULE, AND MILESTONES CANNOT BE DEVELOPED UNTIL MATERIALS ARE SELECTED.														
I.C.5.3	DEVELOP ADVANCED CANDIDATES																	
I.C.5.4	EVALUATE ADVANCED CANDIDATES TO ESTABLISH PERFORMANCE LIMITATIONS FOR REACTOR APPLICATIONS																	
	MILESTONES																	
I.C.5.a	INITIATE SCOPING STUDIES ON PROMISING PATH D CONCEPTS (I-16)																	

ORNL—DWG 78-14752

OBJECTIVE: TO ESTABLISH IRRADIATION CREEP BEHAVIOR OF PATH A ALLOYS AS A FUNCTION OF MATERIAL AND IRRADIATION VARIABLES, TO DEVELOP IMPROVED ALLOYS; AND TO PRODUCE IRRADIATION CREEP DESIGN DATA ON OPTIMIZED ALLOYS.

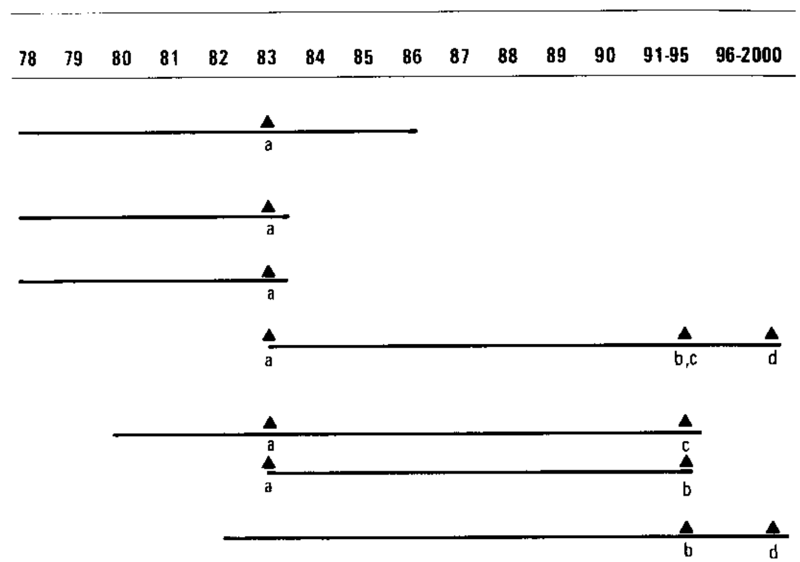
SCOPE: IRRADIATION CREEP EXPERIMENTS WILL ESTABLISH CONTROLLING MECHANISMS. MOST TESTING WILL USE THE PRESSURIZED TUBE APPROACH FOR IRRADIATIONS IN FISSION REACTORS. SUPPLEMENTAL TECHNIQUES WILL BE USED AS REQUIRED.

TASK NUMBER: I.C.6

TASK TITLE: IRRADIATION CREEP IN AUSTENITIC ALLOYS (PATH A)

INPUT TO MAJOR MILESTONES:
I-2 TO I-5

SUBTASKS NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.C.6.1	CONDUCT SCOPING STUDIES OF THE EFFECTS OF IRRADIATION VARIABLES ON CREEP OF REFERENCE AND PRIME CANDIDATE ALLOYS	H-2	5
I.C.6.2	SCOPE EFFECTS OF COMPOSITION AND MICROSTRUCTURAL VARIATIONS ON PRIME CANDIDATE ALLOYS	H-2	5
I.C.6.3	INVESTIGATE EFFECTS OF IRRADIATION PARAMETERS UNIQUE TO THE FUSION ENVIRONMENT-CYCLIC FLUX, STRESS, AND TEMPERATURE	H-2	8
I.C.6.4	CONDUCT LONG TERM IRRADIATIONS OF OPTIMIZED ALLOYS WITH INTERIM EXAMINATIONS BETWEEN IRRADIATION CYCLES. INVESTIGATE EFFECTS OF METALLURGICAL VARIABLES	H-2	4
I.C.6.5	CORRELATE DATA AND DEVELOP IMPROVED ALLOYS	H-2	1
I.C.6.6	CONDUCT VERIFICATION TESTING IN HIGH ENERGY NEUTRON SPECTRA	H-2	0
I.C.6.7	GENERATE ENGINEERING DATA FOR OPT-A1 AND 2	H-2	0.5



MILESTONES

I.C.6.a INPUT TO SELECTION OF OPT-AI (I-2)

I.C.6.b ESTABLISH IRRADIATION CREEP DATA BASE AND PERFORMANCE LIMITS OF OPT-A1 (I-3)

I.C.6.c INPUT TO SELECTION OF OPT-A2 (I-4)

I.C.6.d ESTABLISH IRRADIATION CREEP DATA BASE AND PERFORMANCE LIMITS OF OPT-A2 (I-5)

ORNL–DWG 78-14753

OBJECTIVE: TO ESTABLISH THE MECHANISMS CONTROLLING THE IRRADIATION CREEP OF PATH B ALLOYS AS A FUNCTION OF IRRADIATION AND MATERIAL PARAMETERS, DEVELOP IMPROVED ALLOYS, AND DEVELOP DESIGN DATA BASE FOR THESE.

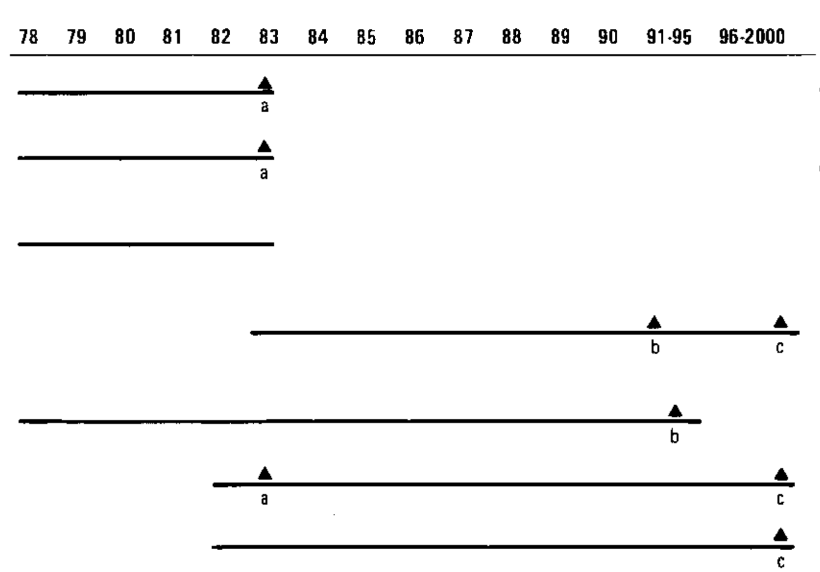
SCOPE: IRRADIATION CREEP PARAMETERS WILL BE ESTABLISHED FOR BASE RESEARCH ALLOYS TO ESTABLISH CONTROLLING MECHANISMS AND TO IDENTIFY ALLOY COMPOSITIONS FOR OPTIMIZATION. HIGH FLUENCE EXPERIMENTS WILL QUALIFY THEM FOR FUSION REACTOR APPLICATION. PRESSURIZED TUBE TECHNIQUES WILL BE USED TO GENERATE MOST OF THE CREEP DATA.

TASK NUMBER: I.C.7

TASK TITLE: IRRADIATION CREEP IN HIGH STRENGTH/HIGH TEMPERATURE Fe-Ni-Cr ALLOYS (PATH B)

INPUT TO MAJOR MILESTONES: I.7 TO I.9

SUBTASKS NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.C.7.1	SCOPE THE EFFECTS OF IRRADIATION VARIABLES ON THE CREEP OF PATH B BASE RESEARCH ALLOYS	H-2	5
I.C.7.2	SCOPE EFFECTS OF COMPOSITIONAL AND MICROSTRUCTURAL VARIATIONS ABOUT BASE COMPOSITIONS (INCLUDING PRECIPITATE EFFECTS)	H-2	5
I.C.7.3	INVESTIGATE EFFECTS OF IRRADIATION PARAMETERS UNIQUE TO FUSION – CYCLIC VARIATION OF PARAMETERS. (BUILD FROM BASE ON PATH A ALLOYS)	M-2	7
I.C.7.4	CONDUCT LONG TERM IRRADIATIONS OF PRIME CANDIDATE ALLOYS, WITH INTERIM EXAMINATIONS PERIODICALLY DURING SCHEDULED IRRADIATIONS. INVESTIGATE METALLURGICAL VARIABLES.	H-2	5
I.C.7.5	CORRELATE DATA WITH OTHER TASKS AND DEVELOP IMPROVED ALLOYS	H-3	0.5
I.C.7.6	CONDUCT VERIFICATION TESTING IN HIGH ENERGY NEUTRON SPECTRA	H-3	0
I.C.7.7	GENERATE ENGINEERING DATA ON LEADING PRIME CANDIDATE AND OPTIMIZED ALLOYS	H-3	0.5



MILESTONES

I.C.7.a INPUT TO SELECTION OF PATH B PRIME CANDIDATE ALLOYS (I-7)

I.C.7.b INPUT TO SELECTION OF OPT-B (I-8)

I.C.7.c ESTABLISH IRRADIATION CREEP DATA BASE AND PERFORMANCE LIMITS FROM OPT-B (I-9)

ORNL–DWG 78-14754

OBJECTIVE: TO ESTABLISH A DATA BASE ON THE IRRADIATION CREEP OF PATH C ALLOYS INCLUDING IDENTIFICATION OF CONTROLLING MECHANISMS AND THE FUNCTIONAL DEPENDENCE ON IRRADIATION AND MATERIALS VARIABLES. IDENTIFY PROMISING ALLOY SYSTEMS AND DEVELOP OPTIMIZED ALLOYS.

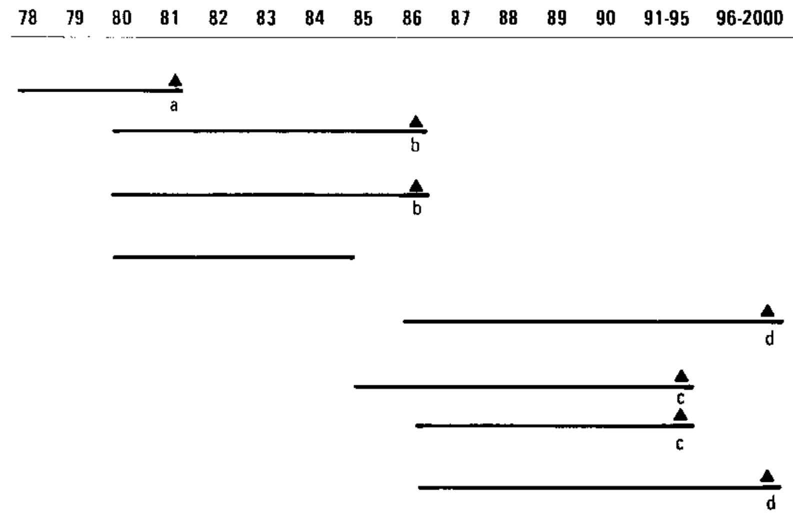
SCOPE: USE IRRADIATION IN ORR, FAST REACTORS AND ACCELERATORS TO ESTABLISH THE EFFECTS OF IRRADIATION AND TEST VARIABLES ON THE IRRADIATION CREEP OF REPRESENTATIVE ALLOYS. DEVELOP ALLOY SYSTEMS FOR OPTIMUM FUSION REACTOR PERFORMANCE, AND QUALIFY THE LEADING CANDIDATES FOR REACTOR USE. PRESSURIZED TUBE TECHNIQUES WILL BE USED FOR MOST OF THE EXPERIMENTS.

TASK NUMBER: I.C.8

TASK TITLE: IRRADIATION CREEP OF REACTIVE/ REFRACTORY ALLOYS (PATH C)

INPUT TO MAJOR MILESTONES: I-11 TO I-14

SUBTASKS NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.C.8.1	INVESTIGATE IRRADIATION CREEP RESONSE OF SCOPING ALLOYS	M-3	6
I.C.8.2	EVALUATE EFFECTS OF IRRADIATION VARIABLES AND IDENTIFY CONTROLLING MECHANISMS IN BASE RESEARCH ALLOYS	M-3	1
I.C.8.3	EVALUATE EFFECTS OF COMPOSITIONAL AND MICROSTRUCTURAL VARIABLES ON CREEP OF BASE RESEARCH ALLOYS	M-3	1
I.C.8.4	INVESTIGATE EFFECTS OF PULSED OPERATION ON IRRADIATION CREEP	M-3	1
I.C.8.5	CONDUCT HIGH FLUENCE CREEP OF MEASUREMENTS OF PRIME CANDIDATE AND OPTIMIZED ALLOYS	M-3	1
I.C.8.6	CORRELATE DATA AND DEVELOP IMPROVED ALLOYS	M-3	0
I.C.8.7	ESTABLISH METALLURGICAL VARIABLES EFFECTS IN PRIME CANDIDATE ALLOYS	M-3	0
I.C.8.8	MEASURE HIGH FLUENCE CREEP OF PRIME CANDIDATE AND OPTIMIZED ALLOYS	M-3	0



MILESTONES

I.C.8.a	INPUT TO SELECTION OF PATH C BASE RESEARCH ALLOYS (I-11)
I.C.8.b	INPUT TO SELECTION OF PATH C PRIME CANDIDATE ALLOYS (I-12)
I.C.8.c	INPUT TO IDENTIFICATION OF OPT-C (I-13)
I.C.8.d	ESTABLISH IRRADIATION CREEP FOR ENGINEERING DATA BASE AND PERFORMANCE LIMITS OF OPT-C (I-14)

ORNL–DWG 78-14755

OBJECTIVE: TO DETERMINE THE FUNCTIONAL DEPENDENCE OF THE IRRADIATION CREEP OF PATH D MATERIALS ON IRRADIATION PARAMETERS AND MATERIALS VARIABLES.

SCOPE: THIS WORK CANNOT BE SCOPED UNTIL THE MATERIAL OR DESIGN CONCEPT HAS BEEN CHOSEN. WHEN CHOICES ARE MADE TEST MATRICES WILL BE DEVELOPED USING THE BEST AVAILABLE MIX OF IRRADIATION AND EVALUATION METHODS.

TASK NUMBER: I.C.9

TASK TITLE: IRRADIATION CREEP OF SPECIAL AND INNOVATIVE MATERIALS (PATH D)

INPUT TO MAJOR MILESTONES: I-17 TO I-20

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82	78	79	80	81	82	83	84	85	86	87	88	89	90	91-95	96-2000
	INITIATE IRRADIATION CREEP STUDIES WHEN CANDIDATE MATERIALS AND/OR CONCEPTS ARE DEVELOPED. THE SUBTASKS ARE:	M-3	(UNKNOWN)			▲ a												
I.C.9.1	EVALUATE IRRADIATION PARAMETER EFFECTS			{ BUDGET, SCHEDULE, AND MILESTONES CANNOT BE DEVELOPED UNTIL MATERIALS ARE IDENTIFIED. }														
I.C.9.2	EVALUATE MATERIAL PARAMETER EFFECTS																	
I.C.9.3	DEVELOP ADVANCED CANDIDATES																	
I.C.9.4	ESTABLISH PERFORMANCE LIMITS FOR REACTOR APPLICATIONS																	
	MILESTONES																	
I.C.9.a	INITIATE SCOPING STUDIES ON PROMISING PATH D CONCEPTS (I-16)																	

ORNL-DWG 78-14756

OBJECTIVE: TO DEVELOP ADVANCED TEST METHODS NEEDED TO DETERMINE THE IN-REACTOR DEFORMATION BEHAVIOR OF ALL CANDIDATE MATERIALS IN ALL AVAILABLE IRRADIATION FACILITIES.

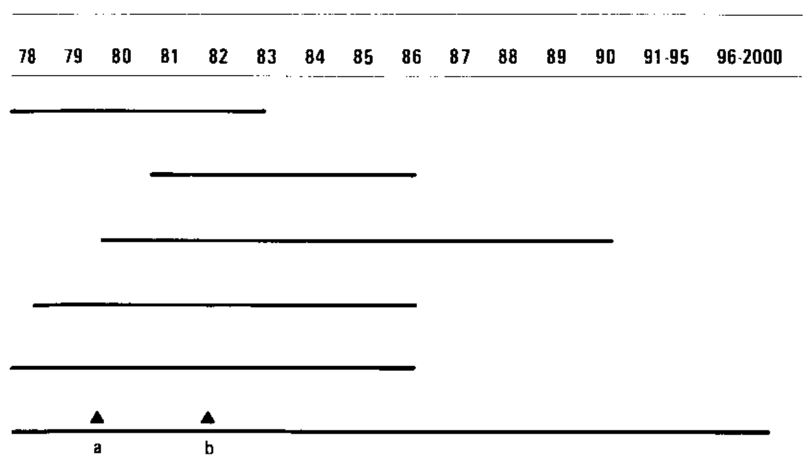
SCOPE: TECHNIQUES WILL BE DEVELOPED TO MAXIMIZE THE USE OF AVAILABLE FACILITIES, ECONOMIZE ON IRRADIATION VOLUME, MAXIMIZE THE RATE OF DATA PRODUCTION, AND MINIMIZE COSTS. PARTICULAR PROBLEMS ARE ASSOCIATED WITH THE PROTECTION OF THE REACTIVE/REFRACTORY METALS IN OXYGEN-CONTAINING ENVIRONMENTS.

TASK NUMBER: I.C.10

TASK TITLE: TEST METHODS DEVELOPMENT FOR IN-REACTOR DEFORMATION

INPUT TO MAJOR MILESTONES: I-1 TO I-20

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82
I.C.10.1	DEVELOP HELIUM DOPING METHODS TO BE USED WITH IRRADIATIONS NOT PRODUCING THE CORRECT He/dpa RATIO	M-2	3
I.C.10.2	DEVELOP TECHNIQUES FOR THE RAPID DETERMINATION OF ALLOY PHASE STABILITY	D-2	1
I.C.10.3	DEVELOP ADVANCED TECHNIQUES FOR GENERATION OF IRRADIATION CREEP INFORMATION	D-2	1
I.C.10.4	DEVELOP THE TECHNIQUES NEEDED TO BUILD REACTOR EXPERIMENTS CONTAINING PREVIOUSLY IRRADIATED SAMPLES	M-2	3
I.C.10.5	DEVELOP TECHNIQUES TO PROTECT REACTIVE/REFRACTORY METALS DURING IRRADIATION	H-3	3
I.C.10.6	DEVELOP METHODS FOR USE IN ADVANCED FACILITIES (a—FFTF, b—D-Li)	H-2	4



ORNL–DWG 78-14757

OBJECTIVE: TO PROVIDE AN INVENTORY OF COMMON MATERIAL TO BE USED IN ALL PHASES OF THE MFE MATERIALS RESEARCH PROGRAMS.

SCOPE: THE MFE MATERIALS INVENTORY WILL BE MAINTAINED TO MEET THE NEEDS OF THE MFE PROGRAMS. MATERIALS WILL BE PURCHASED FROM COMMERCIAL VENDORS, WORKING WITH WELL DOCUMENTED STATE-OF-THE-ART TECHNOLOGY. EXPERIMENTAL ALLOYS WILL BE OBTAINED FROM COMMERCIAL VENDORS, DOE FACILITIES OR OTHER APPROPRIATE SOURCES. THE STOCKPILE WILL MAINTAIN QUALITY ASSURANCE RECORDS.

TASK NUMBER: I.D.1

TASK TITLE: MATERIALS STOCKPILE FOR MFE PROGRAMS

INPUT TO MAJOR MILESTONES: I-1 TO I-20

SUBTASK NO.	ACTIVITY	PRIORITY	MAN YEARS FY 78-82	78	79	80	81	82	83	84	85	86	87	88	89	90	91-95	96-2000
I.D.1.1	PROCURE PATH A & B ALLOYS	H-2	0	a,b,c					b,e								e	
I.D.1.2	PROCURE PATH C ALLOYS	H-3	0	d			c					b					e	
I.D.1.3	PROCURE PATH D MATERIALS	H-3	0			d			c					b				e

PROCUREMENT MILESTONES

I.D.1.a	OBTAIN REFERENCE HEATS OF 316 AND PE-16
I.D.1.b	ORDER PRIME CANDIDATE ALLOYS
I.D.1.c	ORDER BASE RESEARCH MATERIALS
I.D.1.d	ORDER SCOPING MATERIALS
I.D.1.e	ORDER OPTIMIZED ALLOYS

APPENDIX A

ANALYSIS OF IRRADIATION FACILITY REQUIREMENTS

Irradiation programs are invariably paced by their constituent irradiation experiments. The factor limiting progress of the Magnetic Fusion Energy Alloy Development Program is more basic; the program will be built around irradiation facilities. The reason for this is easy to understand. We have no fusion reactor irradiation environment and are unlikely to obtain one within at least the first decade of the program. Incomplete simulation facilities and techniques must be developed and used. These facilities will pace both the progress and the direction of the program.

This is a reasonable response within the framework of the program schedule. At this time the program requirements are defined only in general terms, and the range of materials options is unusually broad for an alloy development program. During the next ten or fifteen years the program will draw on existing and proposed (d-Li) facilities to define performance limits for materials on paths A and B, to determine the validity of mixed spectrum fission reactor irradiations of materials containing nickel, to perform scoping studies of materials on paths C and D, and to establish criteria for an advanced testing facility.

It is not possible to make a definite statement of irradiation facility requirements for the entire program because early work will answer a number of *yes/no* and *either/or* questions that will influence future actions. For example, if early results show that mixed spectrum fission reactors provide a good simulation of fusion reactor irradiation of materials containing nickel and if results indicate that such alloys have high potential for meeting fusion reactor performance goals, the advanced testing facility would probably be a high flux-large volume mixed spectrum reactor. If, however, results show that materials containing nickel cannot meet commercial fusion reactor requirements, the advanced testing facility would probably be a driven fusion device.

In an accelerated program immediate action must be taken on the advanced testing facility (both options discussed above may even be explored).

Any acceleration of the program will call for an immediate reassessment of program facilities.

In the following paragraphs we consider the use of and requirements for irradiation facilities in terms of the present schedule. We define near term as the period between the present and the time for Title I design of EPR (1983—86). Intermediate term is the time from 1986 to 1992—96, the point for Title I design of *DEMO*. Long term, the commercial phase of the program, is the time period beyond about 1992—96.

NEAR TERM

In the near term, mixed spectrum fission reactors, especially ORR, will allow extensive testing of materials containing nickel under He/dpa conditions appropriate to fusion reactor operation. Such an approach, which will explore a broad range of compositional and microstructural variables, will provide a design basis for EPR. Several fission reactors will probably be required to furnish the full design data base. Higher fluence reactor irradiations will give information on the ultimate performance limits of these materials. Fast reactors, EBR-II and FTR, will allow preliminary scoping of Paths C and D materials under conditions of high displacement damage. The low flux-high energy neutron sources that will be available in this period, RTNS II and D-Be, will be used to answer basic questions related to the production of damage by high-energy neutrons.

INTERMEDIATE TERM

Early in the intermediate term the d-Li source should become operational. This will allow evaluation of the mixed spectrum fission reactor simulation of fusion reactor damage in materials containing nickel and of the value of fast-reactor irradiations of reactive and refractory metal alloys. When this information has been assessed, a decision will be required on an advanced testing facility for reaching commercial fusion reactor conditions. A logic diagram for this decision is given in Fig. A-1. The d-Li source will also be used to answer a series of critical questions and for specialized tests that cannot be conducted easily in fission reactors — flux cycling, for example. Because of experimental volume limitations, the d-Li source will probably never be used to generate engineering data; it will be used to answer a series of critical questions that will determine the future direction of the program. It is a key element in the overall program that should be authorized and constructed as early as possible. It is important to realize that through the intermediate term, fission reactors are the only neutron sources available to us for obtaining engineering data. The d-Li source will tell us how to use these data for design purposes. As such, it is absolutely essential to the program.

LONG TERM

In the period 1992–96 the advanced testing facility will become operational. Its volume is expected to be large enough that it will be the principal irradiation source for the program. It will probably become operational too late to influence the materials decisions for *DEMO*, but will be used to verify properties measured elsewhere.

The essence of this discussion is that for the near term the existing sources are probably adequate. A d-Li source must be developed and made available as soon as possible. Eventually, a large volume-high flux source, probably a driven fusion reactor, will be required. If the program is accelerated or if implementation of the program is delayed several years, construction of additional sources will be required to meet the compressed schedule.

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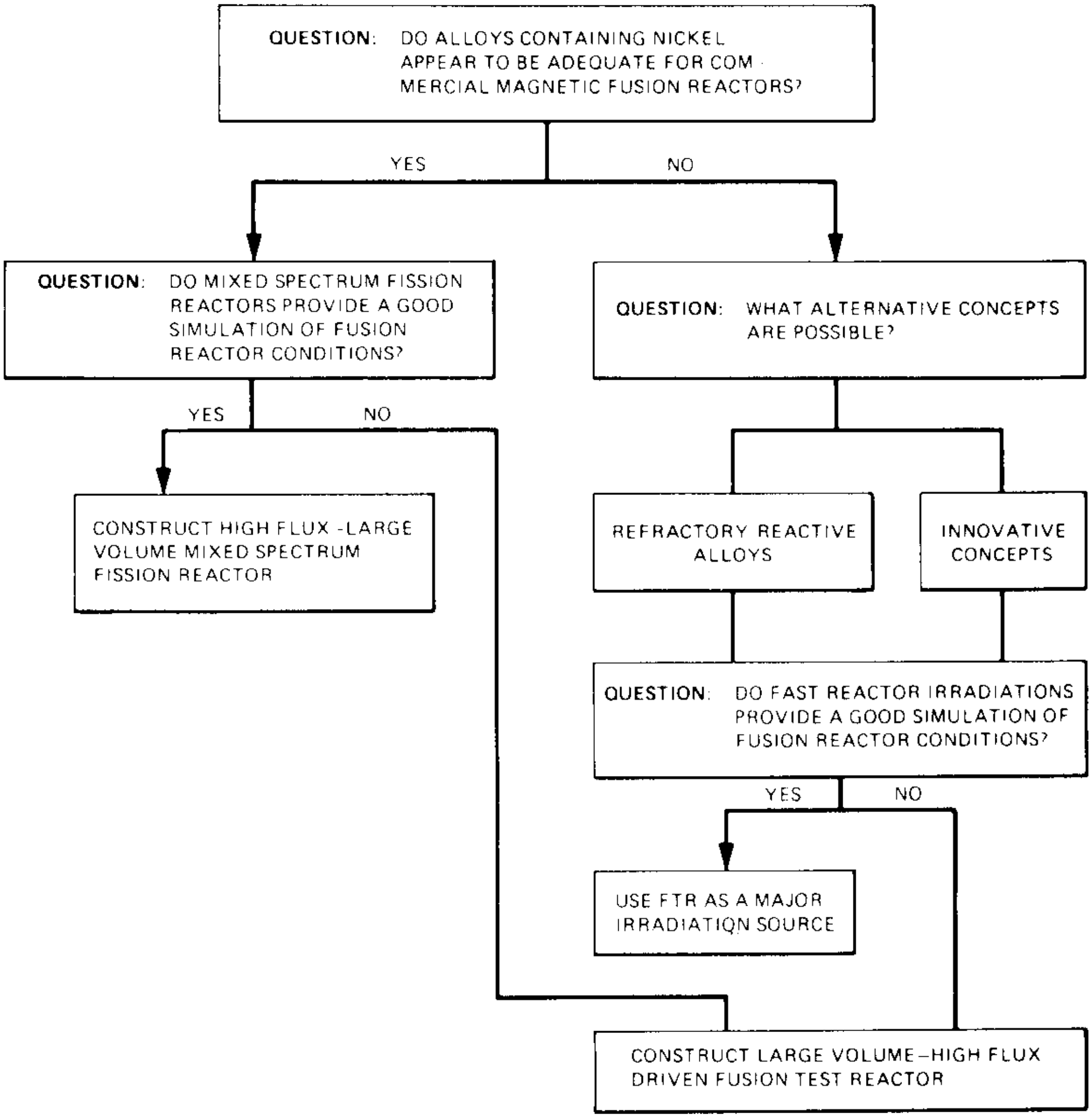

Fig. A-1. Logic Sequence for Identifying Advanced Testing Facility.

APPENDIX B

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