CENTER FOR NUCLEAR WASTE REGULATORY ANALYSIS

MEETING REPORT
February 18-21, 1991

SUBJECTS:

1. Lecture by Larry McKague re. new sedimentary nomenclature and drill holes at Yucca Mountain, NV. February 19th.

2. Technical Exchange meeting on NRC's proposed Staff Technical Position (STP), Investigations to Identify Fault Displacement and Seismic Hazards at a Geologic Repository. February 20th.

3. Discussion of the Probabilistic Seismic Hazards Analysis Work Plan, prepared by CNWRA, with Phil Justus and Buck Ibrahim of the NRC. February 19th and 20th.

DATE AND PLACE: February 19 and 20, 1991 - NRC/White Flint

AUTHOR: Renner B. Hofmann

DISTRIBUTION:

CNWRA	NRC-NMSS
J. Latz	S. Fortuna
CNWRA Directors	P. Justus
CNWRA Managers	D. Brooks
G. Stirewalt	R. Ballard

PERSONS PRESENT:

R. B. Hofmann	P. Justus
G. Stirewalt	M. Blackford
S. Young	A. Ibrahim

Others - see attached list of attendees

BACKGROUND AND PURPOSE:

P. Justus and A. Ibrahim of NRC telephoned on 17 January 1991, requesting that Renner Hofmann of CNWRA attend a DOE/NRC technical exchange meeting at the NRC White Flint offices to proved them with seismic expertise as needed. Dr Larry McKague of Lawrence Livermore laboratories who made a presentation to the NRC on February 19th day regarding Yucca Mountain geologic issues. On February 8, 1991, the Center accepted a Technical Direction 1.1/1-91 for attendance at, and participation in, the technical exchange. In addition, this trip report documents activities accomplished under

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Technical Direction 1.2/1-91 which was a presentation by the Centers consultant. CNWRA had previously forwarded a Work Plan for probabilistic seismic hazard analysis to the NRC. NRC staff desired a discussion which was accomplished on the trip.

SUMMARY OF PERTINENT POINTS:

1. On the 19th, Renner Hofmann and Gerry Stirewalt attended Larry McKague's lecture regarding USGS' stratigraphic nomenclature for Yucca Mountain. Dr. McKague also discussed existing and planned boreholes for the Yucca Mountain repository site and existing and anticipated well logs.

2. On the 20th, Hofmann and Stirewalt attended the DOE/NRC technical exchange meeting. The meeting was attended by many from various concerned organizations including the State of Nevada, the TRB, the ANCW, USGS and EEI. A list of attendees and materials distributed at the technical exchange are attached to this report

   The meeting topic was a presentation by the NRC of its new draft Staff Technical Position (STP) and comments by others concerning its provisions. This STP was derived from a previous STP regarding seismic hazards which also included analysis guidelines. Commentary on the original STP was varied and contentious. Consequently the NRC decided to split the STP, issue only the required investigations portion and add investigations required for fault displacement. NRC desired input from CNWRA concerning PSHA before issuing a second STP concerning analysis of fault displacement and seismic risk.

   The concept of two STPs was not well received. All who commented preferred an STP with both investigation and analysis. In this way they could comment on the appropriateness of the investigations to provide data for the analysis. The State of Nevada argued that the STP being presented was sufficiently different from the one previously reviewed that it should again go out for public comment. A DOE representative stated that DOE would prefer that the four STPs (also including tectonic models and repository engineering) be provided in a single package. NRC management agreed to put the new STP up for public comment and take details of comments by attendees under advisement.

   Other comments were expressions that the new term "susceptible fault", as far as Yucca Mountain was concerned, meant all faults, and therefore served no useful purpose. The 200 mile radius for fault and earthquake investigations was argued by DOE to be too large. DOE stated that the NRC criteria for the 200 mile radius was in error - that 0.1 g was observed at only a 100 km radius from large Western U.S. earthquakes, not 200 miles (although arguments could be made to the contrary). Further, they pointed out that the 200 mile radius took in portions of the San Andreas fault system but that earthquakes on this fault would not affect the repository site in excess of 0.1g. Investigating the San Andreas, however would greatly increase the amount of geological work required to characterize the repository.

DOE pointed out NRC's requirement that a fault must have a date of most recent movement earlier than 2,000,000 years, to eliminate it from characterization studies. They noted that the requirement could not be met at Yucca Mountain because Quaternary sediments extend only to 1.3 million years before present. Consequently the NRC definition would preclude use of undisturbed Quaternary sediments as criteria that a fault need not be considered for further study.

EEI (presented by Jay Smith, their consultant) preferred the guidance be in the form of a regulation, e.g. an "Appendix A" for Part 60 to eliminate legal arguments that would arise with an STP. Others objected to implementing an "Appendix A" type approach and pointed out that NRR had started a project to rewrite 10 CFR 100 Appendix A to eliminate its restrictive terms.

Phil Justus indicated that there was an increased priority for CNWRA's preparation of a technical basis for a probabilistic fault displacement and seismic hazard analysis STP.

3. Discussions were held on both the 19th (briefly) and the 20th concerning the Probabilistic Seismic Hazard Analysis (PSHA) Work Plan. About 3 hours were spent by Renner Hofmann, Gerry Stirewalt, Philip Justus and Buck Ibrahim in discussions of the Work Plan.

IMPRESSIONS/CONCLUSIONS:

Funds available probably are not adequate to provide the in-depth research desired as a technical basis for the combined STP recommended by those attending the meeting. This thought was expressed by CNWRA staff. However, broad topics could be addressed to the extent that funds were available. NRC staff stated that they had a better idea of the work plan's concepts, following our discussions, but expressed a need for more technical details of the proposed work. It appears that those attending the technical exchange meeting believe that the problems they enumerated regarding the STP for investigations, should be reconciled and intimated that supporting technical bases for NRCs guidance should be presented with the STP. This suggests that a substantial amount of work remains before a combined STP can be successfully maneuvered through the comment and approval process.

PROBLEMS ENCOUNTERED:

A more thorough investigation appears to be required than NRC has requested that CNWRA undertake, regarding these issues. The problem is further compounded by the departure of the NRC's DHLWM seismologist, Dr. Blackford and the impending departure of their geologist, Keith McConnell, for a year of management training in the form of rotating assignments to other NRC facilities.

PENDING ACTIONS: None

RECOMMENDATIONS: None

SIGNATURE:

3/13/91

Renner B. Hofmann, Senior Research, Scientist - Geologic Setting — Date

3/13/91

Gerry Stirewalt, Principal Scientist - Washington Technical Support Office — Date

3/13/91

John L. Russell, Manager - Geologic Setting — Date

REFERENCES: See attached handouts from the technical exchange meeting.

Initial signature 3 days to accompany a timely submission of the Trip Report

PENDING ACTIONS: None

RECOMMENDATIONS: None

SIGNATURE:

Renner B. Hofmann, Senior Research, Scientist - Geologic Setting — Date

Gerry Stirewalt, Principal Scientist - Washington Technical Support Office — Date

John L. Russell, Manager - Geologic Setting — Date

REFERENCES: See attached handouts from the technical exchange meeting.

Final signature copy
To be forwarded to D.C. for Stirewalt
signature and returned for placement
in the file

February 20, 1991

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UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

FEB 1 8 1991

AGENDA

NRC-DOE TECHNICAL EXCHANGE ON DRAFT FINAL NRC STAFF TECHNICAL POSITION (STP) ON INVESTIGATIONS TO IDENTIFY FAULT DISPLACEMENT AND SEISMIC HAZARDS AT A GEOLOGIC REPOSITORY

February 20, 1991
8:30 am - 5:00 pm

U.S. Nuclear Regulatory Commission
One White Flint North
11555 Rockville Pike
Rockville, Maryland 20852
Room 6B11

PURPOSE: To discuss NRC's draft final STP on investigations to identify fault displacement and seismic hazards at a geologic repository. In addition, NRC will brief DOE on the staff's strategy for tectonics guidance.

SCOPE: In presenting its draft final STP, NRC will discuss how it has responded to the comments received on the earlier draft technical position. NRC will in particular explain how this STP and other work under development in its tectonics guidance program will address the need for guidance in the areas identified by DOE.

AGENDA TOPIC	DISCUSSION LEADER
° Opening Remarks	NRC, DOE, NV
° NRC Strategy for Tectonics Guidance (30 minutes)	NRC
Discussion	All
° Draft Final STP (90 minutes)	NRC
- Introduction	
- Faulting	
- Seismic Hazards	
Discussion	All
° NRC Staff Resolution of Public Comments (30 minutes)	NRC
Discussion	All
Lunch	
° Comments by DOE, the State of Nevada, and/or EEI/UWASTE	DOE, State, EEI
° Open Discussion	All
° Final Remarks	NRC, DOE, State, EEI

STAFF TECHNICAL POSITION ON INVESTIGATIONS TO IDENTIFY FAULT DISPLACEMENT AND SEISMIC HAZARDS AT A GEOLOGIC REPOSITORY

INTRODUCTION: PHILIP S. JUSTUS
FAULT DISPLACEMENT HAZARD: KEITH I. McCONNELL
SEISMIC HAZARD: ABOU-BAKR K. IBRAHIM
GEOSCIENCES & SYSTEMS PERFORMANCE BRANCH
DIVISION OF HIGH-LEVEL WASTE MANAGEMENT

FEBRUARY 20, 1991

CHRONOLOGY OF DEVELOPMENT OF STP ON FAULTING/SEISMIC HAZARD INVESTIGATIONS

PUBLIC COMMENT DRAFT TP ISSUED	AUGUST 1989
DOE/NRC TECHNICAL EXCHANGE ON DRAFT TP ON METHODS OF EVALUATING THE SEISMIC HAZARD AT A GEOLOGIC REPOSITORY	DECEMBER 1989
DOE/NRC TECHNICAL EXCHANGE ON TECTONICALLY SIGNIFICANT FAULTS	JUNE 1990
DOE/NRC TECHNICAL EXCHANGE ON STP ON INVESTIGATIONS TO IDENTIFY FAULT DISPLACEMENT AND SEISMIC HAZARD AT A GEOLOGIC REPOSITORY	FEBRUARY 20, 1991

PRINCIPAL DIFFERENCES BETWEEN TP AND STP

DRAFT TP	STP
• EMPHASIZED SEISMIC HAZARD	• BOTH FAULTING AND SEISMIC HAZARD
• APPEARS TO REQUIRE 10 CFR PART 100, APPENDIX A	• DRAWS FROM APPENDIX A EXPERIENCE

OBJECTIVES OF STP

- PROVIDE ACCEPTABLE APPROACHES TO INVESTIGATIONS FOR COLLECTION OF SUFFICIENT DATA FOR INPUT TO FAULT DISPLACEMENT AND SEISMIC HAZARD ANALYSES FOR PRECLOSURE AND POSTCLOSURE PERIOD OF PERFORMANCE

STP DOES NOT ADDRESS

- METHODS OF HAZARD ANALYSES
- ANTICIPATED AND UNANTICIPATED PROCESSES AND EVENTS
- EFFECTS ON GROUNDWATER
- RELATION TO VOLCANISM

STRATEGY FOR TECTONICS GUIDANCE ON FAULTING AND SEISMIC HAZARDS, TECTONIC MODELS AND APPLICATION TO DESIGN

PHILIP S. JUSTUS

GEOSCIENCES & SYSTEMS PERFORMANCE BRANCH

DIVISION OF HIGH-LEVEL WASTE MANAGEMENT

FEBRUARY 20, 1991

OBJECTIVES OF DHLWM GUIDANCE

HELP ENSURE DOE'S PROGRAM IS SUFFICIENT TO

- IDENTIFY AND ADDRESS LICENSING ISSUES EARLY
- PROVIDE APPROPRIATE INPUT TO ASSESSMENTS
- PROVIDE BASELINE DATA
- DEVELOP COMPLETE LICENSE APPLICATION

REGULATIONS REQUIRING ASSESSMENT OF TECTONICS

10 CFR PART 60

SITING CRITERIA	(60.122)
DESIGN CRITERIA	(60.130-135)
PERFORMANCE OBJECTIVES	(60.111-113)
40 CFR PART 191 (CONFORMED)	(60.112)
TECHNICAL ASSESSMENTS	(60.21)
PERFORMANCE CONFIRMATION	(60.140-141)

SELECTION OF TECTONICS GUIDANCE TOPICS

- INPUT
  - STAFF EVALUATION OF REGULATIONS
  - STAFF EVALUATION OF DOE'S PROGRAM
  - DOE'S REQUEST FOR GUIDANCE
- OUTPUT
  - FAULTING HAZARD
  - SEISMIC HAZARD
  - TECTONIC MODELS
  - APPLICATION TO DESIGN

TOPICS FOR WHICH TECTONICS GUIDANCE IS BEING DEVELOPED

1. INVESTIGATION OF FAULT DISPLACEMENT AND SEISMIC HAZARDS [TOPIC FOR TODAY'S TECHNICAL EXCHANGE]

2. ANALYSIS OF FAULT DISPLACEMENT AND SEISMIC HAZARDS

3. USE OF TECTONIC MODELS

TOPIC UNDER CONSIDERATION

4. APPLICATION OF FAULT DISPLACEMENT AND SEISMIC HAZARD TO REPOSITORY DESIGN

1. STP - INVESTIGATIONS OF FAULT DISPLACEMENT AND SEISMIC HAZARDS [TOPIC FOR TODAY'S TECHNICAL EXCHANGE]

SCOPE OF STP

- Methodology to Identify Fault Displacement and Seismic Sources
- Methodology to Identify Faults Susceptible to Displacement
- Response to DOE Request for Guidance

PRINCIPAL PART 60 REQUIREMENTS

- 60.21(c)(1)(ii) Analysis of Geology and Geophysics
- 60.122(A)(2) Adequate Investigation
- 60.131(b)(1) Protect SSCIS Against Natural Phenomena

STATUS

- Final STP FY91 (4th Qtr)

2. STP - ANALYSES OF FAULT DISPLACEMENT AND SEISMIC HAZARDS

SCOPE OF STP

- Acceptable Analysis Methodology
- Response to DOE's Request for Guidance
- Deterministic Supplemented by Probabilistic
- Consider Issue of Setback

PRINCIPAL PART 60 REQUIREMENTS

-60.112 Meet EPA Standard

-60.113 Meet Subsystem Performance Objectives

-60.122(a)(2) Analyses Not to Underestimate Effects

-60.131(b)(1) Maintain Safety Functions

STATUS

- Draft for Public Comment FY92

3. STP - USE OF TECTONIC MODELS

SCOPE OF STP

- Acceptable Approaches for Supporting & Implementing Predictive Models
- Response to DOE's Request for Guidance

PRINCIPAL PART 60 REQUIREMENTS

-60.21(c)(1)(ii)(F) Explain Support for Models

STATUS

- Final FY92

GUIDANCE ON APPLICATION OF FAULT DISPLACEMENT AND SEISMIC HAZARDS TO DESIGN

SCOPE UNDER CONSIDERATION

- Acceptable Methods of Compliance With Design Criterion - 60.131(b)(1)
- Acceptable Methods of Compliance With Certain Portions of 60.113(A), (B)

PRINCIPAL PART 60 REQUIREMENTS

-60.21(c)(3)	Analysis of Design
-60.111	Preclosure Protection From Releases
-60.131(a)	General Design Criteria for GROA
-60.131(b)(1)	Maintain Essential Safety Functions
-60.113(A),(B)	Maintain Essential Safety Functions

STATUS

- Under Consideration

FAULT DISPLACEMENT HAZARD INVESTIGATIONS

KEITH I. McCONNELL
GEOSCIENCES & SYSTEMS PERFORMANCE BRANCH
DIVISION OF HIGH-LEVEL WASTE MANAGEMENT

FEBRUARY 20, 1991

FAULT DISPLACEMENT HAZARD INVESTIGATIONS
(OUTLINE OF PRESENTATION)

1. NEED FOR THE POSITION
2. DEFINITION OF "SUSCEPTIBLE" FAULT
3. WHAT THE CONCEPT PROVIDES
4. WHAT THE CONCEPT DOES NOT NECESSITATE

108.14/MB/89/06/12

TECHNICAL POSITION ON

METHODS OF EVALUATING THE SEISMIC HAZARD

AT A GEOLOGIC REPOSITORY

Public Comment Draft - June 1989

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CONTENTS

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TECHNICAL POSITION ON

METHODS OF EVALUATING THE SEISMIC HAZARD PRESENT

AT A GEOLOGIC REPOSITORY

Public Comment Draft - June 1989

1. INTRODUCTION

The purpose of this Technical Position (TP) is to provide regulatory guidance to the U.S. Department of Energy (DOE) on appropriate methodologies that address seismic hazard at a geologic repository. This paper considers the seismic hazard for the construction and operation period through permanent closure ("preclosure"), and the period following permanent closure ("postclosure"). This position also considers differences that may exist, during the preclosure, among the surface facilities and the underground facility. The applicability of existing methodologies for establishing the seismic basis for the determination of the maximum vibratory ground motion at a geologic repository is discussed. This position does not address probabilistic seismic hazard analysis nor does it address the interpretation of anticipated and unanticipated processes and events, which are being addressed in other technical positions and potential rulemakings. The term seismic hazard, as used in this TP, is meant to encompass the hazard due to either vibratory ground motion or coseismic faulting, or both, that can affect the design and performance of the geologic repository.

TPs are issued to describe and make available to the public criteria for methods acceptable to the U.S. Nuclear Regulatory Commission (NRC) staff for implementing specific parts of the Commission's regulations, or to provide guidance to DOE. TPs are not substitutes for regulations and compliance with them is not required. They suggest one approach which is acceptable to the NRC staff for meeting regulatory requirements. Methods and solutions different from those set out in the position will be acceptable if they provide a basis for the findings requisite to the issuance or continuance of a permit or license by the Commission. A glossary of selected technical terms used in this paper may be found in Appendix A of this paper.

2. REGULATORY BACKGROUND

2.1 Regulations concerning Seismic Hazard

The regulatory background section of this TP outlines the significant elements of Title 10, Chapter I of the Code of Federal Regulations (10 CFR) that contain provisions for protection [illegible] seismic hazard. The elements of 10 CFR that will be discussed are: 10 CFR Part 50, Appendix A, "General Design Criteria for Nuclear Power Plants" (see Ref. 1); 10 CFR Part 100, Appendix A, "Seismic and Geologic Siting Cr[illegible] clear Power Plants" (see Ref. 2); 10 CFR Part

72, "Licensing Requirements for the Storage of Spent Fuel in an Independent Spent Fuel Storage Installation (ISFSI)" (see Ref. 3); 10 CFR Part 40, Appendix A, "Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material from Ores Processed Primarily for Their Source Material Content" (see Ref. 4); and 10 CFR Part 60, "Disposal of High-Level Radioactive Waste in Geologic Repositories" (see Ref. 5). With the exception of 10 CFR 100, Appendix A, the relevant text from the aforementioned parts of 10 CFR can be found in Appendix B of this paper. An outline of 10 CFR Part 100, Appendix A is found in Appendix C of this paper.

2.2 10 CFR Part 50, Appendix A

Early in the development of the use of nuclear material, it was generally recognized that special provisions would be needed in order to provide reasonable assurance that these materials could be used without undue hazard to the public health and safety. With regard to seismic hazard, these provisions were first embodied in Criterion 2 of 10 CFR Part 50, Appendix A, "Design bases for protection against natural phenomena." Criterion 2 generally requires that structures, systems, and components important to safety be designed so that their safety functions are preserved under the impact of the most severe adverse natural phenomena.

2.3 10 CFR Part 100, Appendix A

Appendix A of 10 CFR Part 100, hereafter referred to as Part 100, Appendix A, is the most comprehensive of the NRC regulations dealing with seismic and geologic criteria. Part 100, Appendix A, which was initially included in the Commission regulations in 1973, provides more specific regulatory guidance for the siting of nuclear power plants than 10 CFR Part 50, Appendix A. Although the guidance is primarily directed toward an assessment of hazards due to vibratory ground motion and surface faulting, it also includes guidance on floods, water waves, and other related natural hazards. Part 100, Appendix A describes three aspects of seismic and geologic hazard evaluation: 1) the required investigations; 2) the development of seismic and geologic design bases; and 3) the application of these bases to engineering design.

2.4 10 CFR Part 72 and 10 CFR Part 40, Appendix A

Following its issuance, Part 100, Appendix A came to be relied on during the promulgation of regulations addressing seismic hazard for nuclear facilities other than nuclear power plants. This reliance on Part 100, Appendix A sets an important precedent that needs to be considered when new types of nuclear facilities that require seismic hazard review are considered for licensing. 10 CFR Part 72 and 10 CFR Part 40, Appendix A are examples of such regulations that refer to Part 100, Appendix A.

The evaluation of geological and seismological characteristics of acceptable sites for independent spent fuel storage installations (ISFSIs), described in Section 72.66 of 10 CFR Part 72, defers to the techniques of 10 CFR Part 100, Appendix A, for sites west of the Rocky Mountain Front and other areas of potential seismic activity. Criterion 4(e) of the technical criteria of 10 CFR Part 40, Appendix A discusses the siting of impoundment structures for uranium mill tailings, with respect to capable faults as defined in 10 CFR Part 100, Appendix A.

2.5 10 CFR Part 60

In contrast to the aforementioned examples given for other nuclear facilities, 10 CFR Part 60 does not specifically rely on Part 100, Appendix A for guidance regarding provisions for dealing with the seismic hazard nor does it specifically require the development of a design basis earthquake. Instead, the performance objectives and siting and design criteria described in 10 CFR Part 60 establish the bases for considering seismic hazard for both the preclosure and the postclosure periods. According to Section 60.111, during the preclosure period, the geologic repository operations area is to be designed to provide protection against radiation exposures and releases of radioactive material in accordance with standards set forth in 10 CFR Part 20 (see Ref. 6) and standards established by the U.S. Environmental Protection Agency (EPA) in 40 CFR Part 191 (see Ref. 7). Also, during the preclosure period, the geologic repository operations area is to be designed so that the option to retrieve the emplaced radioactive waste is preserved. The criterion set forth in Subsection 60.131(b)(1), which requires that facilities important to safety in the geologic repository operations area be designed so that natural phenomena do not interfere with their safety functions, forms the basis for evaluating the preclosure seismic hazard.

The overall performance objective presented in Section 60.112 requires that the geologic setting, the engineered barrier system, shafts and any boreholes and their seals be designed to limit the release of radioactive materials to the accessible environment in accordance with standards established by EPA. Section 60.113 provides specific performance requirements for both the engineered barrier system and the geologic setting. The seismic hazard associated with the engineered barrier system, as well as the overall system, is to be evaluated in accordance with the appropriate siting criteria of Subsection 60.122(c).

The evaluations performed, using the aforementioned postclosure and preclosure criteria, are necessary in order to satisfy the required input to the Safety Analysis Report (SAR) described in Subsections 60.21(1)(ii)(B) and (C) and Subsection 60.21(c)(3), respectively. It is expected that much of the information gathered to support the seismic hazard evaluation required by Subsection 60.131(b)(1) for the preclosure period can also be used to support the postclosure seismic hazard evaluation.

3. TECHNICAL POSITION

It is the NRC staff's position that the methodologies prescribed in Appendix A of 10 CFR Part 100 for investigating seismic and related faulting phenomena, for determining the need to design for surface faulting, and for establishing the seismic basis for the determination of the maximum vibratory ground motion at a site are considered to be appropriate for addressing preclosure and postclosure seismic and faulting hazards at a geologic repository operations area. Further, it is the position of the staff that the results of Part 100, Appendix A investigations can generally provide input for probabilistic and other methods of assessing seismic and faulting hazards for the postclosure period. The NRC staff will rely on the principles espoused in Part 100, Appendix A, in its review of the appropriate sections related to seismic investigations in the SAR, which forms a major portion of the license application for a repository. In particular, the NRC staff will review those sections of the SAR addressing Subsections 60.21(c)(1)(ii)(B) and (C) and Subsection 60.21(c)(3) of 10 CFR Part 60, in the light of Appendix A of 10 CFR Part 100. In addition, the methodology outlined in this Technical Position can be used in developing seismic and geologic bases for earthquake design criteria pertinent to Subsection 60.131(b)(1) of 10 CFR Part 60 and in assisting in demonstrating compliance with Sections 60.111, 60.112, and 60.113.

4. DISCUSSION

4.1 Seismic Hazard before and after Permanent Closure

Two very different timeframes are addressed with regard to the performance of a geologic repository. The first is the initial period of about one-hundred years, during which time nuclear material will be received and emplaced in the repository and the option to retrieve the nuclear material must be preserved. This "operational period" is comparable to the operational periods of other nuclear facilities. The second period of time is that following the permanent closure of the repository, during which time engineered and natural barriers must isolate the nuclear material from the accessible environment, in accordance with standards established by EPA. The surface facilities necessary during the operational period will not remain in the postclosure period. Since the repository location remains unchanged, the data that can be acquired to allow an estimation of the expected seismic hazard will be similar for both periods.

4.2 Other Nuclear Waste Facilities

For the preclosure period, [illegible]s reasonable to consider the way seismic hazard is treated at other nuclear waste facilities. One type of facility is the ISFSI, which is regulated under 10 CFR Part 72. Subsection 72.66(a)(2), which addresses massive w[illegible]nd air-cooled canyon types of ISFSI structures.

states, "West of the Rocky Mountain Front (west of approximately 104° west longitude), and in other areas of known potential seismic activity, seismicity will be evaluated by the techniques of Appendix A of Part 100 of this chapter [10]." Subsection 72.66(a)(6)(i) goes on to to state, "For sites that have been evaluated under the criteria of Appendix A of 10 CFR Part 100, the ISFSI-DE [ISFSI design earthquake] shall be equivalent to the safe shutdown earthquake (SSE) for a nuclear power plant." It is important to consider the guidance given for the ISFSI, because NRC has used this guidance to evaluate the DOE proposal for the Monitored Retrievable Storage (MRS) facility. The MRS facility is similar to the surface facilities of a geological repository operations area. Clearly, this presents a strong argument for following a similar path for evaluating the seismic hazard at a geologic repository, at least for the preclosure surface facilities.

Impoundment structures built to contain the tailings and wastes from a uranium mill constitute a second type of facility for which regulatory language exists regarding seismic hazard evaluation. In Section I, "Technical Criteria," of 10 CFR Part 40, Appendix A, Criterion 4(e) states, "The impoundment may not be located near a capable fault that could cause a maximum credible earthquake larger than that which the impoundment could reasonably be expected to withstand. As used in this criterion, the term 'capable fault' has the same meaning as defined in Section III(g) of Appendix A of 10 CFR Part 100. The term 'maximum credible earthquake' means that earthquake which would cause the maximum vibratory ground motion based upon an evaluation of earthquake potential considering the regional and local geology and seismology and specific characteristics of local subsurface material." Although this type of facility is not necessarily similar to a geologic repository, it does demonstrate that the NRC staff considers Appendix A of 10 CFR Part 100 to be applicable to nuclear facilities other than power plants.

4.3 Consideration of Part 100, Appendix A

A primary reason for taking the position that Part 100, Appendix A is an appropriate methodology for investigating the seismic hazard at a geologic repository is that much of the technology presented in Part 100, Appendix A is generic in nature. This is particularly true for the required investigations described in Section IV of Part 100, Appendix A. The following is a summary of these required investigations.

4.3.1 Part 100, Appendix A, Required Investigations

The types of investigations required by Part 100, Appendix A for both vibratory ground motion and surface faulting investigations are:

- determination of the lithologic, stratigraphic, hydrologic, and structural geologic conditions of the site and the region surrounding the site, including its geologic history;

2) identification and evaluation of tectonic structures underlying the site and the region surrounding the site, whether buried or expressed at the surface, including, in particular, consideration of the possible effects caused by man's activities, such as withdrawal of fluid from or addition of fluid to the subsurface, extraction of minerals, or the loading effects of dams or reservoirs;

3) listing of all historically reported earthquakes, including appropriate parametric data that describe time, location and earthquake size; in particular, for investigations for vibratory ground motion, the compilation of any additional information on the nature of strong ground motion, and effects of local-site materials on seismic wave transmission;

4) determination of capable faults;

5) for a capable fault, a listing of the length of the fault, its relationship to regional tectonic structures, and the nature, amount, and geologic history of displacements along the fault, including, particularly, the estimated amount of the maximum Quaternary displacement related to any one earthquake along the fault; and

6) correlation of earthquakes, where possible, with capable faults or tectonic structures or, at least in the case of vibratory ground motion

investigations, with tectonic provinces, when specific structures cannot be identified.

The types of investigations required by Part 100, Appendix A specifically for vibratory ground motion investigation are:

1) evaluation of physical evidence on the behavior, during prior earthquakes, of the surficial geologic materials and the substrata underlying the site, considering the information acquired from the lithologic, stratigraphic, and structural geologic studies; and

2) determination of the static and dynamic engineering properties of the materials underlying the site, including properties needed to determine the behavior of the underlying material during earthquakes and the characteristics of the underlying material in transmitting earthquake-induced motion.

A specific investigation required by Part 100, Appendix A for surface faulting is the determination of geologic evidence of fault offset at or near the ground surface, at or near the site.

For some of the investigations summarized above, Section IV of Part 100, Appendix A establishes specific limits on the extent of the investigations. For vibratory ground motion, investigations are generally limited to ranges that are within 200 miles of the site. For surface faulting, investigations are also generally limited to faults greater than 1000 feet in length that are within five miles of the site. Additional guidance is provided in Section IV, through footnotes, that makes it unnecessary to investigate features more remote from a site if it can be shown that features closer to the site will control the design basis.

4.3.2 Part 100, Appendix A, Seismic and Geologic Bases Development

Using information gathered from the vibratory ground motion investigations, Section V of Part 100, Appendix A describes specific procedures for establishing the seismic and geologic bases for developing design criteria related to earthquake protection. Section V(a) of Part 100, Appendix A states, "The design basis for the maximum vibratory ground motion and the expected vibratory ground motion should be determined through evaluation of the seismology, geology, and the seismic and geologic history of the site and surrounding region." Section V(a)(1) then prescribes a set of specific steps to take in evaluating the data gathered through the required investigations, to arrive at the earthquake that produces the maximum vibratory acceleration at the site above a threshold of 0.1g. This earthquake is termed the Safe Shutdown Earthquake (SSE). These basic procedures form the framework for establishing the seismic basis for determination of the maximum vibratory motion at any site at relevant times and are therefore considered to be appropriate to a geologic repository.

Section V(a)(2) addresses the determination of an Operating Basis Earthquake (OBE). In contrast to a nuclear power plant, a geologic repository is not likely to have components possessing high energy driving forces capable of broadly dispersing the contained radioactivity. Even with a gross failure of those components of a repository involved in containment, a loss of containment integrity would not be as likely to have as significant a consequence for public health and safety as a nuclear power plant, because the systems would be passive. Consideration should also be given to the safety of onsite personnel in recovering from such a gross failure. Since an OBE is intended to provide the basis for regulating those features of a nuclear power plant necessary for continued operation without undue risk to the health and safety of the public, and since those features are not likely to be incorporated into a geologic repository, the OBE will not be given further consideration in this discussion.

Section V(b) of Part 100, Appendix A discusses the need to design for surface faulting. This section prescribes specific guidelines to follow in order to make this determination. For a geologic repository, it is necessary to consider these specific guidelines in light of the consequences of faulting. First, any guidelines for surface faulting should be considered applicable to the underground facility of a geologic repository as well, since it is very unlikely that a fau t tha- - -tures the surface above the underground facility would not also crea.e a ru...-e within the underground facility. Second, any faults discovered within the perimeter of the underground facility, through drifting or other m - - site characterization, that cannot be associated with surface faults, require special investigation similar to surface faults. Finally, faulting in a geologic repository can affect the integrity of the facilities important to safety at the surface, the integrity of the waste canisters in the underground facility, and the retrievability of the radioactive waste. Thus, the values used in the specific guidelines of Section V(b) need to be examined, but the basic principle, that is, the determination of a need to design for faulting, remains unchanged.

5. REFERENCES

1. U.S. Code of Federal Regulations, "General Design Criteria for Nuclear Power Plants," Chapter 10, Part 50, Appendix A, January 1988.

2. U.S. Code of Federal Regulations, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," Chapter 10, Part 100, Appendix A, January 1988.

3. U.S. Code of Federal Regulations, "Licensing Requirements for the Storage of Spent Fuel in an Independent Spent Fuel Storage Installation (ISFSI)," Chapter 10, Part 72, Jaunuary 1988.

4. U.S. Code of Federal Regulations, "Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material from Ores Processed

Primarily for Their Source Material Content," Chapter 10, Part 40, Appendix A, January 1988.

5. U.S. Code of Federal Regulations, "Disposal of High-Level Radioactive Wastes in Geologic Repositories," Chapter 10, Part 60, January 1988.

6. U.S. Code of Federal Regulations, "Standards for Protection against Radiation," Chapter 10, Part 20, January 1988.

7. U.S. Code of Federal Regulations, "Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," Chapter 40, Part 191, January 1988.

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U.S. Nuclear Regulatory Commission, "Staff Analysis of Public Comments on

Proposed Rule 10 CFR Part 60, 'Disposal of High-Level Radioactive Wastes in Geologic Repositories,'" USNRC Report NUREG-0804, December 1983.

U.S. Nuclear Regulatory Commission, "Staff Evaluation of U.S. Department of Energy Proposal for Monitored Retrievable Storage," USNRC Report NUREG-1168, March 1986.

U.S. Nuclear Regulatory Commission, "Summary Report of the Symposium on Seismic and Geologic Siting Criteria for Nuclear Power Plants," USNRC Report NUREG/CP-21039, June 1987.

APPENDIX A

GLOSSARY

As used in this guidance:

"Accessible environment" means: (1) the atmosphere, (2) land surface, (3) surface water, (4) oceans, and (5) the lithosphere that is outside the controlled area. (10 CFR 60)

"Anticipated operational occurrences" mean those conditions of normal operation which are expected to occur one or more times during the life of the geologic repository operations area and to include the loss of functionality of structures, systems, or components within the regulatory safety limits. (Based on 10 CFR 50, Appendix A; "geologic repository operations area" has been substituted for "nuclear power unit" and "the loss of functionality ... safety limits" has been substituted for "but are not limited to loss of power to all recirculation pumps, tripping of turbine generator set, isolation of main condenser, and loss of all offsite power.")

"Anticipated processes and events" means those natural processes and events that are reasonably likely to occur during the period the intended performance objective must be achieved. To the extent reasonable in the light of the geologic record, it shall be assumed that those processes operating in the geologic setting during the Quaternary Period continue to operate but with perturbations caused by the presence of emplaced radioactive waste superimposed thereon. (10 CFR 60)

"Barrier" means any material or structure that prevents or substantially delays movement of water or radionuclides. (10 CFR 60)

A "capable fault" is a fault which has exhibited one or more of the following characteristics:

(1) Movement at or near the ground surface at least once within the past 35,000 years or movement of a recurring nature within the past 500,000 years.

(2) Macro-seismicity instrumentally determined with records of sufficient precision to demonstrate a direct relationship with the fault.

(3) A structural relationship to a capable fault according to characteristics (1) or (2) of this paragraph, such that movement on one could be reasonably expected to be accompanied by movement on the other.

In some cases, the geologic evidence of past activity at or near the ground surface along a particular fault may be obscured at a particular site. This might occur, for example, at a site having deep overburden. For these cases, evidence may exist elsewhere along the fault from which an evaluation of its characteristics in the vicinity of the site can be reasonably established. Such evidence shall be used in determining whether the fault is a capable fault within this definit

THE CONCEPT OF 'SUSCEPTIBLE' FAULT IS INTRODUCED TO:

1. TAKE ADVANTAGE OF PAST REGULATORY EXPERIENCE IN USING EXPLICIT CRITERIA FOR IDENTIFYING FAULT HAZARDS;
2. OUTLINE THE BASELINE INFORMATION RELATIVE TO FAULT INVESTIGATIONS UNDER CRITERIA LISTED IN 10CFR60.122(a)(2) AND 60.131(B)(1);
3. IDENTIFY THE <u>ENTIRE</u> QUATERNARY RECORD AS THE PERIOD OF GEOLOGIC TIME THAT SHOULD BE CONSIDERED;
4. INDICATE THAT FAULTS WITH AN UNCERTAIN QUATERNARY RECORD SHOULD BE INVESTIGATED;
5. FORM A UNIFORM BASIS FOR DESIGN CONSIDERATIONS.
6. ELIMINATE CONFUSION RESULTING FROM THE INTRODUCTION OF MULTIPLE TERMS FOR FAULTS OF SIGNIFICANCE (VIEWGRAPH 3A);
7. ADDRESS AMBIGUOUS AND POTENTIALLY INADEQUATE FAULT-RELATED CHARACTERIZATION PARAMETERS IN THE SCP (VIEWGRAPHS 3B AND 3C) .

TERMS USED TO DEFINE FAULTS OF SIGNIFICANCE TO A REPOSITORY

1. POTENTIALLY ACTIVE FAULT (DRAFT STUDY PLAN 8.3.1.17.4.6);
2. POTENTIALLY ACTIVE GEOLOGICAL STRUCTURES (DRAFT STUDY PLAN 8.3.1.17.4.6);
3. SIGNIFICANT LATE QUATERNARY FAULTS (SCP; STUDY PLAN 8.3.1.17.4.2) (Slip-rate >0.001mm/yr over last 100ka);
4. LATE QUATERNARY FAULTS (STUDY PLAN 8.3.1.17.4.2) (?);
5. POTENTIALLY SIGNIFICANT QUATERNARY FAULTS (CHARACTERIZATION PARAMETER - SCP) (Slip-rate >0.001mm/yr; or offset of materials <u>less</u> than 100ka);
6. SIGNIFICANT QUATERNARY FAULTS (DESIGN PARAMETER - SCP) (> 1m offset of Quaternary material; or > 100m offset of Tertiary rocks).

AMIBIGUITIES IN THE APPLICATION OF "CHARACTERIZATION PARAMETERS"

- "A PHYSICAL PROPERTY OR CONDITION (EITHER MEASURABLE OR CALCULABLE) WHOSE VALUE IS TO BE DETERMINED IN THE SITE PROGRAM IN ORDER TO OBTAIN, COMPUTE, OR EVALUATE A PERFORMANCE PARAMETER FOR A DESIGN OR PERFORMANCE ISSUE" (SCP, 1988).
- "...A PRELIMINARY ESTIMATE OF FAULT SIGNIFICANCE." (SCA RESPONSE DOCUMENT)
- "...THE MINIMUM AMOUNT OF OFFSET FOR GIVEN AGE MATERIALS THAT THE FIELD INVESTIGATIONS SHOULD BE GEARED TO DETECT." (SCA RESPONSE DOCUMENT)

EXAMPLES OF POTENTIALLY INADEQUATE CHARACTERIZATION PARAMETERS

PRECLOSURE:

- Quaternary slip-rates of › 0.001 mm/yr or that measurably offset materials less than 100,000 yrs;
- Surface locations of faults in repository with › 1 m offset of Quaternary materials;

POSTCLOSURE:

- faults that penetrate the repository with total offset of › 10 m.

'SUSCEPTIBLE' FAULT:

1. HAS HAD MOVEMENT WITHIN THE PAST TWO MILLION YEARS; OR
2. HAS SEISMICITY, INSTRUMENTALLY DETERMINED WITH RECORDS OF SUFFICIENT PRECISION, THAT SUGGESTS A DIRECT RELATIONSHIP WITH THE FAULT; OR
3. IS ORIENTED SUCH THAT IT IS SUBJECT TO FAILURE IN THE EXISTING STRESS FIELD; OR
4. HAS A STRUCTURAL RELATIONSHIP (i.e., MOVEMENT ON ONE FAULT COULD CAUSE MOVEMENT ON ANOTHER) TO A FAULT THAT MEETS ONE OR MORE OF THE ABOVE CRITERIA.

WHAT THE CONCEPT OF 'SUSCEPTIBLE' FAULT PROVIDES:

1. PARALLELISM WITH FAULT HAZARD CONCEPTS USED IN SITING AND LICENSING OTHER NUCLEAR FACILITIES;
2. SPECIFIC CRITERIA FOR DETERMINING WHICH FAULTS ARE OF POTENTIAL IMPORTANCE
   Specific criteria for determining which "susceptible" faults need characterization;
3. A SINGLE SET OF IDENTIFICATION CRITERIA FOR PRE- AND POSTCLOSURE FAULT HAZARD ASSESSMENT;
4. CONFIRMS THE ENTIRE QUATERNARY PERIOD AS THAT PART OF GEOLOGIC TIME THAT MUST BE EXAMINED;
5. FLEXIBILITY TO DOE TO DEMONSTRATE THAT CERTAIN CLASSES OF 'SUSCEPTIBLE' FAULTS DO NOT NEED CHARACTERIZATION;
   (e.g., limiting characterization of faults outside of the controlled area);
6. BASIS FOR FUTURE CONSIDERATION OF "SETBACKS";
7. A CLEAR AND UNIFORM BASIS FOR PERFORMANCE ALLOCATION.

WHAT THE CONCEPT OF 'SUSCEPTIBLE' FAULT DOES NOT NECESSITATE:

1. CONSIDERATION OF "CAPABLE" FAULTS FROM 10CFR100, APPENDIX A;
2. DETAILED CHARACTERIZATION OF ESSENTIALLY ALL FAULTS WITHIN THE SITE AREA. [STP DOES NECESSITATE THAT ALL FAULTS IN THE CONTROLLED AREA THAT ARE SUSCEPTIBLE TO MOVEMENT BE CONSIDERED AND ADDRESSED];
3. SUSCEPTIBLE FAULT, AS USED IN THIS STP, IS NOT A SITE SUITABILITY TOOL.

4

VIBRATORY GROUND MOTION INVESTIGATIONS

UNITED STATES NUCLEAR REGULATORY COMMISSION

ABOU-BAKR K. IBRAHIM

GEOSCIENCES & SYSTEMS PERFORMANCE BRANCH

DIVISION OF HIGH-LEVEL WASTE MANAGEMENT

FEBRUARY 20, 1991

VIBRATORY GROUND MOTION INVESTIGATIONS

1. LIST ALL HISTORICALLY REPORTED SEISMIC EVENTS

   - DATES, AND EPICENTER COORDINATES
   - DEPTH, DISTANCE, AND ORIGIN TIME
   - MAGNITUDES OR HIGHEST INTENSITY
   - FOR EVENTS WITH ACCELERATION > .1G AT THE SITE, PROVIDE DURATION AND FREQUENCY CONTENT
   - SOURCE PARAMETERS (e.g., FOCAL MECHANISM, SEISMIC MOMENT, AND STRESS DROP)
   - PLOT THOSE EVENTS WITHIN 200 MILES
   - IDENTIFY WHETHER THE EVENT IS AN EARTHQUAKE, UNE, OR CAVITY COLLAPSE

VIBRATORY GROUND MOTION INVESTIGATIONS

2. CORRELATE EARTHQUAKE EPICENTERS WITH GEOLOGICAL STRUCTURES

   - IDENTIFY METHODS AND ACCURACY USED TO LOCATE EARTHQUAKES
   - PROVIDE RATIONALE FOR THOSE WHICH CANNOT BE ASSOCIATED

3. IDENTIFY GEOLOGIC STRUCTURES SIGNIFICANT FOR EARTHQUAKE POTENTIAL

   - BURIED OR EXPRESSED AT THE SURFACE
   - INDUCED BY LOADING

VIBRATORY GROUND MOTION INVESTIGATIONS

4. IDENTIFY FAULTS IMPORTANT FOR SEISMIC DESIGN BASIS

- FAULT LENGTH
- RUPTURE LENGTH
- RUPTURE AREA
- TYPE OF FAULT
- SLIP RATE

5. DETERMINE ENGINEERING PROPERTIES OF MATERIALS UNDERLYING THE SITE

- RESPONSE TO EARTHQUAKES
- SEISMIC WAVE VELOCITIES
- WATER TABLE ELEVATION
- DENSITY
- RIGIDITY
- POROSITY

VIBRATORY GROUND MOTION INVESTIGATIONS

6. DETERMINE REGIONAL ATTENUATION OF VIBRATORY GROUND MOTION

7. INVESTIGATE RELATION BETWEEN SURFACE AND SUBSURFACE GROUND MOTIONS

   - VARIATION IN HORIZONTAL AND VERTICAL ACCELERATION
   - VARIATION IN FREQUENCY CONTENT

RESPONSE TO COMMENTS ON DRAFT TECHNICAL POSITION

UNITED STATES NUCLEAR REGULATORY COMMISSION

ABOU-BAKR K. IBRAHIM

GEOSCIENCES & SYSTEMS PERFORMANCE BRANCH

DIVISION OF HIGH-LEVEL WASTE MANAGEMENT

FEBRUARY 20, 1991

COMMENTERS

- U.S. DEPARTMENT OF ENERGY
- EDISON ELECTRIC INSTITUTE/UTILITY NUCLEAR WASTE & TRANSPORTATION PROGRAM
- STATE OF NEVADA

CATEGORIES OF COMMENTS RECEIVED

1. THOSE CONCERNING THE USE OF 10 CFR PART 100, APPENDIX A

2. THOSE DEALING WITH INVESTIGATIONS, ANALYSES, AND DESIGN

NRC RESPONSE TO APPENDIX A COMMENTS

- STAFF DOES NOT ADVOCATE THE APPLICATION OR IMPLEMENTATION OF 10 CFR PART 100, APPENDIX A FOR REPOSITORY

- CURRENT STP NO LONGER DEFERS TO 10 CFR PART 100, APPENDIX A

- ANALYSES AND DESIGN CONSIDERATIONS REMOVED FROM CURRENT STP AND DEFERRED TO SUBSEQUENT GUIDANCE DOCUMENTS

- STAFF WILL PROVIDE AND WILL TAKE INTO CONSIDERATION APPLICABLE DETERMINISTIC AND PROBABILISTIC APPROACHES FOR THE SEISMIC DESIGN OF THE REPOSITORY

NRC RESPONSE TO THE INVESTIGATIONS, ANALYSES, AND DESIGN COMMENTS

- RELEVANT COMMENTS DEALING WITH THE INVESTIGATIONS OF FAULT DISPLACEMENT AND SEISMIC HAZARDS ARE CONSIDERED AND ADDRESSED IN THIS STP

- A COMMENT RESOLUTION PACKAGE WILL BE PUBLISHED WITH THE FINAL STP

- COMMENTS DEALING WITH ANALYSES AND SEISMIC DESIGN WILL BE DEFERRED TO SUBSEQUENT GUIDANCE DOCUMENTS

Notwithstanding the foregoing paragraphs (1),(2), and (3), structural association of a fault with geologic structural features which are geologically old (at least pre-Quaternary) such as many of those found in the Eastern region of the United States shall, in the absence of conflicting evidence, demonstrate that the fault is not a capable fault within this definition. (10 CFR 100, App. A)

"Commission" means the Nuclear Regulatory Commission or its duly authorized representatives. (10 CFR 60)

"Containment" means the confinement of radioactive waste within a designated boundary. (10 CFR 60)

"Controlled area" means a surface location, to be marked by suitable monuments, extending horizontally no more than 10 kilometers in any direction from the outer boundary of the underground facility, and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be restricted following permanent closure. (10 CFR 60)

The "design basis earthquake" is that earthquake which is based on an evaluation of the maximum earthquake potential, considering the regional and local geology and seismology and specific characteristics of local subsurface material. It is that earthquake which produces the maximum vibratory ground motion for which certain structures, systems, and components are designed to remain functional. These structures, systems, and components are those necessary to assure the capability to prevent or mitigate the consequence of accidents which could result in potential offsite exposures comparable to the guideline exposures of this part. (Based on 10 CFR 100, App. A, Safe Shutdown Earthquake definition; reactor-specific references have been eliminated.)

"Disposal" means the isolation of radioactive wastes from the accessible environment. (10 CFR 60)

"Disturbed zone" means that portion of the controlled area the physical or chemical properties of which have changed as a result of underground facility construction or as a result of heat generated by the emplaced radioactive wastes such that the resultant change of properties may have a significant effect on the performance of the geologic repository. (10 CFR 60)

"Engineered barrier system" means the waste packages and the underground facility. (10 CFR 60)

A "fault" is a tectonic structure along which differential slippage of the adjacent earth materials has occurred parallel to the fracture plane. It is distinct from other types of ground disruptions such as landslides, fissures, and craters. A fault may have gouge or breccia between its two walls and includes any associated monoclinal flexure or other similar geologic structural feature. (10 CFR 100, App. A)

"Geologic repository" means a system which is intended to be used for, or may be used for, the disposal of radioactive wastes in excavated geologic media. A geologic repository includes: (1) the geologic repository operations area, and (2) the portion of the geologic setting that provides isolation of the radioactive waste. (10 CFR 60)

"Geologic repository operations area" means a high-level radioactive waste facility that is part of a geologic repository, including both surface and subsurface areas, where waste-handling activities are conducted. (10 CFR 60)

"Geologic setting" means the geologic, hydrologic, and geochemical systems of the region in which a geologic repository operations area is or may be located. (10 CFR 60)

"Ground water" means all water which occurs below the land surface. (10 CFR 60)

"High-level radioactive waste" or "HLW" means (1) irradiated reactor fuel, (2) liquid wastes resulting from the operation of the first cycle solvent extraction system, or equivalent, and the concentrated wastes from subsequent extraction cycles, or equivalent, in a facility for reprocessing irradiated reactor fuel, and (3) solids into which such liquid wastes have been converted. (10 CFR 60)

"Important to safety" with reference to structures, systems, and components means those engineered structures, systems, and components essential to the prevention or mitigation of an accident that could result in a radiation dose to the whole body, or any organ, of 0.5 rem or greater at or beyond the nearest boundary of the unrestricted area at any time until permanent closure. (10 CFR 60)

"Isolation" means inhibiting the transport of radioactive material so that amounts and concentrations of this material entering the accessible environment will be kept within prescribed limits. (10 CFR 60)

The "magnitude" of an earthquake is a measure of the size of an earthquake and is related to the energy released in the form of seismic waves. "Magnitude" means the numerical value on a Richter scale. (10 CFR 100, App. A)

The "Operating Basis Earthquake" is that earthquake which, considering the regional and local geology and seismology and specific characteristics of local subsurface material, could reasonably be expected to affect the plant site during the operating life of the plant; it is that earthquake which produces the vibratory growth [sic] motion for which those features of the nuclear power plant necessary for continued operation without undue risk to the health and safety of the public are designed to remain functional. (10 CFR 100, App. A)

"Permanent closure" means final backfilling of the underground facility and the sealing of shafts and boreholes. (10 CFR 60)

"Quaternary (Period)" means the period of time ranging from the present to approximately two million years before the present.

"Radioactive waste" or "waste" means HLW and other radioactive materials other than HLW that are received for emplacement in a geologic repository. (10 CFR 60)

A "response spectrum" is a plot of the maximum responses (acceleration, velocity, or displacement) of a family of idealized single-degree-of-freedom damped oscillators against natural frequencies (or periods) of the oscillators to a specified vibratory motion input at their supports.

"Retrieval" means the act of intentionally removing radioactive waste from the underground location at which the waste had been previously emplaced for disposal.

"Safe Shutdown Earthquake" (See "design basis earthquake")

"Seismic hazard" is a set of conditions, based on the potential for the occurrence of earthquakes, that might operate against the health and safety of the public. Seismic hazard may be characterized in either deterministic or probabilistic terms.

"Site" means the location of the controlled area. (10 CFR 60)

"Site characterization" means the program of exploration and research, both in the laboratory and in the field, undertaken to establish the geologic conditions and the ranges of those parameters of a particular site relevant to the procedures under this part. Site characterization includes boring, surface excavations, excavation of exploratory shafts, limited subsurface lateral excavations and borings, and in situ testing at depth needed to determine the suitability of the site for a geologic repository, but does not include preliminary borings and geophysical testing needed to decide whether site characterization should be undertaken. (10 CFR 60)

"Surface faulting" is differential ground displacement at or near the surface caused directly by fault movement and is distinct from nontectonic types of ground disruptions such as landslides, fissures, and craters. (10 CFR 100, App. A)

A "tectonic structure" is a large scale dislocation or distortion within the earth's crust. s measured in miles. (10 CFR 100, App. A)

"Unanticipated processes and events" means those processes and events affecting the geologic setting that are judged not to be reasonably likely to occur during the period the intended performance objective must be achieved, but which are nevertheless sufficiently credible to warrant consideration. Unanticipated processes and events may be either natural processes and events or processes and events initiated by human activities other than those activities licensed under this part. Processes and events initiated by human activities may only be found to be sufficiently credible to warrant consideration if it is assumed that: (1) The monuments provided for by this part are sufficiently permanent to serve their intended purpose; (2) the value to future generations of potential resources within the site can be assessed adequately under the applicable provisions of this part; (3) an understanding of the nature of radioactivity, and an appreciation of its hazards, have been retained in some functioning institutions; (4) institutions are able to assess risk and to take remedial action at a level of social organization and technological competence equivalent to, or superior to, that which was applied in initiating the processes or events concerned; and (5) relevant records are preserved, and remain accessible, for several hundred years after permanent closure. (10 CFR 60)

"Underground facility" means the underground structure, including openings and backfill materials, but excluding shafts, boreholes, and their seals. (10 CFR 60)

"Unrestricted area" means any area, access to which is not controlled by the licensee for the purposes of protection of individuals from exposure to radiation and radioactive materials, and any area used for residential quarters. (10 CFR 60)

APPENDIX B

RELEVANT TEXT FROM TITLE 10, CHAPTER I, OF THE CODE OF FEDERAL REGULATIONS

10 CFR Part 40, Appendix A, Criterion 4(e)

The impoundment may not be located near a capable fault that could cause a maximum credible earthouake larger than that which the impoundment could reasonably be expected to withstand. As used in this criterion, the term "capable fault" has the same meaning as defined in section III(g) of Appendix A of 10 CFR Part 100. The term "maximum credible earthquake" means that earthquake which would cause the maximum vibratory ground motion based upon an evaluation of earthquake potential considering the regional and local geology and seismology and specific characteristics of local subsurface material.

10 CFR Part 50, Appendix A, Criterion 2, Design bases for protection against natural phenomena

Structures, systems, and components important to safety shall be designed to withstand the effects of natural phenomena such as earthquakes, tornadoes, hurricanes, floods, tsunami, and seiches without loss of capability to perform their safety functions. The design bases for these structures, systems, and components shall reflect: (1) Appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area, with sufficient margin for the limited accuracy, quantity, and period of time in which the historical data have been accumulated, (2) appropriate combinations of the effects of normal and accident conditions with the effects of the natural phenomena and (3) the importance of the safety functions to be performed.

10 CFR Part 60

Section 60.21(c)(1)(ii)(B)

[The assessment of the site at which the proposed geologic repository operations area is to be located, that is to be included in the Safety Analysis Report of the license application, shall contain:] Analyses to determine the degree to which each of the favorable and potentially adverse conditions, if present, has been characterized, and the extent to which it contributes to or detracts from isolation. For the purpose of determining the presence of the potentially adverse conditions, investigations shall extend from the surface to a depth sufficient to determine critical pathways for radionuclide migration from the underground facility to the accessible environment. Potentially adverse conditions shall be investigated outside of the controlled area if they affect isolation within the controlled area.

Section 60.21(c)(1)(ii)(C)

[The assessment of the site at which the proposed geologic repository operations area is to be located, that is to be included in the Safety Analysis Report of the license application, shall contain:] An evaluation of the performance of the proposed geologic repository for the period after permanent closure, assuming anticipated processes and events, giving the rates and quantities of releases of radionuclides to the accessible environment as a function of time; and a similar evaluation which assumes the occurrence of unanticipated processes and events.

Section 60.21(c)(3)

[The Safety Analysis Report of the license application, shall include:] A description and analysis of the design and performance requirements for structures, systems, and components of the geologic repository which are important to safety. This analysis shall consider -- (i) The margins of safety under normal conditions and under conditions that may result from anticipated operational occurrences, including those of natural origin; and (ii) the adequacy of structures, systems, and components provided for the prevention of accidents and mitigation of the consequences of accidents, including those caused by natural phenomena.

Section 60.111, Performance of the geologic repository operations area through permanent closure.

(a) Protection against radiation exposures and releases of radioactive material. The geologic repository operations area shall be designed so that until permanent closure has been completed, radiation exposures and radiation levels, and releases of radioactive materials to unrestricted areas, will at all times be maintained within the limits specified in Part 20 of this chapter and such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency.

(b) Retrievability of waste. (1) The geologic repository operations area shall be designed to preserve the option of waste retrieval throughout the period during which wastes are being emplaced and, thereafter, until the completion of a performance confirmation program and Commission review of the information obtained from such a program. To satisfy this objective, the geologic repository operations area shall be designed so that any or all of the emplaced waste could be retrieved on a reasonable schedule starting at any time up to 50 years after waste emplacement operations are initiated, unless a different time period is approved or specified by the Commission. This different time period may be established on a case-by-case basis consistent with the emplacement schedule and the planned performance confirmation program.

(2) This requirement shall not preclude decisions by the Commission to allow backfilling part or all of, or permanent closure of, the geologic

repository operations area before the end of the period of design for retrievability.

(3) For purposes of this paragraph, a reasonable schedule for retrieval is one that would permit retrieval in about the same time as that devoted to construction of the geologic repository operations area and the emplacement of wastes.

Section 60.112, Overall system performance objective for the geologic repository after permanent closure

The geologic setting shall be selected and the engineered barrier system and the shafts, boreholes and their seals shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency with respect to both anticipated processes and events and unanticipated processes and events.

Section 60.113, Performance of particular barriers after permanent closure

(a) General provisions -- (1) Engineered barrier system. (i) The engineered barrier system shall be designed so that assuming anticipated processes and events: (A) Containment of HLW will be substantially complete during the period when radiation and thermal conditions in the engineered barrier system are dominated by fission product decay; and (B) any release of radionuclides from the engineered barrier system shall be a gradual process which results in small fractional releases to the geologic setting over long times. For disposal in the saturated zone, both the partial and complete filling with ground water of available void spaces in the underground facility shall be appropriately considered and analyzed among the anticipated processes and events in designing the engineered barrier system.

(ii) In satisfying the preceding requirement, the engineered barrier system shall be designed, assuming anticipated processes and events, so that:

(A) Containment of HLW within the waste packages will be substantially complete for a period to be determined by the Commission taking into account the factors specified in Subsection 60.113(b) provided, that such period shall be not less than 300 years nor more than 1,000 years after permanent closure of the geologic repository; and

(B) The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided, that this requirement does not apply to any radionuclide which is released at a rate less than 0.1% of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that [illegible] radioactive decay.

(2) Geologic setting. The geologic repository shall be located so that pre-waste-emplacement ground water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such other travel time as may be approved or specified by the Commission..

(b) On a case-by-case basis, the Commission may approve or specify some other radionuclide release rate, designed containment period or pre-waste-emplacement ground water travel time, provided that the overall system performance objective, as it relates to anticipated processes and events, is satisfied. Among the factors that the Commission may take into account are:

(1) Any generally applicable environmental standard for radioactivity established by the Environmental Protection Agency;

(2) The age and nature of the waste, and the design of the underground facility, particularly as these factors bear upon the time during which the thermal pulse is dominated by the decay heat from the fission products;

(3) The geochemical characteristics of the host rock, surrounding strata and ground water; and

(4) Particular sources of uncertainty in predicting the performance of the geologic repository.

(c) Additional requirements may be found to be necessary to satisfy the overall system performance objective as it relates to unanticipated processes and events.

Section 60.122(c), Potentially Adverse Conditions

[Selected conditions considered directly or indirectly related to seismic hazard]

The following conditions are potentially adverse conditions if they are characteristic of the controlled area or may affect isolation within the controlled area.

(3) Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such a magnitude that large-scale surface water impoundments could be created that could change the regional ground water flow system and thereby adversely affect the performance of the geologic repository.

(4) Structural deformation, such as uplift, subsidence, folding, or faulting that may adversely affect the regional ground water flow system.

(11) Structural deformation such as uplift, subsidence, folding, and faulting during the Quaternary Period.

(12) Earthquakes which have occurred historically that if they were to be repeated could affect the site significantly.

(13) Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or magnitude of earthquakes may increase.

(14) More frequent occurrence of earthquakes or earthquakes of higher magnitude than is typical of the area in which the geologic setting is located.

Section 60.131(b)(1), Protection against natural phenomena and environmental conditions

[With respect to the general design criteria for the geologic repository operations area,] The structures, systems, and components important to safety shall be designed so that natural phenomena and environmental conditions anticipated at the geologic repository operations area will not interfere with necessary safety functions.

10 CFR Part 72

Section 72.66, Geological and seismological characteristics

(a) Massive water basin and air-cooled canyon types of ISFSI structures. (1) East of the Rocky Mountain Front (east of approximately 104 west longitude), except in areas of known seismic activity including but not limited to the regions around New Madrid, Mo., Charleston, S.C., and Attica, N.Y., sites will be acceptable if the results from onsite foundation and geological investigation, literature review, and regional geological reconnaissance show no unstable geological characteristics, soil stability problems, or potential for vibratory ground motion at the site in excess of an appropriate response spectrum anchored at 0.2 g.

(2) West of the Rocky Mountain Front (west of approximately 104 west longitude), and in other areas of known potential seismic activity, seismicity will be evaluated by the techniques of Appendix A of Part 100 of this chapter.

Sites that lie within the range of strong near-field ground motion from historical earthquakes on large capable faults should be avoided.

(3) Sites other than bedrock sites shall be evaluated for their liquefaction potential or other soil instability due to vibratory ground motion.

(4) Site-specific investigations and laboratory analyses must show that soil conditions are adequate for the proposed foundation loading.

(5) In an evaluation of alternative sites, those which require a minimum of engineered provisions to correct site deficiencies are preferred. Sites with unstable geologic characteristics should be avoided.

(6) The [Independent Spent Fuel Storage Installation] ISFSI design earthquake (ISFSI-DE) for use in the design of structures shall be determined as follows:

(i) For sites that have been evaluated under the criteria of Appendix A of 10 CFR Part 100, the ISFSI-DE shall be equivalent to the safe shutdown earthquake (SSE) for a nuclear power plant.

(ii) For those sites that have not been evaluated under the criteria of Appendix A of 10 CFR Part 100, that are east of the Rocky Mountain Front, and that are not in areas of known seismic activity, a standardized ISFSI-DE described by an appropriate response spectrum anchored at 0.25 g may be used. Alternatively, a site-specific ISFSI-DE may be determined by using the criteria and level of investigation required by Appendix A of Part 100 of this chapter.

(iii) Regardless of the results of the investigations anywhere in the continental U.S., the ISFSI-DE shall have a value for the horizontal ground motion of no less than 0.10 g with the appropriate response spectrum.

(b) Other types of ISFSI designs. For ISFSI designs that do not use massive water basins or air-cooled canyons, such as canisters, casks, or silos, a site-specific investigation is required to establish site suitability commensurate with the specific requirements of the proposed ISFSI.

[45 FR 74699, Nov. 12, 1980; 45 FR 80271, Dec. 4, 1980]

APPENDIX C

OUTLINE OF 10 CFR PART 100, APPENDIX A

10 CFR Part 100, Appendix A, Seismic and Geologic Siting Criteria for Nuclear Power Plants

I. PURPOSE

II. SCOPE

III. DEFINITIONS

(a) "magnitude"

(b) "intensity"

(c) "Safe Shutdown Earthquake"

(d) "Operating Basis Earthquake"

(e) "fault"

(f) "Surface faulting"

(g) "capable fault"

(h) "tectonic province"

(i) "tectonic structure"

(j) "zone requiring detailed faulting investigation"

(k) "control width"

(l) "response spectrum"

IV. REQUIRED INVESTIGATIONS

(a) Required Investigations for Vibratory Ground Motion

(1) Determination of geologic conditions of the site and vicinity

(2) Identification and evaluation of tectonic structures

(3) Evaluation of the behavior of geologic materials during prior earthquakes

(4) Determination of engineering properties of the materials

(5) Listing of all historically reported earthquakes affecting the site

(6) Correlation of epicenters with tectonic structures or provinces

(7) Determination of capable faults

(8) For capable faults, determination of:

(i) Length of the fault

(ii) Relationship of the fault to regional tectonic structures

(iii) Nature of displacements along the fault

(b) Required Investigations for Surface Faulting

(1) Determination of geologic condition of the site and vicinity

(2) Evaluation of tectonic structures

(3) Determination of geologic evidence of fault offset

(4) For faults greater than 1000 feet long, determination of whether these faults are capable faults

(5) Listing of all historically reported earthquakes associated with capable faults greater than 1000 feet long

(6) Correlation of epicenters of historically reported earthquakes with capable faults greater than 1000 feet long

(7) For capable faults, determination of:

(i) Length of the fault

(ii) Relationship of the fault to regional tectonic structures

(iii) Nature of displacements along the faults

(iv) Extent of the fault zone in the site vicinity

(c) Required Investigation for Seismically Induced Floods and Water Waves

(1) For coastal sites, determination of:

(i) Information regarding distantly and locally generated waves or tsunami affecting the site

(ii) Local features which might tend to modify tsunami effects

(iii) Appropriate evidence to provide information for designing for the effects of a local offshore earthquake

(2) For sites located near lakes and rivers, determination of effects of seismically-induced floods and water waves

V. SEISMIC AND GEOLOGIC DESIGN BASES

(a) Design Basis for Vibratory Ground Motion

(1) Determination of Safe Shutdown Earthquake

(2) Determination of Operating Basis Earthquake

(b) Need to Design for Surface Faulting

(1) Determination of zone requiring detailed faulting investigation

(c) Design Bases for Seismically Induced Floods and Water Waves

(d) Other Design Conditions

(1) Soil stability

(2) Slope stability

(3) Cooling water supply

(4) Distant structures

VI. APPLICATION TO ENGINEERING DESIGN

(a) Vibratory Ground Motion

(1) Safe Shutdown Earthquake

(2) Operating Basis Earthquake

(3) Required seismic instrumentation

(b) Surface Faulting

(c) Seismically induced floods and water wave and other design considerations

Department of Energy
Washington, DC 20585

NOV 3 1989

John Linehan, Director
Repository Licensing and Quality
Assurance Project Directorate
Division of High-Level
Waste Management
Office of Nuclear Material
Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Mr. Linehan:

Enclosed are the Department of Energy (Department) comments on the Nuclear Regulatory Commission's (NRC) draft Technical Position on Methods of Evaluating the Seismic Hazard at a Geologic Repository, published for comment on August 24, 1989, (54 FR 35286). As previously expressed in our earlier comment letter transmitted to you on September 20, 1989, the Department believes that there are numerous disadvantages with the potential use of 10 CFR Part 100, Appendix A for development and evaluation of a geologic repository. This belief is based on: (1) in applying Appendix A, the draft technical position does not consider the different levels of risk associated with a passive geologic repository as contrasted to a dynamic nuclear power reactor; and (2) the terminology and concepts addressed in the regulation appear to be outdated, limiting the use of state-of-the-art concepts such as probabilistic seismic hazard evaluation; and (3) Appendix A provides insufficient guidance on concepts such as underground vibratory ground motion and postclosure tectonic scenarios. These concerns are expanded in the enclosed set of comments.

The Department suggests that a DOE-NRC Technical Exchange be scheduled in the near future to discuss our comments on this important subject. We believe that such an interaction will facilitate your understanding of our concerns. Additionally, we believe that it would be appropriate to re-issue this technical position as a draft document for comment, once the critical issues have been fully discussed and mutual understanding has been reached on the most appropriate methods for evaluating seismic hazards at a geologic respository.

Please feel free to contact Mr. Steven H. Rossi of my staff on 586-9433 with any questions regarding this correspondence.

Sincerely,

Gordon Appel

Gordon Appel, Chief
Licensing Branch
Office of Civilian Radioactive
Waste Management

Enclosure: Comments On NRC Draft Technical Position on Methods of Evaluating the Seismic Hazard at a Geologic Repository

cc: R. Loux, State of Nevada
M. Baughman, Lincoln County, NV
D. Bechtel, Clark County, NV
S. Bradhurst, Nye County, NV

COMMENTS ON THE NRC DRAFT TECHNICAL POSITION ON METHODS OF EVALUATING THE SEISMIC HAZARD AT A GEOLOGIC REPOSITORY

MAJOR COMMENTS

1. As the draft technical position points out, 10 CFR Part 60 does not rely on 10 CFR Part 100, Appendix A for guidance regarding provisions for dealing with seismic hazard. There are two reasons that this omission was deliberate. (1) The provisions of Part 100 were written with operating nuclear power plants in mind, not waste disposal systems. Disposal systems lack the active cooling systems and energetic physical mechanisms for dispersing contaminates, which nuclear power plants possess. (2) Appendix A to Part 100, written over 25 years ago, no longer reflects state-of-the-art professional practice in characterizing seismic hazards and developing seismic design bases. Its application has been found to be too prescriptive in some areas, too vague in others, and generally difficult to apply without creating considerable controversy. In addition, some of the methodologies in Appendix A may be particularly inappropriate for application in the Basin and Range Province, where recurrence intervals for earthquakes on particular faults are typically tens of thousands of years.

   For the reasons given above, the DOE strongly disagrees with the proposition that 10 CFR Part 100, Appendix A should be considered as general guidance for the characterization of seismic hazards and the development of seismic design bases for a geologic repository. If the NRC believes there are specific methodologies from Appendix A that are directly applicable to a geologic repository and are more appropriate than the studies described in the Site Characterization Plan (SCP), then those methodologies should be specifically identified in a "stand alone" guidance document without reference to Appendix A. This would eliminate many of the problems that are inherent in applying a rule designed for nuclear reactor regulation to a geologic repository.

2. <u>Page 4, Section 2.4</u>

   The technical position states that: "Appendix A sets an important precedent that needs to be considered when new types of nuclear facilities that require seismic hazard review are considered for licensing."

   We agree with this statement, however, there is no evidence that the other regulations which refer to Appendix A, (i.e. 10 CFR Part 72 and 10 CFR Part 40) or this draft technical position, have made that important consideration.

   10 CFR Part 100, Appendix A, appears to have been used in licensing other nuclear facilities in the United States principally because it is the only regulation for nuclear facilities that provides detailed instructions for seismic-hazard investigations.

The Department notes that a recent revision of DOE Order 6430.1A (U.S. Department of Energy General Design Criteria), which is applicable to non-reactor DOE facilities, incorporates state-of-the-art criteria for seismic design, including specific criteria for vibratory ground motion input and seismic engineering analytical methods. The approach described in DOE Order 6430.1A may be of sufficient scope and conservatism to meet the appropriate 10 CFR 60 requirements.

3. Page 10, Section 4.3

The TP states that "a primary reason for taking the position that Part 100, Appendix A is an appropriate methodology for investigating the seismic hazard at a geologic repository is that much of the technology presented in Part 100, Appendix A is generic in nature."

We disagree; Appendix A is not generic. If it were, why would it apply to only some cases? For example, according to 10 CFR Part 72 Appendix A applies West of the Rocky Mountain Front, but does not apply East of the Front. Likewise, Appendix A applies to massive water basin and air-cooled canyon types of independent spent fuel storage installations (ISFSI), but may not apply to other types of ISFSI designs, such as canisters, casks, or silos. It appears that Appendix A applies only where potential risk warrants. In our opinion, Appendix A should not apply to a repository at Yucca Mountain, in part, because the potential risks are lower than most other nuclear facilities.

Any design methodology must reflect the risks associated with the engineered facility, as well as the hazards posed by the Earth. Although design-basis methodology prescribed by Appendix A is appropriate for nuclear power plants, it is not necessarily appropriate for lower-risk facilities, such as a high-level waste repository, or generic to all tectonic environments.

Even this TP admits that nuclear power plants (for which Appendix A was written) pose a greater risk than a repository. The TP states that, "in contrast to a nuclear power plant, a geologic repository is not likely to have components possessing high energy driving forces capable of broadly dispersing the contained radioactivity. Even with a gross failure of those components of a repository involved in containment, a loss of containment integrity would not be as likely to have as significant a consequence for public health and safety as a nuclear power plant, because the systems would be passive."

The NRC staff uses the above statement to explain why the TP does not consider the Appendix A requirements for an operating basis earthquake. We agree this statement, and suggest that it also justifies rejecting the concept of the applicability of 10 CFR 100, Appendix A.

In addition to its biased (rather than generic) nature, Appendix A has been criticized by the NRC and industry. Appendix A was codified in November 1973, and was largely based on professional practice and state-of-the-art in the 1960's and early 1970's. Since that time, there have been numerous technical advancements in evaluating fault and earthquake hazards, particularly in probabilistic evaluations. It would be counterproductive to ignore these advancements simply for the sake of complying with an less than current regulation.

In the late 1970's, the NRC considered revising Appendix A because, even at that time, the regulation was considered outdated, complicated and the cause of licensing delays. The NRC staff summarized these problems as follows:

> Having geoscience assessments detailed and cast in Appendix A, a regulation, has created difficulty for applicants and the staff in terms of inhibiting the use of needed judgment and latitude. Also, it has inhibited flexibility in applying basic principles to new situations and the use of evolving methods of analyses in the licensing process. Additionally, various sections of Appendix A lack clarity and are subject to different interpretations and dispute. Also, some sections in the Appendix do not provide sufficient information for implementation. As a result of being both overly detailed in some areas and not detailed enough in others, the Appendix has been the source of licensing delays and debate, has inhibited the use of some types of analyses, and has inhibited the development of regulatory guidance (SECY-79-300, April 27, 1979).

More recently, at an October 1986 symposium on seismic and geologic siting criteria for nuclear power plants, the technical community renewed the drive to revise Appendix A. The symposium found a number of problems with Appendix A, but the most important was the need to incorporate probabilistic concepts into the regulation with an appropriate mix of deterministic criteria. At that time, the NRC staff stated that their management may not endorse a rule-making until 1987 (Lawrence Livermore National Laboratory, Summary Report of the Symposium on Seismic and Geologic Siting Criteria for Nuclear Power Plants, NUREG/CP-0087, June 1987).

Design motions, derived from Appendix A, can misstate the seismic hazards in some tectonic environments, because Appendix A specifies that design motions be estimated without specific consideration of the style of deformation particular to a tectonic environment. The Appendix A specification of the Safe Shutdown Earthquake requires a review of the historic distribution of earthquake magnitudes and intensities, the distribution of tectonic structures, and "capable faults". For an Appendix A site motion evaluation, the largest earthquake(s) would be placed at locations closest to the site on geologic structures or at seismotectonic boundaries. Where the largest historic earthquakes cannot be associated with a geologic structure, that earthquake will be located at the closest point within the tectonic province. For an application of Appendix A to a critical facility in the vicinity of a major fault, a "maximum" earthquake magnitude is determined from historical correlations between earthquake magnitude and corresponding surface fault rupture. A common way to estimate maximum earthquake magnitude is to take a point estimate from a statistical distribution of empirical correlations between earthquake magnitude and the length of mapped surface fault traces.

Application of this methodology to active fault segments in the Southern Great Basin could lead to unconservative or uncertain design earthquakes because of the relatively complicated nature of faulting in an extensional environment, and the corresponding difficulty of estimating, a priori, maximum fault rupture lengths.

Yucca Mountain has been characterized as having a number of closely spaced (2-4 km) anastomosing normal faults (Scott and Bonk, 1984). Thus, estimating maximum fault length and correspondingly "maximum" earthquake magnitude for any surface rupture scenario is extremely difficult, and could easily be under or overestimated. This difficulty is compounded as a result of the paucity of instrumental seismicity to define continuity in a fault trace.

Given these problems with application of Appendix A, we disagree with its imposition for the repository. The SCP offers an approach and methodology, based on a Cumulative Slip Earthquake (CSE), that would better postulate a design basis earthquake.

A CSE is defined in the SCP to be a postulated earthquake that occurring every 10,000 years, would produce the observed or estimated average Quaternary slip rate on a fault. The CSE approach results in a design basis with a corresponding exceedance probability between 10-3 and 10-4 per year.

Preliminary information indicates that the CSE methodology will produce a sufficient seismic design basis for surface facilities important to safety during the preclosure period of repository operation. Specifically, preliminary analysis indicates the resulting seismic design basis would correspond to a postulated earthquake on the Paintbrush Canyon fault (an apparently normal fault located about 1 kilometer east of prospective surface waste-handling facilities) with a magnitude of about 6 to 6 1/2 and a peak ground acceleration at the site of about 0.5 to 0.6g. A recent analysis of alternative seismic design levels (SAND 88-1600, "Preliminary Seismic Design Cost-Benefit Assessment of the Tuff Repository Facilities") suggests that the accident risks associated with a seismic design level of 0.2g or greater for surface waste-handling facilities would be extremely small. Important factors which contribute to this finding are that the surface facility cells would be inherently "hard" against seismic loading, because of shielding requirements and the resulting thick shear-wall construction, the low probability of severe ground motion during the operating life of the facility and the lack of an energetic mechanism for dispersing contaminants during an accident. In addition, the target range of exceedance probabilities 10-3 to 10-4 per year) for the design basis has been found to correspond to the accepted design bases for a number of U.S. nuclear power plants (Reiter and Jackson 1983, NUREG-0967), lending further confidence that the CSE methodology will provide more than sufficient conservatism.

Before the NRC issues this TP, we would like an opportunity to build on the concept of a CSE and offer an alternative to Appendix A. Basically, we propose a more risk-based approach to assessing hazards where risk is the integrated product of event probability and consequences. Hazard would then be defined as the probability of exceeding a specified event magnitude.

Although it postdates Appendix A, there is nothing new about a risk based approach. The Environmental Protection Agency (EPA) Standards for geologic repository (50 FR 38066 September 19, 1985) translates an acceptable risk (1,000 health effects to a world population) into limits for cumulative releases and recommends a complementary cumulative distribution function to express the hazard (1 chance in 10 and 1 chance in 1,000) of exceeding multiples of those limits. More recently, the EPA proposed "National Emissions Standards for Hazardous Air Pollutants; Regulation of Radionuclides; Proposed Rule and Notice of Public Hearing" (40 CFR Part 61, 54 FR 9612 March 7, 1989). Here, the EPA proposes three levels of risk, each corresponding to a radiation dose. The final rule will codify one of these doses to limit the radioactive emissions from nuclear and non-nuclear industries.

This risk based approach has clear advantages over Appendix A. Collegial recommendations, such as those made by the International Committee on Radiation Protection, have established values for an acceptable risk. However, various licensing boards, as well as utilities, have never agreed to what constitutes the maximum earthquake that Appendix A expounds. Risk takes into account the nature of the facility and its site. Appendix A examines only the site and was written for nuclear power plant sites, not repositories. Finally, risk assessments can more equitably allocate the design precautions needed to protect the public health and safety. Appendix A would force an unnecessary (and expensive) design basis on a repository without a commensurate benefit to the public.

Unlike Appendix A, a risk-based approach would account for the reduced seismic hazards in areas, such as Yucca Mountain, where the deformation rate is low. The historic rate of seismicity in the Southern Great Basin (SGB) can be characterized by the average annual number of earthquakes of magnitude 4.0 and greater (denoted N4) per 1,000 sq km. For the SGB, N4 is approximately 0.01 events/1,000 sq km (Greensfelder et al., 1980). This rate of seismicity is extremely low compared to interplate seismotectonic environments, (i.e. southern California), where seismic hazards are common design considerations. Using a conservative value for N4 of 0.015 earthquakes per 1,000 sq km for the rate of seismicity in the Yucca Mountain area, this value of seismicity is about a factor of ten less than the Los Angeles Basin area of southern California. An example of the critical nature of relative deformation rates are comparisons of the preliminary probabilistic hazards between southern California and the Yucca Mountain vicinity. Preliminary estimates of the probability of exceeding peak ground motion indicates return periods an order of magnitude greater than that estimated for similar levels of motion for the Los Angeles Basin, a region that supports a variety of critical facilities. Preliminary geologic trenching data in the vicinity of the site also supports low deformation rates: apparent vertical slip rates on Quaternary faults are between 0.001 to 0.0001 cm/yr (SCP section 1.5.2.2). The pre- and postclosure design methodology should account for the tectonic deformation rate, otherwise an inconsistent design basis will occur. For example, a maximum earthquake magnitude cannot define the difference in seismic hazard between a fault that can produce a magnitude 7 earthquake in 100 years, and one that produces a magnitude 7 every 100,000 years. A consistent and defensible design basis must account for the level of hazard.

4. Page 13, Section 4.3.2

The TP states that "Section V(a)(1) [of Part 100, Appendix A] prescribes a set of specific steps to take in evaluating the data gathered through the required investigations, to arrive at the earthquake that produces maximum vibratory acceleration at the site above a threshold of 0.1g. This earthquake is termed the Safe Shutdown Earthquake (SSE). These basic procedures form the framework for establishing the determination of the maximum vibratory motion at any site at relevant times and are therefore considered to be appropriate to a geologic repository.

The underscored phrases have little meaning when applied to a repository that has been closed and decommissioned.

The TP states that the maximum vibratory ground motion would be predicted "at the site." Appendix A, in contrast, states that the motion would occur at each of the various foundation locations of the nuclear power plant structures at a given site" (10 CFR 100, Appendix A, Section V, (a)(1)(1V).
The repository site would be at least as large as the controlled area, which according to 40 CFR 191.12(g), encompasses 100 square kilometers and would extend underground. The foundation locations are smaller, more discrete and lie on the surface. Conceivably, Appendix A could be applied to repository surface facilities, but Appendix A could not be applied to a large mass of earth. Moreover, a closed repository has no surface facilities.

We disagree that Appendix A applies during time periods that are relevant to a geologic repository. Appendix A was written for nuclear power plants which have an operational life of about 40 years. Because of the relative short lifetime of the facility and the safety concern being addressed (ability to safely shut down the reactor), the Appendix A methodology relies on the concept of designing for a single, large event ("maximum credible event occurring on a specific fault. While this concept may ensure power-plant safety for 40 years, it is not suitable for evaluating repository performance.

Instead of Appendix A, we propose a more probabilistic methodology that would take into account not only the effects of single, but also the cumulative effects of multiple events that are reasonably likely to occur during the postclosure time period. We suggest that, if the TP is issued, the last sentence should be revised to read: "These basic procedures form the framework for establishing the seismic basis for determination of the maximum vibratory motion <u>at repository surface facilities during the operational phase</u> (Revisions are underscored.)

5. <u>Page 7, Section 3</u>

The TP states that "...it is the position of the staff that the results of Part 100 Appendix A investigations can generally provide input for probabilistic and other methods of assessing seismic and faulting hazards for the postclosure period."

Appendix A recommends an investigative methodology that is not appropriate for assessing seismic and faulting hazards for the postclosure period. The prescribed investigations gather information that hypothesizes the vibratory ground motion produced by the Safe-Shutdown Earthquake (SSE), which:

> "Produces the maximum vibratory ground motion for which certain structures, systems, and components are designed to remain functional. These structures, systems, and components are those necessary to assure: (1) The integrity of the reactor coolant pressure boundary, (2) The capability to shut down the reactor and maintain it is a safe shutdown condition, or (3) The capability to prevent or mitigate the consequences of accidents which could result in potential off site exposures comparable to the guideline exposures of this Part" (10 CFR Part 100, Appendix A, III. Definitions).

The terms and concepts included in the definition of the SSE do not exist at a repository that has been permanently closed. A repository has no "coolant pressure boundary"; a closed repository cannot be "shut down"; and there can be no "accidents" at a closed repository, because the operations have stopped.

COMMENTS

1. Page 1, Section 1

The introduction states that the technical position "...considers differences that may exist, during the preclosure, among the surface facilities and the underground facility." However, this consideration is not apparent in the remaining text of the technical position.

2. Page 1, Section 1

Section 1 states that the purpose of the technical position is to provide: "...regulatory guidance to the U.S. Department of Energy (DOE) on appropriate methodologies that address seismic hazard at a geologic repository."

Later, in the same Section, it is stated that: "this position does not address probabilistic seismic hazard analysis...[which is] ...addressed in other technical positions...."

Additionally, Section 3 (page 7) states that: "...the results of Part 100, Appendix A investigations can generally provide input for probabilistic and other methods of assessing seismic and faulting hazards for the postclosure period."

Based on such conflicting statements, we find it difficult to understand this draft technical position without understanding the NRC position on probabilistic seismic hazard evaluations, especially since the evaluations specified in 10 CFR Part 100, Appendix A are deterministic.

3. Page 5, Section 2.5

The technical position states that: "10 CFR Part 60 does not specifically rely on Part 100, Appendix A for guidance regarding provisions for dealing with the seismic hazard nor does it specifically require the development of a design basis earthquake. Instead, the performance objectives and siting and design criteria described in 10 CFR Part 60 establish the bases for considering seismic hazard for both the preclosure and the postclosure periods."

We agree, with the above statement and consider that the omission of references to 10 CFR Part 100, Appendix A was deliberate.

10 CFR Part 100, Appendix A was codified in the regulations and available for consideration at the time 10 CFR Part 60 was promulgated. However, as stated in the supplementary information to the proposed 10 CFR Part 60 rule on disposal of high-level radioactive waste in geologic repositories dated July 8, 1981 (46 FR 35280), the Commission considered their past experience and practice with other facilities and acknowledged that there were important differences between a repository and those facilities. We must conclude that if the Commission believed

Appendix A to be applicable to a geologic repository, it would have codified the Appendix in the regulation at that time.

Since 10 CFR Part 60 was promulgated more than eight years ago, the NRC has concurred on the DOE siting guidelines, commented on the DOE environmental assessments, and reviewed and commented on the SCP. On any of these occasions, the relevance of Appendix A to the repository program could have been raised, but was not. Moreover, the NRC staff agreed with the DOE that: "the need to consider specific pre-closure and post-closure events, processes, and phenomena should be based upon a consideration of their effects on compliance with the performance requirements of 10 CFR 60" (summary of the NRC/DOE meeting on seismic/tectonic investigations, December 3-4, 1985).

4. Page 10, Section 4.3.1

Since Appendix A details the required geoscience assessments, the use of evolving methods, such as probabilistic seismic hazard analysis (PSHA), which is a generally accepted procedure to describe the seismic hazard (National Research Council, 1988), is limited. State-of-the-art seismic zoning maps rely to some degree on probabilistic considerations to assess relative hazards at different sites. As described in the SCP, the DOE plans to use PSHA to assess the sensitivity of input parameters and examine uncertainties in ground motion estimates.

5. Page 11, Section 4.3.1(6) and Page 13, Section 4.3.2

Appendix A requires the correlation of past earthquakes with capable faults, tectonic structures and tectonic provinces. However, Appendix A does not specify a method for quantifying future rates of activity, including determining a maximum credible earthquake. We believe that more definitive criteria than that provided in Appendix A are needed to avoid conflicting interpretations.

6. Page 14, Section 4.3.2

The TP states that "...any guidelines [Section V(b) of Part 100, Appendix A] for surface faulting should be considered applicable to the underground facility of a geologic repository as well, since it is very unlikely that a fault that ruptures the surface above the underground facility would not also create a rupture within the underground facility."

We agree that surface faulting would be expressed underground, but disagree that guidelines for one should apply to the other.

The guidelines in Appendix A clearly apply to the foundations of nuclear power plants. There are no "foundations" underground. Moreover, Appendix A was never written for mines, and the NRC has recognized this. Otherwise it would have referenced Appendix A in 10 CFR Part 60, instead of the Federal Mine Safety and Health Act of 1977 and the mining regulations of Title 30, the Code of Federal

Regulations.

7. Page 14, Section 4.3.2

The technical position states that "...any faults discovered within the perimeter of the underground facility, through drifting or other means during site characterization, that cannot be associated with surface faults, require special investigation [given in Appendix A] similar to surface faults." It is not practical to investigate surface and subsurface faults in the same way. According to Section V(b) of 10 CFR Part 100, Appendix A fault traces "...are mapped along the trend of the fault for 10 miles in both directions from the point of its nearest approach to the nuclear power plant...." If a subsurface fault is not expressed on the surface, it cannot be mapped for more than a few feet.

8. Page 7, Section 3

The TP states that: "...the NRC staff will review those sections of the SAR (Safety Analysis Report) addressing Subsections 60.21(c)(1)(ii)(B) and C and Subsection 60.21(c)(3) of 10 CFR Part 60, in light of Appendix A of 10 CFR Part 100. In addition, the methodology outlined in this TP can be used in developing seismic and geologic bases for earthquake design criteria pertinent to Subsection 60.131(b)(1) of 10 CFR Part 60 and in assisting in demonstrating compliance with Sections 60.111, 60.112, and 60.113."

The underscored provisions require an assessment of repository postclosure performance. We fail to understand how these provisions could be reviewed "in light of Appendix A of 10 CFR Part 100" or how Appendix A could assist "in demonstrating compliance" with them.

Subsection 60.21(c)(1)(ii)(B) requires analyses of favorable and potentially adverse conditions as specified in 60.122. The right combination of these conditions will "provide reasonable assurance that the performance objectives relating to the isolation of the waste will be met" (10 CFR 60.122(a)(1)).

Note that the favorable and potentially adverse conditions are not related to repository construction and operation, but only to the "isolation of the waste". In contrast, the scope of Appendix A is to "provide reasonable assurance that a nuclear power plant can be constructed and operated at a proposed site without undue risk to the health and safety of the public" (10 CFR 100 Appendix A, II Scope.)

We submit that the scope of 10 CFR 60.21(c)(1)(ii)(B) differs from the scope of 10 CFR 100 Appendix A, and therefore, compliance with the former cannot be demonstrated in light of the requirements of the latter.

Subsection 60.21(c)(1)(ii)(C) requires "an evaluation of performance of proposed geologic repository for the period after permanent closure, assuming anticipated processes and events, giving the rates and quantities of releases of radionuclides to the accessible environment as a function of time; and a similar evaluation which assumes the occurrence of unanticipated processes and events." As stated previously, the criteria in Appendix A were written for an operating nuclear facility; not one that has been permanently closed and decommissioned.

Also, 60.21(c)(1)(ii)(C) requires an assessment of anticipated processes and events, while Appendix A requires an assessment of a seismic event (the Safe Shutdown Earthquake) that originates along a "capable fault." Anticipated processes and events are based on "those processes operating in the geologic setting during the Quaternary Period" (last 1.8 million years) (pages A-1 and A-2). Capable faults, defined in Appendix A, exhibit one or more of the following characteristics:

1. At least one movement in the past 35,000 years, or multiple movements in the past 500,000 years;

2. Instrumental seismicity that can be correlated to a fault; and

3. A structural relationship to a fault described by 1 or 2 such that the movement on one could reasonably result in movement on the other.

There may be faults on which "anticipated" events have occurred in the Quaternary, but which occur at such low frequency (less than 2 events in the last 500,000 years) that the faults are not considered capable. This discrepancy between anticipated events and events originating along capable faults is particularly significant in the Basin and Range Province where intervals between faulting events may be 200,000 years or more on some faults. Thus, the postclosure performance evaluations in 10 CFR 60.21(c)(1)(ii)(C) are not congruent with the evaluations of capable faults prescribed in Appendix A.

Subsection 60.112 requires that releases of radioactive material following permanent closure "conform to such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency [EPA] with respect to both anticipated processes and events and unanticipated processes and events."

The deterministic criteria in Appendix A are of limited utility, if any, for demonstrating compliance with the EPA's probabilistic standards. To determine compliance with 40 CFR 191.13, the EPA recommends a complementary cumulative distribution function "that indicates the probability of exceeding various levels of cumulative release" (40 CFR 191, Appendix B).

These release probabilities will be derived from the probabilities of processes and events that cause the releases. The EPA states that the DOE may discount certain processes and events of low probability or if omission does not significantly affect the remaining probability distribution of cumulative releases.

In contrast, Appendix A would compel the DOE to assess the consequences of a "maximum earthquake," the "maximum vibratory ground motion," and the epicenters of earthquakes of "greatest magnitude" or the locations of "highest intensity." The superlatives: "maximum," "greatest," and "highest" loose meaning when signifying the types of events that may occur in the next 10,000 years. This would lead to extended debate of limited practical utility regarding what such an event might be. Also, the superlatives connote a deterministic methodology that is antithetical to the probabilistic analyses prescribed by the EPA. In other words, Appendix A advances worst case scenarios regardless of probabilities or consequences, while the EPA effectively dismisses scenarios when probabilities are low or the resulting consequences are insignificant.

Finally, we fail to see how the criteria in Appendix A could assist the DOE in demonstrating compliance with 60.113, which idnetifies objectives for the performance of the waste package, the engineered barrier systems, and groundwater travel time.

The purpose of the investigations required by Appendix A is to obtain the information needed to describe the vibratory ground motion produced by the Safe Shutdown Earthquake. A safe shutdown earthquake is defined by terms and concepts that do not relate to a waste package or an engineered barrier system. The waste package and engineered barrier system have no "coolant pressure boundary"; cannot be "shut down"; and they cannot cause "accidents," because, according to 60.113, these function after the repository operations have stopped.

Even more so, the Safe Shutdown Earthquake has no bearing on calculating ground-water travel time. The Safe Shutdown Earthquake provides a design basis, and ground-water travel time cannot be designed. Moreover, Part 60 constrains ground-water travel time calculations to present-day conditions. The occurrence of a Safe Shutdown Earthquake would not be typical of current-day conditions.

For the above-mentioned reasons, NRC should delete references to 10 CFR 60.21(c)(1)(ii)(B) and (C), 60.112 and 60.113.

9. <u>Page 8, Section 4.1</u>

Although data used in assessing the preclosure seismic hazard may very well be used to assess the postclosure seismic hazard, there are distinct differences. For example 10 CFR Part 100, Appendix A offers no guidance for assessing the seismic hazard for a subsurface facility, where vibratory ground motion appears to be of little or no concern and only faulting through the repository or the effect of tectonic processes on site or regional hydrology may affect repository performance. Such considerations need to be addressed in the technical position.

10. Page 13, Section 4.3.2

Regarding the determination of the Safe Shutdown Earthquake, the last sentence states that Appendix A provides for "...determination of the maximum vibratory motion at any site at relevant times...." We do not understand what is meant by the term "at relevant times." This implies that the Safe Shutdown Earthquake for nuclear power plants is applicable to the preclosure and postclosure periods of a geologic repository, even though it has different facilities, operating periods, and levels of risk. These differences in risk need to be addressed by the technical position.

11) Page 2, Section 2.2

The general design criteria of 10 CFR Part 50, Appendix A are applicable only to nuclear power reactors. Therefore, we suggest substituting "power" for "material" and "reactors" for "materials" in the first sentence.

12) Page 6, Section 2.5

The regulation referenced for input to the SAR [60.21(1)(ii)(B) and (C)] is incorrect. The correct citation is 60.21(c)(1)(ii)(B) and (C).

13) Page 16, Section 6

We do not believe it is appropriate for a technical position to contain a bibliography. The usefulness of these documents in providing guidance to the DOE is questionable. Only those documents directly referenced in the technical position should be listed.

14) Appendix A

Appendix A contains several minor errors that should be corrected to be consistent with 10 CFR Part 60. These include:

- Page A-1, Accessible Environment, insert "portion of the" between "the" and "Lithosphere."

- Page A-6, Important to Safety, insert "the completion of" between "until" and "permanent."

- Page A-7, Retrieval, insert "10 CFR Part 60" as the reference for this term.

15) Appendix B, Page B-9, 10 CFR Part 72

It is not clear as to whether sites east of the Rocky Mountain Front have a minimum spectral anchor of 0.2g (Paragraph (a)) or 0.25g (Paragraph (a)(6)(ii)).

16) <u>References</u>

There are various useful documents that address seismic hazard evaluation and 10 CFR Part 100, Appendix A that appear to have not been considered in preparing the draft technical position. We suggest that the NRC consider the following documents when evaluating these comments on the draft technical position. These include:

1. Bernreuter, D.L., Savy, J.B., Chen, J.C. and B. Davis, Seismic Hazard Characterization of the Eastern United States, Lawrence Livermore National Laboratory, UCID-20421, Vols. 1 and 2, 1985.

2. Electric Power Research Institute, Development and Application of a Seismic Hazard Methodology for Nuclear Facilities in the Eastern United States, RP-P101-29, Vols. 1-3, 1985.

3. International Atomic Energy Agency, Earthquakes and Associated Topics in Relation to Nuclear Power Plant Siting: A Safety Guide, No. 50-SG-S1, 1979.

4. National Research Council, Probabilistic Seismic Hazard Analysis, National Academy Press, 1988.

5. U.S. Nuclear Regulatory Commission, Geologic and Seismic Siting Policy and Practice for Nuclear Power Plants, SECY-77-288A, 1977.

6. U.S. Nuclear Regulatory Commission, Identification of Issues Pertaining to Seismic and Geologic Siting Regulation, Policy and Practice for Nuclear Power Plants, SECY-79-300, 1979.

7. U.S. Nuclear Regulatory Commission, Regulatory Analysis for USI A-40, "Seismic Design Criteria", NUREG-1233, 1988.

8. U.S. Nuclear Regulatory Commission, Summary Report of the Symposium on Seismic and Geologic Siting Criteria for Nuclear Power Plants, NUREG/CP-0087, 1987.

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October 23, 1989

Chief, Regulatory Publications Branch
Division of Freedom of Information
and Publications Services
Office of Administration
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Re: Review comments on NRC Draft Technical Position on Methods of Evaluating the Seismic Hazard at a Geologic Repository. (54 Fed. Reg. 35266)

Dear Sir:

These comments on the above-referenced document are submitted by the Edison Electric Institute/Utility Nuclear Waste and Transportation Program (EEI/UWASTE). EEI is the association of the nation's investor-owned electric utilities. UWASTE is a group of electric utilities providing active oversight of the implementation of federal statutes and regulations related to radioactive waste management and nuclear transportation.

First, EEI/UWASTE endorses the content of the September 20, 1989 letter from Mr. Gordon Appel (DOE) to Mr. John L. Linehan (NRC). Second, our remaining comments fall into two areas: a) differences among facilities, and b) designing for seismic hazards -- both of which, in EEI/UWASTE's opinion, lead to the conclusion that 10 CFR Part 100 Appendix A does not apply to geologic repositories. These comments are amplified below.

Differences Among Facilities

The Technical Position "considers differences that may exist. . .among the surface facilities and the underground facility" of a repository, but it is silent on what those differences are. Moreover, the Technical Position does not acknowledge the very significant difference between repositories on the one hand, and nuclear power plants, spent-fuel storage facilities, and tailings ponds/dams for uranium mills on the other. In the latter context, the Technical Position offers some very weak justification for applying 10 CFR Part 100 Appendix A (Seismic and Geologic Siting Criteria for Nuclear Power Plants) to repositories.

If a seismic event exceeds the design basis for a nuclear power plant, there are high energy forces present within the plant that may result in release of radionuclides to the accessible environment. On the other hand, if a seismic event exceeds the design basis for a repository, the resulting interaction of the geologic and engineered-barrier systems is so complex that release of radionuclides to the accessible environment is not immediate, if ever, and not necessarily catastrophic as determined by performance assessment and probability analyses. Yet, this Technical Position specifically excludes addressing probabilistic seismic-hazard analysis. The Technical Position should directly acknowledge these differences and permit the use of probabilistic analyses.

Investigation vs. Design for Seismic Hazards

It may be appropriate for this Technical Position to describe the nature and scope of investigations into potential seismic hazards for repositories. However, Appendix A is sorely out-of-date with seismic-hazards knowledge and investigatory techniques. The Technical Position should require state-of-the-art investigations and not be limited to those that evolved in the 1960s and early 1970s when 10 CFR Part 100 Appendix A was promulgated.

The Technical Position states, "The term seismic hazard. . .is meant to encompass the hazard due to either vibratory ground motion or coseismic faulting, or both, that can affect the design and performance of the geologic repository." The Technical Position also states that design criteria require "structures, systems, and components important to safety be designed so that their safety functions are preserved under the impact of the most severe, adverse natural phenomena." "In addition," it says, "the methodology outlined in this Technical Position can be used in developing seismic and geologic bases for earthquake design criteria. . ." And finally, it introduces 10 CFR Part 100 Appendix A, and says that for a repository as for a nuclear power plant, "the determination of a need to design for faulting" is applicable. And yet, Appendix A implies that a facility can be designed for both vibratory ground motion and faulting.

When the above statements are considered in the context of 10 CFR Part 100 Appendix A, they translate into a requirement that faulting-potential be investigated and either: 1) avoided by a setback distance, or 2) that the repository may be designed to accommodate faulting. However, the history of AEC/NRC licensing of nuclear power plants has established the precedent of absolutely rejecting designs to accommodate faulting (e.g., Bodega Bay, California, of Pacific Gas and Electric; and Malibu, California, of Los Angeles Department of Water and Power).

Without specifically acknowledging the ability and the acceptability of accommodating fault displacement in design, the Technical Position is perpetuating a misleading impression given by 10 CFR Part 100 Appendix A. Furthermore, the Technical Position should indicate the criteria by which setback-distance from faults, and designs to accommodate faulting will be judged by the NRC staff.

Recommended NRC Actions

This technical position should be carefully reconsidered, especially with respect to its implementation of 10 CFR Part 100 Appendix A as discussed above, and in DOE's letter of September 20, 1989.

In addition, since the establishment of seismic design and acceptance criteria is critical to the ultimate licensing and construction of the nation's first geologic repository for the disposal of civilian high-level waste and spent nuclear fuel, EEI/UWASTE strongly recommends that NRC develop a regulation for a generic repository and supplemental Regulatory Guides on this topic. Regulatory Guides will provide the technical rigor that is appropriate for development of regulatory requirements and guidance in this area. In addition, requirements and guidance provided by regulations are durable and legally binding on all parties in any licensing proceeding.

We appreciate the opportunity to comment on the subject Draft Technical Position. If you have any questions, or desire additional information regarding our comments, please contact Mr. Christopher J. Henkel, EEI/UWASTE Program Manager for high-level waste at (202) 778-6693.

Sincerely yours,

David L. Swanson
Senior Vice President

DLS/chm

cc: Messrs: J. Linehan, NRC
K. Stablein, NRC
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October 23, 1989

Chief, Regulatory Publications Branch
Division of Freedom of Information
and Publications Services
Office of Administration
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555

Dear Sirs:

RE: DRAFT TECHNICAL POSITION ON METHODS OF EVALUATING THE SEISMIC HAZARD AT A GEOLOGIC REPOSITORY. (FR., Vol. 54, No. 163, August 24, 1989, p. 35266).

The following are the Nevada Agency for Nuclear Projects / Nuclear Waste Project Office comments on the subject draft Technical Position. The comments are organized in a format of General Comments and Specific Comments.

GENERAL COMMENTS:

The draft Technical Position, for the most part, accomplishes its stated purpose of providing regulatory guidance on appropriate methodologies that address seismic hazard(s) at a geologic repository, however, the document contains little to justify its being titled a Technical Position. In effect, it constitutes a policy statement by the NRC staff that the methodologies and principles espoused in 10 CFR Part 100, Appendix A are appropriate for addressing the earthquake hazards at a geologic repository, and that the staff will rely on 10 CFR Part 100, Appendix A in its review of a geologic repository license application. What the Technical Position does not say (nor should it say) is that only 10 CFR Part 100, Appendix A methodologies are acceptable, or that the results from following the Appendix A methodologies will be treated the same way in application to the engineering design questions.

The Technical Position can be improved in content, particularly in regard to the critical issue of capable and active faults. Given that all capable faults are active faults, yet not all active faults are considered capable faults, a basic question arises regarding the extent to which the existence of capable and/or active faults at a repository site will be acceptable to the NRC staff under any principles, including those espoused in 10 CFR 100, Appendix A. If a site which exhibits both capable and active faults is acceptable to the staff, the extensive studies associated with application of 10 CFR Part 100, Appendix A methodologies will provide little more to license review than some of the information eventually used in a probabalistic seismic hazards analysis. This would serve only to expose (as a matter of interest) the degree to which such faulting was acceptable to the staff, on a probabilistic basis, since acceptability of a site with both capable and active faults had already been established.

While we know of no NRC regulation that prohibits siting a nuclear facility astride a capable fault, it is difficult to believe that the NRC would license a nuclear reactor if it were exposed to such a condition, nor would a prudent utility be likely to seek a reactor licence in close proximity to a capable fault. Furthermore, it is even difficult to conceive of a utility seeking a reactor license for a facility astride an active (Quaternary) fault, in the western U.S., unless possibly there were unequivocal evidence that the fault could be demonstrated as not capable.

Because of the licensing delays that almost certainly will develop if this issue f active and capable faults is not clarified, the NRC should consider providing more specific, early guidance on how known capable and/or active faults underlying, bounding and/or transecting a repository will be considered in meeting the requirements of 10 CFR Part 60. If the existence of capable and/or active faults underlying, bounding and/or transecting a repository is unacceptable to the NRC, as the reactor siting situation might suggest it should be, then potential repository sites where such conditions exist can be removed quickly from further consideration.

SPECIFIC COMMENTS:

Page 2, line 1 - Use of the term "coseismic" is too limiting in the sense that the term could be interpreted to exclude appropriate consideration of synthetic faulting.

Page 2, par. 1, final sentence - A number of terms important to understanding 10 CFR Part 100, Appendix A, 10 CFR Part 60, and their interrelationships, as discussed in this Technical Position, should be included in the glossary, eg. active fault, seismotectonic province, site region, and operations area.

Page 5, par. 1, final sentence - Documentation is provided on how 10 CFR Part 100, Appendix A and 10 CFR Part 40 are linked.

There should be an explanation of why this approach is not taken with 10 CFR Part 60.

Page 5, par. 2, first sentence - It is stated that 10 CFR Part 60 does not specifically rely on 10 CFR Part 100, Appendix A for guidance regarding provisions for dealing with seismic hazards. This is in apparent conflict with the Technical Position, on page 7, which states that the NRC staff will rely on the principles of 10 CFR Part 100, Appendix A in its review of whether the requirements of 10 CFR Part 60 are met. This appearance of conflict should be clarified and resolved.

Page 5, par. 2, first sentence - It is stated that 10 CFR Part 60 does not specifically require the development of a design basis earthquake. However, the Technical Position (page 7) and the following text strongly imply that a design basis earthquake (maximum vibratory ground motion) will be required. This ambiguity should be resolved, and there should be a specific statement of the kind of design basis earthquake (eg. SSE equivalent) that will be required.

Page 7, final sentence - This statement incorporates the 10 CFR 60 requirement to design the operations area in a manner so as to preserve the preclosure option of waste retrieval. Allowing for the existence of capable and active faults within the repository seems to be in direct conflict with this requirement. Designing to accommodate a fault rupture that isolates a part of the subsurface operations area from surface access will present extreme difficulties and likely result in a compromise of safety.

Page 6, par.2, first sentence - This sentence should be rewritten to reflect the 10 CFR Part 60 language regarding selection of the geologic setting and design of the remaining elements. The geologic setting cannot be designed to limit releases to the accessible environment.

Pages 12 and 13 - For purposes of evaluating a geologic repository site, application of the general limitation of investigations of surface faulting to faults only within five miles of the site is arbitrary and excessively restrictive, as it neglects the fact that faults may be linked in space and time, especially over the time period that must be considered. To understand the seismic behavior of a single fault, or set of faults commonly requires a thorough understanding of the entire system of faults, regardless of their exact distance from the site under consideration.

Page 14, par. 1 - It seems a bit cavalier to dismiss so easily the need for determination of an Operating Basis Earthquake (OBE). The text seems to imply that risk to onsite personnel is unimportant and that there is no risk to the public in this context. Simply qualitatively comparing the level of risk of a repository containment failure to that of a reactor under earthquake conditions does not justify the assumption of no significant consequence. This is especially true, given the allowed possibility of a capable fault within the repository creating a gross and uncontrollable loss of containment.

Page 15, par. 1, first sentence - Underground facilities important to safety should be included among elements that can be affected by faulting in a geologic repository.

Page A-1 - See earlier comment regarding the Glossary.

Page A-3, par. 1 - At some point in the Technical Position, there should be a clear statement that, in the context of a geologic repository, generalizations regardirg whether pre-Quaternary faults are capable faults are an unacceptable basis for excluding the need for rigorous investigation of existing "geologically old" faults.

Page C-1 - The purpose of including an outline of 10 CFR Part 100, Appendix A, without supporting text is not clear. An annotated outline which may include summaries of past experiences (case histories) with 10 CFR Part 100, Appendix A, and references would be much more useful than the bare outline.

We appreciate the opportunity to review and provide comment on the subject draft Technical Position. If there are questions regarding these comments, please do not hesitate to contact this office.

Sincerely,

Robert R. Loux
Executive Director

RRL/CAJ/cs

DRAFT

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STAFF TECHNICAL POSITION ON

INVESTIGATIONS TO IDENTIFY FAULT DISPLACEMENT

AND SEISMIC HAZARDS AT A GEOLOGIC REPOSITORY

***

Revised Public Comment Draft - January 1991

Michael E. Blackford
Keith I. McConnell

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PREFACE

(To be prepared)

ABSTRACT

The U.S. Nuclear Regulatory Commission staff considers that a deterministic approach to investigations of fault displacement and seismic phenomena should be applied to geologic repository investigations. Further, the staff considers that the approach taken in this technical position to investigations for fault displacement and seismic phenomena is appropriate for the collection of sufficient data for input to analyses of the fault displacement and seismic hazards, both for the preclosure period and for the period after permanent closure.

Section 2.0 of this staff technical position describes the 10 CFR Part 60 requirements that form the basis for investigations to describe the fault displacement and seismic hazards at a geologic repository. Staff technical position statements and corresponding discussions are presented in Sections 3.0 and 4.0 respectively. Staff technical positions are organized according to the following topics: (1) investigation considerations, (2) investigations for fault displacement hazard, and (3) investigations for vibratory ground motion hazard.

DRAFT

CONTENTS

CONTENTS (continued)

STAFF TECHNICAL POSITION ON INVESTIGATIONS TO IDENTIFY FAULT DISPLACEMENT AND SEISMIC HAZARDS AT A GEOLOGIC REPOSITORY

1.0 INTRODUCTION

According to 10 CFR Part 60 (see Ref. 1), the applicant for a license to dispose of high-level radioactive waste (HLW) at a geologic repository shall investigate potential fault displacement and seismic or vibratory ground motion hazards that may affect the design, operation, and performance of the geologic repository. However, 10 CFR Part 60 does not specify the manner in which these fault displacement and seismic hazards are to be investigated. The purpose of this Staff Technical Position (STP), therefore, is to provide regulatory guidance to the U.S. Department of Energy (DOE) on appropriate investigations that can be used to identify fault displacement and seismic hazards at a geologic repository. The terms "fault displacement" and "seismic hazards," as used in this STP, are limited to the hazards resulting from fault displacement and vibratory ground motion that can affect the design and performance of the geologic repository.

The objective of the investigations is to provide information needed for both deterministic and probabilistic analyses of the fault displacement and seismic hazards. Ultimately, these investigations provide input to the determination of the design bases of fault displacement and vibratory ground motion that need to be taken into account for the design of structures, systems, and components, of a geologic repository, that are important to safety, containment, or waste isolation. Consideration of the geologic history of faults, in the geologic settings that are thought to be capable of generating earthquakes and displacement, in accordance with criteria described in this STP, contributes to the determination of the most severe earthquakes and displacement that are likely to be associated with these faults. Likewise, the design basis for both the maximum vibratory ground motion and the expected vibratory ground motion reflects the seismology, geology, and the seismic and geologic history of the site and the surrounding region. Consideration of historical earthquakes that can be associated with tectonic structures or with the geologic setting, and other factors, can help to identify the most severe earthquakes associated with these features. An analysis of the information acquired through the investigations should lead to an estimation of the rates of fa lt displacement and of seismic activity. Knowledge of such rates and of the fault and seismic characterisics of the site and the geologic setting is fundamental to the development of design bases.

In general terms, this STP draws on experience gained in applying the concepts in Appendix A of 10 CFR Part 100 (see Ref. 2), to establish appropriate investigations for providing input for the determination of design basis fault displacement and vibratory ground motion hazards for a geologic repository. Certain parts of Appendix A of 10 CFR Part 100, with modification, are appropriate for addressing the investigations of the fault displacement and seismic hazard at a geologic repository.

This STP does not address fault displacement analysis or seismic hazard analysis; guidance on these analyses will be treated separately. Furthermore, it does not address the interpretation of the "anticipated processes and events" and "unanticipated processes and events" concepts, as defined in 10 CFR Part 60. Also, this STP does not address the effects of fault displacement on ground water. Finally, the criteria contained in this STP do not address investigations of volcanic or volcano-tectonic phenomena for candidate sites located in areas of such activity. Guidance on the investigation of the volcano-tectonic aspects of such sites also is being considered separately. It is emphasized here that this position in no way suggests deferring to Appendix A of 10 CFR Part 100 for guidance in addressing the fault displacement and seismic hazards at a geologic repository. This is particularly true for those sections of Appendix A of 10 CFR Part 100 that address the determination of the need to design for fault displacement and the design bases for vibratory ground motion.

STPs are issued to describe and make available to the public criteria for methods acceptable to the Nuclear Regulatory Commission (NRC) staff, for implementing specific parts of the Commission's regulations, or to provide guidance to the DOE. STPs are not substitutes for regulations, and compliance with them is not required. They suggest one approach that is acceptable to the staff for meeting regulatory requirements. Methods and solutions differing from those set out in the STP will be acceptable if they provide a basis for the findings requisite to the issuance or continuance of a permit or license by the Commission. Published STPs will be revised, as appropriate, to accommodate comments and to reflect new information and experience. In addition, the staff will review in detail the information provided by DOE in light of Standard Format and Content Guide(s) currently being developed by the staff in preparation for license applications and such other guidance and regulatory documents (for example, those detailing quality assurance requirements) as may have been provided to the public and the DOE.

2.0 REGULATORY BACKGROUND

The criteria set forth in 10 CFR 60.21(c)(1)(ii) form the basis for investigations to describe the fault displacement and seismic hazards at a geologic repository operations area. The following is an excerpt of the appropriate text of 10 CFR 60.21(c)(1)(ii):

> "§60.21(c) The Safety Analysis Report shall include: (1) A description and assessment of the site at which the proposed geologic repository operations area is to be located with appropriate attention to those features of the site that might affect geologic repository operations area design and performance. The description of the site shall identify the location of the geologic repository operations area with respect to the boundary of the accessible environment.
> (i) The description of the site shall also include the following information regarding subsurface conditions. This

description shall, in all cases, include such information with respect to the controlled area [see glossary]. In addition, where subsurface conditions outside the controlled area may affect isolation within the controlled area, the description shall include such information with respect to subsurface conditions outside the controlled area to the extent such information is relevant and material...." (ii) The assessment shall contain: (A) An analysis of the geology [and] geophysics ... of the site[.]"

This description and analysis must be in sufficient depth to support the assessment of the effectiveness of engineered and natural barriers (10 CFR 60.21(c)(1)(ii)(D)), as well as the analysis of design and performance requirements for structures, systems, and components important to safety (10 CFR 60.21(c)(3)).

Performance objectives, siting, and design criteria described in 10 CFR Part 60 establish the bases for considering the fault displacement and seismic hazard for the preclosure and postclosure periods. According to 10 CFR 60.111, during the preclosure period, the geologic repository operations area is to be designed to provide protection against radiation exposures and releases of radioactive material in accordance with standards set forth in 10 CFR Part 20 (see Ref. 3). Also, during the preclosure period, 10 CFR 60.111 requires that the geologic repository operations area be designed so that the option to retrieve the emplaced radioactive waste is preserved. 10 CFR 60.131(b)(1) states that structures, systems, and components important to safety be designed so that natural phenomena and environmental conditions expected at the geologic repository operations area will not interfere with necessary safety functions.

It is expected that much of the information gathered to support the fault displacement and seismic hazard evaluation required by 10 CFR 60.131(b)(1), for the preclosure period, can also be used to support fault displacement and seismic hazard evaluation, after permanent closure, with due consideration given to the uncertainties associated with projections over a much longer period of postclosure performance.

Unlike other nuclear facilities that handle, process, or use high-level radioactive materials, a geologic repository is unique in that it is a facility that not only processes the material, but also becomes the site of the final disposal of this material. Other nuclear facilities, once they have served their usefulness, are decommissioned, and radioactive material associated with the facility is removed to appropriate disposal facilities, including a geologic repository. The investigations performed to address the requirements of 10 CFR 60.131(b)(1) should be conducted concurrently with investigations for postclosure evaluations, such as the potentially adverse conditions regarding the fault displacement and seismic hazards found in 10 CFR 60.122(c)(12), 60.122(c)(13), and 60.122(c)(14), and the fault displacement conditions addressed in 10 CFR 60.122(c)(3), 60.122(c)(4), and 60.122(c)(11). These potentially adverse conditions are to be addressed according to the provisions of 10 CFR 60.122(a)(2).

3.0 STAFF TECHNICAL POSITIONS

It is the NRC staff's position that a deterministic approach to investigations of fault displacement and seismic phenomena, defined in detail in succeeding parts of this section, should be applied to geologic repository investigations. Further, it is the position of the staff that the approach to investigations for fault displacement and seismic phenomena described in this section is appropriate for the collection of sufficient data for input to analyses of the fault displacement and seismic hazards, both for the preclosure period and for the period after permanent closure.

3.1 Investigation Considerations

This section provides guidance on the "Identification of the Region to be Investigated," and the "Identification of Faults in the Geologic Setting

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Susceptible to Displacement," that form the basis for more detailed investigations described by the technical positions in Sections 3.2 and 3.3.

3.1.1 Identification of the Region to be Investigated.

The size of the region to be investigated should be determined by the nature of the proposed site's geologic setting. For the purposes of the identification of faults susceptible to displacement, the term "geologic setting" applies to both preclosure and postclosure periods. With respect to the identification of fault displacement hazard, the identification process should be based on a review of the pertinent literature and relevant field investigations, and the consideration of alternative tectonic models. Technical position 3.3 provides specific guidance on the size of the area for which historical data are to be compiled in the identification of seismic hazards.

3.1.2 Identification of Faults in the Geologic Setting Susceptible to Displacement.

The purpose of this technical position is to provide DOE with an acceptable approach for identifying those faults in the geologic setting that should be considered for further investigation. These faults are termed faults susceptible to displacement ("susceptible" fault). The staff defines a fault within the geologic setting susceptible to displacement, as one that (a) has had movement within the Quaternary Period; or (b) has seismicity, instrumentally determined with records of sufficient precision, that suggests a direct relationship with the fault; or (c) is oriented such that it is subject to failure in the existing stress field; or (d) has a structural relationship (i.e., movement on one fault could cause movement on another) to a fault that meets one or more of the forementioned criteria.

An acceptable approach to the the identification of "susceptible" faults should include:

(1) Consideration of geologic conditions of the geologic setting, such as its lithology, stratigraphy, structural geology, stress field, and geologic history;

(2) Determination of existence of Quaternary-age displacement on faults within the geologic setting;

(3) Consideration of alternative tectonic models; and

(4) Listing of all historically reported earthquakes that can reasonably be associated with faults, any part of which is within the geologic setting, including date of occurrence and the following measured or estimated data: magnitude or highest intensity, and a plot of the epicenter or region of highest intensity.

3.2 Investigations for Fault Displacement Hazard.
The investigations described in this section together with the investigations described in subsection 3.1.2 should be sufficient to provide input for the determination of the design basis fault displacement related to structures, systems, and components important to safety, containment, or waste isolation in the surface and underground facilities; these investigations apply to both faults expressed at the surface and those faults with no surface expression.

3.2.1 Investigation of Faults Susceptible to Displacement.
Following the identification of faults susceptible to displacement, consideration should be given to which "susceptible" faults need to undergo further investigation. "Susceptible" faults inside the controlled area should be investigated in detail, based on the approach described in subsection 3.2.2. For "susceptible" faults outside of the controlled area, iterative assessments of their possible impact on structures, systems, and components important to safety, containment, or waste isolation can be used as screening criteria for determining the need for detailed investigation. Those "susceptible" faults outside the controlled area to be investigated in detail should also be investigated based on the approach described in subsection 3.2.2.

3.2.2 Detailed Investigation of "Susceptible" Faults.
An acceptable approach to the detailed investigation of "susceptible" faults should include:

(1) Character of the fault or fault zone, including its length, width, and three-dimensional geometry;

(2) Relationship of the fault to other tectonic structures in the controlled area and the geologic setting;

(3) Nature, amount, and geologic history of displacements along the fault, including particularly the estimated amount of Quaternary-age displacement; and

(4) Correlation of hypocenters, or locations of highest ...tensity, of historically reported earthquakes with faults, any part of which is within the controlled area.

"Susceptible" faults encountered in the underground facility should be correlated with their expressions at the surface. If "susceptible" faults encountered in the underground facility cannot be correlated with surface expressions, then investigations should be performed in accordance with this subsection. Finally, for "susceptible" faults in the controlled area and those selected from beyond the controlled area for detailed investigation, the investigations should also include consideration of alternative tectonic models at the scale of the controlled area or larger area, as appropriate.

3.3 Investigations for Vibratory Ground Motion Hazard.

The investigations described in this section should be conducted to obtain information needed to provide input for the analysis of the vibratory ground motion. In addition to the investigations described in item (1) of technical position 3.1.2, an acceptable vibratory ground motion hazard investigation should also include the following:

(1)(a) Listing of all historically reported earthquakes that have affected or that could reasonably be expected to have affected the site, including the date of occurrence and the following measured or estimated data: magnitude or highest intensity, and a plot of the epicenter or location of highest intensity. Where historically reported earthquakes could have caused a maximum ground acceleration of at least one-tenth the acceleration of gravity (0.1g) to the site, the acceleration or intensity, time history, and duration of ground-shaking at these facilities should also be estimated. (Since earthquakes have been reported in terms of various parameters such as magnitude, intensity at a given location, and effect on ground, structures, and people at a specific location, some of these data may have to be estimated by use of appropriate empirical relationships. Measured data are preferable to estimated data, when available.); and

(1)(b) A description of the comparative characteristics of the material underlying the epicentral location or region of highest intensity, and of the material underlying the site in transmitting earthquake vibratory motion. Investigations in this regard should include:

(i) A determination of the static and dynamic engineering properties of the materials underlying the site, as well as an assessment of the properties needed to determine the behavior of the underlying materials during earthquakes, and the characteristics of the underlying materials in transmitting earthquake-induced motions to those structures, systems, and components important to safety, containment, or waste isolation, such as seismic wave velocities, density, water content, porosity, and strength; and

(ii) An assessment of the physical evidence concerning the behavior, during prior earthquakes, of the surficial geologic materials and the substrata underlying the site from the lithologic, stratigraphic, and structural geologic studies described by technical position 3.1.2;

(2) Determination of regional attenuation of vibratory ground motion;

(3) Correlation of epicenters or locations of highest intensity of historically reported earthquakes, where possible, with tectonic structures, any part of which is located within 200 miles of the site. Epicenters or locations of highest intensity that cannot be reasonably correlated with tectonic structures should be associated with seismic source zones, any part of which is located within 200 miles of the site;

(4) Determination of which "susceptible" faults may be of importance in determining the design basis vibratory ground motion. The "susceptible" faults that should be studied are those faults that could generate the equivalent of 0.1g or greater maximum ground acceleration at the location of the controlled area; and

(5) Determination of the fault parameters described in Subsection 3.2 for those "susceptible" faults that may be of importance in establishing the design basis vibratory ground motion.

It should be noted that vibratory ground motion determinations for a point on the surface using accepted attenuation functions, which are typically derived from surface observations, will generally be conservative for the underground facility beneath the surface point (except for cases of unusual channeling of the motion). However, if "susceptible" faults are located such that there is a potential for vibratory ground motion to impact the underground facility, investigations should be undertaken to determine if areas exist, within the underground facility, where vibratory ground motion at depth would be higher than at the surface. If feasible, vibratory ground motion should be monitored as early as possible during the site characterization phase of investigations, both on the surface above the proposed underground facility and at the level of the proposed underground facility itself, to observe possible differences in the motion between these locations. Observed differences should be used to estimate the vibratory ground motion attenuation with depth.

4.0 DISCUSSION

The reader of this STP will find that the elements of investigation presented in Sections 3.2 and 3.3 are similar to the elements presented in Section IV of Appendix A of 10 CFR Part 100. The NRC staff could have adopted Appendix A of 10 CFR Part 100 for guidance concerning seismic and geologic criteria, as it has done in 10 CFR Part 40 (see Ref. 4) with regard to tailings dams for uranium processing mills or in 10 CFR Part 72 (see Ref. 5) with regard to independent spent fuel storage installations or monitored retrievable storage systems. However, Appendix A of 10 CFR Part 100 was not adopted because of the inherent differences between nuclear power plants and a geologic repository. For example, the very long performance period following permanent closure at a geologic repository results in significant differences between preclosure and postclosure performance assessment requirements; requirements not addressed by the investigative approaches described in 10 CFR Part 100, Appendix A.

The following discussion parallels the list of technical positions given in Section 3.0.

4.1 Investigation Considerations.

This section provides supporting discussion for the identification of the region to be investigated and the concept of "susceptible" fault.

4.1.1 Identification of the Region to be Investigated.

The areal extent of the region to be investigated should be such that the geologic and seismic characteristics are understood in sufficient detail so as to permit an evaluation of the proposed site, to provide sufficient information to support the determinations based on these investigations, and to provide input for engineering solutions to actual or potential geologic and seismic effects at the proposed site.

4.1.2 Identification of Faults in the Geologic Setting Susceptible to Displacement.

The concept of "susceptible" fault is based on 10 CFR Part 60 requirements, and builds on past regulatory experience (10 CFR Part 100, Appendix A). For the purposes of this STP, the definition of a "susceptible" fault serves only as an indicator (i.e., investigative tool) to identify faults to be considered for investigation. The term "capable fault," as defined in 10 CFR Part 100, Appendix A, was not used in this STP because "capable fault" was originated to help define the hazard posed to nuclear power facilities and thus was developed in a substantially different context than HLW repository performance. In contrast to "susceptible" fault, as defined in this STP, "capable fault" was used as a site suitability tool, with established criteria under which nuclear power station sites that include capable faults are not considered suitable (see Refs. 6 and 7).

After an assessment of existing geologic data and alternative tectonic models for the site, faults within the geologic setting that meet one, several, or all of the criteria listed in the aforementioned technical position 3.1.2 would be designated as "susceptible" faults. The identification of "susceptible" faults is considered to be an iterative process in that faults recognized during the characterization process must be evaluated using the criteria established in technical position 3.1.2. Where it is impossible to clearly demonstrate that faults are not "susceptible to displacement" under the criteria listed in technical position 3.1.2, these faults should be assumed to be susceptible to displacement. Faults or fault zones that are clearly demonstrated to not meet any of the criteria for "susceptible" faults would generally require no further investigation, under the guidance provided by the technical positions in Section 3.2.

This STP does not provide specific limits on the dimensions of "susceptible" faults that require investigation. DOE is afforded the flexibility to demonstrate that displacement along "susceptible" faults of a certain dimension will not adversely affect the performance of structures, systems, and components of a geologic repository important to safety, containment, or waste isolation. "Susceptible" faults that fall in this category will require no further investigation, under the guidance in this STP. Consequently, the staff's concept of "susceptible" fault is considered to be size-independent.

The definition of "susceptible" fault considers the Quaternary Period as the basic time increment for the determination of fault significance. The staff does not believe that the use of this time increment as a baseline for characterization is unnecessarily conservative. The use of the entire Quaternary record in characterization activities is based on requirements of 10 CFR Part 60 and supported by the staff analysis of public comments on the draft of 10 CFR Part 60 (see page 373 in Ref. 8). Based on this analysis, it was concluded that in regard to the investigation of potentially adverse conditions, "...all that is important is that processes 'operating during the Quaternary Period' be identified and evaluated...." (48 FR 28211; dated June 21, 1983). The use of the entire Quaternary record also reflects technical points of view such as those expressed by Allen (see Ref. 9), who indicates that "...the distribution of faults with Quaternary displacements seems to be a valid general guide to modern seismicity" and "... understanding the Quaternary Period is much more important than understanding earlier periods, and this is where attention should first be concentrated." In addition, Hays (see Ref. 10) indicates that "...stratigraphic offset of Quaternary deposits by faulting is indicative of an active fault." Finally, consideration of the record for the entire Quaternary Period is necessary to ensure that faults having long recurrence intervals (i.e., greater than 100,000 years) will be investigated.

The definition of "susceptible" fault is not intended to preclude an examination of the pre-Quaternary record. An assessment of the pre-Quaternary movement history may be needed to establish whether temporal or spatial clustering of fault activity is of importance to the repository. DOE is afforded the flexibility to determine the need or lack of need for an examination of the pre-Quaternary record of fault movements.

The definition of "susceptible" fault also incorporates a criterion that a fault is "susceptible" if it is susceptible to failure in the existing stress regime. This criterion reflects two separate conditions. First, this criterion reflects situations where the existing stress regime is interpreted to suggest that faults that trend in certain directions (i.e., favorably-oriented faults) are in a state of incipient failure. An example of this occurs at the proposed repository site at Yucca Mountain where Rogers and others (see Ref. 11) have indicated that faults in the region with azimuths ranging from about north to east-northeast should be considered favorably oriented for activation in the current stress regime. The second condition reflected by this criterion is the possible perturbations to the stress regime by the emplaced radioactive waste. In the iterative process of the identification of "susceptible" faults in the underground facility, the term "existing stress regime" is intended to include the stress regime that will exist in the repository after the emplacement of radioactive waste. Therefore, the effect(s) of emplaced radioactive waste should be considered in the identification of, and further study of "susceptible" faults in the underground facility.

It is emphasized that of the criteria for definition of "susceptible" faults, documented evidence of movement within the Quaternary Period is the most important criterion with respect to determining the significance of a fault to the repository. In cases where documentation of movement in the Quaternary Period is lacking or accompanied by high levels of uncertainty, the other criteria for the identification of "susceptible" faults should be considered.

4.2 Investigations for Fault Displacement Hazard.

All faults that are susceptible to displacement are not equally hazardous. Thus, the level of investigation can vary from that sufficient for the purpose of identification (such as stated in technical position in subsection 3.1.2) to that sufficient as input for the determination of design fault displacement (such as stated by the technical positions in Section 3.2). "Susceptible" faults in the controlled area for which it can be clearly demonstrated that they will not adversely affect the performance of a geologic repository can be investigated in lesser detail than those faults that may adversely affect the performance of structures, systems, and components of the repository. DOE also is afforded the flexibility to demonstrate that displacement along " susceptible" faults outside the controlled area will not adversely affect the performance of structures, systems, and components of a geologic repository important to safety, containment, or waste isolation, and thus these faults will require no further investigation under guidance in this STP.

It is unlikely that fault displacement could occur at the surface above an underground facility without also occurring within the underground facility. If, however, faults are encountered in the underground facility, it may be impractical to study such faults in the manner described in Section 3.2. Instead, special emphasis should be given to the nature of the fault trace, its extent as observed in other openings, and its orientation relative to the trends of faults identified as "susceptible" faults in the vicinity of the underground facility.

4.3 Investigations for Vibratory Ground Motion.

A key element driving the investigations for vibratory ground motion is the peak horizontal accelera.ion value of 0.1g, below which the staff does not have a regulatory concern. Using 0.1g as a discriminator to determine the scope of investigations to be undertaken or the type of information to be gathered, facilitates the use of various relationships between maximum ground acceleration and parameters of interest. It should not be construed that maximum ground acceleration alone provides the necessary input for the determination of the design basis vibratory ground motion. A value of 0.1g is reasonable when considering the uncertainties encountered in the earthquake data base as well as in the various relationships that have been derived for earthquakes and faulting. This value has been cited in a number of regulatory and guidance documents as a discriminator for the minimum value of consideration for the determination of design basis earthquakes and is so used here. (For example, see section IV, "Required Investigations" in 10 CFR Part 100, Appendix A.)

The 200-mile radius, within which earthquakes should be correlated with structures or associated with seismic source zones, was chosen because this distance approximates the distance at which the peak horizontal acceleration due to the largest ear[illegible]es expected in the contiguous United States would be attenuated to 0.1g. In a similar fashion, the "susceptible" faults that should be studied are those faults that lie within circles, centered on the location of the controlled area, whose radii are a function of earthquake magnitude and the vibratory ground motion attenuation determined for the region. Each radius represents the distance at which vibratory ground motion of a particular magnitude earthquake would be attenuated to the equivalent of 0.1g, the acceleration of minimum concern at the location of the controlled area.

It is generally observed that vibratory ground motion at depth is less than that observed on the surface above the underground observation point for sources at some distance from the observation points (see Ref. 12). Obviously, if the underground facility is to encompass "susceptible" faults, and these faults experience movement resulting in earthquakes, then there will exist some zone surrounding the faults where vibratory ground motion might exceed that experienced at the surface. For such vibratory ground motion, it might be necessary to identify the extent of zones of potentially higher vibratory ground motion that may exist in the underground facility.

5.0 REFERENCES

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2. U.S. Code of Federal Regulations, "Seismic and Geologic Siting Criteria for Nuclear Power Plants," Chapter 10, Part 100, Appendix A, January 1990.

3. U.S. Code of Federal Regulations, "Standards for Protection against Radiation," Chapter 10, Part 20, January 1990.

4. U.S. Code of Federal Regulations, "Environmental Radiation Protection Standards for the Management and Disposal of Spent Nuclear Fuel, High-Level and Transuranic Radioactive Wastes," Chapter 40, Part 191, January 1988.

5. U.S. Code of Federal Regulations, "Licensing Requirements for the Storage of Spent Fuel in an Independent Spent Fuel Storage Installation (ISFSI)," Chapter 10, Part 72, January 1988.

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GLOSSARY

As used in this guidance:

"Controlled Area" means a surface location, to be marked by suitable monuments, extending horizontally no more than 10 kilometers in any direction from the outer boundary of the underground facility, and the underlying subsurface, which area has been committed to use as a geologic repository and from which incompatible activities would be restricted following permanent closure (10 CFR Part 60).

"Fault susceptible to displacement" is a fault in the geologic setting that:

a) has had movement within the Quaternary; or
b) has seismicity, instrumentally determined, with records of sufficient precision to demonstrate a direct relationship with the fault; or
c) is oriented such that it is subject to failure in the existing stress field; or
d) has a structural relationship to a fault that meets one or more of the above criteria.

"Geologic Setting" means the geologic, hydrologic, and geochemical systems of the region in which a geologic repository operations area is or may be located (10 CFR Part 60).

"Seismic hazard" is a set of conditions, based on the potential for the occurrence of earthquakes, that might operate against the health and safety of the public. Seismic hazard may be characterized in either deterministic or probabilistic terms.

"Site" means the location of the controlled area (10 CFR Part 60).

APPLICABLE 10 CFR PART 60 REGULATIONS

10 CFR 60.21(c)(1)

(c) The Safety Analysis Report shall include:

(1) A description and assessment of the site at which the proposed geologic repository operations area is to be located with appropriate attention to those features of the site that might affect geologic repository operations area design and performance. The description of the site shall identify the location of the geologic repository operations area with respect to the boundary of the accessible environment.

(i) The description of the site shall also include the following information regarding subsurface conditions. This description shall, in all cases, include such information with respect to the controlled area. In addition, where subsurface conditions outside the controlled area may affect isolation within the controlled area, the description shall include such information with respect to subsurface conditions outside the controlled area to the extent such information is relevant and material.

(ii) The assessment shall contain:

(A) An analysis of the geology [and] geophysics ... of the site[.]

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[The assessment of the site at which the proposed geologic repository operations area is to be located, that is to be included in the Safety Analysis Report of the license application, shall contain:]

(C) An evaluation of the performance of the proposed geologic repository for the period after permanent closure, assuming anticipated processes and events, giving the rates and quantities of releases of radionuclides to the accessible environment as a function of time; and a similar evaluation which assumes the occurrence of unanticipated processes and events.

§60.21(c)(3)

[The Safety Analysis Report of the license application shall include:] (3) A description and analysis of the design and performance requirements for structures, systems, and components of the geologic repository which are important to safety. This analysis shall consider -- (i) The margins of safety under normal conditions and under conditions that may result from anticipated operational occurrences, including those of natural origin; and (ii) the adequacy of structures, systems, and components provided for the prevention of accidents and mitigation of the consequences of accidents, including those caused by natural phenomena.

§60.111, Performance of the geologic repository operations area through permanent closure.

(a) Protection against radiation exposures and releases of radioactive material. The geologic repository operations area shall be designed so that until permanent closure has been completed, radiation exposures and radiation levels, and releases of radioactive materials to unrestricted areas, will at all times be maintained within the limits specified in Part 20 of this chapter and such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency.

(b) Retrievability of waste. (1) The geologic repository operations area shall be designed to preserve the option of waste retrieval throughout the period during which wastes are being emplaced and, thereafter, until the completion of a performance confirmation program and Commission review of the information obtained from such a program. To satisfy this objective, the geologic repository operations area shall be designed so that any or all of the emplaced waste could be retrieved on a reasonable schedule starting at any time up to 50 years after waste emplacement operations are initiated, unless a different time period is approved or specified by the Commission. This different time period may be established on a case-by-case basis consistent with the emplacement schedule and the planned performance confirmation program.

(2) This requirement shall not preclude decisions by the Commission to allow backfilling part or all of, or permanent closure of, the geologic repository operations area before the end of the period of design for retrievability.

(3) For purposes of this paragraph, a reasonable schedule for retrieval is one that would permit retrieval in about the same time as that devoted to construction of the geologic repository operations area and the emplacement of wastes.

§60.112, Overall system performance objective for the geologic repository after permanent closure.

The geologic setting shall be selected and the engineered barrier system and the shafts, boreholes and their seals shall be designed to assure that releases of radioactive materials to the accessible environment following permanent closure conform to such generally applicable environmental standards for radioactivity as may have been established by the Environmental Protection Agency with respect to both anticipated processes and events and unanticipated processes and events.

§60.113, Performance of particular barriers after permanent closure.

(a) General provisions -- (1) Engineered barrier system. (i) The engineered barrier system shall be designed so that assuming anticipated processes and events: (A) Containment of HLW will be substantially complete during the period when radiation and thermal conditions in the engineered barrier system are dominated by fission product decay; and (B) any release of radionuclides from the engineered barrier system shall be a gradual process which results in small fractional releases to the geologic setting over long times. For disposal in the saturated zone, both the partial and complete filling with ground water of available void spaces in the underground facility shall be appropriately considered and analyzed among the anticipated processes and events in designing the engineered barrier system.

(ii) In satisfying the preceding requirement, the engineered barrier system shall be designed, assuming anticipated processes and events, so that:

(A) Containment of HLW within the waste packages will be substantially complete for a period to be determined by the Commission taking into account the factors specified in 10 CFR 60.113(b) provided, that such period shall be not less than 300 years nor more than 1,000 years after permanent closure of the geologic repository; and

(B) The release rate of any radionuclide from the engineered barrier system following the containment period shall not exceed one part in 100,000 per year of the inventory of that radionuclide calculated to be present at 1,000 years following permanent closure, or such other fraction of the inventory as may be approved or specified by the Commission; provided, that this requirement does not apply to any radionuclide which is released at a rate less than 0.1 percent of the calculated total release rate limit. The calculated total release rate limit shall be taken to be one part in 100,000 per year of the inventory of radioactive waste, originally emplaced in the underground facility, that remains after 1,000 years of radioactive decay.

(2) Geologic setting. The geologic repository shall be located so that pre-waste-emplacement ground water travel time along the fastest path of likely radionuclide travel from the disturbed zone to the accessible environment shall be at least 1,000 years or such other travel time as may be approved or specified by the Commission.

(b) On a case-by-case basis, the Commission may approve or specify some other radionuclide release rate, designed containment period or pre-waste-emplacement ground-water travel time, provided that the overall system performance objective, as it relates to anticipated processes and events, is satisfied. Among the factors that the Commission may take into account are:

(1) Any generally applicable environmental standard for radioactivity established by the Environmental Protection Agency;

(2) The age and nature of the waste, and the design of the underground facility, particularly as these factors bear upon the time during which the thermal pulse is dominated by the decay heat from the fission products;

(3) The geochemical characteristics of the host rock, surrounding strata and ground water;and

(4) Particular sources of uncertainty in predicting the performance of the geologic repository.

(c) Additional requirements may be found to be necessary to satisfy the overall system performance objective as it relates to unanticipated processes and events.

<u>§60.122(a)(2), Siting Criteria.</u>

[Selected requirements considered directly or indirectly related to seismic hazard]

(2) If any of the potentially adverse conditions specified in paragraph (c) [§60.122(c)] of this section is present, it may compromise the ability of

the geologic repository to meet the performance objectives relating to the isolation of waste. In order to show that a potentially adverse condition does not so compromise the performance of the geologic repository the following must be demonstrated:

(i) The potentially adverse human activity or natural condition has been adequately investigated, including the extent to which the condition may be present and still undetected taking into account the degree of resolution achieved by the investigations; and

(ii) The potentially adverse human activity or natural condition on the site has been adequately evaluated using analyses which are sensitive to the potentially adverse human activity or natural condition and assumptions which are not likely to underestimate its effect; and

(iii)(A) The potentially adverse human activity or natural condition is shown by analysis pursuant to paragraph (a)(2)(ii) of this section not to affect significantly the of the geologic repository to meet the performance objectives relating to the isolation of waste, or

(B) The effect of the potentially adverse human activity or natural condition is compensated for by the presence of a favorable combination of the favorable characteristics so that the performance objectives relating to the isolation of waste are met, or

(C) The potentially adverse human activity or natural condition can be remedied.

§60.122(c), Potentially adverse conditions.

[Selected conditions considered directly or indirectly related to seismic hazard]

(c) Potentially adverse conditions. The following conditions are potentially adverse conditions if they are characteristic of the controlled area or may affect isolation within the controlled area.....

(3) Potential for natural phenomena such as landslides, subsidence, or volcanic activity of such a magnitude that large-scale surface water impoundments could be created that could change the regional ground-water flow system and thereby adversely affect the performance of the geologic repository.

(4) Structural deformation, such as uplift, subsidence, folding, or faulting that may adversely affect the regional ground-water flow system.

(11) Structural deformation such as uplift, subsidence, folding, and faulting during the Quaternary Period.

(12) Earthquakes which have occurred historically that if they were to be repeated could affect the site significantly.

(13) Indications, based on correlations of earthquakes with tectonic processes and features, that either the frequency of occurrence or magnitude of earthquakes may increase.

(14) More frequent occurrence of earthquakes or earthquakes of higher magnitude than is typical of the area in which the geologic setting is located.

§60.131(b)(1), Protection against natural phenomena and environmental conditions.

[With respect to the general design criteria for the geologic repository operations area.]

(b) Structures, systems, and components important to safety -- (1) Protection against natural phenomena and environmental conditions. The structures, systems, and components important to safety shall be designed so that natural phenomena and environmental conditions anticipated at the geologic repository operations area will not interfere with necessary safety functions.

U.S. DEPARTMENT OF ENERGY

OCRWM

YUCCA MOUNTAIN

YUCCA MOUNTAIN SITE CHARACTERIZATION PROJECT

U.S. DEPARTMENT OF ENERGY PRELIMINARY COMMENTS ON FINAL DRAFT NRC STAFF TECHNICAL POSITION ON INVESTIGATIONS TO IDENTIFY FAULT DISPLACEMENT AND SEISMIC HAZARDS AT A GEOLOGIC REPOSITORY

PRESENTED AT

NRC-DOE TECHNICAL EXCHANGE

PRESENTED BY

DR. JERRY L. KING
ASSISTANT PROJECT MANAGER
SCIENCE APPLICATIONS INTERNATIONAL CORPORATION

DEPARTMENT OF ENERGY UNITED STATES OF AMERICA

FEBRUARY 20, 1991

UNITED STATES DEPARTMENT OF ENERGY

OUTLINE

1. GENERAL COMMENTS
2. WARM FUZZIES
3. MAJOR COMMENTS
4. OTHER COMMENTS
5. QUESTIONS

GENERAL COMMENTS

- DOE UNDERSTANDS STP APPLIES TO SITE CHARACTERIZATION ONLY, NOT DESIGN-BASIS DEVELOPMENT.

- DOE AGREES THAT A SINGLE APPROACH TO INVESTIGATING PRE- AND POST-CLOSURE SEISMIC HAZARDS IS APPROPRIATE. HOWEVER, DOE INTENDS TO USE DIFFERENT APPROACHES FOR DEVELOPING PRE- AND POST-CLOSURE DESIGN BASES.

- DOE WILL CAREFULLY REVIEW THE FINAL STP BEFORE TAKING ANY DECISION TO ENDORSE. HOWEVER, WITH A FEW EXCEPTIONS, THE DRAFT STP APPEARS TO BE CONSISTENT WITH DOE'S PUBLISHED PLANS FOR SITE CHARACTERIZATION.

WARM FUZZIES

- STP ACKNOWLEDGES BOTH DETERMINISTIC AND PROBABILISTIC ANALYSES OF SEISMIC HAZARDS WILL BE NEEDED. (§1.0, ¶2)

- STP "IN NO WAY SUGGESTS DEFERRING TO APPENDIX A OF 10 CFR PART 100 FOR GUIDANCE ...." (§1.0, ¶4)

- PART 100 "NOT ADOPTED BECAUSE OF THE INHERENT DIFFERENCES BETWEEN NUCLEAR POWER PLANTS AND A GEOLOGIC REPOSITORY." (§4.0, ¶4)

- NO LIMITS SET ON THE DIMENSIONS OF "SUSCEPTIBLE" FAULTS THAT REQUIRE INVESTIGATION. DOE CAN DEMONSTRATE THAT SAFETY PERFORMANCE WOULD NOT BE ADVERSELY IMPACTED BY DISPLACEMENT ON SMALL FAULTS. (§4.1.2, ¶2)

- "ALL FAULTS THAT ARE SUSCEPTIBLE TO DISPLACEMENT ARE NOT EQUALLY HAZARDOUS. THUS, THE LEVEL OF INVESTIGATION CAN VARY ...." (§4.2, ¶1)

MAJOR COMMENTS

- THE PROPOSED TERMINOLOGY IS UNACCEPTABLE. "SUSCEPTIBLE FAULT" CONVEYS THE IDEA OF A SIGNIFICANT PROBABILITY OF MOVEMENT, BUT MANY FAULTS WOULD MEET THE PROPOSED DEFINITION, AND YET HAVE AN EXTREMELY SMALL LIKELIHOOD OF MOVEMENT.

- DOE SUGGESTS THAT A GENERIC DESCRIPTION SUCH AS, "CANDIDATE FAULTS FOR CHARACTERIZATION," BE SUBSTITUTED FOR "SUSCEPTIBLE," AND THAT A FAULT SIZE AND DISTANCE CRITERION BE ADDED.

- DOE NEEDS TO KNOW WHETHER THE NRC STAFF INTENDS TO USE "SUSCEPTIBLE" FAULTS IN GUIDANCE ON DESIGN-BASIS DEVELOPMENT AND, IF SO, HOW. STATEMENT (§4.1.2, ¶2) THAT DOE SHOULD CONSIDER FAULTS TO BE "SUSCEPTIBLE" THAT CANNOT CLEARLY BE SHOWN TO NOT BE "SUSCEPTIBLE," DOES NOT APPEAR TO BE AIMED AT SITE CHARACTERIZATION.

MAJOR COMMENTS
(CONTINUED)

- "SUSCEPTIBLE" FAULTS ARE DEFINED TO HAVE ONE, SEVERAL, OR ALL OF: (A) QUATERNARY MOVEMENT, (B) SUGGESTIVE ASSOCIATION WITH RECORDED EARTHQUAKES, (C) FAVORABLE STRESS-FIELD ORIENTATION, OR (D) STRUCTURAL RELATIONSHIP TO A FAULT WITH A, B, OR C. IF A FAULT DOES NOT DISPLACE QUATERNARY MATERIAL, IT SHOULD HAVE TO MEET ONE OF THE REMAINING CRITERIA TO BE A CANDIDATE FOR FURTHER CHARACTERIZATION.

- THE STP STATES THAT ALL "SUSCEPTIBLE" FAULTS IN THE GEOLOGIC SETTING SHOULD BE IDENTIFIED (§3.1.1), BUT THAT THE DEGREE OF FURTHER CHARACTERIZATION CAN CONSIDER POTENTIAL IMPACTS ON SAFETY (§4.2). RELEVANCE TO SAFETY (E.G., MINIMUM FAULT LENGTH THAT COULD BE A CONCERN) SHOULD BE FACTORED INTO THE INITIAL EFFORT TO IDENTIFY FAULTS.

MAJOR COMMENTS

(CONTINUED)

- THE PROPOSED 200-MI RADIUS FOR CORRELATING EARTHQUAKES WITH STRUCTURES OR SOURCE ZONES IS INAPPROPRIATE:

  -- 200 MI WOULD ENCOMPASS THE PACIFIC/NORTH AMERICAN PLATE MARGIN, CLEARLY NOT IN THE GEOLOGIC SETTING OF THE SITE.

  -- IN THE <u>WESTERN</u> UNITED STATES, THE MAXIMUM DISTANCE FOR 0.1 g ON COMPETENT GROUND IS ABOUT 100 KM, NOT 200 MI.

OTHER COMMENTS

- §1.0, ¶2 REFERS TO "THE DESIGN BASIS FOR BOTH THE MAXIMUM VIBRATORY GROUND MOTION AND THE EXPECTED VIBRATORY GROUND MOTION," INFERRING THAT THESE ENTITIES SHOULD BE A BASIS FOR SEISMIC DESIGN. THESE TERMS ARE NOT DEFINED IN THE STP, AND DEVELOPMENT OF THE DESIGN BASIS IS NOWHERE ELSE DISCUSSED. SUGGEST DELETING REFERENCE.

- §4.1 AND §4.2 CONTAIN A NUMBER OF CLARIFYING STATEMENTS THAT WOULD BEST BE MOVED UP TO §3.2:

  -- "SUSCEPTIBLE" FAULTS IN CONTROLLED AREA THAT WILL NOT AFFECT PERFORMANCE CAN BE INVESTIGATED IN LESS DETAIL. (§4.2)

  -- "SUSCEPTIBLE" FAULTS TOO SMALL TO AFFECT PERFORMANCE REQUIRE NO FURTHER INVESTIGATION. (§4.1.2)

  -- RECOGNITION OF PRACTICALITIES OF INVESTIGATING FAULTS IN THE UNDERGROUND FACILITY (§4.2)

OTHER COMMENTS

(CONTINUED)

- §3.3(1)(a) STATES THAT TIME HISTORIES SHOULD BE ESTIMATED FOR HISTORICALLY REPORTED EARTHQUAKES THAT COULD HAVE CAUSED AT LEAST 0.1 g AT THE SITE. TIME HISTORIES NEED ONLY BE ESTIMATED FOR POTENTIAL EARTHQUAKES THAT MIGHT CONTROL THE DESIGN BASIS.

[illegible]

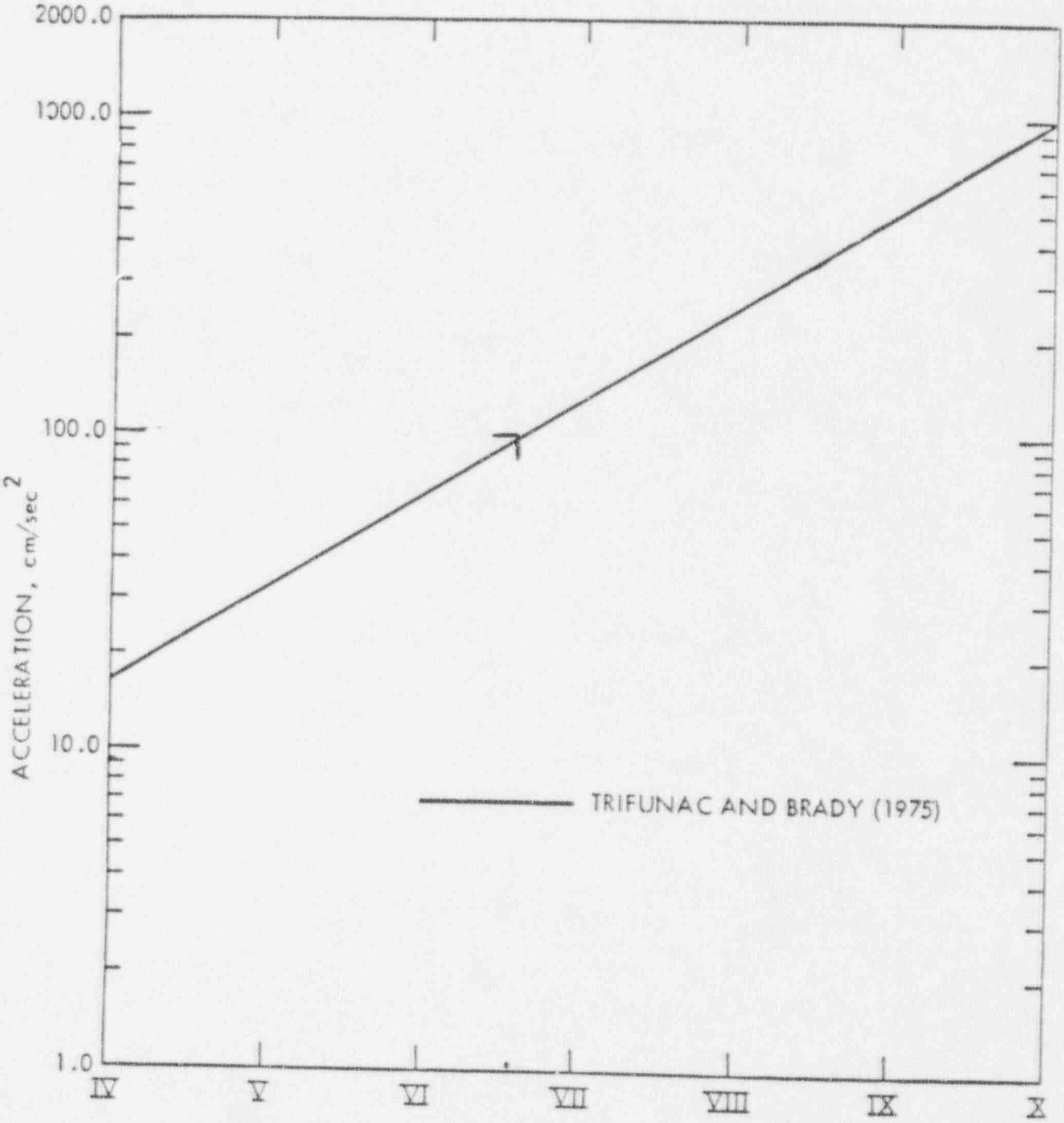
[illegible] time history.

QUESTIONS

- DOES "HISTORICALLY REPORTED EARTHQUAKES" MEAN FELT EARTHQUAKES? [E.G., §3.1.2(4)]

- WHAT DOES "FAULTS THAT COULD GENERATE THE EQUIVALENT OF 0.1 g OR GREATER" MEAN? [§3.3(4)]

- IN §3.3, WHAT IS INTENDED BY "'SUSCEPTIBLE' FAULTS ... LOCATED SUCH THAT THERE IS A POTENTIAL FOR VIBRATORY GROUND MOTION TO IMPACT THE UNDERGROUND FACILITY"? THE CASE DESCRIBED IN §4.3, WHERE THE U/G FACILITY ENCOMPASSES "SUSCEPTIBLE" FAULTS?



2000.0
1000.0
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ACCELERATION, cm/sec²
TRIFUNAC AND BRADY (1975)
IV
V
VI
VII
VIII
IX
X

Center for Nuclear Waste Regulatory Analyses

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December 20, 1990
Contract No. NRC-02-88-005
Project No. 20-3704-040

U. S. Nuclear Regulatory Commission
ATTN: Ms. Sharon Mearse
Division of Contracts and Property Management
7920 Norfolk Ave. (P-902)
Bethesda, MD 20814

Subject: Modified Integrated Waste Package Experiments (Major Milestone 20-3704-040-005) and Comments Response (Major Milestone 20-3704-040-010)

References: 1) Letter from P. J. Edgeworth to J. Latz, dated December 6, 1990;
2) Letter from J. Latz to P. J. Edgeworth, dated December 17, 1990

Dear Ms. Mearse:

Enclosed is Revision 3 of the Integrated Waste Package Experiments Project Plan (IWPE) (Major Milestone 20-3704-040-005) and the detailed response to the Comments (Major Milestone 20-3704-040-010) (enclosure) provided in the referenced letter.

Several changes were made to the IWPE Project Plan Revision 2 following discussions with the NRC Project Officer, Philip Reed, during December 4-6, 1990. These changes have resulted in schedule modifications and cost reallocations. The text changes are dispersed throughout the document and a change-page approach to the old plan was determined to be impractical. As a result, the text and the schedules and milestones chart have been revamped and an IWPE Project Plan Revision 3 is being submitted.

426.1

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delete all distribution except cf ; NUDOCS abstract. NHXD

If you need any additional information or have any questions, please contact Dr. Prasad Nair, at (512) 522-5150.

Very truly yours,

for John E. Latz
President

PKN/cg/blg

Enclosure

cc: J. Funches
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ENCLOSURE

RESPONSE TO NRC STAFF COMMENTS ON THE PROPOSED INTEGRATED WASTE PACKAGE EXPERIMENT PROJECT PLAN, REVISION 2

INTRODUCTION

The IWPE project plan was formally submitted to NRC in May 1990 and the official comments were received from the NRC staff in October 1990. The comments consisted of two parts: I) General Comments on Structure and Basis for the Project Plan, and II) Specific Comments on Proposed Research Tasks in the Project Plan. Under the specific comments, several tasks were approved and more detail was requested on other tasks. Based on these specific comments, certain actions have been initiated. These action items consist of making changes in certain parts of the IWPE project plan to clarify the approaches and including intermediate milestones for delivery of detailed test plans of some subtasks to NRC staff for approval prior to commencement of these subtasks. As a result of these action items, a revised IWPE will be sent as a separate package for approval. The purpose of the present document is to respond to the general and specific comments and clarify the Center's viewpoint with regard to the proposed IWPE plan. The responses will address the comments in the order they occur in the NRC comments.

I. Responses to General Comments on Structure and Basis for Project Plan

1. The scope of the IWPE plan is to perform confirmatory research and exploratory research. The purpose of the exploratory research is to clarify areas of uncertainty and areas where understanding/information is incomplete or lacking. These two aspects of the IWPE plan are stated in Section 2 (Technical Objectives) and 3.1 (Technical Approach). The term "anticipatory" is used instead of "exploratory" as explained in response II.20 of this document.

2. The focus of the IWPE Project Plan is the development of a phenomenological understanding of the most important degradation modes for the candidate container materials. It is expected that the experimental approach adopted in the program, as indicated in several subtasks, will lead to a mechanistic understanding of the fundamental processes involved in those degradation modes. In a separate program sponsored by NMSS, mathematical modeling for long-term prediction is being done. Phenomenological and mechanistic understanding of the degradation modes are necessary in order to perform modeling of these processes for long-term prediction.

3. The identification of failure modes for components of the HLW package, as well as the development of methods for the evaluation of uncertainties in prediction, has been addressed in a separate activity, sponsored by NMSS with joint participation of NRC and CNWRA staff. This activity has resulted in the publication of three documents addressing the issue of "substantially complete containment" within the waste package (Ref.1). Regarding the extrapolation of short-term and accelerated laboratory tests to predictions involving long-term performance of the waste package through mathematical modeling, it should be remarked, as noted above, that this activity is currently being conducted in the Engineered Barrier System (EBS) program supported by NMSS. The focus of research in the IWPE Project Plan is to develop a phenomenological and mechanistic understanding of failure modes for the container materials through experimental investigation.

4. The Center proposes to evaluate all six of the current candidate materials plus alloy C-22 as a reference material. However, as stated in the NRC's response to the NSRR Committee, it is neither the intent nor is it feasible, given the funding constraints, to study all seven materials intensively. The Center staff feels that focus should be on alloy 825 among the Fe-Ni-Cr-Mo alloys not only because it has been advanced by DOE/LLNL as the most viable of this family of alloys (Ref. 2), but also because there is a paucity of information on this alloy in comparison to the other alloys in this family, types 304L and 316L stainless steels. Among the copper-based alloys, the Center staff feels the Cu-Ni alloy (CDA-715) has been presented by DOE/LLNL as the most likely candidate (Ref. 2) and, hence, should be the alloy of focus. Alloy C-22 has been chosen not only to act as a reference material to compare the performance of the other Ni-Fe-Cr-Mo alloys, but also as a representative of yet another family of Ni-Cr-Mo alloys containing low Fe. It is likely that DOE/LLNL will revise its list of candidate materials [illegible] examine an alloy in this class (Ref. 3). As can be realized from the above discussion, the approach of the IWPE plan is to examine classes of materials in terms of one or more representative alloy from each class. The IWPE plan, Section 3.1, will be amplified to reflect the above explanation. It should also be noted that Task 5 in the IWPE was created cognizant of the possibility of an alternate candidate material.

II. Responses to Specific Comments on Proposed Research Tasks in Project Plan

1. As mentioned in the introduction, the IWPE plan revisions will provide more clarification and specify intermediate milestones for delivery of specific test plans on those subtasks that are not detailed currently.

2. Task Details: The main comment is that tasks 2, 3, and 4 were much less detailed than Task 1 and approval of these tasks can be made only upon receipt of detailed work plans. In examining the IWPE plan, it must be emphasized that the objectives are both confirmatory and exploratory. The levels of detail of confirmatory research tasks depend on the level of details of prior research performed by DOE/LLNL and other NRC sponsored research (Cortest). In the areas of stress corrosion cracking (Task 2), metallurgical stability of alloys other than 304 stainless (Task 3), and microbiologically influenced corrosion pertinent to HLW (Task 4), the experimental investigation of DOE has not been extensive. In contrast, investigations of localized corrosion (Task 1) by DOE and Cortest have been defined well enough to plan this task in greater detail than the other tasks. For Tasks 2 through 5, detailed test plans will be submitted for approval prior to commencement of the subtasks involving experimental work. The test plans will be identified in the revised program plan as intermediate milestone deliverables and indicated in Figure 3.1 of the Project Plan, as well as in the schedules and milestones chart. This approach is consistent with those of other research projects at the Center. Some subtasks have already been conducted under Revision 1 of IWPE, and others are ongoing under the recently approved IWPE Project Plan, Revision 2.

3. Changes in Experimental Plans: It is agreed that, in those subtasks in which a detailed work plan cannot be developed at the present time because the results obtained in other subtasks are needed, a separate test plan will be submitted for approval before beginning the experimental work. Accordingly, Figure 3.1 will be revised to incorporate, as intermediate milestones, the delivery of appropriate test plans.

4. Other Degradation Modes: Task 5 of the IWPE plan is intended to study the degradation modes of alternative materials in addition to studying the hitherto unidentified degradation modes of existing candidate materials. The alternative material concept includes not only nonmetallic materials, but also higher Ni alloys such as alloy C-22, Ti, and bimetallic structures. At the present time, the Center's effort in this task is considered to be mainly a critical assessment of the state of knowledge of degradation modes of alternate materials. It is premature at the present time, both due to the status of the DOE program and due to budget constraints, to expand our effort in this area or to create a new task. According to the current waste package plan document of DOE (YMP Waste Package Plan, July 1990), for the reference design, the selection of a candidate list of materials will involve an upgrading and modification of the current list of six metallic materials by the end of FY92. Hence, a greater definition of experimental work on alternative materials can be made at that time. An intermediate milestone report on a survey of degradation modes of alternate materials has been added to Task 5. This report will recommend further testing if necessary.

5. Literature Awareness: The EBS staff is well aware of the technical literature published in scientific journals as well as in specific publications or reports of research organizations involved in the nuclear industry. Several reports were referenced in the IWPE Project Plan (i.e., Ref. 2, 6, 9, 12, 2, 26, 27, 29, 36, and 46) as appropriate, although in many cases the work reported has not been published in peer reviewed journals. The NRC/NIST/CNWRA database was consulted and references were used when applicable. The recent review of the literature by ANL that was cited by the NRC staff in their comments was received by G. Cragnolino, directly from the author P. S. Maiya. Unfortunately, it was received after the project plan was prepared in May 1990. Nevertheless, it was concluded, after careful review, that the report had no impact on the logical organization, scope, or prioritization of the planned work.

6. Literature Review Task Completion: As noted in the Comments, it is the aim of the EBS staff to conduct a comprehensive literature review for each of the four proposed tasks at several stages of these tasks. The schedule adopted in Revision 2 is shown in Figure 3.1. The reason for conducting the reviews at several stages of the program is to remain current by including updated information provided by other authors and organizations, either as peer-reviewed papers or as reports. Reviews of the literature will also be made more thorough, by comparison, to the experimental results obtained in the IWPE program. Such a comparison to our experimental data will enable a critical appraisal of the experimental methodologies and data obtained by others. Coupling of these reviews to the review of models which is being done under NMSS sponsorship will also be highly beneficial in evaluating the ability to extrapole short-term data to long-term performance. In the particular case of Task 4, Microbiologically Induced Corrosion, no experimental work is contemplated until the end of the first literature review.

7. Factorial Matrix for Pitting and Redox Potentials: Questions were raised regarding the choice of environmental species in the factorial experiments, omission of some species such as bicarbonate and oxygen, and the necessity of a meeting with chemists and geochemists for planning the factorial matrix. The factorial matrix that was developed contained a uniform concentration of bicarbonate (85.5 ppm) and included all the anions that remain in solution in groundwaters of the Yucca Mountain area. The effect of silicon-containing species was studied independently due to the low solubility of some of these compounds. The predominant cationic species, sodium, was used as a single cation to avoid chemical interactions with the anions that may affect the validity of the full factorial tests. Oxygen was removed from the solution to avoid the well- known interference of its cathodic reduction with the anodic behavior of the alloys under study. The pH was measured at room temperature at the beginning and end of the test. In

selected cases, the chloride concentration was measured at room temperature at the beginning and end of the test. The ranges of other chemical species were considered in consultation with geochemists (Drs. W. Murphy and R. Pabalan) and after a thorough review of published literature from LLNL and Cortest. The test matrix was formulated in consultation with a statistician (Dr. R. L. Mason). Calculations by W. Murphy, based on the EQ3/EQ6 code, have shown that the ionic concentrations of various species in selected solutions do not change significantly due to an increase in temperature to 95°C with the exception of pH. His calculations agree well with the measured pH changes at room temperature after heat-up and cool-down (Report on Research Activities, August 1990 through October 1990).

The test matrix proposed for the study of redox potential (Table 3.4) involves H_2O_2 because it has been shown to be one of the stable products of water radiolysis in the presence of air. The purpose of these studies is to simulate the effect of radiolysis on aerated, aqueous solutions by intentional additions of H_2O_2. In this case, the source of H_2O_2 is not as important as its concentration. The concentrations used (0.5mM) are within the anticipated steady-state concentrations resulting from gamma radiolysis. The interaction of H_2O_2 with other species such as nitrate is important and is the very reason for conducting a matrix of experiments. In connection with the redox potential tests, the need to generate kinetic data on many redox reactions of interest to the repository environment has been ably pointed out in a recent paper by Macdonald (Ref. 4).

8. Internal Corrosion: The Center staff agrees that internal corrosion is an important issue that has been paid scant attention in the past. However, the current budget is not sufficient to examine this aspect of container performance in detail. Therefore, the intent of this subtask is to collect the necessary preliminary information on the possible range of internal environments that can lead to a better definition of more detailed study later. The current regulation requires the waste to be in a solid form, though the practical matter of being able to achieve this condition for spent fuel remains to be understood. The Center staff will consult with various experts familiar with the spent fuel and reactor components and operation in carrying out this subtask. The end product is anticipated to be a report on the various possibilities of internal corrosion and recommendation for future experimental research. If the need for experimental research is justified, a detailed test plan will be submitted.

9. Gamma Irradiation Studies: Experiments under radiation are proposed in Subtask 1.1.4, Long-Term Corrosion Studies. As presently scheduled, the radiation experiments activities will be carried out after sufficient experience is gained in nonradiation environments in which possible radiolysis products have been added. A test plan will be submitted in FY 93 which will describe in detail the experimental approach and program and the facilities to be used. Southwest Research Institute has a licensed hot cell facility with a Co-60 source and counting equipment particularly suitable for this type of experiment.

10. Microbiologically Induced Corrosion: The Center staff is acquainted with current developments in this area. A substantial amount of the relevant scientific literature has been briefly reviewed, including some of the EPRI Reports. An additional effort in this area has been initiated since the IWPE Project Plan, Revision 2, was sent to NRC for review. G. Cragnolino attended the International Congress on Microbiologically Influenced Corrosion held in Knoxville, TN, on October 7-12, 1990. Contact has been made with microbiologists at Idaho National Engineering Laboratory and other well known experts in the field. Provisions have been made for additional consultation with microbiologists during the course of the preparation of a critical review of the literature. In this context, another resource available to the Center staff is the staff of the

Southwest Foundation for Biomedical Research who can be consulted on microbiological organisms of relevance. As indicated, no experimental work is planned until that review is completed. It is expected that within the conclusions of that review, a recommendation can be made about the advantage of initiating an experimental program. At this time, a detailed test plan will be submitted for approval.

11. Effect of Alloy Impurities: The Center staff wholeheartedly agrees with the eventual need to investigate heat-to-heat variations in properties and, hence, the effect of minor variations in chemistry as well as impurities such as P, S, etc. The Center staff is quite aware of the issue of minor alloying elements effect not only in the nuclear industry, but also in other industries. However, it is too premature to examine the heat-to-heat variations in properties until a selection is made of the two final candidate materials in the design (a main and an alternate material), which is not expected before FY94. The effort in terms of evaluating multiple heats of all the present and future candidate materials, as well as model heats containing varying concentrations of impurities, is beyond the budget of both NRC and DOE. The assumption should be made, and the selection of an initial list of candidate materials can be made to satisfy this assumption, that the differences in the performance between the various candidate materials are far greater than the differences between various heats of any given material.

12. Bulk vs. Surface Degradation: As a matter of clarification, bulk degradation processes are those that affect mechanical and physical properties. In terms of container performance, this refers to loss of toughness and embrittlement through metallurgical changes. All other forms of degradation (i.e., dealloying, hydrogen effects, stress corrosion cracking, etc.) must have surface mediation, though in some cases the rate controlling step may be transported through the bulk. Hence, it can be seen that degradation modes involving surface reactions dominate both in number and probability to purely bulk degradation. Additionally, changes in the bulk through phase transformations can have adverse effects on surface reactions as in the case of intergranular corrosion or hydrogen embrittlement. The approach adopted by the Center staff in the organization of the IWPE Project Plan was the consideration of degradation modes that may have a dominant impact on the performance of container materials. The main bulk effects expected under high-level nuclear waste repository conditions seem to be related to the heating resulting from radioactive decay that may induce phase transformation and precipitation of other phases or intermetallics, impurity segregation, depletion of alloying elements, etc. The impact of these changes are not only on mechanical properties or internal embrittlement (bulk properties), but also on materials degradation through surface reactions. The Center staff has given priority to Subtask 3.1, focusing the main effort on Alloy 825. A review of literature (Ref. 2) has indicated that there is no updated information on the precipitation-temperature-time behavior of this alloy with the current chemical composition. Studies will be done on AISI 304 and 304L stainless steel as reference materials and for the purpose of validating/calibrating CNWRA test procedures. A test plan for Subtask 3.1 will be submitted for approval before the beginning of the experimental work. As indicated in Fig 3.1 of Revision 1, a literature review covering the behavior of the Fe-Cr-Ni alloys of interest in the IWPE Project Plan will be delivered as an intermediate milestone. Upon meeting with the NRC Project Officer, Subtask 3.4 has been merged into Subtask 3.1 and designated as Long-term Materials Stability. Detailed test plans will be submitted for each of the subtasks within Task 3 for approval before proceeding with the experimental work.

13. Hydrogen Attack: Hydrogen attack and hydrogen embrittlement are degradation processes that rank much lower in priority than other degradation modes such as localized corrosion and stress corrosion cracking. Hydrogen attack is considered to be a lower priority because the repository temperatures are significantly lower than the temperatures at which hydrogen attack commonly

occurs. Additionally, the carbon contents of the candidate alloys are lower than those encountered in alloys susceptible to hydrogen attack. Hydrogen transport and embrittlement of some candidate materials are being studied by Prof. Wilde under a subcontract with The Ohio State University. Nevertheless, a review of available information will be conducted under Task 5 to explore the possibilities of these degradation modes for the current list of materials. Recommendations for future testing, if needed, will be provided.

14. Effects of Welding: At this time, the method of closure of the containers has not been decided. Many different welding techniques have been investigated by the DOE contractor (Babcock & Wilcox). Friction welding has been touted as the best of these for the current list of candidate materials. Claims have been made in terms of their narrow heat-affected-zones (HAZ) and low segregation in the joint area. While the fusion welding techniques have been investigated in some detail in terms of weldmetal corrosion and stability, much less is known about friction welds, their microstructures, and corrosion resistance. Even in the case of fusion welds, their performance in low chloride environments encountered in the repository is not known. Hence, the current IWPE plan proposes to conduct a preliminary evaluation under Subtask 1.1.3 of both the friction weld and fusion weld (Gas Tungsten Arc Weld) in terms of microstructure and corrosion resistance. A more detailed program on closure involving a study of metallurgical stability, as well as long-term corrosion performance, will be necessary once the choice of a closure process is known.

15. Standard ASTM Tests: Appropriate modifications will be made in the text and in the references to incorporate the title of these standardized ASTM tests. While much is known and published about the application of these tests to various materials, there are still some unknowns in terms of application to specific material on hand and the type of transformations anticipated under repository conditions. Any eventual shortcoming and limitations of the standard tests used will be reported in the context of the experimental work conducted in the IWPE project through the quarterly reports and the corresponding final reports for each task or subtask, as appropriate.

16. Characterization of Materials: The Revision 2 of the IWPE plan specifically emphasized the need to fully characterize the specific heats of materials being examined. The characterization of the current as well as future candidate materials is listed as one of the first subtasks (Task 1.1.2) in the program. Indeed, it is one of the Center staff's criticism of past programs that they did not characterize the materials sufficiently.

17. Short Term vs. Long Term Tests: The distinction between short- and long-term tests, as well as the implications in terms of prediction of materials behavior, is clearly stated for Task 2, Stress Corrosion Cracking. Subtasks 2.2 and 2.3 describe the short-term tests, whereas, Subtask 2.4 deals with long term-tests. For Task 3, Materials Stability, the distinction between short- and long-term tests cannot be so easily drawn. Evaluation tests, which may be short term and long term as listed in Tasks 1 and 2, will be performed after appropriate exposure times to the conditions established in each particular subtask. Methods of accelerating thermal instability such as cold-work will be explored in Task 3 after development of suitable test plans and approval of the same. For Tasks 4 and 5, no experimental work is planned at the present time other than the one currently ongoing at The Ohio State University and, hence, the distinction as such is not relevant.

18. Integration Between Tasks: It is true that tests integrating all the features present in a repository are not contemplated in the IWPE Project Plan. Such tests can be done only as "pilot plant" studies involving prototypical components. However, the concept of integrated research studies is present throughout the IWPE project plan, and partial integration of environmental factors and

experimental conditions leading to more than a single degradation mode can be found in the long-term tests. For example, the long-term corrosion tests will involve effects of metallurgical changes as well as radiolysis effects in those specific experiments which are performed under radiation. Similarly, long-term stress corrosion cracking studies will include localized and uniform corrosion effects, metallurgical changes and eventually radiation effects. The effect of microbial activity on localized corrosion is planned to be included at a later date after a thorough review of the conditions that may lead to the growth of microbes in repository conditions has been made.

19. Explicit Listing of Candidate Materials: The DOE candidate containers materials were listed in Page 4, Section 3.1. However, following the NRC staff comments, a table of the nominal chemical compositions of the DOE's current candidate materials as well as the Center's reference material will be provided.

20. Exploratory vs. Anticipatory Tests: In our prior versions of this plan, the unofficial copy of which was given to NRC staff in February of 1990, we referred to some tasks as exploratory. However, during our presentation to The Nuclear Safety Research Review Committee (currently the Morrison Committee), we were corrected in this and requested to use "anticipatory tasks" instead of "exploratory tasks." Semantics aside, we prefer "anticipatory" because in addition to confirming the research performed by DOE, we anticipate that some research tasks will become important issues in the future. The word "exploratory" conveys the feeling that we are going in a direction without any hope of anyone following us.

    The NRC staff seems to be concerned that the number of "anticipatory tasks" in Task 1 are more than the number of "confirmatory tasks" and, hence, implies the former's greater importance. The Center staff does not believe this to be so. However, at the current stage of container materials research, the Center staff believes that many areas of material degradation that may affect licensibility have not been addressed adequately by DOE/LLNL and, hence, many anticipatory tasks have been appropriately proposed in the IWPE plan.

21. Deliverables and Subtask Listing: The IWPE Project Plan revision will incorporate these suggestions.

22. Activities vs. Task Description: The word "activities" was used to be consistent with all other Research Project Plans. The outline followed and the terms used in the current revision of the IWPE Project Plan are the same as those used and approved by the Office of Research since 1987.

23. Prioritization Beyond FY92: The prioritization of activities beyond FY92 will be dictated by the results obtained in previous years and by the proposed activities of DOE. Several long-term tests are expected to continue beyond FY92 with a minimal expenditure of man-hours.

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PROJECT PLAN FOR
INTEGRATED WASTE PACKAGE EXPERIMENTS

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PROJECT PLAN FOR INTEGRATED WASTE PACKAGE EXPERIMENTS

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1. PROJECT PLAN FOR INTEGRATED WASTE PACKAGE EXPERIMENTS

1.1 Introduction

The Nuclear Waste Policy Act (NWPAA) of 1982, as amended, establishes the responsibilities of the Department of Energy (the license applicant), the Nuclear Regulatory Commission (NRC) (the license review and license issuing agency), and the Environmental Protection Agency (EPA) (the promulgator of standards for long-term repository performance).

Siting and licensing of a high-level nuclear waste (HLW) repository requires that sophisticated technology, technical complexities, intense public scrutiny, and rigorous schedule constraints be integrated in one program. This mission has the additional complications associated with a complex multi-party legal and regulatory evaluation and approval process.

In support of its high-level waste program under the NWPAA, NRC has established the Center for Nuclear Waste Regulatory Analyses (hereafter referred to as "the Center"). The mission for the Center is to provide a sustained high quality of technical assistance and research in support of NRC's HLW program. Toward accomplishing this mission, the Center conducts research activities to aid in identifying and resolving technical and scientific issues associated with the NRC's licensing of a high-level nuclear waste repository.

The NRC regulation 10 CFR 60.113 requires the waste package to provide substantially complete containment of radionuclides for a period of 300 to 1000 years. Arising from this requirement is the need for the license applicant (DOE) to demonstrate, through proper material selection and design, the long-term performance and corrosion behavior of the waste packages. This need dictates the resolution of key technical issues of (a) mechanisms of waste package degradation and (b) uncertainties in the material data base as they currently exist. NRC, in its role to license the repository, will be required to evaluate DOE's resolution of these critical technical issues. Toward that goal, NRC must develop an understanding of the important parameters that affect the long-term degradation of container materials. Currently, the state of knowledge in this technical area is limited. The Integrated Waste Package Experiments Research Project supports development of an adequate understanding of the long-term waste package performance so that timely guidance can be provided to DOE and a sound basis is available for evaluating the DOE license application. This document presents the detailed project plan for the Integrated Waste Package Experiments research project to be conducted under the Center's research program.

2. TECHNICAL OBJECTIVES

2.1 Purpose, Goals, and General Objectives

The purposes and basic objectives of the Waste Package Experiments Project are:

(1) To obtain an understanding of the important parameters that affect the long-term performance of the waste package materials in a tuff environment. This objective directly supports evaluations in the context of the requirements in 10 CFR 60.113 for substantially complete containment of radionuclides within the engineered barrier system for a period of 300 to 1000 years.

(2) To assess methodologies used in predicting long-term material degradation where there is limited data and information currently available. This objective will enable NRC and the Center to evaluate the nature of uncertainties in the long-term material degradation processes. This is a key element in ensuring that the radionuclide containment period as defined in 10 CFR Part 60 is technically justifiable.

(3) To perform material evaluations for confirmatory purposes so that a better understanding of the data supplied by DOE is attained.

The goal of this research project is to enable the NRC and the Center to develop the technical capability and, where necessary, independent experimental data to provide appropriate, timely prelicensing guidance to the DOE and to review DOE waste package design licensing submittals to the NRC.

2.2 Specific Objectives

To accomplish the overall goals of the Integrated Waste Package Experiments Project, the following specific objectives are identified:

- To develop a good understanding of the information currently available on metal corrosion and on other material degradation processes.
- To assess the current status of Yucca Mountain Project (YMP) Waste Package Programs.
- To conduct waste package experiments to scope and study the key parameters affecting long-term material performance.
- To assess, experimentally, YMP selected Waste Package materials and designs and provide independent evaluation for reasonable assurance of long-term performance.
- To facilitate a continuous technical integration support to NRC and the Center in the area of waste package performance.

3. TECHNICAL PROGRAM DESCRIPTION

3.1 Technical Approach

The emphasis on the experimental program is to critically assess the experimental techniques and results used to predict degradation of the waste package materials and to develop a phenomenological and mechanistic understanding of the various degradation modes. The research program described in this document will enable NRC and the Center to identify uncertainties in the current database on material degradation pertinent to waste package performance and better evaluate any future data. It will also provide a selectively developed independent database with which to assess long-term performance of the waste package. However, the intent of the program is not to generate all the data independently from the license applicant, but to perform intensive investigation of the techniques used to develop the necessary data and the methodology used to extrapolate the data to repository conditions.

The proposed experiments are classified into six tasks. Task 1 addresses corrosion processes including uniform corrosion, localized corrosion (pitting and crevice corrosion), and internal corrosion arising from interactions of the container material with the spent fuel, cladding and other internal contents. The main thrust of the current effort will be in localized corrosion from the external environment. Concern regarding the selection of J-13 water (natural and simulated) as an environment representative of the unsaturated zone water in the proposed Yucca Mountain repository has been raised [1]. It has been indicated, for example, that the chloride content of the pore water may differ substantially from that of the J-13 well water. Variations in pH and in the concentration ratio for other ionic species may also be significant. On the other hand, there is an interest to provide a means of comparison between the results that will be generated in this program and those obtained by other authors in the past. To accommodate this, J-13 water (natural and simulated) is included in this program in order to conduct selected tests. However, it is essential for a phenomenological understanding of the localized corrosion processes and also for predictive purposes, that a representative range of environmental variables be examined in a systematic manner. Hence, a major part of Task 1 is devoted to this purpose. Task 2 will address stress corrosion cracking. Here again, the emphasis initially will be on the external environment. Task 3 will focus on the long-term microstructural stability of the waste package materials. Corrosion induced or accelerated by microbiological organisms is a concern that has not been addressed extensively in this connection. Task 4 will initially review the current literature on microbiologically influenced corrosion pertinent to the waste package environments. Several degradation modes have been only minimally considered by other previous investigations. The purpose of Task 5 will be to identify and examine these other degradation modes and determine whether there is any merit in investigating these degradation modes in any further detail. Currently, hydrogen embrittlement has been identified as a possible degradation mode. A research activity has already been underway as part of the IWPE project at the Fontana Corrosion Center under Prof. B. E. Wilde to develop methodologies for determining the hydrogen absorption and embrittlement from repository environments. Galvanic corrosion between the container material and the borehole liner is also a potential mode of degradation. As part of the NRC research program, Cortest Columbus, Inc., is conducting a preliminary investigation of the subject. Depending on the findings of their initial experiments, further investigation will be carried out at the Center on galvanic corrosion. Future activities under this task may involve investigation of cavitation phenomena due to repeated evaporation and condensation of water droplets at the top of the waste container. The quarterly and annual progress reports of the research tasks are planned under Task 6.

It must be noted that the program as proposed here will concentrate on DOE's current list of six metallic materials and the Center's reference alloy (Hastelloy alloy C-22) (Table 3.1). However, the revised Yucca Mountain Project Waste Package Plan proposed by LLNL has scheduled the selection of a new list of candidate container materials for 1992. The revised list of candidate materials may not have some of the materials currently being examined and may have other materials not currently being examined. To avoid any future divergence between the Center's and DOE's programs, the Center's program will address evaluation of test methodology that can be applied to classes of metallic materials and use of this data for predictive purposes. This is accomplished by examining three classes of metallic materials: the Iron-based alloys (304L and 316L stainless steels), the Nickel-based alloys with the low end of this class being alloy 825 and the high end being Hastelloy alloy C-22, and the Copper-based alloys with emphasis on the Cu-Ni alloy. The program will also incorporate provisions in its long-range plan (5 years) for preliminary evaluation of new types of materials that may be proposed by DOE. The latter can be done, for example, through Task 5 (Other Degradation Modes). However, new concepts such as bimetallic cladding, ceramic materials, and composite materials are currently beyond the scope of the activities outlined in the present project plan.

Table 3.1 Chemical Compositions of the Candidate Container Materials in the IWPE Program

Alloy	Composition (wt.%)							
	Ni	Fe	Cr	Mo	W	Cu	Al	Other
304L	8.0-12.0	Bal.	18.0-20.0	-	-	-	-	C < 0.03
316L	10.0-14.0	Bal.	16.0-18.0	2.0-3.0	-	-	-	C < 0.03
Alloy 825	Bal.	30.4	19.5-23.5	2.5-3.5	-	1.5-3.0	-	C < 0.05
Hastelloy Alloy C-22	Bal.	3.0 max.	22.0	13.0	3.0	-	-	C < 0.15
CDA-102	-	-	-	-	-	99.95 min.	-	-
CDA-613	-	3.5 max.	-	-	-	90.0	6.0-8.0	-
CDA-715	29.0-33.0	0.4-0.7	-	-	-	69.5	-	-

Hastelloy is a registered trademark of Haynes International, Inc.

3.2 Technical Tasks

The following sections describe the tasks more fully. An anticipated time sequence for initiation and completion of the tasks is given in Section 3.3.

TASK 1 - CORROSION

The technical approach in studying crevice corrosion and pitting in this task will be: 1) to perform short-term tests to confirm findings by other investigators such as Cortest and LLNL and to determine test and environment related factors which can affect these short-term results, 2) to perform anticipatory tests to examine concepts that can be used to predict the localized corrosion kinetics, and 3) to perform long-term tests. In addition to these tests, tests will be conducted to characterize the initial conditions of the metals being tested. Verification tests will be conducted using ASTM standard samples to ensure that the equipment and test methods are in proper order.

The subtasks are listed below and discussed in detail in the following paragraphs under subtask designations:

1.1 Localized Corrosion

- 1.1.1 Critical review of experimental results from DOE- and NRC-sponsored research in this area.
- 1.1.2 Characterization of the initial condition of the metals under study.
- 1.1.3 Short-term tests under potentiostatic and potentiodynamic conditions.
- 1.1.4 Long-term studies in vapor, aqueous, and wet-dry conditions.

1.2 Internal Corrosion

Subtask 1.1 Localized Corrosion

Subtask 1.1.1 Review of Experimental Results From Other Programs Related to Localized Corrosion of Container Materials

OBJECTIVE

Perform and document a critical review of results from experimental studies conducted by Lawrence Livermore National Laboratories (LLNL), Cortest Columbus Laboratories (CCL), and the Center.

JUSTIFICATION

Many experimental programs have been underway sponsored by both DOE and NRC. Some of these results have already been reviewed [2a]. However, results generated subsequently have not been analyzed critically. These include results from NRC-sponsored research conducted by Cortest Columbus Laboratories [2b], NIST and CNWRA, and DOE-sponsored research conducted by LLNL. A review of the results from these programs will guide future experimental programs. For example, the factorial experimental study conducted by Beavers and Thompson [2b] will be used to reduce the number of environmental variables evaluated in simulated J-13 water to those that have a dominant effect on corrosion so that the Center can focus on these environmental and material variables. Furthermore, it is necessary to examine whether the relationships between variables determined by these studies are reasonable or whether they arise out of experimental artifacts. For example, both the LLNL and CCL studies have tended to rely heavily on potentiodynamic polarization technique. It is necessary to examine critical issues in the use of this technique such as the appropriate use of break-off potential as a measure of pitting initiation resistance, the use of hysteresis in polarization curves as a predictor of crevice corrosion, the independence of environmental variables considered in a factorial experiment, and the use of controlled potential testing to examine the effect of oxidizing radiolysis products. Other issues pertain to the details of the experimental techniques and how they affect the results.

ACTIVITIES

The reports by Beavers and Thompson [2b] will be reviewed with respect to the composition of the electrolytes prepared to simulate J-13 water, electrochemical techniques used, their interpretation, and the statistical significance of the results. This will form the basis for recommendations for future investigations by the Center. Similarly, the results published by LLNL (Glass et al., and Farmer et al.) will be reviewed.

A report will be issued on the basis of the above reviews.

Subtask 1.1.2 Characterization of Materials in the Initial Condition

OBJECTIVES

Examine, quantify, and document the initial microstructural conditions, surface chemistry, and mechanical properties of the alloys in the program.

JUSTIFICATION

It is essential that the as-received microstructural and surface chemical characteristics be evaluated before long-term studies are undertaken. This characterization will establish the starting conditions of the alloys being tested and will answer the following questions:

1. Is the as-received alloy in acceptable microstructural condition, i.e., no observable grain-boundary or intra-granular precipitation?

2. What is the inclusion content of the material? - This is important in examining the pitting resistance of the alloys, especially stainless steels (3). Sulfide inclusions such as MnS are more detrimental than others such as oxides.

3. Is there surface depletion of alloying elements? - This has been observed in numerous cases in the past and has accounted for the observed unexpected corrosion of highly alloyed metals in marine corrosion (4).

ACTIVITIES

Thus far in the program, the Center has performed chemical analyses of all the alloys received. Properties such as yield, tensile strength, and hardness have been included in the material certification from the suppliers of some of the alloys. In order to characterize the materials more fully, a variety of additional tests will be employed. These tests are listed in Table 3.2. These will include:

1. Metallography of as-received plates. This will be combined with image analysis techniques to characterize inclusion content and grain size.

2. ASTM intergranular corrosion tests. These tests will involve either electrolytic etching (A-262 A) or weight-loss corrosion tests combined with metallographic examination of the corroded cross-section. The ASTM intergranular tests are used to detect the adverse effect of grain boundary precipitates on corrosion. The specific test used is dependent on the alloy system and the type of grain boundary precipitate. For example, the ASTM A-262B test (and its equivalent version, the ASTM G-28A Test) is sensitive to grain boundary carbide precipitation (more accurately the associated Cr depletion). It is not sensitive to sigma phase precipitation. Because many of these ASTM corrosion tests are sensitive to Cr depletion, surface changes in Cr can also be detected in the absence of grain boundary carbides. It may be necessary, in the case of some alloys, to modify existing ASTM tests or design new tests. Where necessary, these new tests will be detailed in appropriate tests plans. No ASTM test exists for the Cu-alloys. These tests will be conducted in both the as-received surface and 120-grit polished surface as a measure of surface alloy changes. The metallography can be performed on the same samples as the corrosion tests.

3. If any heat treatment is desired to improve the as-received microstructure, this will be performed and further microstructural examination will be carried out.

4. SEM-EDX analyses of the as-received and polished surfaces to detect surface alloy depletion.

5. Tensile tests at room temperature and 95° or 150°C depending on what temperatures are chosen for the stress corrosion cracking tests (subtasks 2.3 and 2.4). The tensile tests will be done transverse to the rolling direction.

Table 3.2 Initial Material Characterization Tests to be Performed on the Current Candidate Alloys

EXAMINATION METHOD	304L	316L	825	C-22	Cu	Cu-Ni	Cu-Al
METALLOGRAPHY	2	2	2	2	2	2	2
ASTM A-262 A	4	4	-	-	-	-	-
ASTM A-262 B	4	4	-	-	-	-	-
ASTM G-28 A	-	-	4	4	-	-	-
ASTM G-28 B	-	-	-	4	-	-	-
SEM-EDX	1	1	1	1	-	-	1
TENSILE TEST	2	2	2	2	2	2	2
HARDNESS	1*	1	1	1	1	1	1

* - BASED ON AVERAGE OF TEN READINGS ON A SAMPLE

Subtask 1.1.3 Short-term Corrosion And Electrochemical Studies

OBJECTIVES

The objective of these tests will be to compare results with other laboratories, determine the uncertainties in the results, determine the quantitative relationship between the crevice corrosion/pitting parameters and environmental variables, and compare the performance of different candidate alloys. Additionally, the objective of this program is to determine the kinetics of redox reactions pertinent to repository conditions on passive metals which in turn will determine the potential regime in which these metals will operate.

JUSTIFICATION

The short term corrosion tests can be classified as confirmatory tests and anticipatory (or exploratory) tests. The confirmatory tests are performed to evaluate the degradation data and test techniques reported by other investigators and assist in the interpretation and extension of these results. The anticipatory tests examine degradation modes not examined in detail by others and in clarifying issues not clearly addressed by other investigators.

Confirmatory Tests

1. Pitting Variability Tests

Potentiodynamic polarization curves have been used in measuring the relative pitting resistance of various candidate alloys by other investigators [2b, 5]. While there are many limitations to this technique, it can be useful as a screening tool. However, the results from different investigators on the same alloy may differ considerably due to differences in test techniques, environment (simulated J-13 water) preparation, and due to the inherent stochastic nature of the process. For example, Beavers et al. [2b] used an initial cathodic polarization before scanning, whereas ASTM G-61 technique calls for scanning from open-circuit conditions. It has been shown that initial cathodic polarization can lower pitting potential. Similarly, the pH in simulated J-13 water has been adjusted by the addition of HCl which leads to an increase in chloride content from 6 ppm to 20 ppm or H_2SO_4 which leads to an increase in the sulfate to chloride ratio. Another source of variability, especially in the low-conductivity solutions, is the positioning of reference electrode. The inherent variability of pitting potentials from this test has been examined by Fratesi [6] in neutral chloride environments. Hence, it is imperative that these three sources of variations be differentiated through judicious investigation of test techniques, solution preparation, and replication under the same conditions. Replication of tests under the same conditions will yield quantitative information on the variability of critical pitting and protection (repassivation) potentials which then can be used to evaluate the results from factorial experiments. One of the assumptions made in the factorial experiments conducted by Beavers and Thompson [2b] is that the variation in results is uniform across the range of environmental variables. The experiments conducted in this program under the Center's Technical Operating Procedures TOP-008, TOP-009, and TOP-010 will verify this.

2. Full Factorial Tests

Another aspect of the short term tests is the examination of the quantitative dependence of pitting and crevice corrosion on environmental variables such as chloride content, pH and temperature. Beavers and Thompson [2b] have already examined a wide matrix of environmental variables. However, because of the large number of variables, a highly fractionated factorial design was used. This design does not allow evaluation of interaction of environmental variables such as chloride and fluoride, and chloride and sulfate. This can only be attained by a full factorial experimental design. Furthermore, even a full factorial experimental scheme can not yield the functional relationship between pitting and chloride content. The establishment of a functional relationship is desirable in terms of identifying a quantitative acceleration factor. Once this acceleration factor is established, results from shorter-term tests in aggressive solutions can be used to extrapolate to corrosion kinetics in less aggressive, more realistic solutions. Literature in pitting corrosion suggests that pitting corrosion (pitting potential, incubation time, etc.) is dependent on the logarithm of chloride concentration. Hence, tests focusing on one or two important variables (e.g., chloride and pH or temperature) are needed to verify this functional relationship at low chloride levels.

The copper-based alloys can also exhibit pitting in chloride environments, but they may have a different type of sensitivity to environmental parameters than the chromium-containing alloys. It appears from the investigations of Beavers and Thompson [2b] that potentiodynamic test results on Cu-base alloys yield anomalous results in some cases such as hysteresis without noticeable crevice/pitting corrosion. The type of pitting phenomenon has been shown to depend on the environment composition, such as the pH, hardness of water, temperature, and chloride/sulfate ratio [8]. For example, in high hardness waters, at near neutral pH, and low temperatures, wide pits covered by corrosion products have been observed. In soft waters at high temperatures, narrow, deep pits have been observed. Hence, a study of the effects of these environmental variables relevant to repository environment is essential for the Cu-base alloys.

Anticipatory Tests

3. Crevice Corrosion Tests

In many practical systems, crevice corrosion occurs before pitting because the conditions needed to establish an active corrosion already exist inside a crevice, whereas, pitting has to grow to a significant degree before such conditions become established. Previous investigations have not examined crevice corrosion pertaining to the waste package systematically. For example, electrochemical investigations by McCright, et al. [9] have used the difference between pitting and protection potentials as a measure of crevice corrosion. However, the crevice in this test is an uncontrolled crevice and may not be an accurate indication of crevice corrosion susceptibility. Hence, crevice corrosion tests with controlled crevice geometry (crevice gap, creviced/uncreviced area ratio, and crevice device) need to be performed. These tests will be potentiostatic in nature and will complement the long-term exposure studies.

4. Pitting Protection Potential (Repassivation Potential) Validity

Pitting protection potential (repassivation potential) has been used extensively in many tests [1,6,7]. The essential question is the use of a protection potential derived from a short-term test (lasting a few hours) in predicting the behavior for relatively long periods of time. In other words, if the natural corrosion potential of a material in an environment is below the protection potential measured by a short-term test in that environment, will the material be free from pitting in that environment for long periods of time? It has been shown by some authors [10] that protection potential is a function of time allowed for pit growth, i.e., the maximum current attained in the potentiodynamic test. However, others [11] have shown that a protection potential (repassivation) that is independent of the extent of pitting (either number of pits or pit depth) can be established. Obviously, a time-independent protection potential, if it is possible to establish such a value, is of great importance. Hence, experiments where the potential is held above the pitting potential determined by previous testing for various lengths of time ranging from a few hours to a few weeks (the latter in a slowly recirculating system) are needed to establish this concept.

5. Measurement of Redox Potentials (E_h) of Various Simulated Environments

The concept behind all the foregoing tests is that once a potential range in which a certain corrosion phenomenon can take place on a metal is established by *electronic* control of potential, then, if the redox potential of the *natural* environment is known, predictions can be made regarding the bounds of degradation behavior of the metal exposed to that environment. However, the value of E_h (in this case, a mixed potential) in a complex environment such as may exist in the vadose zone of the proposed repository site is far from clear because of unknowns in the equilibria between various redox couples, and because the actual redox potentials of some reactions may be more polarized (activation or chemical polarization) than others. The latter will be reflected by the fact that the measured potential will be significantly lower (more anodic) than predicted by equilibrium considerations. The oxygen electrode is a well-known example [12]. Additionally, the polarization of some reactions (e.g., oxygen reduction) may be controlled by diffusion of the reacting species to the electrode (Concentration polarization). Thus, there may be many deviations from the E_h calculated by codes such as EQ3/EQ6.

The purpose of the experimental program here is not to study the fundamental mechanisms of various redox reactions. For many of the redox species of interest in the repository environment, this has been done quite extensively [13]. Rather, the experimental measurements of redox potentials will be made to characterize the mixed potentials as they exist in the natural environment and the kinetics of the various redox reactions (exchange current density and Tafel slopes) so that reliable estimates as to the bounds of corrosion modes may be made. The experimental measurements of mixed potentials can be made by systematically mixing various redox couples and by ensuring that the measurements are not controlled by diffusion limited processes. The diffusion-controlled reactions are overcome by performing the tests using a rotating electrode system at sufficiently high rotational speeds [14,15]. In this way only the activation or chemical polarization effects can be measured. While measurements on platinum give the kinetics of electron exchange reactions at a bare surface, it is more important to measure the redox kinetics on the surfaces of the candidate alloys many of which will be covered by a passive film. Hence, similar measurements must be made on passive metals by ensuring that other anodic reactions do not take place or take place at negligibly low rates. The redox species of interest in the IWPE program are the O_2/OH^-, H_2O_2/OH^-, NO_3^-/NO_2^-, and Fe^{3+}/Fe^{2+} couples. A source of H_2O_2 and NO_3^- is radiolysis and hence redox potential measurements can be made by either simulated solutions or exposure under conditions of γ-irradiation. A source of Fe^{3+}/Fe^{2+} species may be the corrosion of carbon-steel borehole liners.

6. Effects of Welding On Localized Corrosion

Closure of containers is anticipated to be performed by welding although the type of welding process has not been determined. The containers are fabricated with longitudinal seam welds which will be in the annealed condition. In the case of fusion welds, it is well established [16] that the weld zone has lower pitting and crevice corrosion resistance than the base metal. The weld metal has lower localized corrosion resistance because of segregation of alloying elements during solidification of the weld, creating depleted regions of Cr, Mo, and W [17]. In some highly alloyed materials such as Hastelloy alloy C-22, presence of intermetallic phase in the weld has also been reported [17]. In contrast, these alloys usually have relatively low carbon, and the heat-affected-zone thermal cycles are rapid enough that grain-boundary precipitation of carbides and sensitization have not been as serious a limitation as weld segregation. Indeed, in modern, low interstitial stainless steels and high-Ni alloys, the weakest corrosion link is not the heat-affected zone, but the fusion weld zone itself. In the case of friction welds, the corrosion resistance of weldments has not been characterized much in the literature. Hence, it is imperative that the corrosion resistance of weldments be studied in addition to that of the base metal. It is envisaged that, in the initial stages of the program, focus will be on the base metal and weldments will be studied preliminarily. However, the preliminary investigation of the weldment properties will shed some light on the areas of concern and appropriateness of the welding technique selection.

ACTIVITIES

a. Pitting Variability Tests

Potentiodynamic polarization tests have been performed at the Center on the stainless steels, alloy 825, and Hastelloy alloy C-22. However, these tests have been preliminary in nature, performed mainly to establish procedures. No effort has been made to examine the variations in polarization curves systematically. Further potentiodynamic, cyclic polarization tests will be conducted on three of the candidate alloys in simulated J-13 water, with chloride concentrations ranging from 6 - 10,000 ppm. The proposed test matrix is shown in Table 3.3. This is subject to modifications as the experiment progresses. Additionally, these tests will yield quantitative relationships between chloride content and characteristic pitting potentials. Similar tests will also be done on the CDA-715 (Cu-30% Ni), but only at the 20 ppm chloride level. Additional tests will be done in solutions selected from the factorial test matrix so that an assessment of the confidence intervals on the factor effects can be made.

Specimens for the electrochemical tests will be prepared in accordance with the Center's TOP-003.

Table 3.3 Test matrix for examining the statistical variability of pitting potentials in potentiodynamic tests.

ENVIRONMENTS	316L	825	C-22	CDA-715
Simulated J-13 (6 - 10,000 ppm Cl^-)	7	7	7	
Model solutions from factorial tests	7	7	7	7

All tests run according to ASTM G-61 Procedure

Test temperature: 95°C

b. Effect of Environmental Variables On Pitting - Full Factorial Test

For reasons of economy, these tests will first concentrate on one alloy—alloy 825—since this is one of the "aim alloys" for the DOE waste package program. The environmental variables considered will be chloride (6 ppm - 1000 ppm), temperature (60°C - 95°C), fluoride (2 - 100 ppm), nitrate (10 - 1000 ppm), and sulfate (20 - 1000 ppm). The initial and final pH will be measured. A constant level of bicarbonate corresponding to that in J-13 water will be added to all solutions. Sodium will be the only cation used. The test matrix is given in Table 3.4. The range of variables chosen is intentionally wide to increase the aggressiveness of the environments so that any interactive effects may be observed easily.

Table 3.4 Effect of focused environmental variables on pitting susceptibility using two-level factorially designed experiments. Potentiodynamic tests will be conducted according to ASTM G-61 Procedure.

ALLOY 825

TRIAL NO.	Cl^-	TEMP. (°C)	F^-	NO_3^-	SO_4^{2-}
1	-	-	-	-	-
2	+	-	-	-	-
3	-	+	-	-	-
4	+	+	-	-	-
5	-	-	+	-	-
6	+	-	+	-	-
7	-	+	+	-	-
8	+	+	+	-	-
9	-	-	-	+	-
10	+	-	-	+	-
11	-	+	-	+	-
12	+	+	-	+	-
13	-	-	+	+	-
14	+	-	+	+	-
15	-	+	+	+	-
16	+	+	+	+	-
17	-	-	-	-	+
18	+	-	-	-	+
19	-	+	-	-	+
20	+	+	-	-	+
21	-	-	+	-	+
22	+	-	+	-	+
23	-	+	+	-	+
24	+	+	+	-	+
25	-	-	-	+	+
26	+	-	-	+	+
27	-	+	-	+	+
28	+	+	-	+	+
29	-	-	+	+	+
30	+	-	+	+	+
31	-	+	+	+	+
32	+	+	+	+	+
33	I_1	+	-	-	+
34	+	I_2	-	-	-
35	+	+	-	-	I_3
36	+	+	-	I_4	-
37	+	+	I_5	-	-

Cl^-	:	Minus = 20 ppm;	Plus = 1000 ppm
T	:	Minus = 60°C;	Plus = 95°C
F^-	:	Minus = 2 ppm;	Plus = 200 ppm
NO_3^-	:	Minus = 10 ppm;	Plus = 1000 ppm
SO_4^{2-}	:	Minus = 20 ppm;	Plus = 1000 ppm
I_x	:	Intermediate points.	

The pitting potential alone is not a suitable parameter for statistical analysis because variations in "pitting potential" have no physical meaning when no pitting occurs. Hence, the difference between pitting and protection (repassivation) potential will be used initially. The larger this difference, the greater will be the extent of localized corrosion. However, crevice corrosion can occur at the sample-gasket interface and hence these results will be supplemented by visual observation of the sample after the test.

The result of this test will be an equation of the form:

$$(E_{pit} - E_{prot}) = E_0 + A.[Cl^-] + B.[T] + C.[F^-] + D.[NO_3^-] + E.[SO_4^{2-}]$$
$$+ \{\text{Sum of interactions of above}\}$$

The interaction term of five factors, which is considered unlikely, will be used to block the experimental sequence so that machine or operator biases can be detected. Based on this analysis, a composition can be chosen that can simulate the worst-case condition for localized corrosion within the range of environmental variables tested. Because of the large number of tests required to conduct this matrix, only one alloy is considered. The worst-case condition may not be valid for other alloys. For example, Type 316L stainless steel at the highest chloride and fluoride levels may show more of a general type corrosion and hence $[E_{pit} - E_{prot}]$ may not be very high or meaningful. Another example is Hastelloy alloy C-22, where preliminary results show that pitting was observed at the lowest chloride level and no pitting at the highest chloride level. For these cases, selected tests will be conducted and the results compared to that of alloy 825. Selected tests will also be done on CDA-715 (Cu- 30% Ni). In the case of the copper-based alloy (CDA-715), the environmental factors chosen may be different. For example, the ratio of bicarbonate to chloride has been shown to be important. Additional experiments will also be carried out to investigate the effect of pH, silica, and cations (Ca^{2+} and Mg^{2+}).

Finally, selected tests will be performed in natural J-13 water to characterize the short-term corrosivity of this solution within the range of environmental variables. Procedures for collecting the natural J-13 water have already been established and provisions will be made to visit the collection site along with NRC - research staff member. Laboratory test solutions for the experiments in this task will be prepared according to Center's TOP-010.

c. Crevice Corrosion Tests

The sample configuration for this test would involve sandwiching the sample between two machined crevice blocks (made of an inert material such as zirconia) with a reproducible compressive load. The exact design of the sample will evolve as a result of trials conducted initially. The essential purpose of the design is to control the crevice gap, crevice depth, and crevice/bold surface area ratio. The crevice device has to be chosen carefully to avoid creep. The standard crevice device made of polytetrafluoroethylene (PTFE), may not be suitable. Zirconia crevice devices will be considered. The solution chemistry will be based on previous testing. Initially, the tests will be performed on alloys 316L, 825, and C-22. The Cu-base alloy, CDA-715, will be included subsequently. The following testing will be performed:

1. Apply potential to a creviced sample and measure current vs. time.

    Variables: crevice gap/length, temperature, chloride.

    Measure: Incubation time, protection potential.

Depending on the outcome of these experiments, a more sensitive experiment may be the coupling of an open sample (representing the bulk sample) to a creviced sample via a zero resistance ammeter to detect incubation time and propagation rate of crevice corrosion. This will be performed on a reduced number of samples by utilizing the results from the previous test program.

d. Validity of Pitting Protection Potential

No tests have been performed thus far in any of the waste package materials program to validate the use of protection potential for long-term prediction. The test sequence for this would involve initial trials for the best approach (since no standard ASTM test technique exists), establishing a test procedure, and performing further tests according to these procedures. A preliminary sequence of experiments is given below:

Alloys: Type 304L stainless steel, 316L, alloy 825, Hastelloy alloy C-22

Solution: To be determined from previous step.

Step 1: Identify a pitting potential (E_p) from previous potentiodynamic tests.

Step 2: Hold at constant potential ($E_1 = E_p + 50$ mV) for times t_1, t_2, t_3, t_4.

$t_1 = 24$ hours
$t_2 = 120$ hours
$t_3 = 240$ hours
$t_4 = 720$ hours (1 month)

Step 3: Monitor current vs. time (ensuring that it increases)

Step 4: After each time period at E_1, reduce potential to E_{prot} (measured before potentiodynamically).

Step 5: If current does not decrease, reduce potential in 50 mV steps till it starts decreasing. This will be the new E_{prot}.

Step 6: Correlate the E_{prot} to total charge passed at E_1.

For long periods of time, it will be necessary to construct a recirculating system such that solution contamination by corrosion products is minimized.

e. Measurement of Redox Potentials (E_h):

The E_h of the system is a complex function of the various redox species present and their heterogeneous reaction kinetics on the metal surfaces. Currently, no scheme exists for calculating these values. The experimental method will involve the use of a rotating cylinder or disc electrode made of either platinum, some other suitable inert electrode, or some of the alloys under consideration. The latter will have to be tested in redox systems where no significant corrosion takes place.

Table 3.5 Test matrix for redox potential measurements on Platinum.

TRIAL NO.	O_2/H_2O	NO_3^-/NO_2^-	H_2O_2/OH^-
1	-	-	-
2	+	-	-
3	-	+	-
4	+	+	-
5	-	-	+
6	+	-	+
7	-	+	+
8	+	+	+

O_2	:	Minus	: Deaerated;	Plus : Aerated
NO_3^-	:	Minus	: No addition;	Plus : 10,000 ppm (equimolar nitrite)
H_2O_2	:	Minus	: No addition;	Plus : To be determined
Baseline solution	:	Dilute solution of Na_2SO_4 or Simulated J-13 water.		

To determine the redox potential of a mixture of solutions, a full factorial experimental approach can be used as shown in Table 3.5. Three redox couples are considered to be the most important from the Yucca Mountain repository point of view: O_2/OH^-, NO_3^-/NO_2^-, and H_2O_2/OH^-. For the three redox couples considered, there will be a total of eight experiments. In each of these experiments, a series of cathodic and anodic polarization and a.c. impedance behavior on platinum at a number of rotational speeds will be determined, and from the highest of the speeds, both the Tafel slopes and exchange current densities will be calculated. From the factorial design then the redox potential of each reaction together with interactive effects can be determined as shown below:

$$E(\text{Mixture}) = a_0 \cdot E(O_2) + a_1 \cdot E(NO_3/NO_2) + a_3 \cdot E(H_2O_2)$$
$$+ (\text{Sum of two by two products})$$

An additional redox reaction is Fe^{3+}/Fe^{2+} reaction. This will be investigated separately. A word of caution is appropriate at this point. The effect of individual species in the redox potential of mixture (i.e., the coefficients in the above equation) depends on their concentration range chosen. Thus, at high concentrations, the nitrate/nitrite reaction can overwhelm the other reactions, but at the concentrations expected in the radiolysis products, its effects relative to the oxygen reduction reaction are not known.

In addition to measurements on Platinum, preliminary measurements on other oxide covered electrodes, such as alloy 825 and Hastelloy alloy C-22, will be attempted. The kinetics of these reactions will also be studied on CDA-715.

f. Effect of Welding on Localized Corrosion

The initial activity in this program will be to evaluate the microstructures of fusion welded and friction welded samples. The initial corrosion tests on these welded samples will be in accelerated, laboratory environments designed to show relative performance of welds and base metal. For the stainless steels and the Ni-base alloys, these tests may be variants of ASTM G-48 (6% Ferric chloride) or ASTM G-28B tests. The tests will be done on welds made by fusion welding and by friction welding. For the Cu-base alloys, the appropriate corrosion tests are not known at th. · time and only metallographic investigation will be conducted.

Subtask 1.1.4 Long-term Corrosion Studies

OBJECTIVES

The majo. objective of any long-term test is to gain an understanding of the degradation kinetics in environments similar to the repository environment. However, because of the design life requirement of 1000 years and longer, complete simulation of repository conditions is not a viable approach for laboratory testing. Hence, the long-term tests will concentrate on the follo‹‹ing tasks:

1. Determini‹‹g the corrosion kinetics in more aggressive environments, such as those containing higher chloride, and then extrapolating the results to low chloride environments using results from previous experiments.

2. Evaluation of episodic conditi‹‹ns that result in drying and wetting cycles.

3. Evaluation of radiolysis effects on corrosion in aggressive environments similar to those proposed in Task 1.

JUSTIFICATION

The repository thermal conditions dictate that the environment is likely to be gaseous for long periods of time. Hence, corrosion in air plus steam mixtures is an important consideration. Previous investigations [6] have shown that in these gaseous environments the corrosion rate of stainless steels is quite low and hence is not of concern as a degradation mode. Exposure to the gaseous environments can have an effect on subsequent localized corrosion in an aqueous environment. In addition, other processes need to be considered that may either alter the steam environment or, due to episodic events, produce an aqueous environment. Radiolysis of steam/air mixture has been shown to produce oxidizing components such as nitrates [14], resulting in high corrosion rate of Cu base alloys. Periodic wetting by water intrusion or condensation of droplets followed by drying and rewetting cycles may produce great increases in salt concentration at the surfaces. Finally, the nature and kinetics of the passive films formed in steam at these temperatures is not known. Presence of crevices between the bottom of the containers and the floor or between the sides and the bore hole walls may alter the environment within the crevices. While many studies of the effect of crevices in altering aqueous environments have been conducted, crevice chemistry in a gaseous environment is not well known.

ACTIVITIES

The experimental program will concentrate on the following aspects initially: exposure to a gaseous environment, an alternating aqueous/gaseous environment, an aqueous environment, and long-term exposure to gaseous environment followed by tests in aqueous environments.

1. The apparatus for the gaseous corrosion studies will consist of a glass vessel equipped with appropriate ports from which samples will be exposed by mounting them flush to the vessel walls. The samples will be heated from outside to simulate the internally heated containers. Exposure of specimens to steam for time periods ranging from a few weeks to 5 years are planned. These specimens will be removed periodically for weight-loss measurements and visual examination. This will also prevent condensation of moisture on the samples. The temperature

of the steam will be monitored. Some of the samples removed after various periods of long-term exposure to the gaseous environments will be immersed without cleaning in aqueous solutions, and the surface passive film characteristics will be compared to fresh samples by electrochemical techniques (a.c. Impedance spectroscopy as well as d.c. polarization techniques).

2. The same type of apparatus will be used for the wet/dry environmental testing. In this case, the cell will be half filled with solution and the cell will be periodically turned over so that the samples that were previously completely immersed will now be dry and vice versa. Electrochemical potential will be monitored with time when the samples are immersed in the electrolyte. Samples will be examined periodically through a stereoscope for pitting/crevice corrosion. The aqueous environment will be recirculated from a reservoir which will be periodically refreshed by new solution. The composition of the solution will be both simulated and natural J-13 water, but other solutions augmented with chloride will also be tested.

3. A third aspect of the long-term program will be immersion tests in an aqueous environment such as simulated J-13 water or higher chloride variants. The higher chloride content will be chosen to reflect a realistic upper bound (e.g., 1000 ppm). The samples will contain a number of intentional crevices by the placement of a washer of a material such as zirconia. They will be immersed in a constant temperature bath for relatively long duration and removed periodically for inspection. It is possible in this test to evaluate both pitting of open samples and crevice corrosion due to intentional crevices created between the samples and zirconia. The test procedures will be similar to those outlined in ASTM G-48 and G-46. The samples will be examined periodically for signs of crevice corrosion and pitting under a stereoscope.

Tests Under γ-Radiation

Further long-term localized corrosion testing will involve testing under conditions of γ-radiation using the Co source available at the Institute. This can be done by any or all three of the methods outlined above. This type of testing will be especially of interest in the case of the Cu-base alloys. Tests will concentrate on wet/dry-type environment and dry steam plus air environment. These tests are planned after experience from tests under non-irradiated conditions is gained. The radiation facilities will be evaluated in coordination with the research staff from NRC as well as the Institute and Center staff prior to commencement of the test program. It is envisioned that after the initial phase of the long-term corrosion test, a test plan for experiments under γ-radiation will be formulated and submitted to the NRC for approval.

Subtask 1.2 Internal Corrosion

OBJECTIVE

Evaluate the potential for internal corrosion of the candidate container materials due to the possible presence of internal moisture.

JUSTIFICATION

Most of the prior investigations have concentrated on the degradation of the containers from the external environment. The assumption in this has been that the internal environment will be dry. However, presence of moisture can lead to a high pressure, aqueous environment inside the container and cause many of the same corrosion processes that have been investigated for the external environment. Additional factors such as galvanic contact with fuel cladding and other internal metallic wastes can also play a role in the internal corrosion or cracking. It is premature at this stage to propose a well-defined experimental program. However, preliminary investigation of the internal chemistry as a result of the presence of moisture should be undertaken with the objective of defining future experiments for both DOE- and NRC-sponsored research programs.

ACTIVITY

The activities in this program will consist essentially of taking stock of the possible inventory inside the container and evaluating the consequent chemistry inside as a function of time. No experiments are planned at this time. A critical review report will be the product of this initial phase of the program. It may be necessary after this review to formulate a more detailed experimental plan.

TASK 2 - STRESS CORROSION CRACKING

The overall objectives of this task can be summarized as follows:

1. To assess, select and develop adequate experimental techniques for measuring initiation and propagation of environmentally assisted cracks in the candidate alloys.

2. To develop a phenomenological understanding of the critical steps in the initiation and propagation of environmentally assisted cracks for the candidate materials and determine how these steps are affected by mechanical, metallurgical, and environmental variables.

3. To perform stress corrosion cracking tests under well defined environmental conditions simulating those expected at the repository site that can yield data useful for long-term prediction.

Stress corrosion cracking (SCC) or, in other terms, environmentally assisted cracking under sustained loading conditions, is one of the most undesirable failure modes for container materials because its occurrence is extremely difficult to predict on the basis of current knowledge. It is well known that the development of new alloys or the use of commercial alloys in new processes and applications has been accompanied almost inevitably by the occurrence of failures attributed to SCC.

Two illustrative examples are the environmentally assisted cracking of Zircaloy-4 nuclear fuel cladding in the presence of iodine as a fission product [19] and the rupture of Ti-6Al-4V tanks filled with N_2O_4 during pressure testing in the course of the Apollo Program [20]. In both cases it was not possible to predict the SCC susceptibility of the Zirconium and Titanium alloys in the expected environment prior to the failures. Once the failures occurred, an extensive experimental program was conducted to identify the chemical species responsible for the initiation and propagation of cracks and define the related stress conditions required for crack initiation and growth. Finally, appropriate countermeasures were adopted to avoid new failures.

It is important to note, however, that the knowledge acquired in both cases could not be incorporated to a generalized and well established theory on SCC. Mechanistic ideas were suggested to explain the chemical and metallurgical processes involved but without the possibility of making fruitful generalizations. Nowadays, despite the significant progress made in the interpretation of many aspects of the phenomenon, a theory based on fundamental concepts of physical metallurgy, mechanics and electrochemistry does not yet exist.

In addition, there is not yet a fully accepted empirical model able to be used for estimating with confidence crack growth rates on the assumption that a crack preexists or can be initiated early in the service life of the container. It should be noted that only in recent years there have been attempts to develop quantitative models for predicting crack growth rates [21,22]. The estimations are confined to time scales corresponding to the expected life of nuclear power plants (40 years). However, additional data are still needed to evaluate the accuracy of these predictions, even for such a limited time span as compared to that required for a nuclear waste repository.

In the testing programs conducted by Lawrence Livermore National Laboratory (LLNL) and by Cortest Columbus, attempts were made to obtain experimental data applicable to the conditions expected, at least initially, at the repository site. However, changes with time in the environmental conditions cannot be predicted with confidence at the present time.

For all these reasons there is a need for the development of a sound experimental basis to compare the data with qualitative or semi-quantitative predictions arising from the most widely accepted models of stress corrosion cracking. As noted above, there is no model of stress corrosion cracking which can be used with confidence to generate quantitative predictions of failure times, crack growth rate, etc., for the candidate materials. Therefore, a sensible approach is to correlate experimental data obtained under a variety of environmental conditions which are related to those expected at the repository site with existing models to test their validity. A second step will be improving those models that appear to be more adequate for a quantitative treatment of the experimental results.

We expect that, in the course of this research program, the critical steps in the initiation and propagation of stress corrosion cracks can be identified, and the dependence of SCC on mechanical, metallurgical, and environmental variables can be expressed in a quantitative manner, amenable to reliable and independent experimental confirmation.

The evaluation of several SCC testing methods is an important aspect of this research program. The advantages and limitations of different techniques will be carefully assessed taking into consideration that reliable experimental data needed for long-term prediction must be acquired through prolonged tests.

The overall research program is planned for a period of 5 years. Several partial objectives corresponding to different subtasks, as described below, will be accomplished during the initial 2 years.

Subtask 2.1 Critical Assessment of Test Techniques Used to Generate SCC Data on Container Materials

OBJECTIVE

Perform a critical review of the SCC test techniques available for evaluating the candidate alloys in environments of interest for the tuff repository site.

JUSTIFICATION

A critical review of the currently available SCC test techniques is needed to assess their validity as adequate tools for long-term prediction. However, as emphasized in recent publications [23,24], the selection of appropriate techniques cannot be satisfactorily accomplished without having some knowledge of the relevant processes controlling crack initiation and growth. Therefore, a complete review of the information available on the stress corrosion cracking susceptibility of the candidate materials is required, as well as a reasonable description of the environmental conditions which may prevail at the repository site. The validity of different test methods and experimental techniques should be assessed considering their application to the mechanistic understanding of the phenomenon, in addition to their usefulness as tools for long-term prediction.

The issue of accelerated laboratory tests vs service conditions must be evaluated considering environmental factors (temperature effects, solution composition, applied potential vs. open circuit potential) in addition to stressing or straining methods.

ACTIVITIES

The reports prepared by LLNL [25,26], Cortest Columbus [1] and NIST [27] will be reviewed and updated on the basis of more recent information. The review will essentially provide guidelines to interpret relevant results on the basis of the more accepted models for stress corrosion cracking as a preliminary test to check their applicability and validity. The merits of different test methods will be compared by considering the quality of the data generated and their potential for mechanistic understanding and modeling.

The relevant literature on stress corrosion cracking of Fe-Cr-Ni alloys, as well as that of pure Cu and Cu-based alloys will be reviewed. Particular attention will be paid to the behavior of these materials in environments that resemble those expected to be encountered at the proposed repository site. However, emphasis will be given to the study of different mechanistic theories or models proposed for a wide variety of materials and environmental conditions, since at the present time there is not a unique, accepted interpretation of this complex phenomenon. On the contrary, it has been suggested that various mechanisms may exist or even coexist covering a spectrum of behaviors for different alloy/environment systems [28].

The review process will be used essentially as a guiding tool for the design of relevant experiments to test the validity of a given model and enhance its predictive capability by suitable improvements. It will provide also an assessment of the different techniques taking into consideration two aspects: 1) data acquisition for long-term prediction of service behavior; and 2) quantitative evaluation of environmental and mechanical factors leading to an improved phenomenological characterization. It is expected that this combined approach could be fruitful for improving current models (task to be carried out in a parallel program) or, if it is not the case, will demonstrate the need for a deep and thorough reevaluation of the concepts prevailing in this field of corrosion science.

A report will be issued upon completion of this subtask.

__Subtask 2.2__ __Slow Strain Rate Tests (SSRT)__

OBJECTIVE

To determine the environmental conditions that may promote stress corrosion cracking of the candidate alloys.

JUSTIFICATION

Previous work conducted by Cortest [29], as well as work performed under DOE sponsorship [9], did not show indications of stress corrosion cracking for AISI 304L SS in solutions prepared with simulated J-13 well water and the additions of CO_2, H_2O_2 or NaCl, even at very high Cl^- concentrations (1000 ppm), in slow strain rate tests (SSRT) conducted at 90°C. The concern has been raised that the SSRT may be not appropriate to reveal transgranular stress corrosion cracking (TGSCC) of solution annealed austenitic stainless steels in chloride-containing solutions as compared to constant deformation or constant load tests. However, since the susceptibility to TGSCC is affected by Cl^- concentration, pH, temperature and potential, it is possible that minor variations in the environmental conditions and/or the surface or near-surface properties of the material (roughness, cold work, surface films, etc.) are critical for the occurrence of environmentally assisted cracking. In particular, it is expected that the nucleation and growth of pits or the presence of a crevice, both leading to localized environmental conditions characterized by low pH values and high aggressive anion concentration, may facilitate the initiation of cracks. These conditions can be reached after long exposure times in U-bend or constant load tests but they may not be attainable through the short duration of a slow strain rate test.

It should be noted, however, that some authors [30-33] have successfully used slow strain rate technique to study the transgranular cracking of AISI 304 SS in boiling $MgCl_2$ solutions and in acidic chloride solutions ($NaCl + Na_2SO_4$) at room temperature.

ACTIVITIES

The initial part of this subtask will be conducted by Cortest during the FY90-91 period. Testing will be confined in principle to AISI 304L SS. Depending on the results of the Cortest program, several tests will be conducted at the Center to explore the effect of pre-exposure conditions on cracking susceptibility and the extension of the testing program to AISI 316L SS, Alloy 825 and Hastelloy C-22. A detailed test matrix will be developed on the basis of the Cortest results and the results on Subtask 1.3 where the combined effect of different anions on localized corrosion is studied. It is anticipated that an important aspect to consider is the effect of surface films preformed in moist air at temperatures ranging from 100° to 280°C on the susceptibility to SCC in aqueous environments at 95°C.

Initially, the susceptibility of Copper-based alloys to SCC in selected environments will be studied with the SSRT. The effect of environmental variables will be evaluated by considering temperature, pH and concentration of various aggressive anions. The principal species to be considered is NO_2^-, which is formed by radiolysis of humid air, through nitrogen oxides as intermediates. It is known that NO_2^- promotes cracking of pure Cu and α-brass, but the effect on CDA-613 (Cu-7Al-2Fe) has not been investigated. Experiments conducted recently at Argonne National Laboratory (57) have shown that, in the presence of γ-radiation, NH_3 can be formed in humid air. This observation suggests that in the repository site where mild oxidizing conditions prevail, the presence of NH_3 in the environment cannot be disregarded. Therefore, NH_3, which is a causative agent for the environmentally induced cracking of Cu alloys, will be included in the testing program.

Another N-based species to consider is NO_3^-, which is present in J-13 well water and can be formed also by radiolysis of humid air. In addition, the susceptibility to cracking will be explored in SO_4^{2-}-containing solutions and eventually in solutions with various SO_4^{2-}/Cl^- ratios. Although there are no reported cases of cracking for the selected Cu-based alloys in Cl^--containing solutions, it is important to explore the behavior in simulated natural waters containing HCO_3^- as the predominant anion and variable concentrations of NO_3^-, SO_4^{2-}, Cl^- and other species of interest.

The experimental approach will be based on slow strain rate tests under well-defined potential conditions. Base line tests will be conducted under potentiostatic control to define potential ranges and environmental conditions in terms of solution composition, pH, temperature, etc., in which the candidate alloys may be susceptible to SCC. Selected tests will be conducted under open circuit conditions in the presence of oxidizing species, such as O_2, H_2O_2, Cu^{2+}, Fe^{3+}, etc., to check the validity of the approach based on potentiostatic tests. In these tests the potential will be continuously monitored.

Eventually, the effect of strain rate on SCC susceptibility will be evaluated. The interest on studying strain rate effects is related to mechanistic interpretations and, hence, it will be specifically considered for each alloy group.

A test plan for this subtask will be submitted prior to the initiation of the experimental program. On the basis of the results of the full factorial tests and Cortest's results, as well as the evaluation of the available literature, a selection of the environments and representative alloys to be tested, testing conditions, and other relevant experimental details, will be described in the test plan. Appropriate test materials will be presented and preliminary experiments to better define the testing conditions will be included in the test plan, as appropriate.

Subtask 2.3 Short-term Constant Deflection Tests

OBJECTIVE

To study surface/environment conditions leading to SCC initiation.

JUSTIFICATION

Most of the mechanistic interpretations of SCC deal with the propagation stage. However, in many of the cases of SCC failure, there is indirect evidence that the initiation stage is the dominant term in the lifetime of the component. In this regard the process of film formation, and the alteration of the film properties by environmental changes, should be properly addressed to understand the initiation process in alloys covered with protective, passive films such as the austenitic stainless steels and nickel-base alloys. In addition, pits or the presence of crevice areas may lead to accelerated initiation of cracks. For the alloys of interest, it is important to evaluate the surface conditions that affect crack initiation. Similar considerations should be applied to the Cu-base alloys. In this case, however, the surface films are not so protective and according to some models the kinetics of film growth play a significant role in the crack propagation process.

An additional interest in this subtask is the comparison of results obtained with different techniques. For this purpose results obtained in Subtask 2.2 by using slow strain rate tests will be compared with those obtained with constant deflection tests.

ACTIVITIES

Constant deflection specimens will be used for these initiation studies. Initially, U-bend specimens will be tested to compare different surface preparation conditions, including pre-exposure in moist air leading to the formation of surface films. Particular attention will be paid to the effect of chemical composition changes on the surface of austenitic Ni-base alloys on the SCC susceptibility as related to heat treatment and surface preparation (see Subtask 1.2).

Microscopic examination of specimens removed from the environment at definite time intervals will be used as a preliminary method to measure crack initiation times. However, it is anticipated that other techniques, to be evaluated in Subtask 2.1, will be implemented to detect "in-situ" the initiation of cracks.

The effect of a crevice geometry on the eventual acceleration of crack initiation will be studied under well defined and reproducible conditions. Different geometries will be evaluated and due consideration will be given to non-metal (e.g., ceramics)/metal crevices.

One of the principal environments of interest for the Fe-Cr-Ni alloys is air saturated with water vapor at temperatures ranging from 100° to 350°C in the presence or absence of radiation. Since experiments in this medium can be conveniently conducted in an autoclave, aqueous solutions of varying composition containing the anions present in J-13 water will be used simultaneously as a testing environment to evaluate the effect of the nature and concentration of halide (F^-, Cl^-) anions on the initiation of cracks, as well as the role of passivating anions such as NO_3^-, SO_4^{2-}, as potential inhibitors or cracking suppressors. The influence of pH as related to the CO_2/HCO_3^- equilibrium and the relative predominance of OH^- over H^+ ions will be also evaluated.

Similar environments will be used for Cu-base alloys. In this case, however, the role of N-containing species as cracking promoters will be explored in more detail. In addition, it should be noted that CDA-715

(Cu-30Ni), which is the most resistant of the selected copper alloys to environmentally assisted cracking in the presence of nitrogen compounds, was found to be susceptible to cracking in high temperature steam [34].

In the first 2 years of this program, no testing in the presence of radiation is anticipated. However, specimens previously exposed to water saturated air at temperatures ranging from 100° to 280°C will be tested in aqueous solution at a lower temperature to determine the effect of preformed surface films on the crack initiation time. The effect of other surface conditions (e.g., as-machined vs. mechanically polished surfaces) will be investigated also.

A focus of this activity will be the study of microscopic features on the specimen surface that may be related to crack initiation, such as presence of inclusions, second-phase particles, etc., as well as the properties and characteristics of the oxide films formed in gaseous and aqueous environments. Surface analytical techniques will be used to characterize the oxides.

A detailed test plan will be submitted for this task. Alloys to be tested, specimen configurations, environments, and additional testing conditions will be described in detail.

Subtask 2.4 Long-term SCC Tests

OBJECTIVE

To obtain long-term SCC data to confirm trends observed in short term testing and enhance predictive capability with a more extended data base.

JUSTIFICATION

Although any reasonable testing time in the laboratory could be considered extremely short in terms of confirming SCC predictions required for the nuclear waste repository conditions, it is necessary to conduct some confirmatory research on the alloys tested by DOE. In addition, long-term testing extended over a period of 3-4 years will generate data useful to check the validity of some predictive models for SCC.

ACTIVITIES

One of the limitations for designing a sound long-term testing program is the lack of a precise knowledge of the environment that can be expected at the proposed repository site over an extended period of time (e.g., hundreds of years). As a matter of fact, it is expected that the environment will change with time in a manner that is not currently predictable. The most appropriate criterion to confront this issue is the design of a model environment which, in addition to having a well-defined chemical composition, may retain some of the significant characteristics of the environment expected, at least initially, at the repository site. This environment can be used for a careful checking of the current mechanistic theories under well controlled conditions in terms of physical-metallurgical and surface properties of the materials, loading or stress patterns, and electrochemical or physicochemical definition of the relevant interfaces (e.g., electrode potentials or chemical potentials [gas fugacities] measured on free surfaces and in cracks or crevices). It is expected that the development of the subtasks 2.2, 2.3 and 2.4 will lead during the course of one year to the choice of an appropriate environment for long-term testing.

Long-term exposures will be extremely useful in this testing program to obtain accurate crack propagation rates and explore processes associated with crack growth acceleration or arrest and eventually crack blunting. In addition, it is assumed that under various environmental conditions, or at least for the less aggressive ones, long initiation times may be required before a crack starts to propagate with a sustained rate. This assumption should be experimentally confirmed by appropriate testing.

Different types of specimens will be used in these tests. For crack propagation studies, modified wedge opening loading (WOL) specimens with instrumented bolts [35] will be adopted for monitoring crack growth on a continuous basis.

For tests under constant deflection, 4-point bend samples will be used to define more precisely the stressing conditions. Eventually, constant load tests will be implemented to overcome problems of reproducibility if required.

All long-term tests will be conducted under open circuit conditions. However, the environmental conditions will be carefully controlled and provisions to measure at appropriate intervals the corrosion potentials and other variables of interest, such as pH, redox potential, etc., will be adopted.

As in the other subtasks of Task 3, a detailed work plan will be submitted for NRC approval prior to the initiation of the testing program. The results obtained in Subtask 2.2 and 2.3 will be used to define the scope of this test plan.

TASK 3 - MATERIALS STABILITY

Behavior of materials depends on the environment to which they are exposed. The response is a result of iterative interaction between the material and the changing environment, which can lead to changes in the surface or bulk properties of the material. The resulting changes could influence the useful service-life and the acceptability of the material for fabricating components for a particular application. Examples of surface alteration/degradation phenomena are oxidation and corrosion of metals in gaseous, vapor, and aqueous phases, while an example of a bulk alteration/degradation phenomenon is solid-state diffusion of elements in alloys over long periods of time, producing embrittling phases and pathways more susceptible to attack by gaseous, vapor or aqueous phases.

In the first part of the program under Task 3, Materials Stability of Candidate HLW Container Materials, three higher priority subtasks will be initiated covering both surface and bulk materials properties alteration/degradation phenomena. Experimental work related to radiation effects on material stability (degradation phenomena) will be deferred until FY92 or later. There will, however, be some activities in the areas of radiation effects on degradation behavior of the waste package materials during FY91 and FY92, mostly related to reviews of literature and DOE-generated technical data. The intent would be to identify focused areas of research and prepare plans for experimental work at the CNWRA during the next phase under Task 3 on Materials Stability. The experimental projects identified to begin under the first phase of the Task 3 IWPE are given below. Detailed test plans for each of the subtasks will be provided to the NRC separately prior to initiation of the projects.

Subtask 3.1: Long-Term Materials Stability of HLW Container and Waste Package Materials

A. Austenitic Materials
(Alloy 825, Types 304, 304L, and 316L Stainless Steels, and Hastelloy alloy C-22)

B. Copper-Based Alloys
(Oxygen-free High Purity Copper CDA-102, Aluminum-Bronze Alloy CDA-613, and Cupro-Nickel Alloy CDA-715)

C. Alternate HLW Container and Waste Package Materials
(to be identified later)

Subtask 3.2: Stability of Thick-Oxide Film Formation in Copper and Copper-Based Alloys
(Oxygen-free High Purity Copper CDA-102, Aluminum-Bronze Alloy CDA-613, and Cupro-Nickel Alloy CDA-715)

Subtask 3.3: Dealloying Phenomenon in Binary Copper-Based Alloys
(Aluminum-Bronze Alloy CDA-613, and Cupro-Nickel Alloy CDA-715)

The overall technical approach in all three subtasks identified above will be to identify and quantify (where possible) the key materials parameters that control the particular degradation modes being investigated, through analyses of existing data and information, and generation of new data. These would include parameters related to raw material, wrought material fabrication techniques, closure processes, and service environment in a geologic repository [36]. Investigations of other factors, which are expected to be associated with the HLW package and are recognized as important, viz. γ-radiation emanating from the contents of the HLW package, radiolytic products of gases, vapors and liquids likely to be present in the repository, and heat-transfer across the container/waste package walls due to the heat source within the HLW package, will be factored into the IWPE Task 3 studies at a later date via subtasks that may be initiated in FY92 or later.

<u>**Subtask 3.1 Long-term Materials Stability of HLW Container and Waste Package Materials**</u>

PART A: Austenitic Materials

OBJECTIVE

Study the long-term thermal and thermodynamic stability of the metallurgical phases present in the candidate HLW container and waste package materials, and relate the metastability and slow transformations processes to likely failure in a geologic repository environment.

JUSTIFICATION

A major concern in using austenitic stainless steels for structural applications is their susceptibility to develop a sensitized microstructure when exposed in the 500° to 800°C temperature range [37,38]. Such temperature range exposures could occur during sheet metal production, and container fabrication and welding processes [39]. In the case of HLW containers, high-temperature exposure in the range indicated above would occur during welding closure and possibly during heat treatments that might be used during fabrication of the waste package. It is well-known that microstructural alterations, as a result of the sensitization phenomena, can lead to less desirable or even unacceptable properties (mechanical, corrosion, etc.) of the fabricated component. Since the low temperature sensitization (LTS) process is very slow, it may not lead to readily observable sensitized microstructure in the short period of time between container fabrication and emplacement in the repository. Although some information is available in the literature on the conditions that could lead to LTS in austenitic materials, no direct relationship has been established between various processing parameters and service conditions that could be present in a repository on the kinetics of the LTS phenomena, such as, container fabrication (residual) stresses, welding, alloying and impurity elements, grain size, prior thermomechanical treatments, amount of cold work, microstructure, morphology and size of second phase or impurity particles, γ-radiation, radiolytic products, and chemistry and oxygen content of the environment.

The information generated through this experimental study will be used in evaluating the DOE selected HLW container material from the austenitic materials family, design, fabrication processes, and process and product specifications. The data generated would also serve as an input to model development for evaluating the ability of the container fabricated from austenitic materials in meeting the containment requirements of 10 CFR Part 60.

TASK DESCRIPTION

During FY91, a comprehensive literature survey will be conducted on alloy 825, Types 304, 304L, and 316L austenitic stainless steels, and Hastelloy alloy C-22, to understand the effects of residual stresses, amount of cold work, grain size, welding, post-weld heat treatments, and chemical nature and oxygen content of the test environment, on the activation energy of the LTS phenomena. Based on the existing information and the interpretation of the data and results in the light of the repository service conditions to which the HLW containers are anticipated to be subjected in the geological repository, a test matrix will be prepared to conduct experiments principally on alloy 825 [41,42]. However, specimens of Types 304, 304L, and 316L stainless steels and Hastelloy alloy C-22, will also be included in the tests as reference specimens and for calibrating the CNWRA test procedure with DOE and literature published information. Included in the investigations will be the sensitivity of various experimental techniques in quantifying the degree of sensitization, the susceptibility of microstructures of varying degrees of sensitization to intergranular (IG) and intergranular stress corrosion cracking (IGSCC) attacks [43,44]. Standard metallurgical laboratory practices and examination techniques will be used to obtain the test data. These would include metallography, optical and scanning electron microscopy, fractography, electron microprobe analysis, x-ray diffraction, and Auger electron spectroscopy, as appropriate and necessary. Testing would include slow strain rate tests and tensile tests on samples before and after giving sensitizing treatments [45]. The test samples will be exposed to the sensitizing environment for periods ranging from a few days to several years. This subtask investigations are expected to continue through FY95.

Additional tests to study the effects of alloying elements, heat-to-heat variations, amount and morphology of second-phase particles and impurities, γ-radiation, and radiolytic products of air, moisture, and liquids on the LTS phenomena will be considered after analyzing the effects of the parameters being studied in the FY91 and FY92 test matrices.

PART B: Copper-Based Alloys

OBJECTIVE

Study and understand the kinetics of very slow transformations and thermodynamic stability of copper and copper-based candidate alloys for HLW container materials.

JUSTIFICATION

Some of the materials being considered for the HLW waste package components are known to be thermodynamically unstable. Except for high purity copper, all other candidate container materials are single phase alloys of two or more elements, which could possibly undergo phase separation or transformations resulting in thermodynamically more stable multi-phase microstructure or single-phase structure with second-phase particles or intermetallic compounds. There is a concern that more stable phases, in some cases, may have undesirable or unacceptable characteristics, e.g., lack of adequate ductility, high susceptibility to attack by oxygenated waters or radiolytic products of repository gases, vapors, and liquids, electrochemically anodic to other phase(s) in the microstructure which may lead to a localized galvanic corrosion cell on a microscopic scale, etc., [53, 54]. The kinetics of these very slow transformations, thermodynamic instability of the metallurgical phases, and the properties of resultant more stable microstructure need to be studied and understood in order to determine the acceptability of DOE-selected material for fabricating waste package components for a geological repository.

TASK DESCRIPTION

Activities under this task will initially involve a literature search and evaluation of the phase equilibria, thermodynamic and mechanical stability, and fabrication data and information presented on candidate copper and copper-based alloys for HLW container and waste package components.

The experimental work will involve a kinetics study of phase transformation processes that lead to thermodynamically stable intermetallic phases, decomposition of metastable single-phase into a two or more phase microstructure, segregation of phosphorous at grain boundaries in copper, segregation of alumina at grain boundaries in aluminum bronzes, migration of dispersed iron particles in cupro-nickel and aluminum-bronzes (leading to degradation in corrosion resistance in cupro-nickel alloys, and loss of mechanical strength in aluminum bronzes), etc. It is anticipated that some of the published binary and ternary phase diagrams will have to be validated, and additional ones will have to be generated for particular isotherms of interest. Details of experimental plan(s) under this subtask will be submitted to the NRC prior to initiation of the project.

PART C: Alternate HLW Container and Waste Package Materials

OBJECTIVE

Study and understand the kinetics of thermodynamic stability and degradation kinetics in order to determine the suitability of alternate materials for HLW container and waste package components.

[This part of the subtask has been deferred until FY92 or later. Details will be provided at a later date.]

<u>Subtask 3.2</u> <u>Stability of Thick-Oxide Film Formation in Copper and Copper-Based Alloys</u>

OBJECTIVE

Study the kinetics of thick-oxide film formation, spallation, and regeneration in copper and copper-based alloys.

JUSTIFICATION

The behavior of copper and its alloys depend, to a large extent, on the properties and maintenance of a protective surface film. The oxide films that form on copper-based alloys, in gaseous or aqueous environments, are generally adherent and follow a parabolic growth kinetics, when the oxide thickness is small. However, much less is known about thick films, which are likely to be generated in a repository over the long service-life of the HLW container (spanning hundreds to thousands of years). There is already some evidence that thick oxide films formed on some of the candidate copper-based alloys for the HLW container are susceptible to spallation [46,47]. The mechanism of spallation and regeneration of thick surface films under extended exposures to varying environments, gaseous, vapor, and liquids, is not very well understood. However, such information is necessary in order to evaluate the ability of the surface films to provide protection for the base metal, i.e., in determining the acceptability of the material for fabrication of HLW containers. This would be accomplished through understanding the kinetics of formation, spallation, and the regeneration of thick surface films under repository conditions. It is presently assumed that the repository environment will be dry, followed by the presence of a vapor phase, and finally there is a possibility of water intrusion. It is also essential that the investigations cover the much less studied and understood phenomenon of aqueous corrosion of copper and copper-based alloys with pre-film of oxide(s) formed in gaseous and/or vapor phases.

TASK DESCRIPTION

The experimental activities at CNWRA will involve study of thin as well as thick-oxide formation, spallation, and regeneration kinetics. The intent is to develop mechanistic understanding of the oxidation and corrosion phenomena as related to the ability of the surface oxide film to provide protection of the base metal against degradation. Identification of the factors controlling the spallation of thick-oxide film is a key to such an understanding [48]. The emphasis would be on developing kinetics (rate) equations which would take into account factors such as the alloy composition, temperature of exposure, environment (gaseous, vapor, or liquid), and sequence in which the oxide-film is formed in varying environment. Data generated will be used to develop simple computer model(s) which can be used to evaluate the DOE materials selection and HLW container design.

Experiments will involve exposing coupons of copper and copper-based alloys to gaseous, vapor, and liquid environments for various lengths of time, and evaluating the surface oxide film formation characteristics. Various sequence of oxidation and aqueous corrosion cycles will be used to simulate possible episodic events in a geologic repository, where a period of water intrusion may be followed by a dry or relatively dry period, followed by another wet environment exposure. Such tests could possibly reveal that the surface oxide films provide much lower protection for the base metal than once believed, e.g., exposure of copper and copper-based alloys to alternating dry and wet conditions may lead to spallation of the oxide film at much lower thicknesses or that the surface films formed under such alternating environments may be less dense (porous or fissured or fractured) and may allow local channels for the repository environment to interact with and degrade the base metal under the surface oxide film much faster. Tests will be performed in controlled environments in autoclaves, and are expected to continue into FY92 and beyond. Standard laboratory practices and metallurgical examinations will be used in studying the characteristics of the surface oxide films, including metallography, optical and scanning microscopy, electron microprobe analysis, Auger spectroscopic analyses, and x-ray diffraction techniques. The details of the test matrix will be provided to the NRC separately prior to initiation of the experiment program.

<u>Subtask 3.3 Dealloying (Selective Leaching) Phenomena in Binary Copper-Based Alloys</u>

OBJECTIVE

Study the phenomenon of dealloying (selective leaching) in binary copper-based alloys (Aluminum-Bronze CDA-613, and Cupro-Nickel CDA-715), and develop an understanding of the mechanism of dealloying and kinetics of the reaction.

JUSTIFICATION

Dealloying is a corrosion process in which the more active metal (less noble) is selectively removed (leached) from an alloy, leaving behind a weak spongy structure of more noble metal [49,50]. Unless arrested, dealloying eventually affects the entire bulk of the metal, weakening it structurally and allowing the contents (gases, liquids or leached solids) to be released through the porous mass in the remaining structure. Such a phenomenon, if it occurs in the materials of construction of the HLW package, could compromise its ability to provide the required level of containment for its radioactive contents.

Dealloying of aluminum has been reported in aluminum-bronzes (copper-aluminum alloys), and is especially severe in alloys with continuous γ-phase [51,52]. No effective minor alloying additions have been found for aluminum-bronzes, but heat treatment offers some promise of success in limiting delamination-type of dealloying (one of the two common types). Dealloying of nickel in cupro-nickel alloys, although less common than dealloying in aluminum-bronzes, has been observed at temperatures above 100°C, low flow conditions, and high local heat flux. These service conditions could occur in the repository during the period in which the HLW package is required to provide containment for its radioactive contents.

TASK DESCRIPTION

In the tests at the Center, copper-aluminum alloy CDA-613 and copper-nickel alloy CDA-715 will be exposed in general-corrosion and accelerated tests simulating the proposed repository environment (as far as practical) to determine the extent of dealloying in the two candidate alloys for the HLW containers. Included in this experimental program is development of a standardized procedure for evaluating the dealloying resistance of the two alloys being investigated. [No standardized procedure for studying dealloying phenomenon in copper-based alloys exists at present]. The procedure will include standardized specimen preparation and examination techniques. The test specimens, after exposure to dealloying environment, will be examined visually and at low-magnification for color changes, for the type of dealloying (plug or delamination), microcracking, severity of dealloying, uniformity of surface oxide coverage, morphology of dealloyed plugs and layers, and other qualitative information obtainable through nondestructive examinations.

Quantitative data will be obtained through a combination of nondestructive and destructive examinations, e.g., through specimen weighings to determine the metal wastage, and through metallographic examination to measure the depth of attack and geometry of the crack/attack front. [Such information is important, as cracks formed due to dealloying could act as locations for initiation of stress corrosion cracking (SCC)]. The test specimens, after periodic exposure, will be characterized for the dealloyed plugs and layers using optical and scanning electron microscopy. Energy dispersive spectroscopy (EDS) and other techniques like x-ray diffraction and Auger electron spectroscopy (AES) will be used, as appropriate, for identification of the surface film(s) including composition and phases. Limited specimens may be exposed to simulated radiolysis products likely to be present in a geologic repository. [Tests involving γ-radiation are deferred until later]. The test specimens used for studying the dealloying phenomena are likely to yield additional useful information about the alloys investigated, e.g., general (uniform) corrosion, crevice corrosion, pitting corrosion, filiform-type corrosion, grain boundary attack, etc.

It is planned to initiate the dealloying tests using coupons immersed in liquid phase at room temperature, at 95°C, and using heated (250° to 300°C) coupons exposed to vapor phase. In addition to these static tests, a limited number of coupons will be tested in slowly renewing water (dynamic test) at 95°C, and by using an experimental set-up that will allow heated (250° to 300°C) test specimens to be exposed to periodically dripping droplets of liquid with and without simulated radiolytic products. The tests are designed to be of intermediate-term. As such, the coupons are expected to accumulate 1 to 5 years exposure before the tests are terminated. Initiation of experimental activities related to this subtask have been deferred until FY92. A test plan will be submitted for approval at that time.

TASK 4 - MICROBIOLOGICALLY INFLUENCED CORROSION

OBJECTIVE

To evaluate the possibility that microbiologically influenced corrosion (MIC) is a viable degradation process for the candidate alloys.

JUSTIFICATION

The concern regarding localized corrosion of metallic materials induced or stimulated by the presence of microorganisms and/or its metabolic products has extended to the area of high level nuclear waste disposal in geologic repositories [1,25]. Although high radiation fields and elevated temperatures are anticipated in the repository following closure, the growth of microbial colonies cannot be disregarded after several hundreds of years. It is now well established [55,56] that a variety of bacteria and microorganisms are able to promote severe localized corrosion of stainless steels and Copper-based alloys under appropriate conditions. For these reasons it is necessary to assess the possibility that MIC may affect the integrity of the containers.

ACTIVITIES

A limited effort will be devoted initially to this subtask. A review of the literature and consultation with microbiologists specialized in underground facilities (mining industry, mineral leaching, etc.) will be the approach used to define if some level of experimental work is needed after the end of FY 1992. A report covering the relevant information will be published. A test plan for the experimental work will be submitted afterwards.

TASK 5 - OTHER DEGRADATION MODES

The main purpose of this task is to collect those degradation modes that do not fall logically into any of the other previous task groupings. These degradation modes may include the degradation of nonmetallic materials if they are chosen as candidates for container materials, coatings (metallic and nonmetallic), and composites.

Subtask 5.1 Hydrogen Embrittlement Studies

Currently hydrogen embrittlement is being investigated as a possible degradation mode. The activity is being carried out at the Ohio State University (OSU), through a subcontract with the Center, the principal investigator being Dr. B. E. Wilde. The scope of this work has been described in other documents (NRC contract NRC-02-88-005, SwRI subcontract No. 65582, Project 20-3606-107). Hence, the scope will not be restated here.

ACTIVITY

The program being carried out at the Ohio State University is projected to end by the end of calendar year 1990. Currently, most of the tasks in this program have been on schedule. The results of the program will be mainly:

1. A definition of procedures for measuring hydrogen absorption kinetics in the candidate materials under repository environmental conditions (without the presence of γ-radiation).

2. A preliminary indication of the potential for hydrogen embrittlement under repository environmental conditions.

A report will be prepared summarizing the work going on at OSU.

The activities at the Center will depend on the results of the OSU program. If, based on the OSU studies, hydrogen embrittlement is considered to be a viable degradation mechanism, further embrittlement studies (both short term tests such as slow strain rate tests and long-term tests such as constant deflection tests) will be conducted at the Center. These tests will also be carried out under conditions of γ-radiation at the Institute's radiation cells. Another important feature of these studies will be the effect of thermal stability on hydrogen embrittlement susceptibility. For example, it has been well documented [18] that in many Ni-Cr-Mo alloys, long-term aging at low temperatures (200° - 500°C) can induce ordering reactions and grain boundary segregation resulting in enhanced hydrogen embrittlement susceptibility.

A review of possible degradation modes of alternate materials proposed by DOE will be conducted in this task. The review will identify future areas of research in the alternate materials.

3.3 Schedules, Milestones, and Deliverables

The milestones, with the schedules, for the six tasks are shown in the Gantt Chart in Figure 3.1. The deliverables in the form of reports, also shown in Figure 3.1, are listed in Table 3.6. Upon approval, these milestones and activities will be incorporated into the integrated Center schedule (see WSE&I Operations Plan).

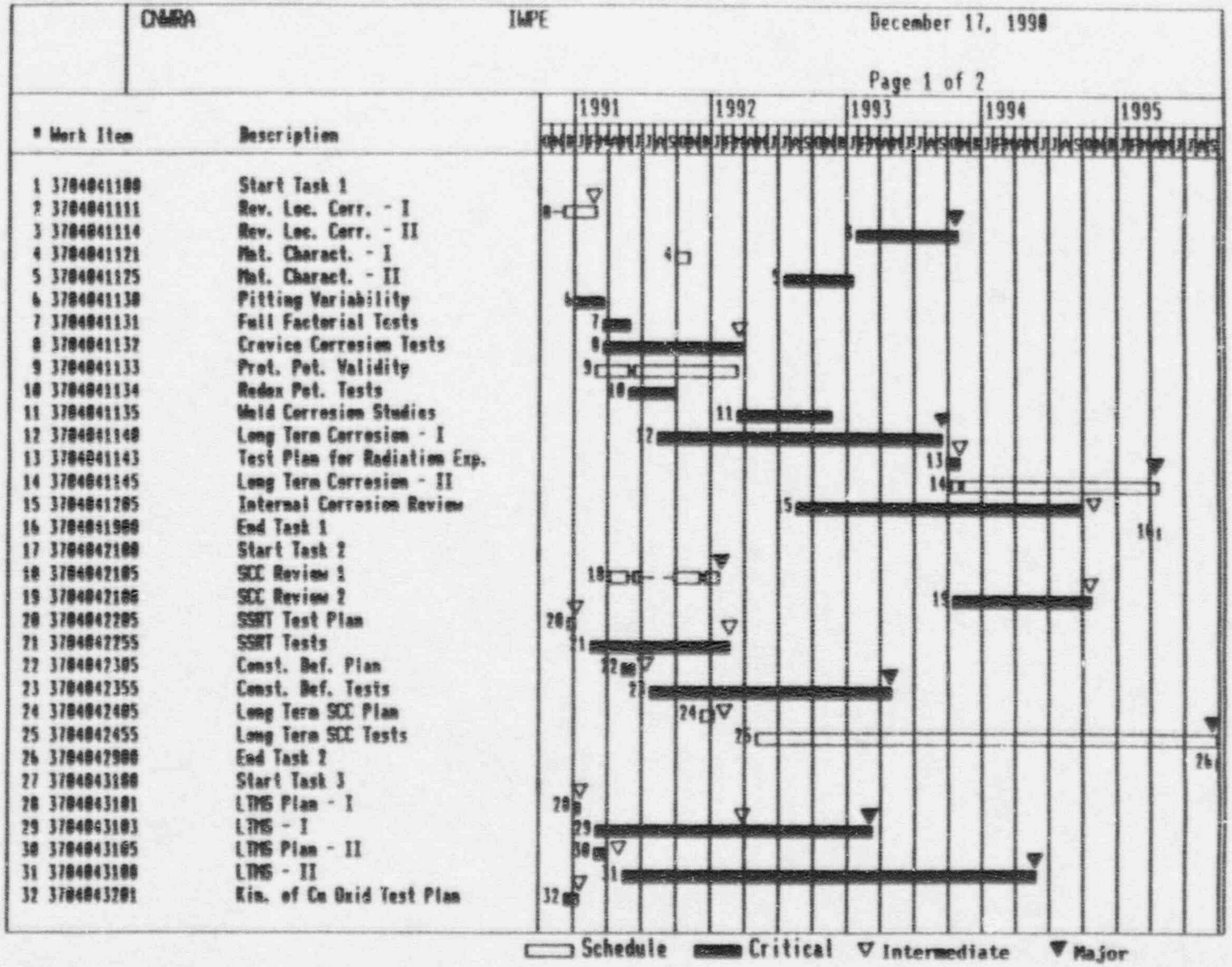

Figure 3.1 Gantt Chart of Activities

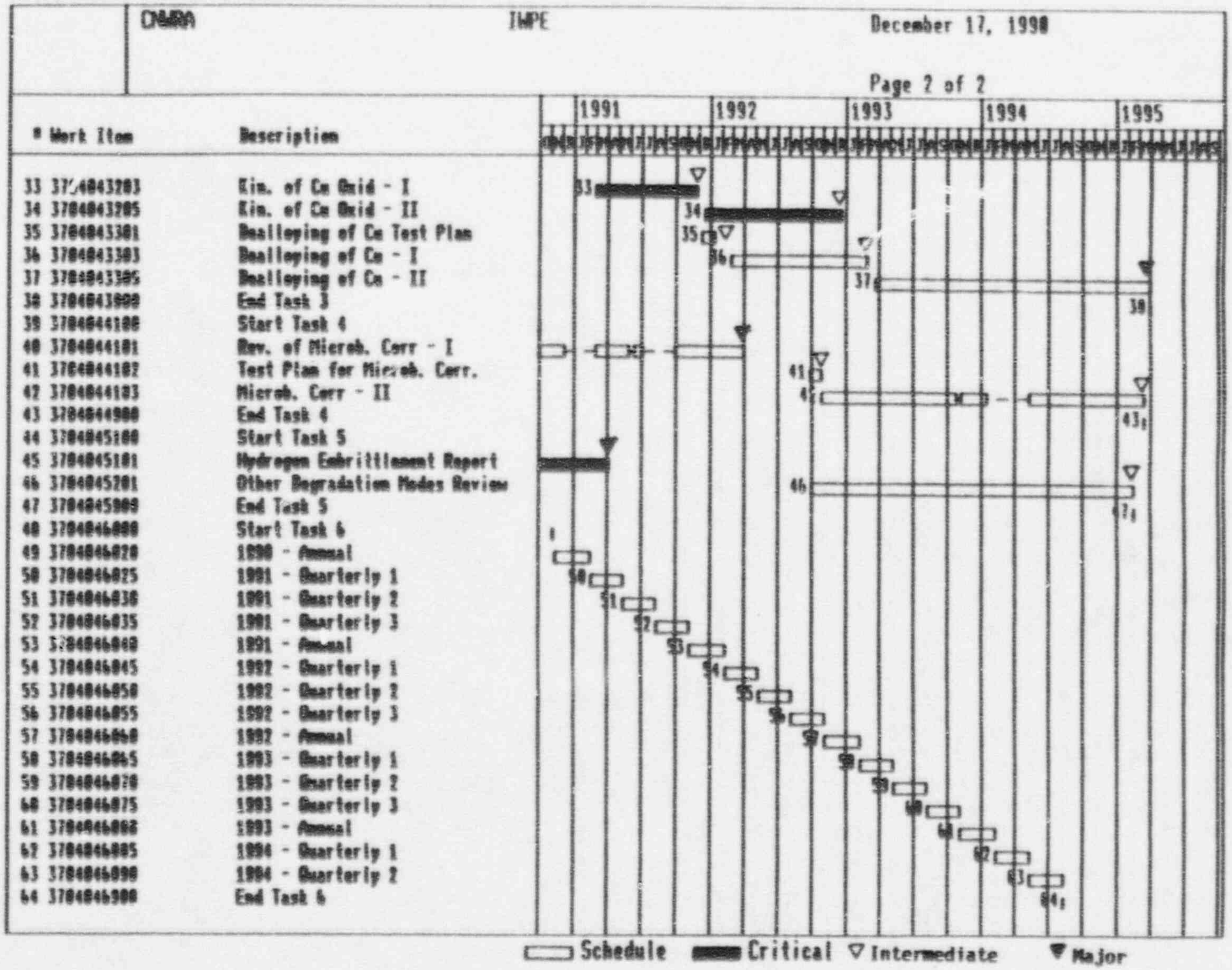

Figure 3.1 Gantt Chart of Activities (cont'd.)

Table 3.6 List of Milestones and Completion Dates

Milestone Number	Task No.	Milestone Type	Deliverable Description	Completion Date
1111	1.1.1	Intermediate	Review Loc. Corrosion - I	02/28/91
1114	1.1.1	Major	Review Loc. Corrosion - II	10/28/93
1132	1.1.241.1.3	Intermediate	Loc. Corr. Exptal. Investigations	03/24/92
1140	1.1.241.1.3	Major	Long-term Corrosion Tests - I	09/15/93
1143	1.1.4	Intermediate	Test Plans for γ-Radiation Expts.	11/01/93
1145	1.1.4	Major	Long-term Corrosion Tests - II	04/24/95
1205	1.2	Intermediate	Review of Internal Corrosion	09/27/94
2105	2.1	Major	SCC Review - I	01/24/92
2108	2.1	Intermediate	SCC Review - II	10/24/94
2205	2.2	Intermediate	SSRT Test Plan	01/04/91
2255	2.2	Intermediate	SSRT Test Results	02/19/92
2305	2.3	Intermediate	Constant Deflection Test Plan	06/11/91
2355	2.3	Major	Constant Deflection Test Results	04/30/93
2405	2.4	Intermediate	Long-term SCC Test Plan	01/10/92
2455	2.4	Major	Long-term SCC Test Results	09/28/95
3101	3.1	Intermediate	Long-term Material Stability Test Plan - I (Austenitic Alloys)	01/18/91
3103	3.1	Intermediate	Long-term Material Stability - I (Austenitic Alloys)	03/30/92
3104	3.1	Major	Long-term Material Stability - I (Austenitic Alloys)	03/08/93
3105	3.1	Intermediate	Long-term Material Stability Test Plan - II (Cu-alloys)	04/01/91
3108	3.1	Major	Long-term Material Stability - II (Cu-alloys)	05/26/94
3201	3.2	Intermediate	Kinetics of Cu-Oxidation Test Plan	01/14/91
3203	3.2	Intermediate	Kinetics of Cu-Oxidation - I	11/26/91
3205	3.2	Intermediate	Kinetics of Cu-Oxidation - II	12/21/92
3301	3.3	Intermediate	Test Plan for Dealloying	01/13/92
3303	3.3	Intermediate	Dealloying of Cu-alloys - I	03/01/93
3305	3.3	Major	Dealloying of Cu-alloys - II	04/03/95
4101	4.0	Major	Review of Microbiologically Influenced Corrosion (MIC)	04/01/92
4102	4.0	Intermediate	Test Plans for MIC	10/27/92
4103	4.0	Intermediate	MIC Tests	03/16/95
5101	5.1	Major	Hydrogen Embrittlement Test at OSU	04/04/91
5201	5.2	Intermediate	Review of Degradation Modes of Alternate Materials	02/17/95

Table 3.6 List of Milestones and Completion Dates
(cont'd.)

Milestone Number	Milestone Type	Deliverable Description	Completion Date
6020	Major	Annual Report 1990	02/11/91
6025	Intermediate	Quarterly 1991 - 1	05/10/91
6030	Intermediate	Quarterly 1991 - 2	08/09/91
6035	Intermediate	Quarterly 1991 - 3	11/11/91
6040	Major	Annual Report 1991	02/11/92
6045	Intermediate	Quarterly 1992 - 1	05/12/92
6050	Intermediate	Quarterly 1992 - 2	08/11/92
6055	Intermediate	Quarterly 1992 - 3	11/11/92
6060	Major	Annual Report 1992	02/11/93
6065	Intermediate	Quarterly 1993 - 1	05/12/93
6070	Intermediate	Quarterly 1993 - 2	08/11/93
6075	Intermediate	Quarterly 1993 - 3	11/11/93
6080	Major	Annual Report 1993	02/10/94
6085	Intermediate	Quarterly 1994 - 1	05/12/94
6090	Intermediate	Quarterly 1994 - 2	08/11/94
6095	Intermediate	Quarterly 1994 - 3	11/11/94
7100	Major	Annual Report 1994	02/11/95

4. PROGRAM MANAGEMENT

4.1 Organizational Structure and Responsibility

The organizational structure, responsibilities, management and control techniques applicable to the research activities at the Center are fully described in the Center Management Plan. The Integrated Waste Package Experiments (IWPE) Project will be conducted under the Engineered Barrier System (EBS) Program Element. Dr. Prasad Nair will be the Center Project Manager for this project. The task support, direction, and resource allocation relationships are shown in Figure 4.1.

The project is to be conducted in six tasks over a five year period. The project staff support and the project organization are shown in Figure 4.2. The project has made allowance for consultants to provide independent review of technical papers and/or technical reports generated by the project.

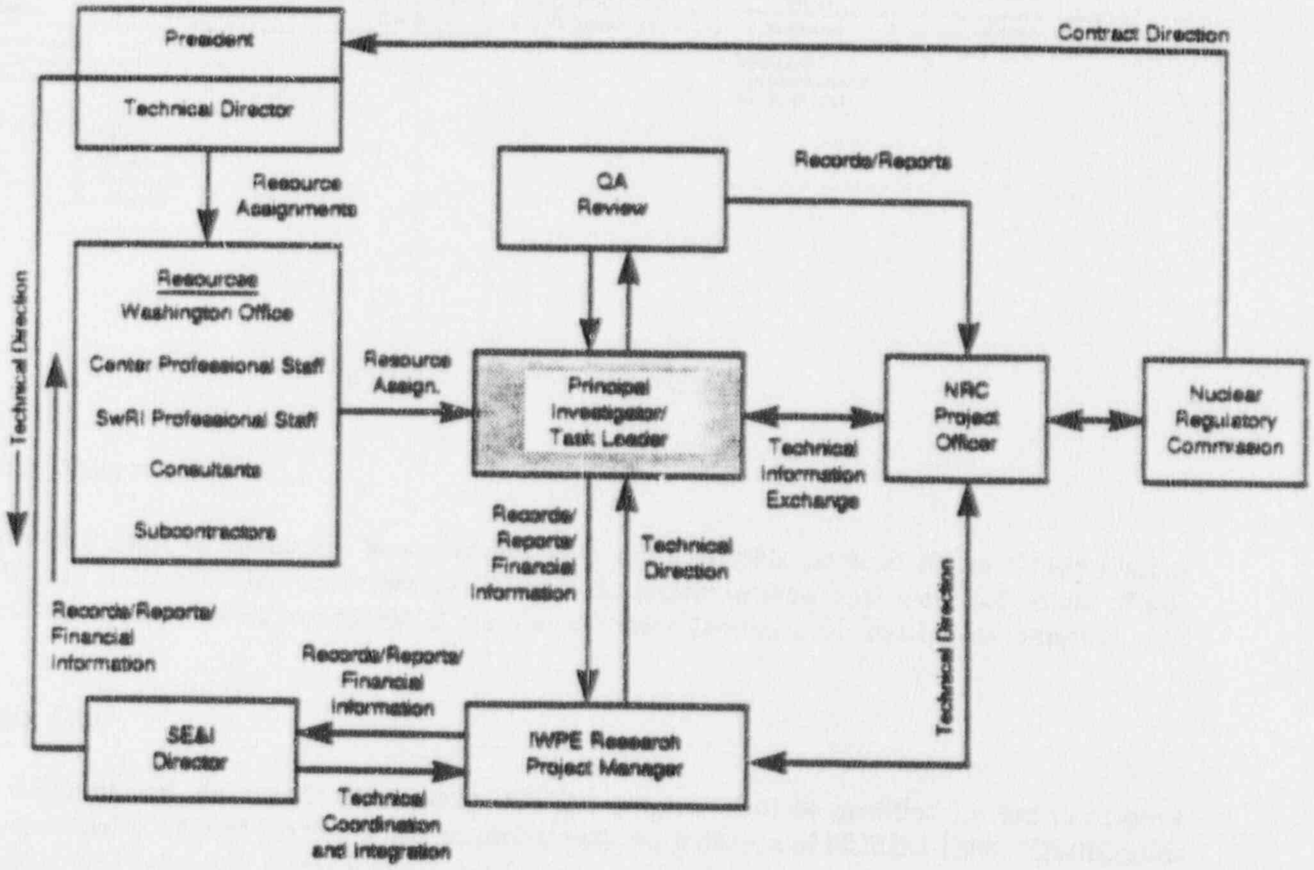

Figure 4.1 Center Management Process for Direction and Control of Research Projects

4.2.3 Control of Experiments and Tests

Experiments and tests which may be conducted during the performance of this research project shall be controlled in accordance with CQAM Section 3.7. Technical operating procedures, industry standard methods, and/or scientific notebooks shall prescribe and describe the conduct of experiments and tests. Periodic surveillance by QA staff shall be conducted as described in CQAM Section 3.8.

4.2.4 Data Interpretation and Analysis

Interpretation of data both from the literature and from experimental results shall be conducted as specified in CQAM Section 3.9.

4.2.5 Reports and Records

The Research Project reports shall receive an independent and/or technical review and Center Management Review as required by CQAM Section 3.10 and applicable technical operating procedures.

4.3 Travel

The project personnel will incur expenses for travel and associated subsistence while conducting the business of the Center in support of the IWPE project. The minimum necessary travel anticipated for the project is shown below in Table 4.1. The travel schedule is divided into two periods--FY90, which is a partial year period, and FY91 through FY94. The travel necessary will be undertaken by the appropriate task personnel. The travel falls into five general categories which are described below:

Technical Interchange Meetings: These meetings are primarily intended for collecting information specific to corrosion of candidate materials in the YMP or other materials that are candidates in other geologic repository systems.

DOE/NRC Interaction Meetings: These are trips undertaken to have technical exchange with DOE and its contractors specifically related to technical topics covering testing and prediction methodologies. The meetings will be set up through the appropriate NRC staff.

Technical program review meetings: These are visits to Washington to meet with the NRC staff to discuss the progress in research activities.

Technical Meetings: These are visits to sub-contractors of the Center (e.g., the Ohio State University) and other NRC contractors (e.g., Cortest, NIST) to coordinate research activities.

Conferences/Seminars: These trips are designed for the staff to present technical papers and participate in technical society activities that are relevant to the corrosion and other materials related issues. They will also present opportunities for peer review of the Center's research program.

Table 4.1 Travel Requirements Schedule - Integrated Waste Package Experiments

PURPOSE/ DESTINATION	FY91 NO. TRIPS	FY91 MAN DAYS	FY92 NO. TRIPS	FY92 MAN DAYS	FY93 NO. TRIPS	FY93 MAN DAYS	FY94 NO. TRIPS	FY94 MAN DAYS
TECHNICAL INTERCHANGE MEETINGS								
1. Foreign Trips to U.K., France	2	16	2	16	1	8	1	8
2. MRS Meeting on HLW	1	3	1	3	2	6	2	6
3. Las Vegas/Collect J-13 Water	1	3	1	3	1	3	1	3
DOE-RELATED VISITS								
Lawrence Livermore Labs	2	4	2	4	2	4	2	4
TECHNICAL AND PROGRAM REVIEW								
Washington, D.C.	3	9	3	9	3	9	3	9
TECHNICAL MEETINGS								
Cortest/Ohio State/NIST	1	3						
CONFERENCES/SEMINARS								
NACE Conference	1	5	2	10	2	10	2	10
Other Conferences	1	5					1	3
ASTM Conference	1	3	1	3	1	3	1	3
TOTALS	13	51	12	46	12	43	13	46

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6. ESTIMATED COST BREAKDOWN

The tables presented in this section delineate the costs for the proposed research effort on a task basis per year, with the year being divided into thirteen four-week periods as an accrual basis. Total dollar costs are enumerated for each of the technical labor categories for the Center, along with SwRI direct labor, SwRI support services, subcontractors, consultants, travel, equipment, materials, cost of facility capital, ADP support, and fee and fringe/overhead charges of the Center and SwRI. Tables showing composite summaries of all the tasks on a yearly basis are also included.

Table 6.1 is the FY91 composite cost estimate, and Figure 6.1 shows a plot of the composite spending for FY91. Table 6.2 shows manpower loading (in hours) for FY91. Tables 6.3 through 6.8 contain the FY91 costs for the project tasks, and Figures 6.2 through 6.7 show plots of the spending plans for the project tasks for FY91.

Table 6.9 is the FY92 composite cost estimate, and Figure 6.8 shows a plot for the composite spending for FY92. Table 6.10 shows manpower loading (in hours) for FY92. Tables 6.11 through 6.16 contain the FY92 costs for the project tasks, and Figures 6.9 through 6.13 show plots of the spending plans for the project tasks for FY92.

Table 6.17 is the FY93 composite cost estimate, and Figure 6.14 shows a plot for the composite spending for FY93. Table 6.18 shows manpower loading (in hours) for FY93. Tables 6.19 through 6.24 contain the FY93 costs for the project tasks, and Figures 6.15 through 6.20 show plots of the spending plans for the project tasks for FY93.

Table 6.25 is the FY94 composite cost estimate, and Figure 6.21 shows a plot for the composite spending for FY94. Table 6.26 shows manpower loading (in hours) for FY94. Tables 6.27 through 6.32 contain the FY94 costs for the project tasks, and Figures 6.22 through 6.27 show plots of the spending plans for the project tasks for FY94.

Table 6.33 is the FY95 composite cost estimate, and Figure 6.28 shows a plot for the composite spending for FY95. Table 6.34 shows manpower loading (in hours) for FY95. Tables 6.35 through 6.40 contain the FY95 costs for the project tasks, and Figures 6.29 through 6.33 show plots of the spending plans for the project tasks for FY95.

Table 6.1 Composite Spending Plan, FY 91

Spending Plan F/Y 91

17 Dec 90

3704-040 INTEGR. WASTE PACKAGE EXP.

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-4	0	45	225	180	180	225	180	225	180	180	225	180	225	2247
Center Pl-3	1443	2828	4095	6447	4958	4340	2152	1987	5354	4064	3801	4424	4419	50313
Center Pl-2	1497	2273	3326	5766	4823	5572	3881	2689	5572	5295	5350	5655	5683	57380
Center Pl-1	0	0	0	812	2321	3117	3432	3449	3283	2520	2586	2736	2752	27009
Center Clerical	0	126	339	348	348	378	368	378	368	368	368	455	503	4346
Center Labor	2940	5272	7985	13553	12631	13631	10013	8727	14756	12426	12330	13450	13582	141296
Center Burden	1249	2241	3394	5760	5368	5793	4255	3709	6271	5281	5240	5716	5773	60051
Center Overhead	3498	6273	9502	16126	15029	16219	11914	10384	17558	14785	14671	16004	16181	168124
Swri Pl-3	0	0	0	135	370	538	538	572	908	303	235	303	404	4305
Swri Pl-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Labor	0	0	0	135	370	538	538	572	908	303	235	303	404	4305
SWRI Burden	0	0	0	57	157	229	229	243	386	129	100	129	172	1829
SWRI Overhead	0	0	0	224	617	897	897	953	1514	505	392	505	673	177
Material/Supply	4286	300	301	1001	2301	2300	511	0	0	0	0	0	0	11000
Report Services	0	31	90	89	90	97	97	96	96	95	95	94	94	1064
Travel	5449	897	898	898	897	404	0	0	666	1543	1543	1762	1845	16802
Consultants	3286	3458	3459	3459	3458	3459	2421	0	0	0	0	0	0	23000
Subcontractors														
Ohio State	2714	2857	2858	2857	2857	2857	2000	0	0	0	0	0	0	19000
Est excl. CFC,Fee	23422	21329	28487	44159	43775	46423	32875	24683	42156	35067	34607	37962	38703	453647
Center CFC	212	381	577	979	913	985	723	630	1066	898	891	972	981	10208
SWRI CFC	0	0	0	28	73	106	106	112	178	59	46	59	79	845
Tot Estimate Cost	23634	21710	29064	45165	44761	47514	33704	25426	43400	36024	35544	38993	39764	464700
Fee	1874	1706	2279	3533	3502	3714	2630	1975	3372	2805	2769	3037	3096	36292
Tot Cost with Fee	25508	23416	31343	48698	48263	51228	36334	27400	46772	38829	38312	42030	42860	500992
% Completion	5.09%	4.67%	6.26%	9.72%	9.63%	10.23%	7.25%	5.47%	9.34%	7.75%	7.65%	8.39%	8.55%	100.00%
Cumulative Cost	25508	48924	80267	128965	177228	228455	264789	292189	338962	377791	416103	458132	500992	
Cumul Completion	5.09%	9.77%	16.02%	25.74%	35.39%	45.60%	52.85%	58.32%	67.66%	75.41%	83.06%	91.45%	100.00%	

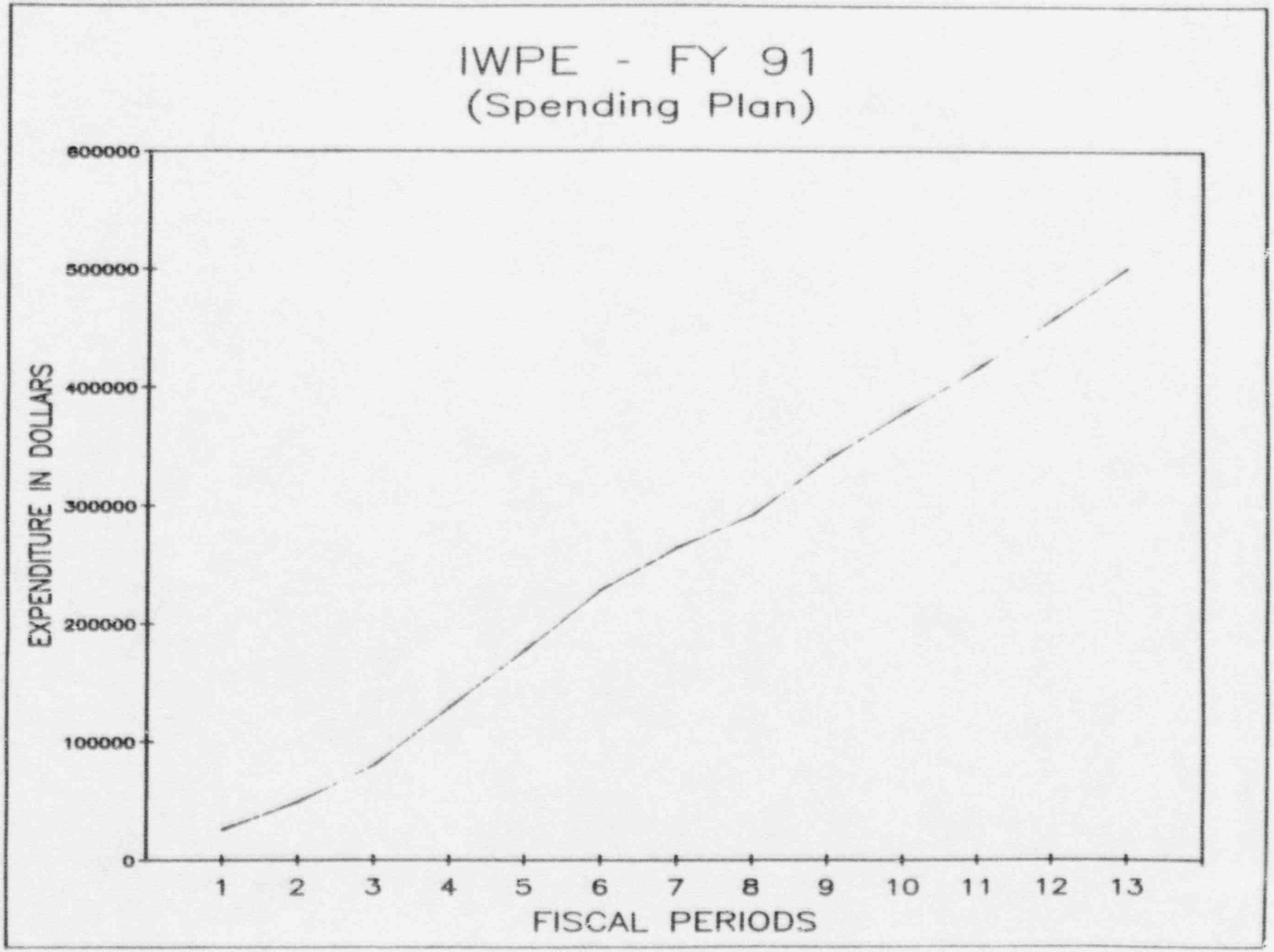

Figure 6.1 Composite Spending Plan, FY 91

Table 6.2 Manpower Plan, FY 91

Manpower Plan F/Y 91

17 Dec 90

3704-040 INTEGR. WASTE PACKAGE EXP.

Center Labor	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-4	0	1	5	4	4	5	4	5	4	4	5	4	5	50
Center Pl-3	44	86	124	195	150	131	65	60	162	123	115	134	134	1523
Center Pl-2	54	82	120	208	174	201	140	97	201	191	193	204	205	2070
Center Pl-1	0	0	0	49	140	188	207	208	198	152	156	165	166	1629
Center Clerical	0	13	35	36	36	39	38	39	38	33	38	47	52	449
Total Center Labor	98	182	284	492	504	564	454	409	603	508	507	554	582	5721

Swri Labor	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Swri Pl-3	0	0	0	4	11	16	16	17	27	9	7	9	12	128
Swri Pl-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Swri Labor	0	0	0	4	11	16	16	17	27	9	7	9	12	128

Table 6.3 Task 1 Spending Plan, FY 91

Spending Plan F/Y 91

17 Dec 90

3704-041 CORROSION

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	1117	2267	2267	2831	3991	2809	494	228	789	1849	1781	2210	2240	24872
Center Pl-2	610	1220	1275	2079	3604	3271	1580	1358	2024	3299	3299	3410	3437	30464
Center Pl-1	0	0	0	812	2321	2421	2537	2570	2122	1360	1343	1409	1442	18337
Center Clerical	0	0	0	0	0	0	0	0	0	0	0	87	136	223
Center Labor	1727	3487	3542	5722	9916	8500	4610	4156	4935	6507	6423	7116	7255	73896
Center Burden	734	1482	1505	2432	4214	3613	1959	1766	2097	2766	2730	3024	3083	31406
Center Overhead	2055	4149	4215	6809	11799	10114	5486	4945	5872	7743	7643	8467	8632	87928
Swri Pl-3	0	0	0	135	370	437	437	471	303	168	101	166	235	2825
Swri Pl-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Labor	0	0	0	135	370	437	437	471	303	168	101	169	235	2825
SWRI Burden	0	0	0	57	157	186	186	200	129	71	43	71	100	1201
SWRI Overhead	0	0	0	224	617	729	729	785	505	280	168	280	392	4710
Material/Supply	0	0	0	700	2000	2000	300	0	0	0	0	0	0	5000
Travel	449	897	898	898	897	404	0	0	451	1290	1290	1510	1592	10576
Est excl. CFC,Fee	4965	10015	10161	16977	29969	25983	13707	12324	14291	18625	18397	20637	21291	217541
Center CFC	125	252	256	413	716	614	333	300	357	470	464	514	524	5339
SWRI CFC	0	0	0	28	73	86	86	92	59	33	20	33	46	554
Tot Estimate Cost	5090	10266	10416	17417	30758	26683	14126	12716	14707	19329	18801	21184	21861	223435
Fee	397	801	813	1358	2398	2079	1097	986	1143	1506	1472	1651	1703	17403
Tot Cost with Fee	5487	11068	11229	18775	33156	28761	15223	13702	15850	20835	20353	22835	23564	240838
% Completion	2.28%	4.60%	4.66%	7.80%	13.77%	11.94%	6.32%	5.69%	6.58%	8.65%	8.45%	9.48%	9.78%	100.00%
Cumulative Cost	5487	16555	27784	46559	79715	108477	123699	137401	153252	174086	194439	217274	240838	
Cumul Completion	2.28%	6.87%	11.54%	19.33%	33.10%	45.04%	51.36%	57.05%	63.63%	72.28%	80.73%	90.22%	100.00%	

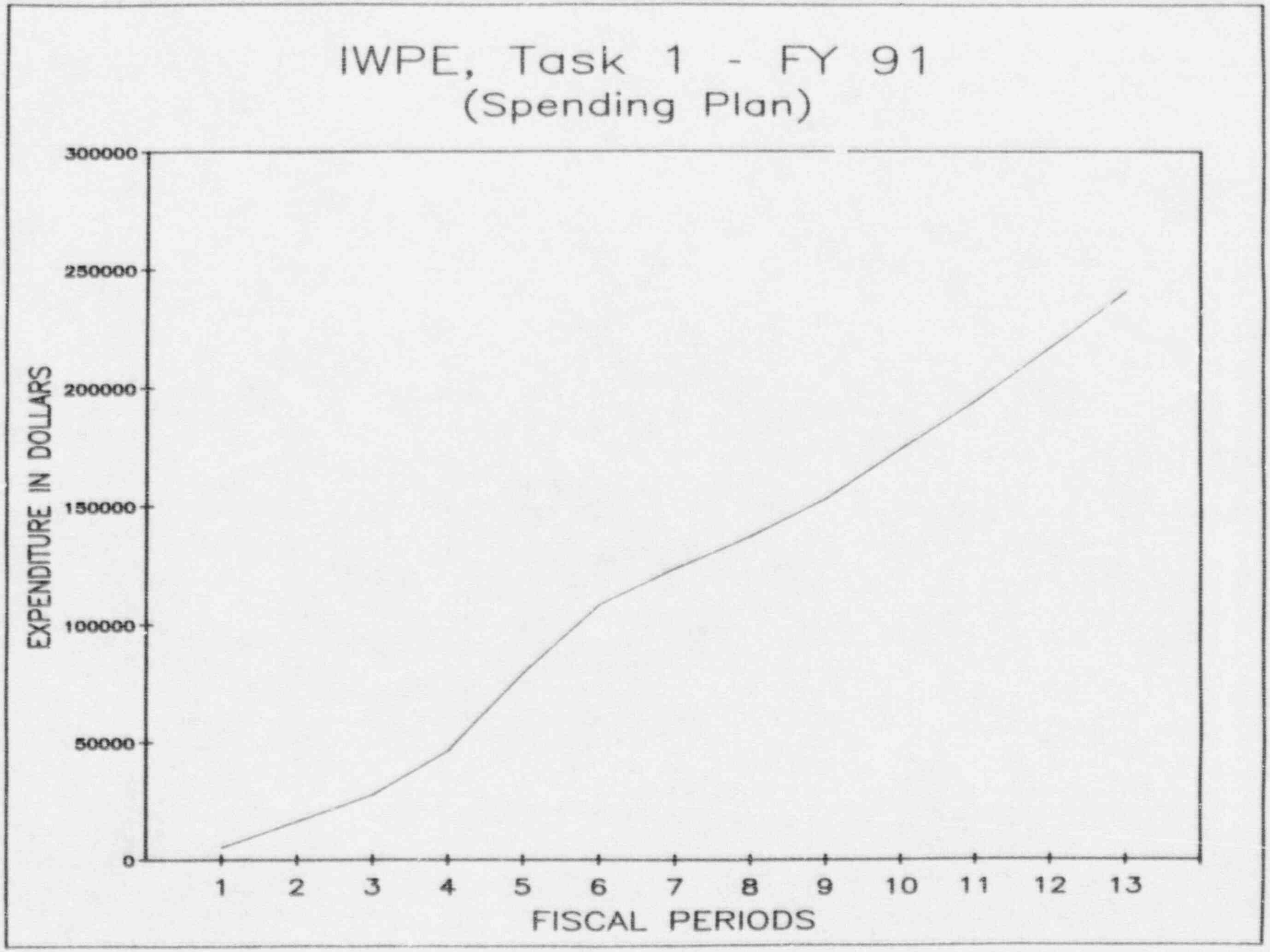

Figure 6.2 Task 1 Spending Plan, FY 91

Table 6.4 Task 2 Spending Plan, FY 91

Spending Plan F/Y 91

17 Dec 90

3704-042 STRESS CORROSION CRACKING

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	0	0	829	2616	0	594	626	724	3400	987	822	987	984	12568
Center Pl-2	0	0	471	1525	0	222	249	305	2051	499	444	721	721	7207
Center Pl-1	0	0	0	0	0	497	514	497	514	497	564	647	647	4377
Center Clerical	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Labor	0	0	1300	4140	0	1313	1390	1526	5965	1983	1829	2354	2352	24153
Center Burden	0	0	552	1760	0	558	591	649	2535	843	777	1001	1000	10265
Center Overhead	0	0	1547	4927	0	1562	1654	1816	7098	2360	2176	2801	2798	28739
Swri Pl-3	0	0	0	0	0	101	101	101	605	135	135	135	168	1480
SWRI Labor	0	0	0	0	0	101	101	101	605	135	135	135	168	1480
SWRI Burden	0	0	0	0	0	43	43	43	257	57	57	57	71	629
SWRI Overhead	0	0	0	0	0	168	168	168	1009	224	224	224	280	2467
Material/Supply	2000	0	0	0	0	0	0	0	0	0	0	0	0	2000
Travel	3000	0	0	0	0	0	0	0	0	0	0	0	0	3000
Est excl. CFC,Fee	5000	0	3399	10827	0	3745	3946	4303	17470	5602	5198	6572	6670	72732
Center CFC	0	0	94	299	0	95	100	110	431	143	132	170	170	1745
SWRI CFC	0	0	0	0	0	20	20	20	119	28	26	26	33	290
Tot Estimate Cost	5000	0	3493	11126	0	3860	4066	4433	18019	5772	5357	6769	6873	74767
Fee	400	0	272	866	0	300	316	344	1398	448	416	528	534	5819
Tot Cost with Fee	5400	0	3765	11992	0	4159	4382	4777	19417	6220	5773	7295	7406	80586
% Completion	6.70%	0.00%	4.67%	14.88%	0.00%	5.16%	5.44%	5.93%	24.09%	7.72%	7.16%	9.05%	9.19%	100.00%
Cumulative Cost	5400	5400	9165	21156	21156	25310	29698	34475	53892	60112	65885	73180	80586	
Cumul Completion	6.70%	6.70%	11.37%	26.25%	26.25%	31.41%	36.85%	42.78%	66.88%	74.59%	81.76%	90.81%	100.00%	

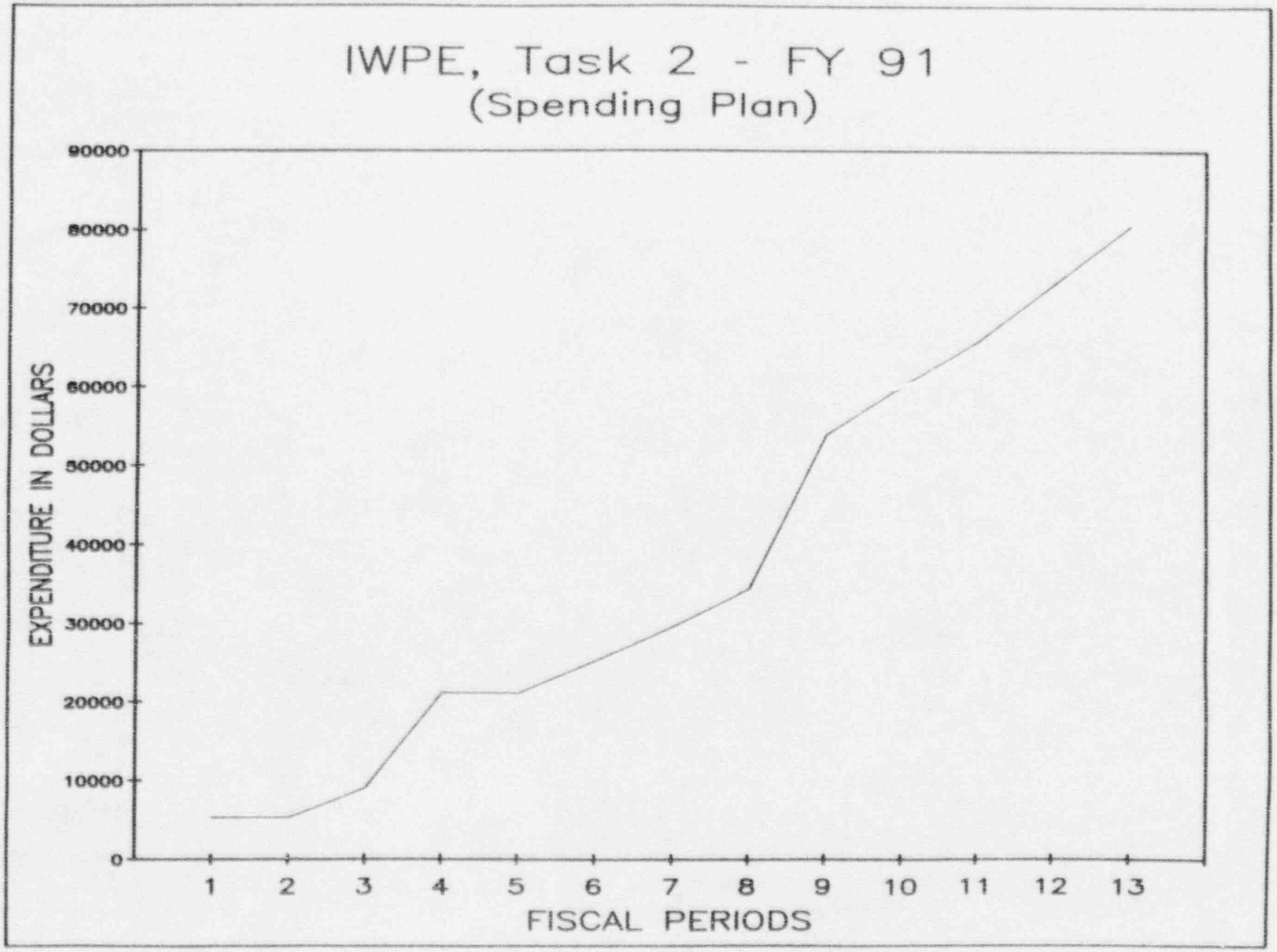

Figure 6.3 Task 2 Spending Plan, FY 91

Table 6.5 Task 3 Spending Plan, FY 91

Spending Plan F/Y 91

3704-043 MATERIALS STABILITY

17 Dec 90

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	0	0	0	0	0	98	228	195	326	423	358	391	358	2377
Center Pl-2	0	0	333	887	0	804	1109	693	1192	1192	1275	1247	1220	9951
Center Pl-1	0	0	0	0	0	199	381	381	647	663	680	680	663	4294
Center Labor	0	0	333	887	0	1101	1718	1270	2164	2278	2313	2318	2241	16623
Center Burden	0	0	141	377	0	468	730	540	920	968	983	985	952	7065
Center Overhead	0	0	398	1055	0	1309	2044	1511	2575	2711	2752	2758	2667	19779
Swri Pl-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Labor	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Burden	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Overhead	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel	2000	0	0	0	0	0	0	0	215	253	253	252	253	3226
Est excl. CFC,Fee	2000	0	870	2319	0	2878	4493	3320	5874	6211	6301	6313	6113	46692
Center CFC	0	0	24	64	0	80	124	92	156	165	167	167	162	1201
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	2000	0	894	2384	0	2957	4617	3412	6030	6375	6468	6480	6275	47893
Fee	160	0	70	186	0	230	359	266	470	497	504	505	489	3735
Tot Cost with Fee	2160	0	963	2569	0	3187	4976	3677	6500	6872	6973	6986	6764	51628
% Completion	4.18%	0.00%	1.87%	4.98%	0.00%	6.17%	9.64%	7.12%	12.59%	13.31%	13.51%	13.53%	13.10%	100.00%
Cumulative Cost	2160	2160	3123	5693	5693	8880	13856	17534	24034	30906	37879	44864	51628	
Cumul Completion	4.18%	4.18%	6.05%	11.03%	11.03%	17.20%	26.84%	33.96%	46.55%	59.86%	73.37%	86.90%	100.00%	

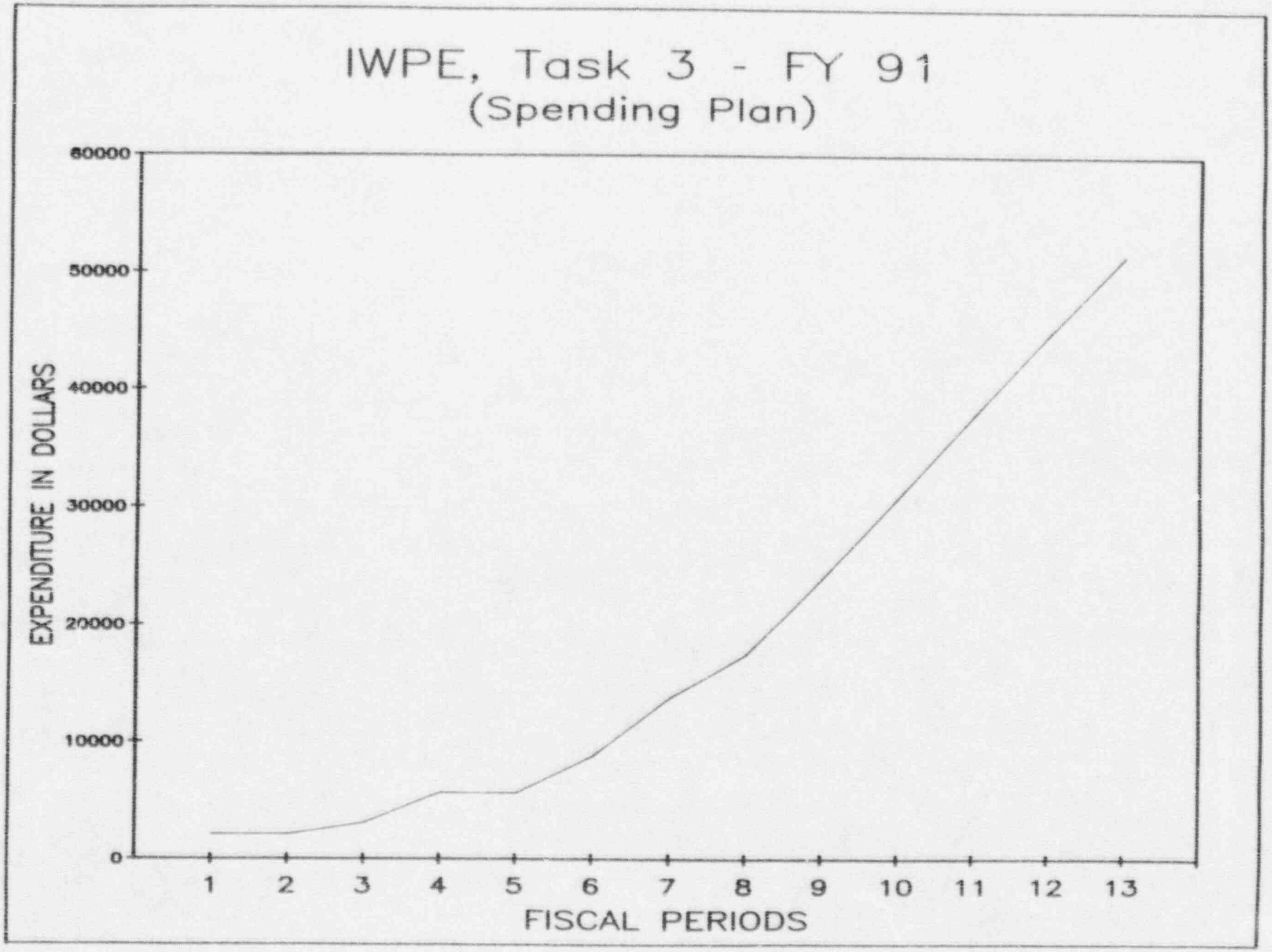

Figure 6.4 Task 3 Spending Plan, FY 91

Table 6.6 Task 4 Spending Plan, FY 91

Spending Plan F/Y 91

17 Dec 90

3704-044 MICROBIOLOGICALL INDUCED CORR.

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	326	326	358	326	326	326	326	326	358	326	326	326	326	4298
Center Pl-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Pl-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Labor	326	326	358	326	326	326	326	326	358	326	326	326	326	4298
Center Burden	138	138	152	138	138	138	138	138	152	138	138	138	138	1827
Center Overhead	387	387	426	387	387	387	387	387	426	387	387	387	387	5114
Material/Supply	2000	0	0	0	0	0	0	0	0	0	0	0	0	2000
Travel	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Consultants	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Est excl. CFC,Fee	2851	851	937	851	851	851	851	851	937	851	851	851	851	13238
Center CFC	24	24	26	24	24	24	24	24	26	24	24	24	24	310
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	2875	875	962	875	875	875	875	875	962	875	875	875	875	13549
Fee	228	68	75	68	68	68	68	68	75	63	68	68	68	1059
Tot Cost with Fee	3103	943	1037	943	943	943	943	943	1037	943	943	943	943	14608
% Completion	21.24%	6.46%	7.10%	6.46%	6.46%	6.46%	6.46%	6.46%	7.10%	6.46%	6.46%	6.46%	6.46%	100.00%
Cumulative Cost	3103	4046	5083	6026	6969	7912	8856	9799	10836	11779	12722	13665	14608	
Cumul Completion	21.24%	27.70%	34.80%	41.25%	47.71%	54.17%	60.62%	67.08%	74.18%	80.63%	87.09%	93.54%	100.00%	

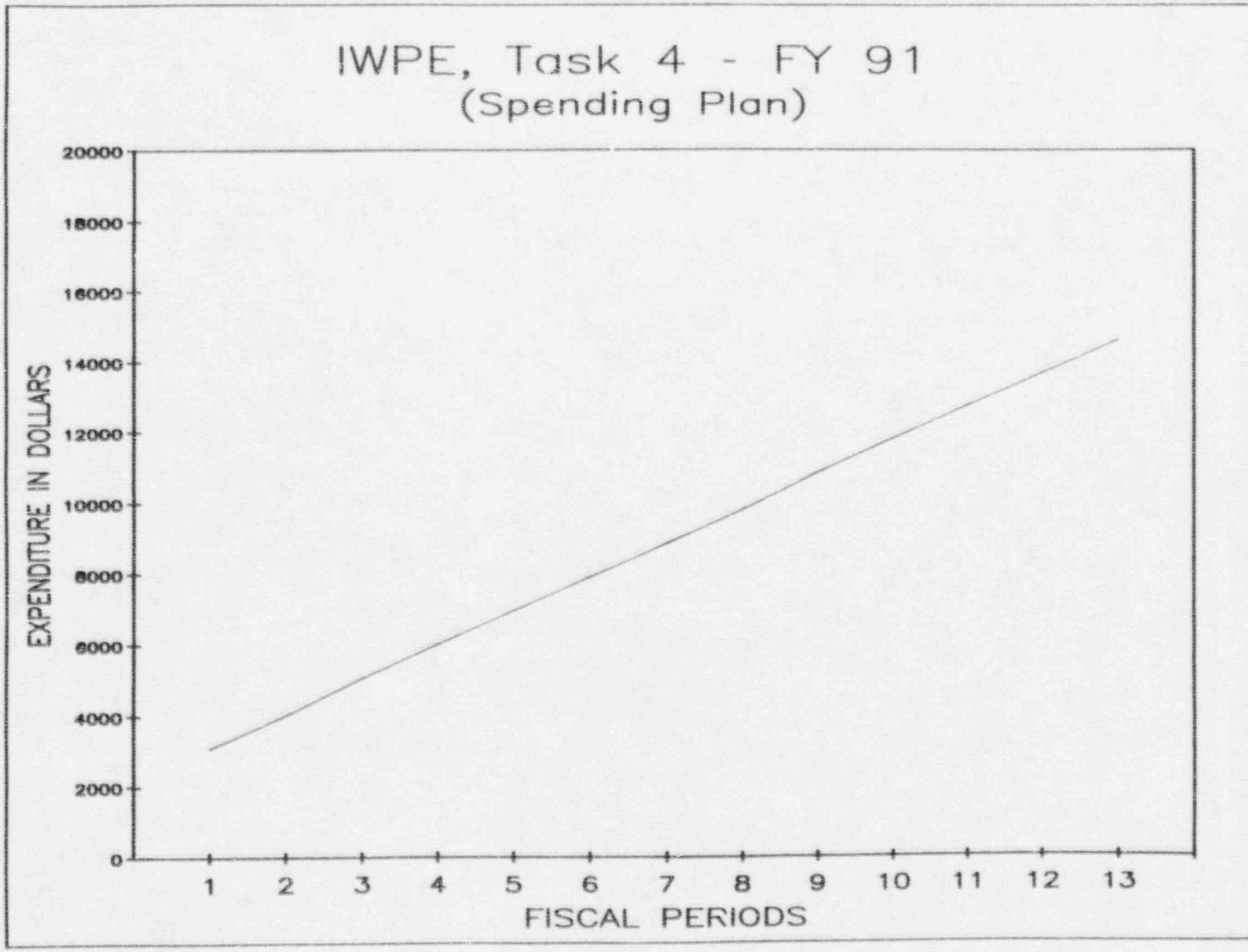

Figure 6.5 Task 4 Spending Plan, FY 91

Table 6.7 Task 5 Spending Plan, FY 91

Spending Plan F/Y 91

17 Dec 90

3704-045 OTHER DEGRADATION MODES

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center P1-2	887	942	942	942	915	942	665	0	0	0	0	0	0	6237
Center Labor	887	942	942	942	915	942	665	0	0	0	0	0	0	6237
Center Burden	377	401	401	401	389	401	283	0	0	0	0	0	0	2651
Center Overhead	1055	1121	1121	1121	1088	1121	792	0	0	0	0	0	0	7421
Material/Supply	286	300	301	301	301	300	211	0	0	0	0	0	0	2000
Travel	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Consultants	3286	3458	3459	3459	3458	3459	2421	0	0	0	0	0	0	23000
Subcontractors														
Ohio State	2714	2857	2858	2857	2857	2857	2000	0	0	0	0	0	0	19000
Est excl. CFC,Fee	8605	9079	9082	9081	9008	9080	6372	0	0	0	0	0	0	60309
Center CFC	64	68	68	68	68	68	48	0	0	0	0	0	0	451
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	8670	9148	9151	9150	9074	9149	6420	0	0	0	0	0	0	60760
Fee	688	726	727	727	721	726	510	0	0	0	0	0	0	4825
Tot Cost with Fee	9358	9874	9877	9876	9795	9875	6929	0	0	0	0	0	0	65584
% Completion	14.27%	15.06%	15.06%	15.06%	14.93%	15.06%	10.57%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Cumulative Cost	9358	19232	29109	38985	48780	58655	65584	65584	65584	65584	65584	65584	65584	
Cumul Completion	14.27%	29.32%	44.38%	59.44%	74.38%	89.43%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	

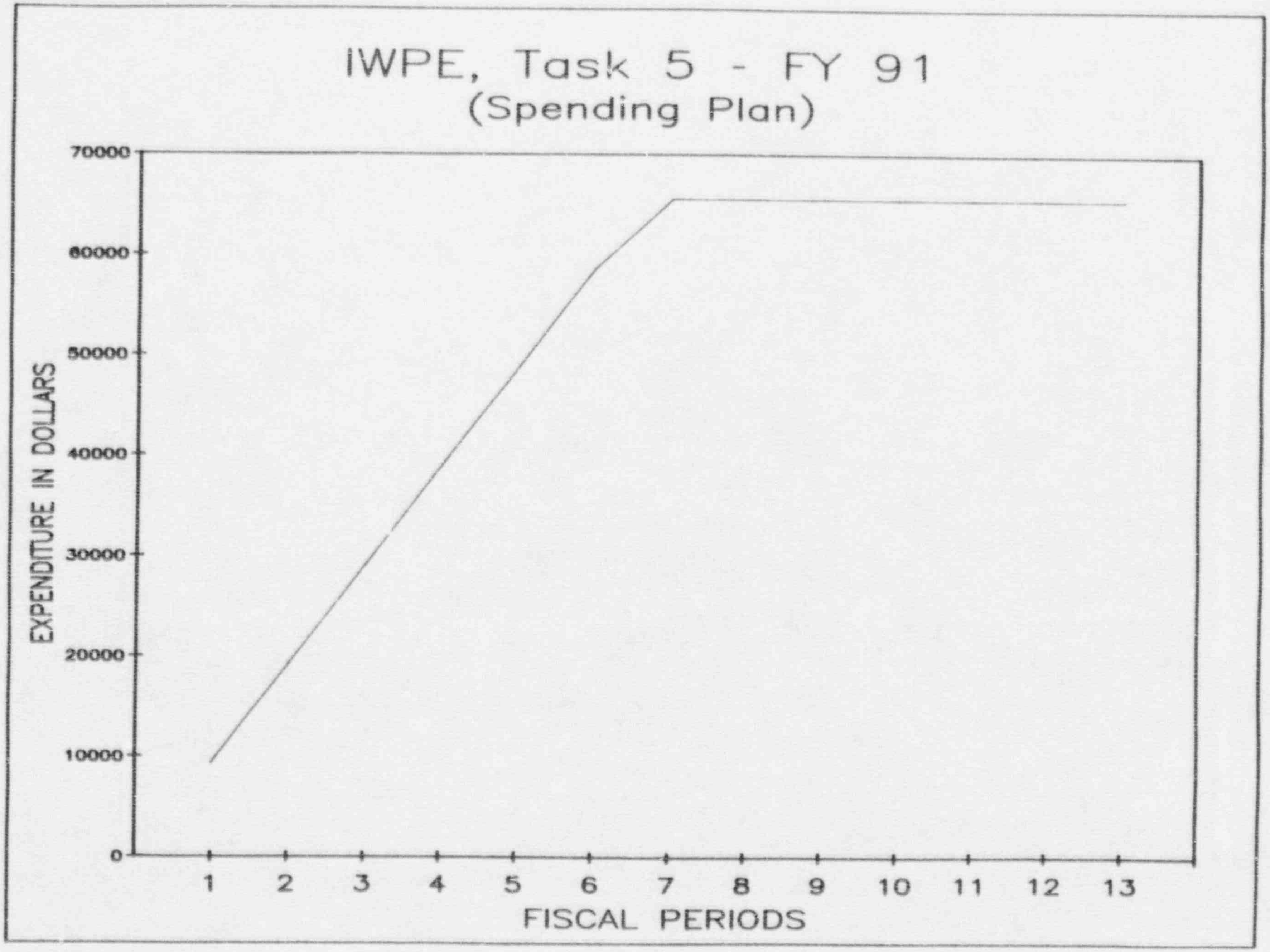

Figure 6.6 Task 5 Spending Plan, FY 91

Table 6.8 Task 6 Spending Plan, FY 91

Spending Plan F/Y 91

17 Dec 90

3704-046 PROGRESS REPORTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-4	0	45	225	180	180	225	180	225	180	180	225	180	225	2247
Center Pl-3	0	236	642	674	642	514	479	514	481	479	514	511	511	6197
Center Pl-2	0	111	305	333	305	333	277	333	305	305	333	277	305	3520
Center Clerical	0	126	339	348	348	378	368	378	368	368	368	368	368	4124
Center Labor	0	517	1510	1535	1475	1449	1304	1449	1334	1331	1439	1336	1409	16089
Center Burden	0	220	642	652	627	616	554	616	567	566	612	568	599	6838
Center Overhead	0	615	1797	1827	1755	1724	1551	1724	1587	1584	1713	1590	1676	19144
Report Services	0	31	90	89	90	97	97	96	96	95	95	94	94	1064
Est excl. CFC,Fee	0	1384	4039	4103	3947	3886	3506	3885	3584	3577	3858	3588	3778	43134
Center CFC	0	37	109	111	107	105	94	105	96	96	104	97	102	1162
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	0	1421	4148	4214	4053	3990	3600	3989	3681	3673	3962	3685	3880	44297
Fee	0	111	323	328	316	311	280	311	287	286	309	287	302	3451
Tot Cost with Fee	0	1532	4471	4542	4369	4301	3881	4300	3967	3959	4271	3972	4182	47748
% Completion	0.00%	3.21%	9.36%	9.51%	9.15%	9.01%	8.13%	9.01%	8.31%	8.29%	8.95%	8.32%	8.76%	100.00%
Cumulative Cost	0	1532	6003	10545	14914	19215	23096	27396	31364	35322	39593	43565	47748	
Cumul Completion	0.00%	3.21%	12.57%	22.09%	31.24%	40.24%	48.37%	57.38%	65.69%	73.98%	82.92%	91.24%	100.00%	

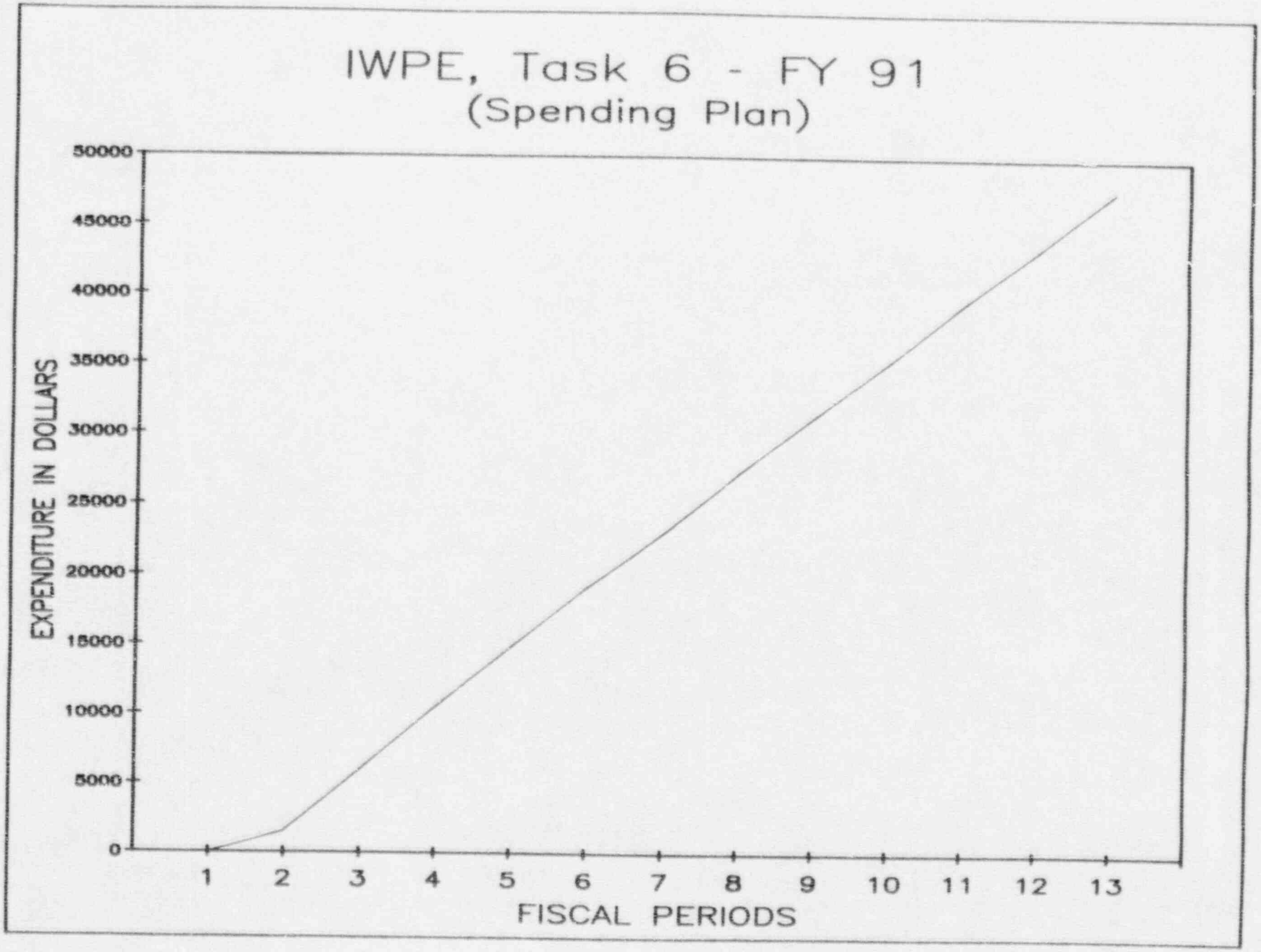

Figure 6.7 Task 6 Spending Plan, FY 91

Table 6.9 Composite Spending Plan, FY 92

Spending Plan F/Y 92

17 Dec 90

3704-040 INTEGR. WASTE PACKAGE EXP.

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-4	187	190	190	237	190	190	237	190	190	237	190	237	190	2656
Center Pl-3	3181	3059	3938	4464	2887	2268	3334	3343	3966	3896	4059	4320	4696	47412
Center Pl-2	3786	3659	4730	5874	3776	3629	5269	5269	5532	5532	5737	6030	6674	65496
Center Pl-1	2300	2224	2101	2189	2154	1786	2294	2241	2504	2504	3607	4763	5008	35674
Center Clerical	525	522	522	502	522	543	532	594	748	737	748	737	737	7970
Center Labor	9980	9654	1:481	13265	9529	8417	11666	11637	12939	12907	14341	16087	17305	159207
Center Burden	4242	4103	4880	5638	4050	3577	4958	4946	5499	5485	6095	6837	7354	67663
Center Overhead	11875	11487	13662	15784	11338	10015	13881	13846	15396	15358	17064	19141	20590	189436
Swri Pl-3	387	320	710	888	391	249	320	355	497	426	604	817	817	6779
Swri Pl-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Labor	387	320	710	888	391	249	320	355	497	426	604	817	817	6779
SWRI Burden	164	136	302	377	166	106	136	151	211	181	257	347	347	2881
SWRI Overhead	645	533	1184	1480	651	414	533	592	829	710	1006	1362	1362	11302
Material/Supply	0	0	23	228	228	365	456	456	457	456	457	620	1004	4750
Report Services	94	91	88	88	89	96	95	95	94	94	93	94	94	1205
Travel	620	620	620	620	620	619	620	732	1070	1070	1070	1069	1070	10420
Consultants	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subcontractors														
Ohio State	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Est excl. CFC,Fee	28007	26942	32950	38368	27061	23857	32665	32809	36993	36688	40986	46373	49943	453642
Center CFC	721	697	830	958	688	608	843	841	935	933	1036	1162	1250	11502
SWRI CFC	76	63	139	174	77	49	63	70	98	84	118	160	160	1330
Tot Estimate Cost	28804	27702	33919	39500	27826	24514	33570	33720	38[illegible]6	37704	42140	47696	51353	466475
Fee	2241	2155	2636	3069	2165	1909	2613	2625	2959	2935	3279	3710	3995	36291
Tot Cost with Fee	31045	29858	36555	42570	29991	26422	36183	36344	40985	40639	45419	51406	55349	502766
% Completion	6.17%	5.94%	7.27%	8.47%	5.97%	5.26%	7.20%	7.23%	8.15%	8.08%	9.03%	10.22%	11.01%	100.00%
Cumulative Cost	31045	60902	97457	140027	170018	196440	232624	268968	309953	350593	396012	447417	502766	
Cumul Completion	6.17%	12.11%	19.38%	27.85%	33.82%	39.07%	46.27%	53.50%	61.65%	69.73%	78.77%	88.99%	100.00%	

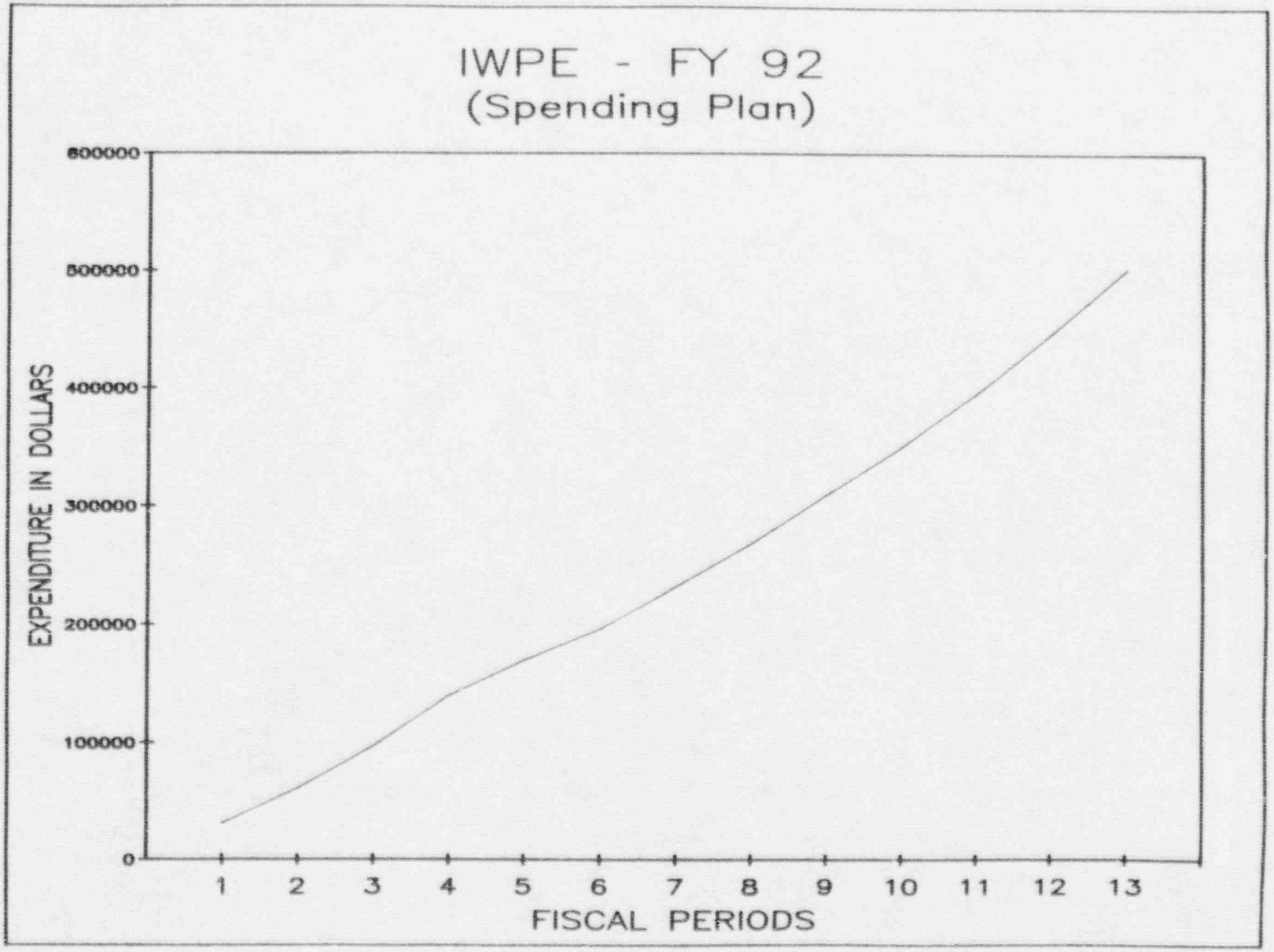

Figure 6.8 Composite Spending Plan, FY 92

Table 6.10 Manpower Plan, FY 92

Manpower Plan F/Y 92

17 Dec 90

3704-040 INTEGR. WASTE PACKAGE EXP.

Center Labor	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-4	4	4	4	5	4	4	5	4	4	5	4	5	4	56
Center Pl-3	96	92	119	135	87	68	101	101	120	118	123	131	142	1433
Center Pl-2	131	125	160	198	129	124	180	180	189	189	196	206	228	2235
Center Pl-1	133	127	120	125	123	102	131	128	143	143	206	272	286	2039
Center Clerical	52	51	51	49	51	53	52	58	73	72	73	72	72	779
Total Center Labor	416	399	454	512	394	351	469	471	529	527	602	686	732	6542

Swri Labor	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Swri Pl-3	11	9	20	25	11	7	9	10	14	12	17	23	23	191
Swri Pl-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Swri Labor	11	9	20	25	11	7	9	10	14	12	17	23	23	191

Table 6.11 Task 1 Spending Plan, FY 92

Spending Plan F/Y 92

17 Dec 90

3704-041 CORROSION

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	981	786	823	753	753	786	1958	2028	1958	1958	2088	2316	2655	19845
Center Pl-2	1420	1229	1142	1142	1142	1112	2693	2864	2864	2664	2839	3220	3805	27734
Center Pl-1	900	805	735	735	735	753	1278	1156	1138	1138	2224	3397	3642	18638
Center Clerical	151	154	154	143	154	154	143	154	154	143	154	154	143	1954
Center Labor	3453	2974	2854	2774	2784	2805	6073	6001	5913	5903	7305	9087	10248	68171
Center Burden	1468	1264	1213	1179	1183	1192	2581	2550	2513	2509	3105	3862	4355	28973
Center Overhead	4109	3539	3395	3300	3313	3337	7226	7140	7036	7024	8692	10812	12191	81115
Swri Pl-3	211	178	249	213	213	213	249	249	249	249	391	568	604	3833
Swri Pl-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Labor	211	178	249	213	213	213	249	249	249	249	391	568	604	3833
SWRI Burden	90	75	106	91	91	91	106	106	106	106	166	241	257	1629
SWRI Overhead	352	296	414	355	355	355	414	414	414	414	651	947	1008	6391
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	164	548	712
Travel	367	367	367	367	367	367	367	367	367	367	367	367	367	4771
Est excl. CFC,Fee	10050	8694	8597	8279	8306	8360	17015	16826	16599	16572	20676	26048	29574	195595
Center CFC	249	215	206	200	201	203	439	434	427	426	528	656	740	4925
SWRI CFC	41	35	49	42	42	42	49	49	49	49	77	112	118	752
Tot Estimate Cost	10341	8943	8852	8521	8548	8604	17502	17309	17075	17047	21281	26816	30432	201272
Fee	804	695	688	662	664	669	1361	1346	1328	1326	1654	2084	2366	15648
Tot Cost with Fee	11145	9639	9540	9183	9213	9273	18863	18655	18402	18373	22935	28900	32798	216920
% Completion	5.14%	4.44%	4.40%	4.23%	4.25%	4.27%	8.70%	8.60%	8.48%	8.47%	10.57%	13.32%	15.12%	100.00%
Cumulative Cost	11145	20784	30324	39507	48720	57993	76857	95512	113914	132287	155222	184122	216920	
Cumul Completion	5.14%	9.58%	13.98%	18.21%	22.46%	26.73%	35.43%	44.03%	52.51%	60.98%	71.56%	84.88%	100.00%	

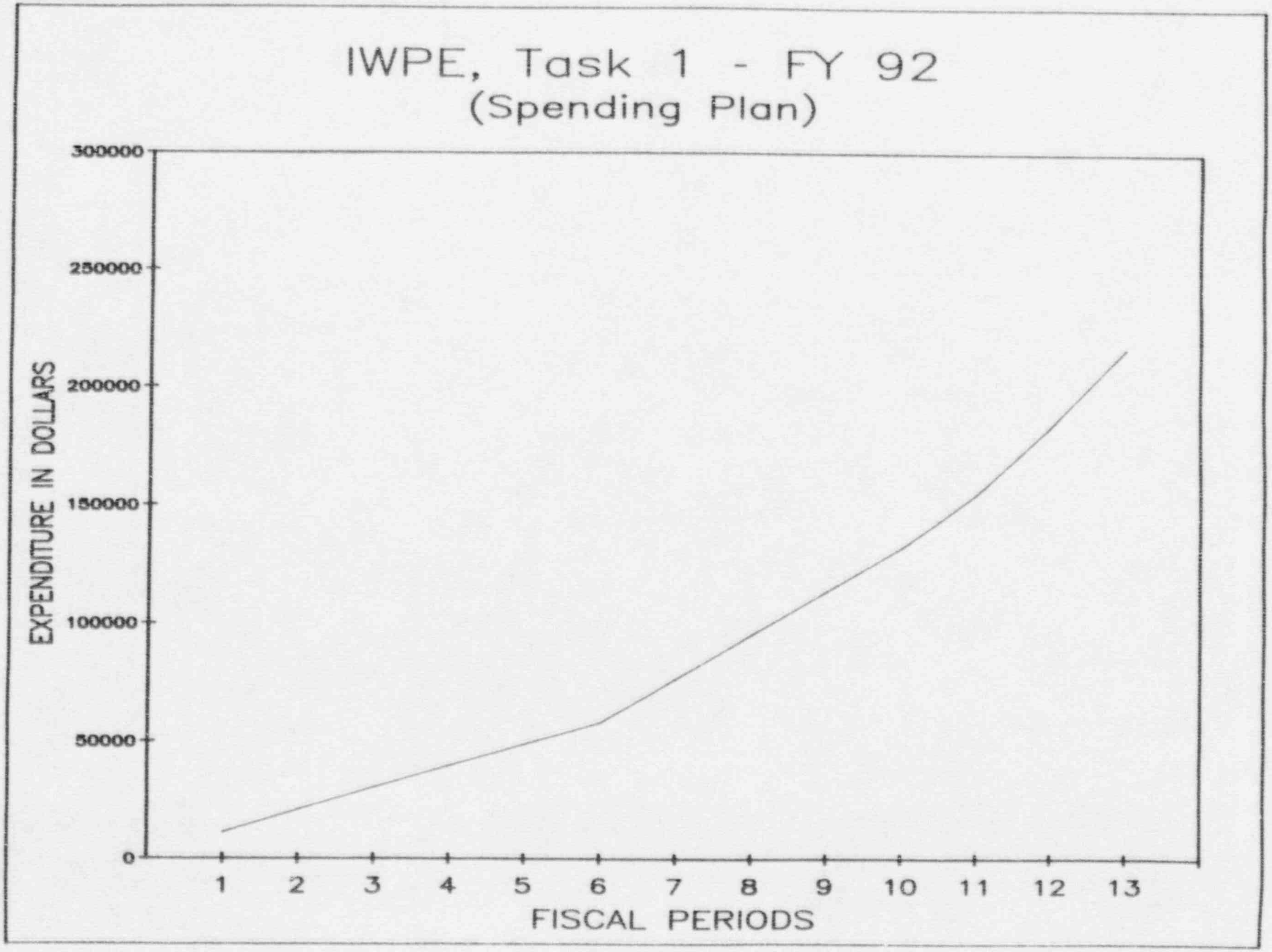

Figure 6.9 Task 1 Spending Plan, FY 92

Table 6.12 Task 2 Spending Plan, FY 92

Spending Plan F/Y 92

17 Dec 90

3704-042 STRESS CORROSION CRACKING

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	923	995	1902	2465	860	298	228	391	1121	1014	1084	1014	1121	13414
Center Pl-2	779	761	1803	2391	732	439	439	556	761	761	732	761	761	11676
Center Pl-1	691	700	700	683	683	245	175	245	543	543	543	560	543	6855
Center Clerical	0	0	0	0	0	0	0	51	205	215	205	205	205	1085
Center Labor	2394	2456	4406	5538	2275	982	842	1243	2629	2533	2563	2540	2629	33030
Center Burden	1017	1044	1872	2354	967	417	358	528	1117	1076	1089	1080	1117	14038
Center Overhead	2848	2923	5242	6590	2707	1168	1002	1479	3128	3014	3050	3022	3128	39301
Swri Pl-3	176	142	391	568	178	36	71	107	249	178	213	249	213	2768
SWRI Labor	176	142	391	568	178	36	71	107	249	178	213	249	213	2768
SWRI Burden	75	60	166	241	75	15	30	45	106	75	91	106	91	1176
SWRI Overhead	293	237	651	947	296	59	118	178	414	296	355	414	355	4615
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel	0	0	0	0	0	0	0	112	450	450	450	450	450	2362
	------	------	------	------	------	------	------	------	------	------	------	------	------	------
Est excl. CFC,Fee	6803	6862	12728	16238	6497	2677	2422	3692	8094	7622	7810	7860	7984	97290
Center CFC	173	177	318	400	164	71	61	90	190	183	185	184	190	2386
SWRI CFC	34	28	77	112	35	7	14	21	49	35	42	49	42	543
Tot Estimate Cost	7010	7068	13123	16750	6697	2755	2496	3803	8333	7840	8037	8093	8216	100220
Fee	544	549	1018	1299	520	214	194	295	648	610	625	629	639	7783
	======	======	======	======	======	======	======	======	======	======	======	======	======	======
Tot Cost with Fee	7554	7617	14141	18049	7216	2969	2690	4098	8980	8449	8662	8722	8855	108003
% Completion	6.99%	7.05%	13.09%	16.71%	6.68%	2.75%	2.49%	3.79%	8.31%	7.82%	8.02%	8.08%	8.20%	100.00%
Cumulative Cost	7554	15171	29312	47361	54577	57546	60236	64335	73315	81764	90427	99148	108003	
Cumul Completion	6.99%	14.05%	27.14%	43.85%	50.53%	53.28%	55.77%	59.57%	67.88%	75.71%	83.73%	91.80%	100.00%	

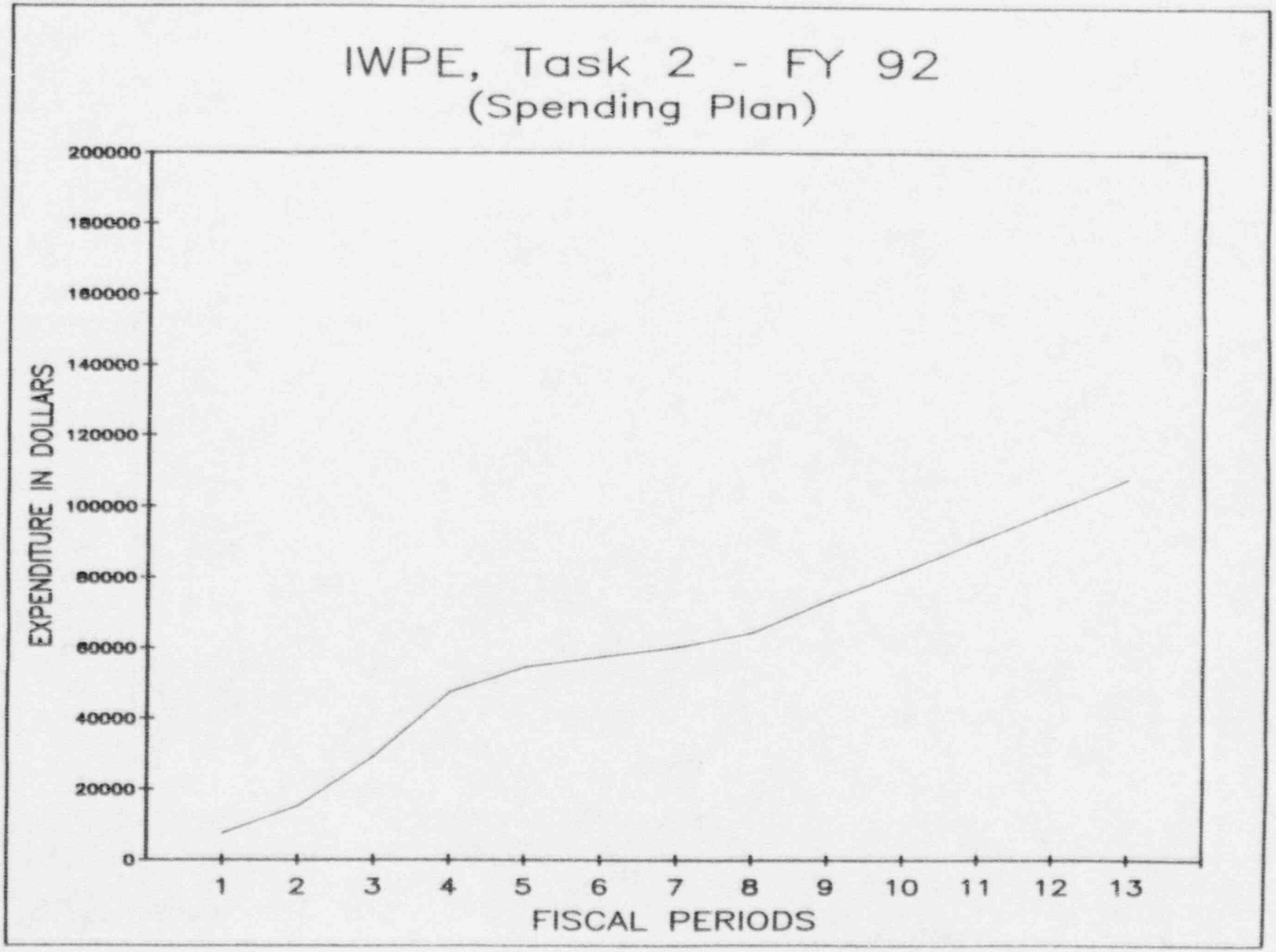

Figure 6.10 Task 2 Spending Plan, FY 92

Table 6.13 Task 3 Spending Plan, FY 92

Spending Plan F/Y 92

17 Dec 90

3704-043 MATERIALS STABILITY

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	391	391	358	391	456	358	423	391	391	423	391	423	391	5177
Center Pl-2	1269	1317	1434	1990	1610	1727	1844	1698	1785	1785	1844	1727	1785	21817
Center Pl-1	709	718	665	770	735	788	840	840	823	823	840	805	823	10182
Center Labor	2369	2426	2458	3152	2801	2873	3108	2929	2999	3032	3075	2956	2999	37175
Center Burden	1007	1031	1045	1339	1190	1221	1321	1245	1275	1288	1307	1256	1275	15800
Center Overhead	2818	2886	2924	3750	3333	3419	3698	3485	3569	3607	3659	3517	3569	44234
Swri Pl-3	0	0	71	107	0	0	0	0	0	0	0	0	0	178
SWRI Labor	0	0	71	107	0	0	0	0	0	0	0	0	0	178
SWRI Burden	0	0	30	45	0	0	0	0	0	0	0	0	0	75
SWRI Overhead	0	0	118	178	0	0	0	0	0	0	0	0	0	296
Material/Supply	0	0	23	228	228	365	456	456	457	456	457	456	456	4038
Travel	253	253	253	253	253	252	253	253	253	253	253	252	253	3287
Est excl. CFC,Fee	6447	6596	6922	9051	7806	8130	8835	8368	8552	8637	8751	8437	8551	105083
Center CFC	171	175	178	228	202	208	225	212	217	219	222	214	217	2686
SWRI CFC	0	0	14	21	0	0	0	0	0	0	0	0	0	35
Tot Estimate Cost	6618	6771	7114	9300	8008	8337	9060	8579	8769	8856	8973	8650	8768	107804
Fee	516	528	554	724	624	650	707	669	684	691	700	675	684	8407
Tot Cost with Fee	7133	7299	7666	10024	8632	8988	9767	9249	9453	9547	9674	9325	9452	116210
% Completion	6.14%	6.28%	6.60%	8.63%	7.43%	7.73%	8.40%	7.96%	8.13%	8.21%	8.32%	8.02%	8.13%	100.00%
Cumulative Cost	7133	14433	22100	32124	40757	49744	59511	68760	78213	87759	97433	106758	116210	
Cumul Completion	6.14%	12.42%	19.02%	27.64%	35.07%	42.81%	51.21%	59.17%	67.30%	75.52%	83.84%	91.87%	100.00%	

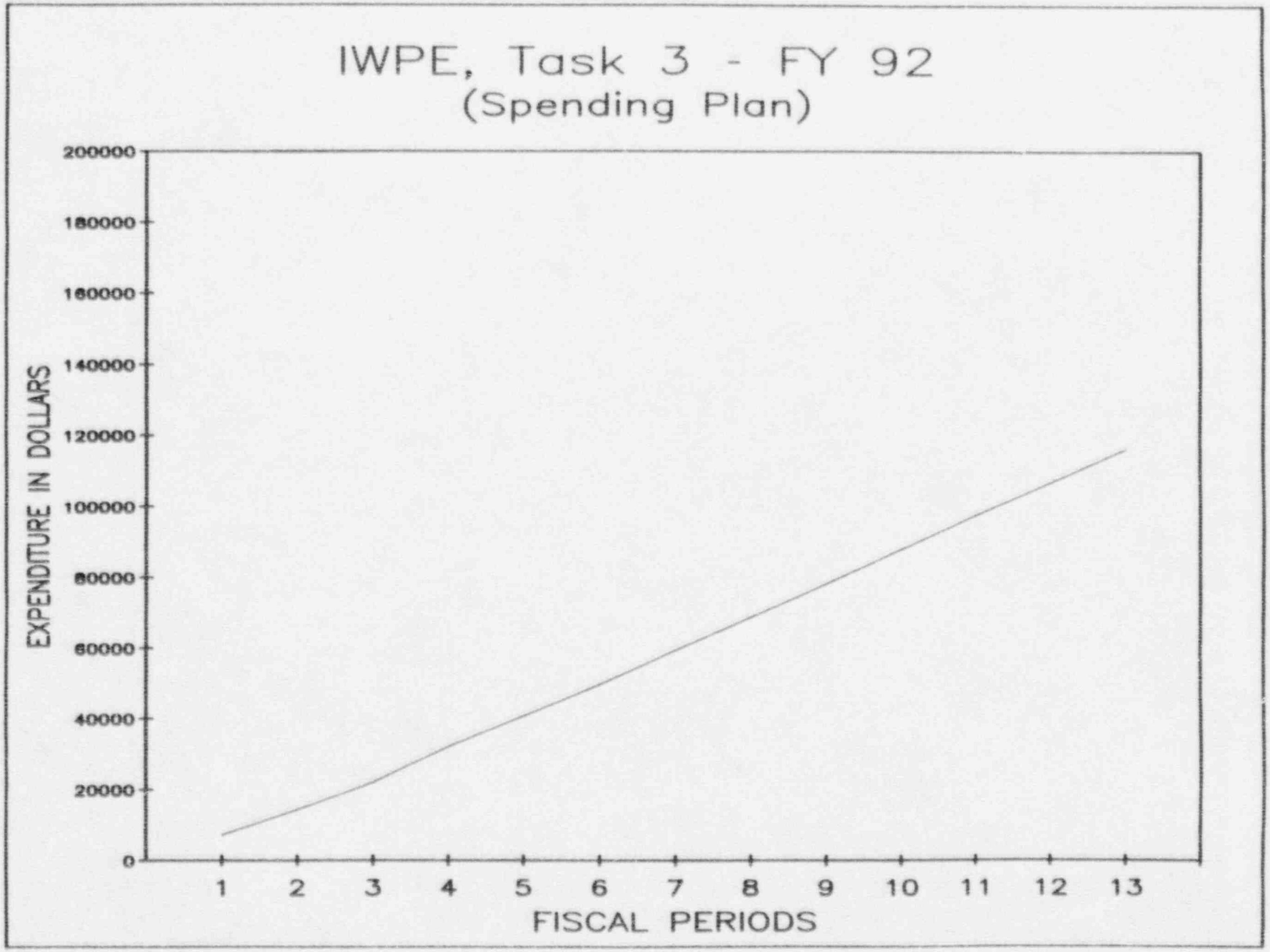

Figure 6.11 Task 3 Spending Plan, FY 92

Table 6.14 Task 4 Spending Plan, FY 92

Spending Plan F/Y 92

17 Dec 90

3704-044 MICROBIOLOGICALL INDUCED CORR.

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	326	358	326	326	326	326	228	0	0	0	0	0	0	2214
Center Pl-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Pl-1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Labor	326	358	326	326	326	326	228	0	0	0	0	0	0	2214
Center Burden	138	152	138	138	138	138	97	0	0	0	0	0	0	941
Center Overhead	387	426	387	387	387	387	271	0	0	0	0	0	0	2634
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Consultants	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Est excl. CFC,Fee	851	937	851	851	851	851	596	0	0	0	0	0	0	5790
Center CFC	24	26	24	24	24	24	16	0	0	0	0	0	0	160
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	875	962	875	875	875	875	612	0	0	0	0	0	0	5949
Fee	68	75	68	68	68	68	48	0	0	0	0	0	0	463
Tot Cost with Fee	943	1037	943	943	943	943	660	0	0	0	0	0	0	6413
% Completion	14.71%	16.18%	14.71%	14.71%	14.71%	14.71%	10.29%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Cumulative Cost	943	1980	2923	3866	4809	5752	6413	6413	6413	6413	6413	6413	6413	
Cumul Completion	14.71%	30.88%	45.59%	60.29%	75.00%	89.71%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	

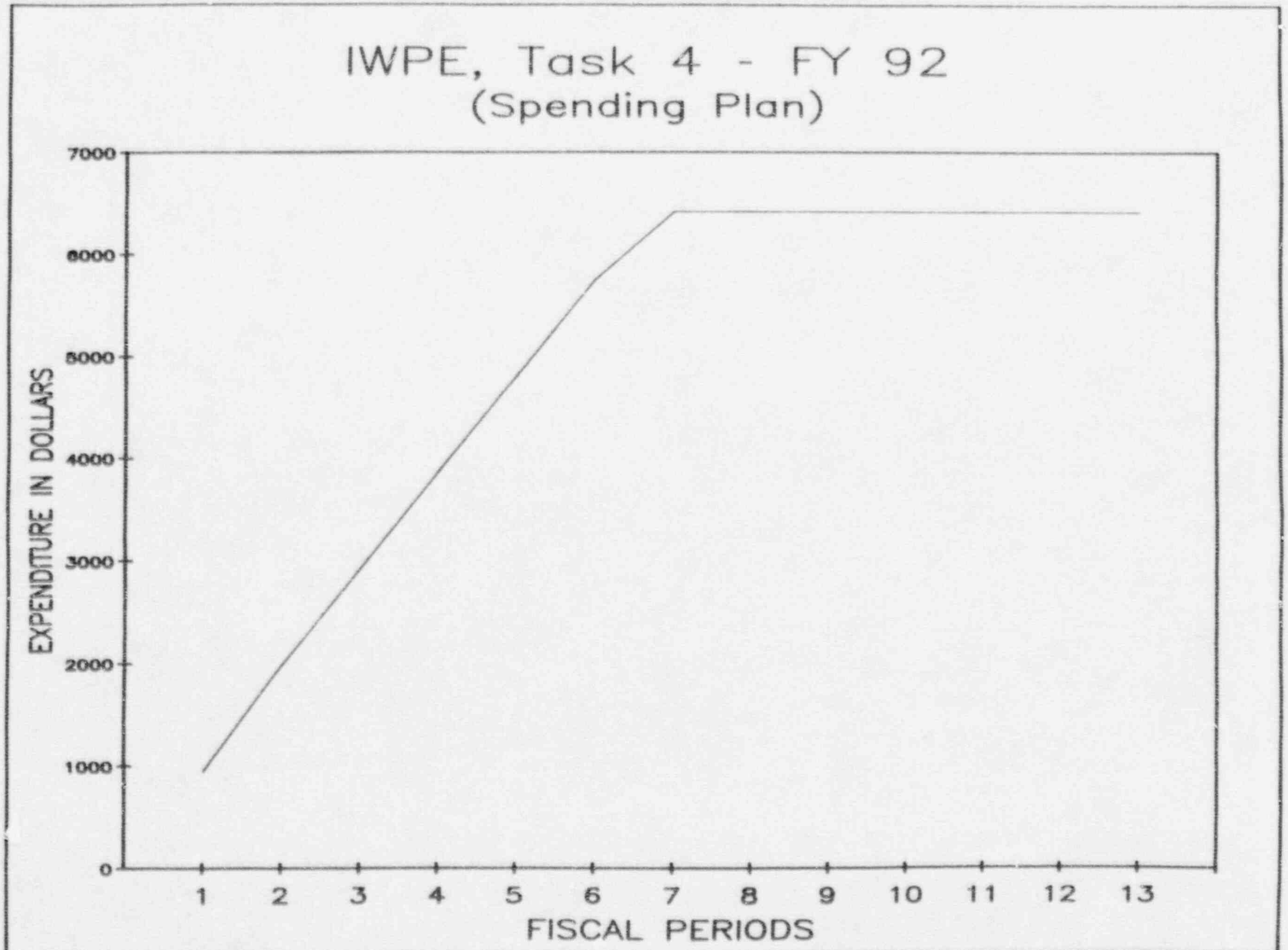

Figure 6.12 Task 4 Spending Plan, FY 92

Table 6.15 Task 5 Spending Plan, FY 92

Spending Plan F/Y 92

17 Dec 90

3704-045 OTHER DEGRADATION MODES

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Labor	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Burden	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Overhead	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Consultants	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subcontractors														
Ohio State	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Est excl. CFC,Fee	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fee	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Cost with Fee	0	0	0	0	0	0	0	0	0	0	0	0	0	0
% Completion	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Cumulative Cost	0	0	0	0	0	0	0	0	0	0	0	0	0	
Cumul Completion	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	

Table 6.16 Task 6 Spending Plan, FY 92

Spending Plan F/Y 92

17 Dec 90

3704-046 PROGRESS REPORTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-4	187	190	190	237	190	190	237	190	190	237	190	237	190	2656
Center Pl-3	560	529	529	529	492	501	497	534	497	501	497	566	529	6761
Center Pl-2	317	351	351	351	293	351	293	351	322	322	322	322	322	4269
Center Clerical	374	369	369	358	369	389	389	389	389	379	389	379	389	4931
Center Labor	1439	1439	1439	1476	1343	1431	1416	1464	1398	1439	1398	1504	1430	18616
Center Burden	612	612	612	627	571	608	602	622	594	612	594	639	608	7912
Center Overhead	1712	1712	1712	1756	1598	1703	1685	1742	1663	1713	1663	1790	1702	22151
Report Services	94	91	88	88	89	96	95	95	94	94	93	94	94	1205
Est excl. CFC,Fee	3856	3854	3851	3948	3602	3839	[illegible]	3923	3748	3858	3747	4028	3834	49885
Center CFC	104	104	104	107	97	10[illegible]	102	106	101	104	101	109	103	1345
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	3960	3958	3955	4055	3699	3942	3899	4029	3849	3962	3848	4137	3937	51230
Fee	309	308	308	316	288	307	304	314	300	309	300	322	307	3991
Tot Cost with Fee	4269	4266	4263	4370	3987	4249	4203	4343	4149	4270	4148	4459	4244	55220
% Completion	7.73%	7.73%	7.72%	7.91%	7.22%	7.70%	7.61%	7.86%	7.51%	7.73%	7.51%	8.07%	7.68%	100.00%
Cumulative Cost	4269	8535	12797	17168	21155	25404	29607	33950	38099	42369	46518	50977	55220	
Cumul Completion	7.73%	15.46%	23.18%	31.09%	38.31%	46.00%	53.62%	61.48%	68.99%	76.73%	84.24%	92.32%	100.00%	

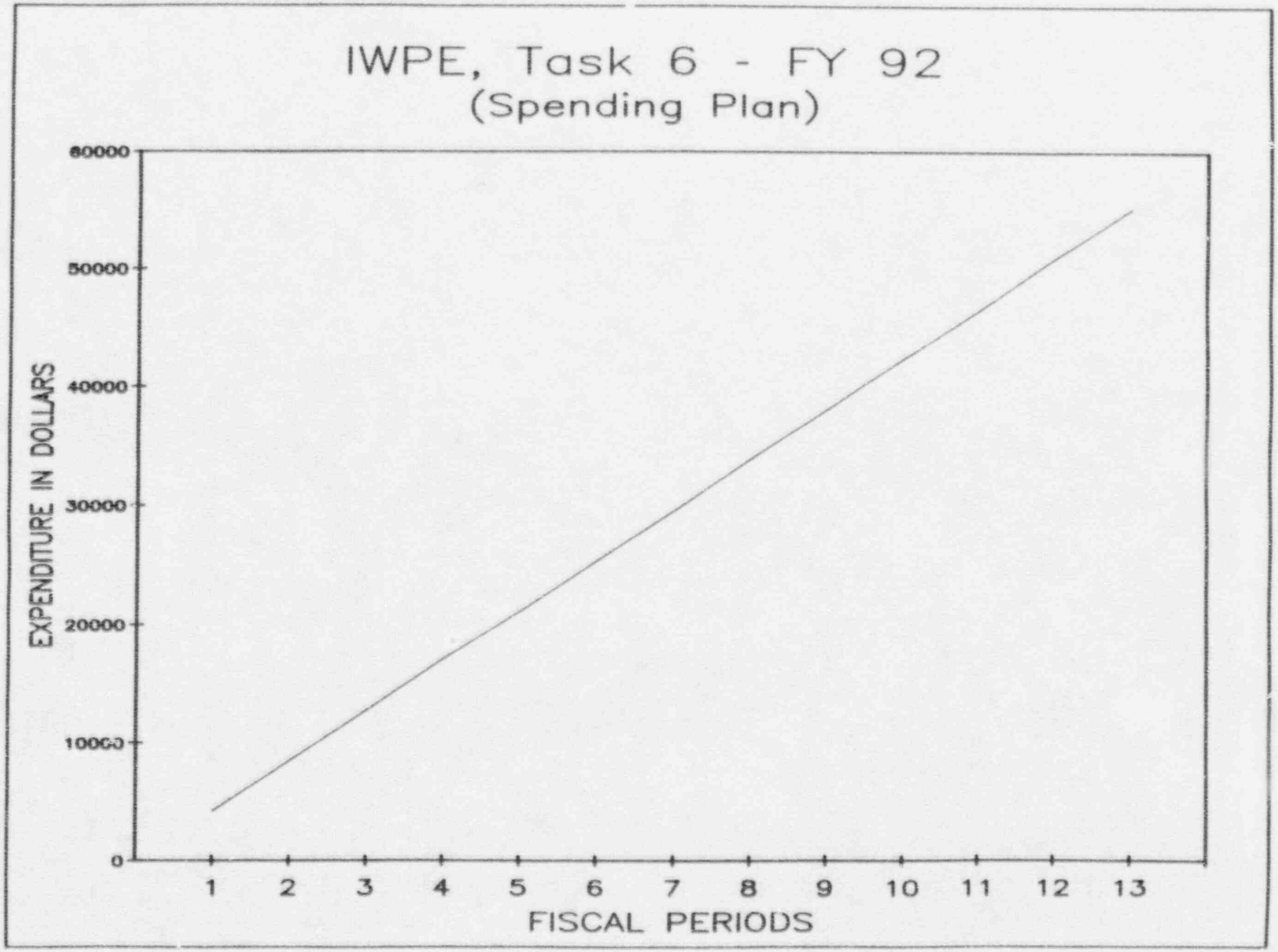

Figure 6.13 Task 6 Spending Plan, FY 92

Table 6.17 Composite Spending Plan, FY 93

Spending Plan F/Y 93

17 Dec 90

3704-040 INTEGR. WASTE PACKAGE EXP.

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-4	199	201	302	201	201	201	252	201	201	252	201	201	252	2868
Center Pl-3	4994	5037	4407	3442	3670	3735	3709	3612	3507	3409	3403	3540	3409	49873
Center Pl-2	7630	7734	6243	4411	4939	4783	4535	4286	4038	4131	4069	4007	4111	64916
Center Pl-1	5290	5500	5444	3827	2007	1784	1858	1802	1747	1709	1747	1709	1616	36040
Center Clerical	780	769	842	769	769	780	791	769	791	780	769	791	693	10191
Center Labor	18893	19241	17338	12650	11585	11283	11144	10670	10283	10281	10188	10248	10082	163888
Center Burden	8029	8178	7369	5376	4924	4795	4736	4535	4370	4370	4330	4355	4285	69652
Center Overhead	22884	23306	21001	15323	14033	13667	13499	12925	12456	12453	12341	12413	12211	198509
Swri Pl-3	858	791	829	678	565	678	678	678	603	565	678	565	603	8771
Swri Pl-2	0	0	0	0	0	0	0	0	0	0	0	0	30	30
SWRI Labor	858	791	829	678	565	678	678	678	603	565	678	565	633	8801
SWRI Burden	365	336	352	288	240	288	288	288	256	240	288	240	269	3740
SWRI Overhead	1467	1353	1418	1160	966	1160	1160	1160	1031	966	1160	966	1083	15050
Material/Supply	1003	1004	1209	775	777	615	548	547	548	547	547	548	547	9215
Report Services	94	90	110	88	91	94	94	93	92	93	92	94	94	1219
Travel	1423	1861	2379	1902	1903	1903	1903	1903	1903	1903	1903	1903	1682	24471
Consultants	0	579	804	643	643	643	643	643	643	643	643	643	644	7814
Subcontractors														
Ohio State	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Est excl. CFC,Fee	55015	56740	52808	38884	35728	35126	34694	33442	32186	32062	32170	31976	31530	502360
Center CFC	1514	1541	1389	1013	928	904	893	855	824	824	816	821	808	13130
SWRI CFC	187	172	180	148	123	148	148	148	131	123	148	123	138	1915
Tot Estimate Cost	56716	58453	54377	40045	36779	36178	35734	34445	33141	33009	33134	32920	32476	517406
Fee	4401	4539	4225	3111	2858	2810	2775	2675	2575	2565	2574	2556	2522	40189
Tot Cost with Fee	61117	62993	58602	43155	39637	38988	38510	37120	35716	35574	35708	35478	34998	557594
% Completion	10.96%	11.30%	10.51%	7.74%	7.11%	6.99%	6.91%	6.63%	6.41%	6.38%	6.40%	6.36%	6.28%	100.00%
Cumulative Cost	61117	124109	182711	225867	265504	304492	343002	380122	415837	451411	487119	522596	557594	
Cumul Completion	10.96%	22.26%	32.77%	40.51%	47.62%	54.61%	61.51%	68.17%	74.58%	80.96%	87.36%	93.72%	100.00%	

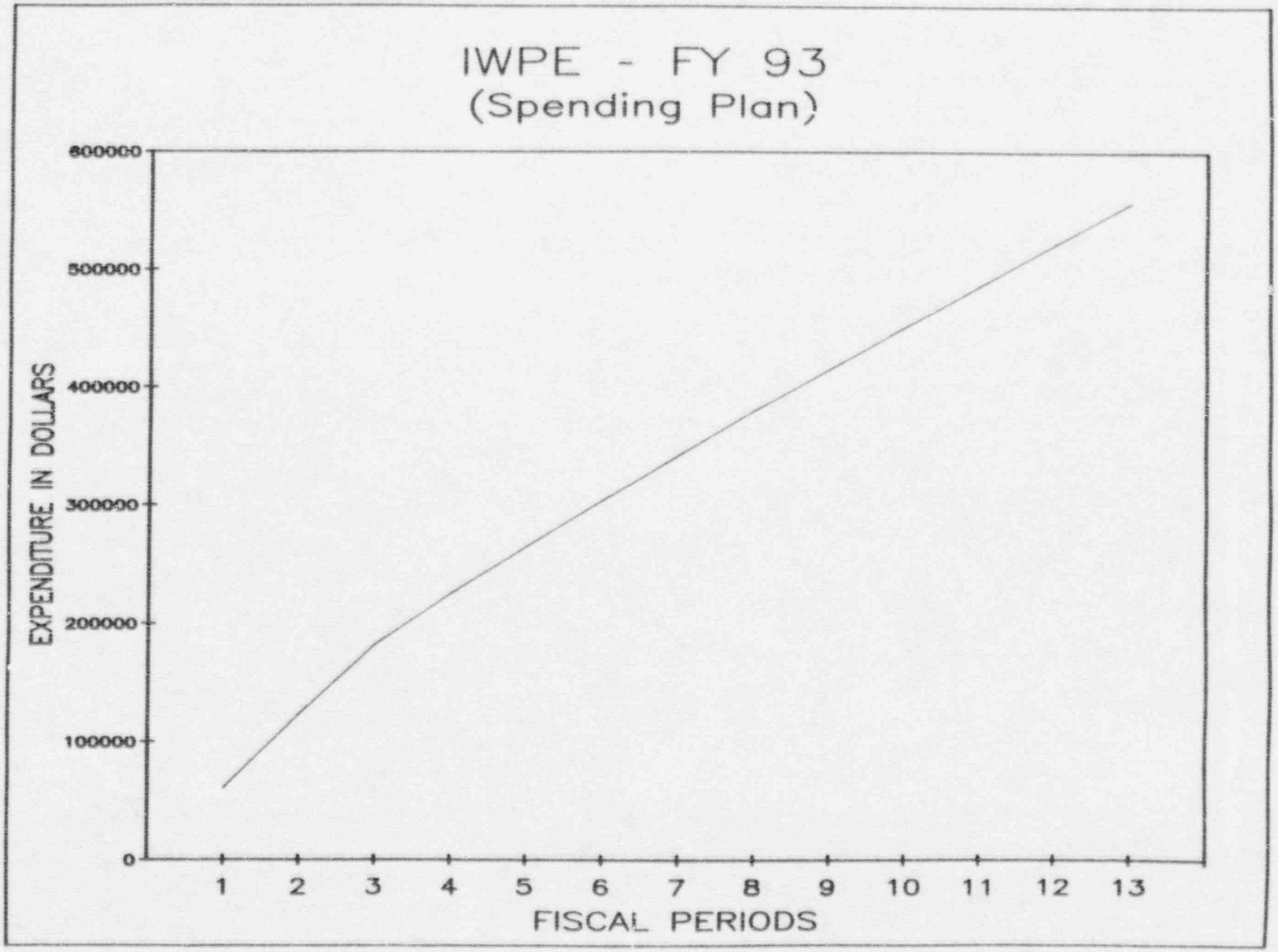

Figure 6.14 Composite Spending Plan, FY 93

Table 6.18 Manpower Plan FY 93

Manpower Plan F/Y 93

17 Dec 90

3704-040 INTEGR. WASTE PACKAGE EXP.

Center Labor	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-4	4	4	6	4	4	4	5	4	4	5	4	4	5	57
Center Pl-3	151	152	132	103	110	112	111	108	105	102	102	106	102	1496
Center Pl-2	249	249	201	142	159	154	146	138	130	133	131	129	132	2093
Center Pl-1	289	298	293	206	108	96	100	97	94	92	94	92	87	1944
Center Clerical	73	71	87	71	71	72	73	71	73	72	71	73	84	942
Total Center Labor	786	772	719	526	452	438	435	418	406	404	402	404	390	8532

Swri Labor	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Swri Pl-3	23	21	22	18	15	18	18	18	16	15	18	15	16	233
Swri Pl-2	0	0	0	0	0	0	0	0	0	0	0	0	1	1
Total Swri Labor	23	21	22	18	15	18	18	18	16	15	18	15	17	234

Table 6.19 Task 1 Spending Plan, FY 93

Spending Plan F/Y 93

17 Dec 90

3704-041 CORROSION

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	2651	2586	1486	1160	1349	1511	1511	1557	1511	1479	1479	1551	1349	21179
Center Pl-2	3949	3976	1833	1367	1833	2019	2050	2050	2019	2081	2050	2050	2061	29336
Center Pl-'	3844	3902	3512	2378	539	557	557	557	557	557	557	557	465	18541
Center Cle .cal	160	162	195	162	152	162	162	152	162	162	152	162	65	2012
Center Lab..	10605	10826	7025	5067	3872	4250	4281	4316	4250	4280	4238	4320	3939	71068
Center Burden	4507	4516	2985	2154	1645	1806	1819	1835	1806	1819	1801	1836	1674	30204
Center Overhead	12845	12870	8509	6138	4689	5148	5186	5228	5148	5184	5133	5233	4771	86082
Swri Pl-3	634	565	565	414	339	452	452	452	452	414	490	414	414	6060
Swri Pl-2	0	0	0	0	0	0	0	0	0	0	0	0	30	30
SWRI Labor	634	565	565	414	339	452	452	452	452	414	490	414	445	6090
SWRI Burden	269	240	240	176	144	192	192	192	192	176	208	176	189	2588
SWRI Overhead	1084	966	966	709	580	773	773	773	773	709	838	709	761	10414
Material/Supply	547	548	684	547	548	547	548	547	548	547	547	548	547	7253
Travel	367	367	458	367	367	367	367	367	367	367	367	367	147	4642
Est excl. CFC,Fee	30858	30699	21433	15572	12184	13536	13619	13711	13537	13496	13621	13604	12473	218342
Center CFC	850	851	563	406	310	340	343	346	340	343	340	346	316	5694
SWRI CFC	138	123	123	90	74	98	98	98	98	90	107	90	97	1328
Tot Estimate Cost	31845	31673	22118	16063	12568	13975	14060	14155	13976	13929	14068	14041	12885	225361
Fee	2469	2456	1715	1246	975	1083	1090	1097	1083	1080	1090	1088	998	17467
Tot Cost with Fee	34314	34129	23833	17314	13543	15058	15150	15252	15059	15008	15157	15129	13883	242829
% Completion	14.13%	14.05%	9.81%	7.13%	5.58%	6.20%	6.24%	6.28%	6.20%	6.18%	6.24%	6.23%	5.72%	100.00%
Cumulative Cost	34314	68443	92276	109590	123134	138191	153341	168593	183651	198660	213817	228946	242829	
Cumul Completion	14.13%	28.19%	38.00%	45.13%	50.71%	56.91%	63.15%	69.43%	75.63%	81.61%	88.05%	94.28%	100.00%	

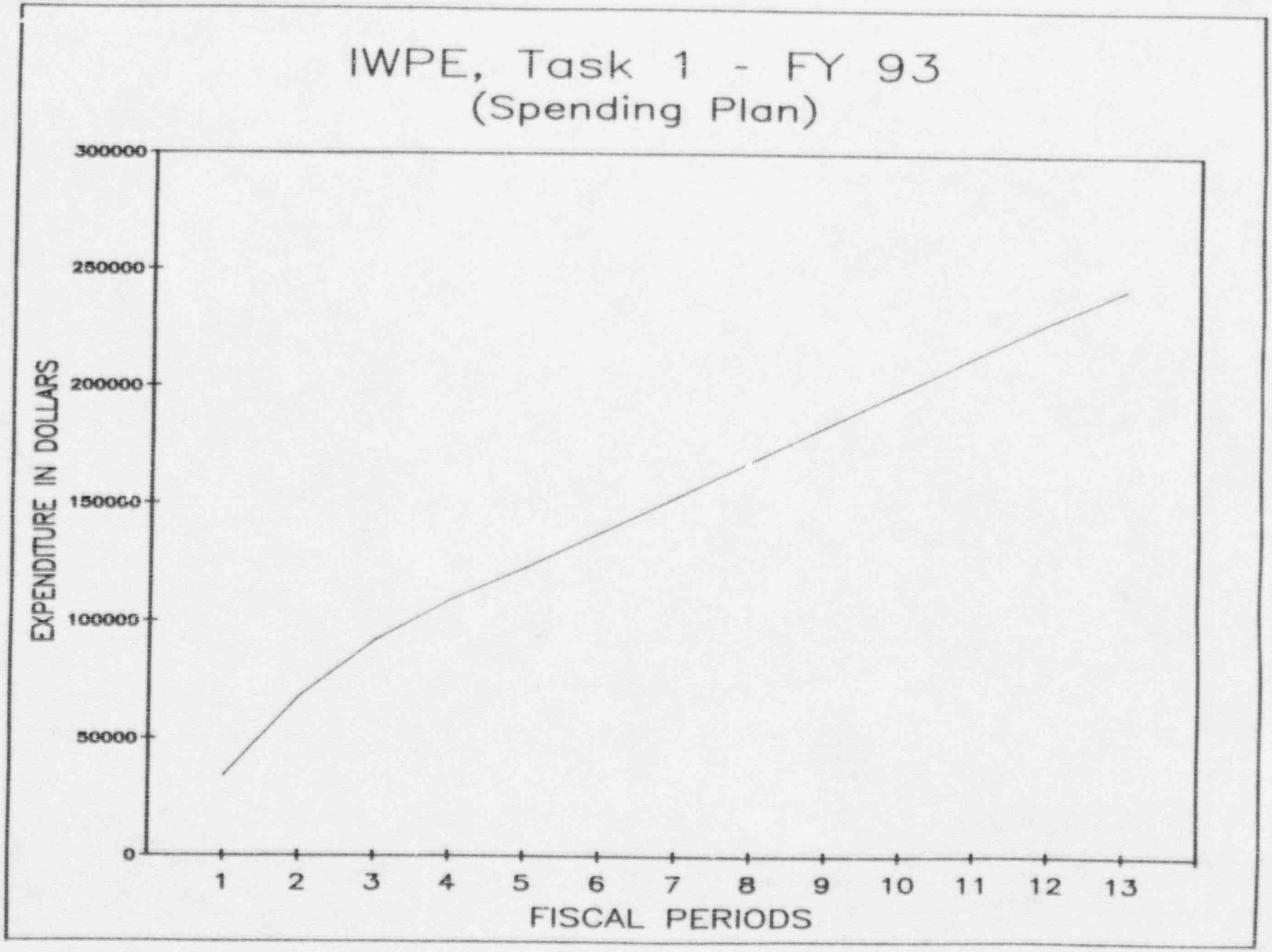

Figure 6.15 Task 1 Spending Plan, FY 93

Table 6.20 Task 2 Spending Plan, FY 93

Spending Plan F/Y 93

17 Dec 90

3704-042 STRESS CORROSION CRACKING

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	1016	1121	1316	1016	1088	1016	1127	918	821	860	821	821	821	12782
Center Pl-2	736	839	963	777	777	839	745	590	311	311	311	311	311	7818
Center Pl-1	568	576	725	576	576	557	576	502	409	409	409	409	409	6700
Center Clerical	224	217	271	217	227	217	217	217	227	217	217	217	227	2910
Center Labor	2546	2752	3274	2585	2668	2629	2665	2227	1768	1796	1757	1757	1768	30191
Center Burden	1082	1170	1392	1099	1134	1117	1133	946	751	763	747	747	751	12831
Center Overhead	3083	3333	3986	3131	3232	3184	3229	2697	2141	2176	2128	2128	2141	36568
Swri Pl-3	224	226	264	264	226	226	226	226	151	151	188	151	188	2711
SWRI Labor	224	226	264	264	226	226	226	226	151	151	188	151	188	2711
SWRI Burden	95	96	112	112	96	96	96	96	64	64	80	64	80	1152
SWRI Overhead	383	387	451	451	387	387	387	387	258	258	322	258	322	4635
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel	450	450	563	449	450	450	450	450	450	450	450	450	450	5962
Est excl. CFC,Fee	7863	8413	10022	8091	8192	8089	8185	7029	5582	5657	5672	5554	5700	94050
Center CFC	204	220	262	207	214	211	214	178	142	144	141	141	142	2419
SWRI CFC	49	49	57	57	49	49	49	49	33	33	41	33	41	590
Tot Estimate Cost	8115	8683	10341	8356	8455	8349	8448	7257	5757	5834	5854	5727	5883	9705[illegible]
Fee	629	673	802	647	655	647	655	562	447	453	454	444	456	7524
Tot Cost with Fee	8744	9356	11143	9003	9111	8996	9103	7819	6203	6287	6307	6172	6339	104583
% Completion	8.36%	8.95%	10.65%	8.61%	8.71%	8.60%	8.70%	7.48%	5.93%	6.01%	6.03%	5.90%	6.06%	100.00%
Cumulative Cost	8744	18100	29243	38246	47357	56353	65456	73275	79478	85765	92072	98244	104583	
Cumul Completion	8.36%	17.31%	27.96%	36.57%	45.28%	53.88%	62.59%	70.06%	76.00%	82.01%	88.04%	93.94%	100.00%	

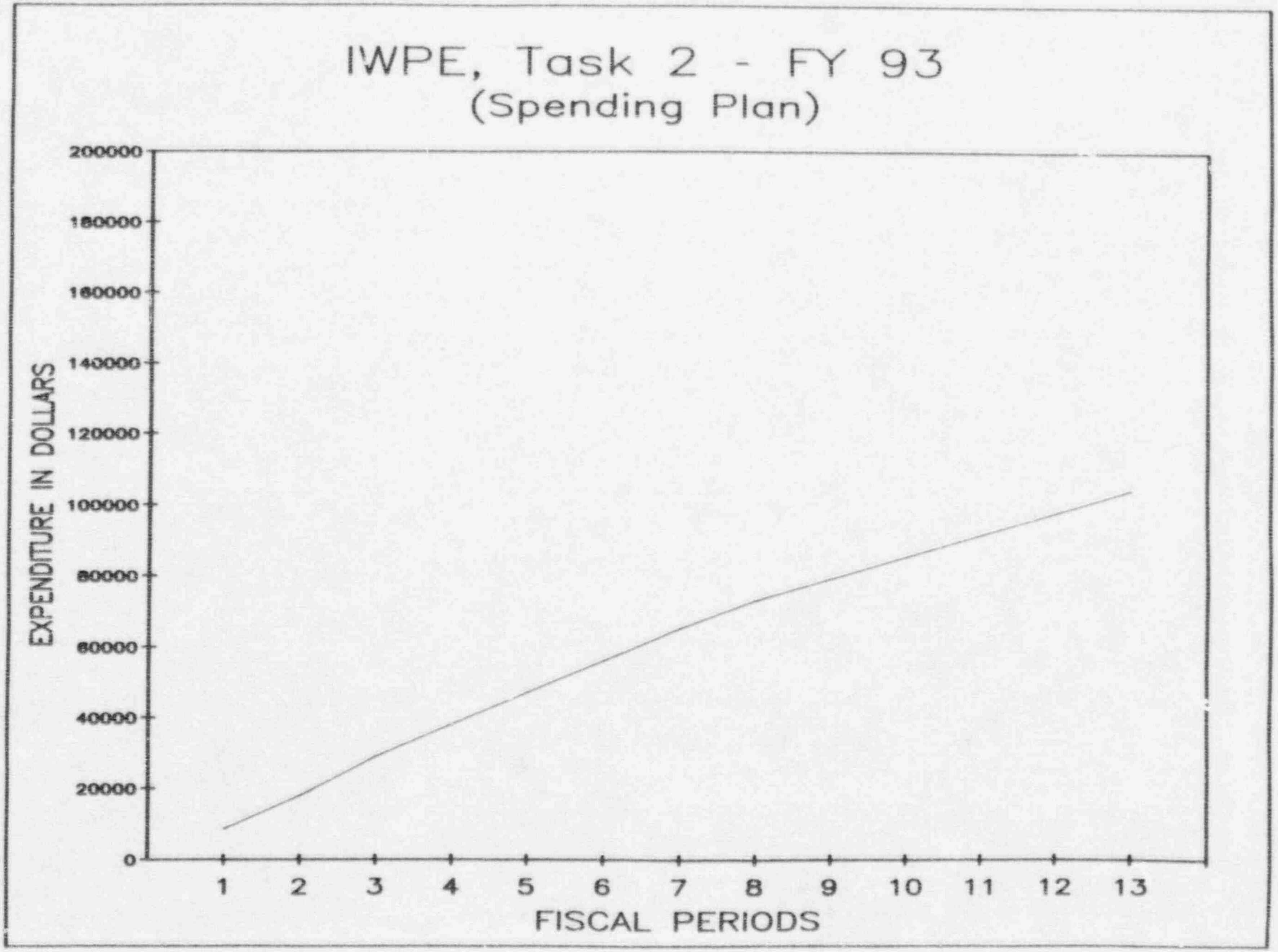

Figure 6.16 Task 2 Spending Plan, FY 93

Table 6.21 Task 3 Spending Plan, FY 93

Spending Plan F/Y 93

17 Dec 90

3704-043 MATERIALS STABILITY

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	391	423	488	391	358	293	228	260	260	228	228	260	260	4070
Center Pl-2	1895	1895	2267	1305	1367	994	777	745	745	808	777	714	808	15098
Center Pl-1	878	892	1040	743	743	539	576	613	632	613	632	613	595	9109
Center Labor	3164	3210	3796	2438	2468	1826	1580	1619	1636	1649	1636	1588	1663	28275
Center Burden	1345	1364	1613	1036	1049	776	672	688	696	701	695	675	707	12017
Center Overhead	3832	3888	4598	2954	2989	2211	1914	1961	1984	1997	1982	1923	2014	34248
Swri Pl-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Labor	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Burden	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Overhead	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Material/Supply	456	456	525	228	229	68	0	0	0	0	0	0	0	1962
Travel	253	253	316	253	253	253	252	253	253	253	253	253	252	3350
Est excl. CFC,Fee	9050	91[illegible]	10849	6909	6988	5134	4418	4521	4570	4599	4566	4439	4635	79851
Center CFC	253	257	304	195	198	146	127	130	131	132	131	127	133	2285
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	9303	9428	11153	7105	7186	5280	4545	4651	4701	4731	4697	4567	4768	82116
Fee	724	734	868	553	559	411	353	362	366	368	365	355	371	6388
Tot Cost with Fee	10027	10162	12021	7657	7745	5691	4898	5013	5067	5099	5063	4922	5139	88504
% Completion	11.33%	11.48%	13.58%	8.65%	8.75%	6.43%	5.53%	5.66%	5.73%	5.76%	5.72%	5.56%	5.81%	100.00%
Cumulative Cost	10027	20189	32210	39867	47612	53304	58202	63215	68282	73381	78444	83365	88504	
Cumul Completion	11.33%	22.81%	36.39%	45.05%	53.80%	60.23%	65.76%	71.43%	77.15%	82.91%	88.63%	94.19%	100.00%	

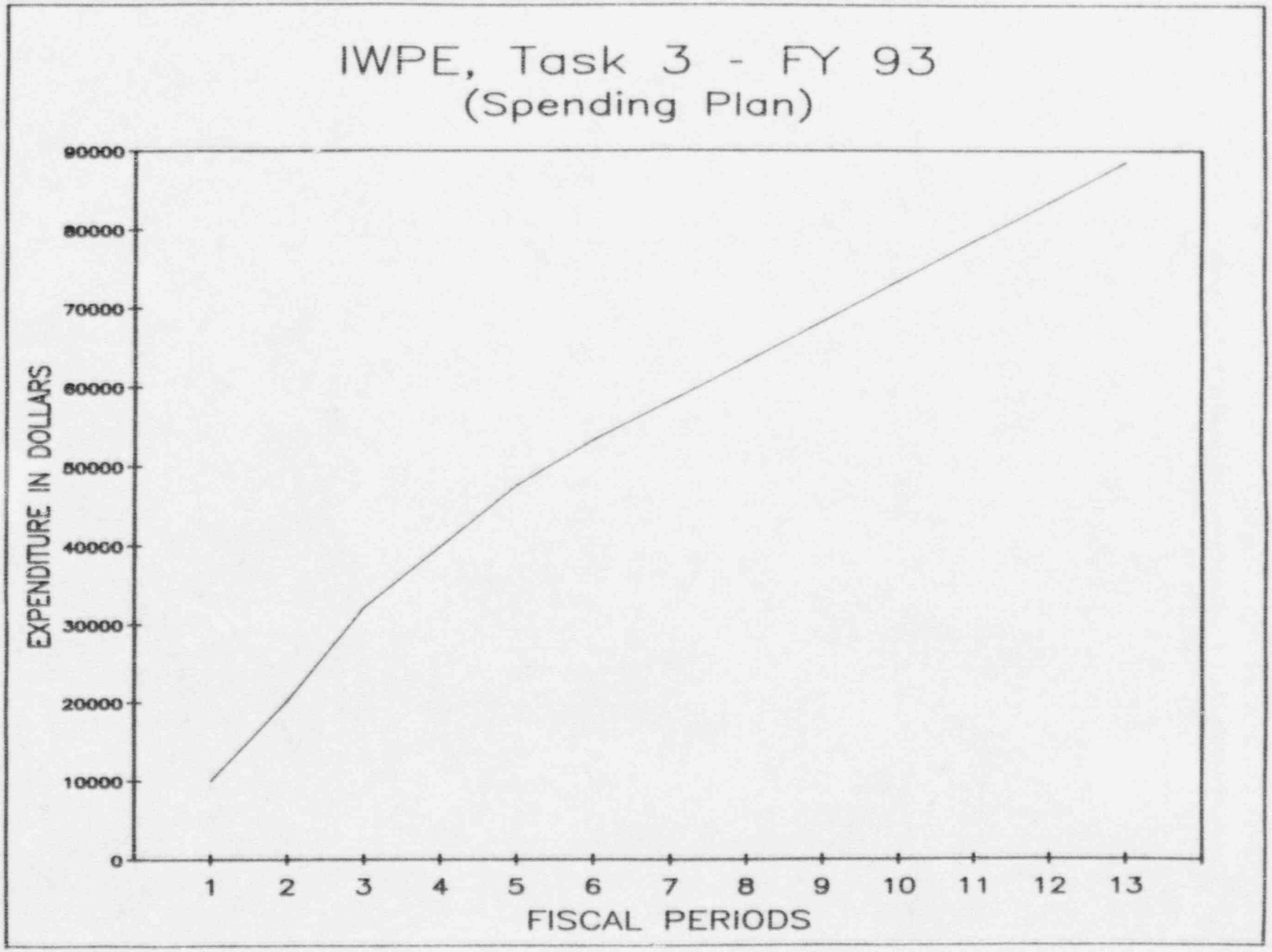

Figure 6.17 Task 3 Spending Plan, FY 93

Table 6.22 Task 4 Spending Plan, FY 93

Spending Plan F/Y 93

17 Dec 90

3704-044 MICROBIOLOGICALL INDUCED CORR.

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	358	358	456	326	358	358	358	358	358	358	358	358	358	4721
Center Pl-2	276	62	62	31	31	62	31	31	31	62	31	31	62	804
Center Pl-1	0	130	167	130	149	130	149	130	149	130	149	130	149	1691
Center Labor	634	550	685	487	538	550	538	519	538	550	538	519	569	7218
Center Burden	270	234	291	207	229	234	229	221	229	234	229	221	242	3067
Center Overhead	768	667	830	590	651	667	651	629	651	667	651	629	689	8740
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel	0	376	523	418	418	418	418	418	418	418	418	418	418	5079
Consultants	0	579	804	643	643	643	643	643	643	643	643	643	644	7814
Est excl. CFC,Fee	1672	2406	3133	2344	2479	2512	2479	2430	2479	2512	2479	2430	2562	31916
Center CFC	51	44	55	39	43	44	43	42	43	44	43	42	46	578
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	1722	2450	3188	2383	2522	2556	2522	2472	2522	2556	2522	2472	2607	32494
Fee	134	192	251	188	198	201	198	194	198	201	198	194	205	2553
Tot Cost with Fee	1856	2642	3439	2571	2720	2757	2720	2666	2720	2757	2720	2666	2812	35047
% Completion	5.30%	7.54%	9.81%	7.33%	7.76%	7.87%	7.76%	7.61%	7.76%	7.87%	7.76%	7.61%	8.02%	100.00%
Cumulative Cost	1856	4499	7937	10508	13228	15985	18706	21372	24092	26849	29569	32235	35047	
Cumul Completion	5.30%	12.84%	22.65%	29.98%	37.74%	45.61%	53.37%	60.98%	68.74%	76.61%	84.37%	91.98%	100.00%	

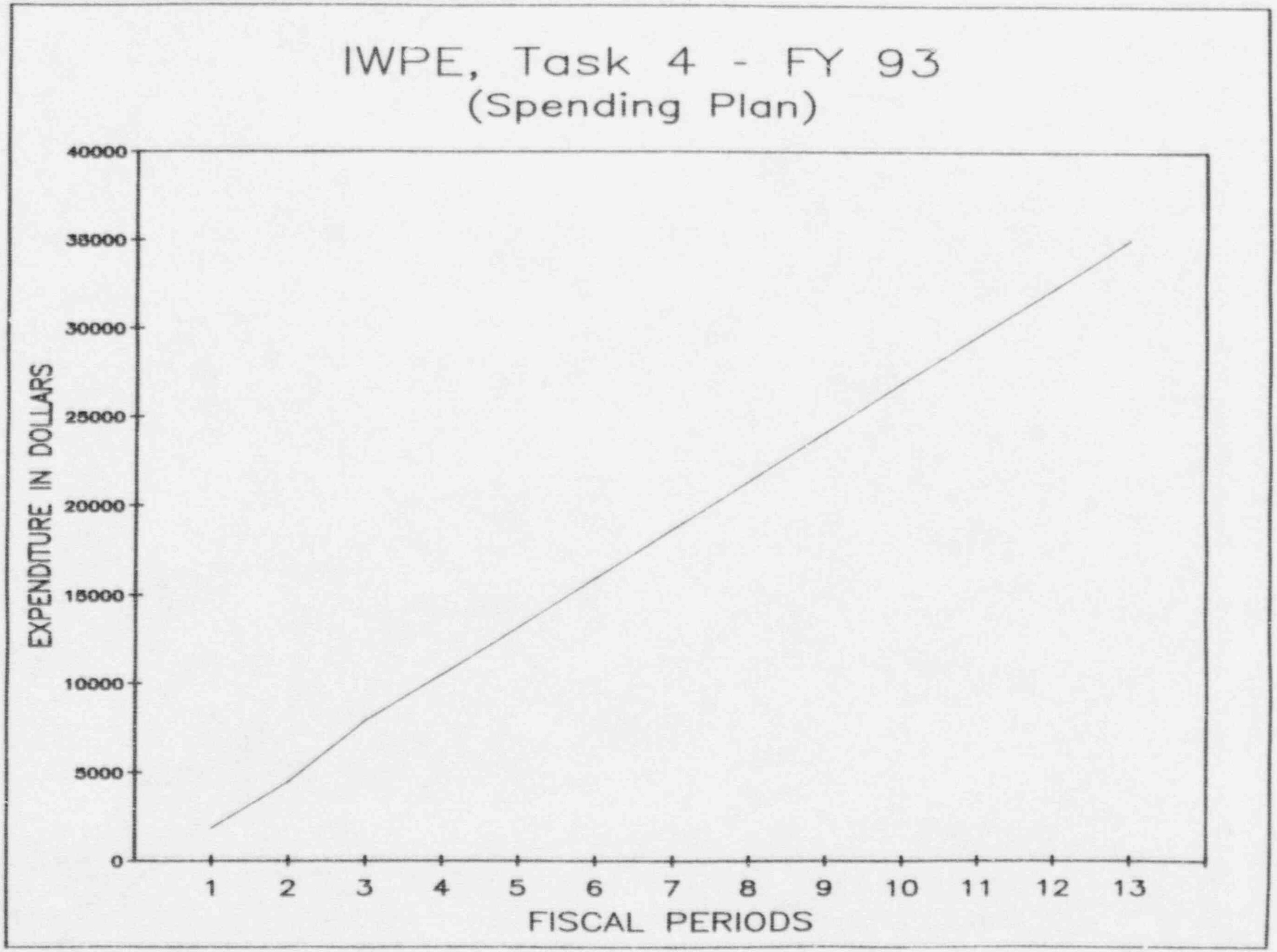

Figure 6.18 Task 4 Spending Plan, FY 93

Table 6.23 Task 5 Spending Plan, FY 93

Spending Plan F/Y 93

17 Dec 90

3704-045 OTHER DEGRADATION MODES

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-2	466	590	683	559	559	528	590	559	559	55S	559	559	528	7299
Center Labor	466	590	683	559	559	528	590	559	559	559	559	559	528	7299
Center Burden	198	251	290	238	238	224	251	238	238	238	238	238	224	3102
Center Overhead	564	715	828	677	677	640	715	677	677	677	677	677	640	8841
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel	353	415	519	415	415	415	416	415	415	415	415	415	415	5438
Consultants	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subcontractors														
Ohio State	0	0	0	0	0	0	0	0	0	0	C	0	0	0
Est excl. CFC,Fee	1581	1971	2320	1889	1889	1807	1972	1889	1889	1889	1889	1889	1807	24680
Center CFC	37	47	55	45	45	42	47	45	45	45	45	45	42	585
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	1619	2018	2375	1934	1934	1849	2019	1934	1934	1934	1934	1934	1849	25265
Fee	127	158	186	151	151	145	158	151	151	151	151	151	145	1974
Tot Cost with Fee	1745	2176	2561	2085	2085	1994	2177	2085	2085	2085	2085	2085	1994	27239
% Completion	6.41%	7.99%	9.40%	7.65%	7.65%	7.32%	7.99%	7.65%	7.65%	7.65%	7.65%	7.65%	7.32%	100.00%
Cumulative Cost	1745	3921	6482	8566	10651	12645	14822	16907	18991	21076	23161	25246	27239	
Cumul Completion	6.41%	14.39%	23.79%	31.45%	39.10%	46.42%	54.41%	62.07%	69.72%	77.37%	85.03%	92.68%	100.00%	

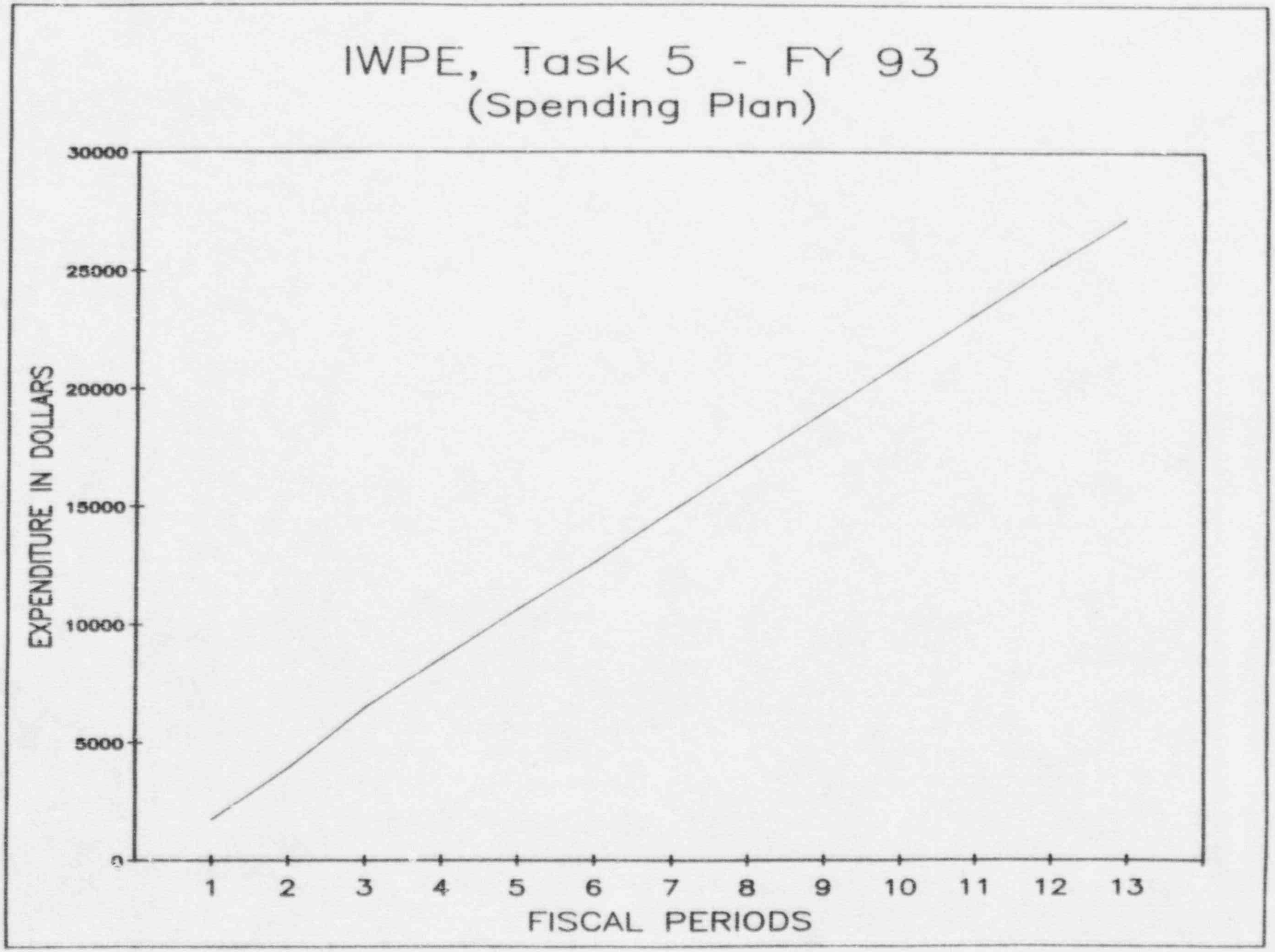

Figure 6.19 Task 5 Spending Plan, FY 93

Table 6.24 Task 6 Spending Plan, FY 93

Spending Plan F/Y 93

17 Dec 90

3704-046 PROGRESS REPORTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-4	199	201	302	201	201	201	252	201	201	252	201	201	252	2868
Center Pl-3	578	550	661	550	517	556	484	517	556	484	517	550	621	7140
Center Pl-2	307	373	435	373	373	342	342	311	373	311	342	342	342	4562
Center Clerical	395	390	477	390	390	401	412	401	401	401	40	412	401	5269
Center Labor	1479	1514	1874	1514	1481	1500	1489	1430	1531	1447	146	1504	1616	19839
Center Burden	628	643	797	643	629	638	633	608	631	615	62.	639	687	8432
Center Overhead	1791	1833	2270	1833	1794	1817	1804	1732	1855	1753	1769	1822	1957	24030
Report Services	94	90	110	88	91	94	94	93	92	93	92	94	94	1219
Est excl. CFC,Fee	3992	4080	5051	4078	3995	4049	4020	3862	4129	3909	3943	4059	4353	53520
Center CFC	118	121	150	121	119	120	119	115	123	116	117	121	129	1589
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	4110	4201	5201	4199	4114	4169	4140	3977	4251	4025	4060	4180	4483	55110
Fee	319	326	404	326	320	324	322	309	330	313	315	325	348	4282
Tot Cost with Fee	4430	4528	5605	4526	4434	4493	4461	4286	4581	4338	4375	4505	4831	59391
% Completion	7.46%	7.62%	9.44%	7.62%	7.46%	7.56%	7.51%	7.22%	7.71%	7.30%	7.37%	7.58%	8.13%	100.00%
Cumulative Cost	4430	8957	14563	19088	23522	28015	32476	36761	41343	45681	50056	54561	59391	
Cumul Completion	7.46%	15.08%	24.52%	32.14%	39.60%	47.17%	54.68%	61.90%	69.61%	76.91%	84.28%	91.87%	100.00%	

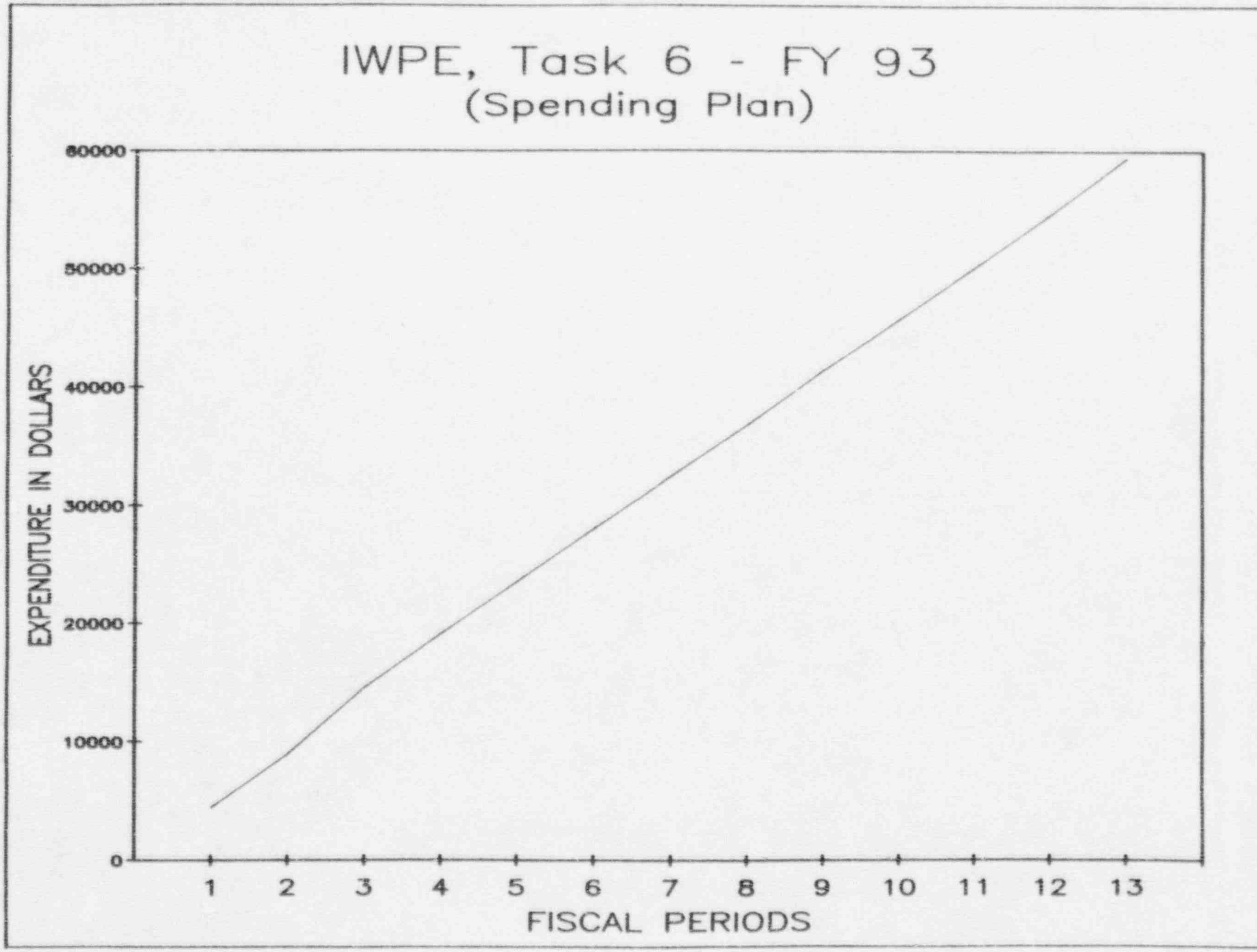

Figure 6.20 Task 6 Spending Plan, FY 93

Table 6.25 Composite Spending Plan, FY 94

Spending Plan F/Y 94

17 Dec 90

3704-040 INTEGR. WASTE PACKAGE EXP.

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-4	213	213	213	213	213	267	213	213	213	267	213	53	0	2507
Center Pl-3	6249	4248	4109	4132	4127	4109	4109	4183	4020	3932	3946	3459	3352	53977
Center Pl-2	8782	5230	5230	5164	5164	5131	5197	5131	4868	4407	4572	4177	4013	67063
Center Pl-1	2675	3285	3305	3285	3324	3246	3305	3285	3108	2951	2931	2951	2891	40540
Center Clerical	1180	1433	1433	1433	1444	1433	1444	1478	1444	1455	1444	1146	1031	17797
Center Labor	19099	14409	14289	14227	14272	14185	14267	14291	13653	13012	13106	11786	11288	181883
Center Burden	8117	6124	6073	6046	6066	6028	6064	6074	5803	5530	5570	5009	4797	77300
Center Overhead	23134	17452	17307	17232	17287	17181	17281	17309	16538	15760	15875	14276	13672	220308
Swri Pl-3	519	160	200	160	200	160	160	200	160	200	160	160	200	2633
Swri Pl-2	547	30	0	0	0	0	0	0	0	0	0	0	0	577
SWRI Labor	1065	190	200	160	200	160	160	200	160	200	160	160	200	3210
SWRI Burden	453	81	85	68	85	68	68	85	68	85	68	68	85	1364
SWRI Overhead	1822	325	341	273	341	273	273	341	273	341	273	273	341	5490
Material/Supply	548	547	548	547	548	547	547	548	547	548	547	548	465	7035
Report Services	93	89	87	86	89	91	91	91	90	91	91	23	0	1012
Travel	2098	2284	2284	2284	2285	2284	2283	2285	2144	2031	2031	2032	2031	28356
Consultants	643	6[illegible]3	643	643	643	643	643	643	643	643	643	644	643	8360
Subcontractors														
Ohio State	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	------	-------	-------	-------	-------	-------	-------	-------	-------	-------	--------	-------	--------	--------
Est excl. CFC,Fee	57072	42143	41856	41588	41818	41459	41677	41866	39918	38240	38363	34818	33522	534317
Center CFC	1530	1154	1145	1140	1143	1136	1143	1145	1094	1042	1050	944	904	14571
SWRI CFC	232	41	43	35	43	35	35	43	35	43	35	35	43	699
Tot Estimate Cost	58834	43339	43045	42740	43003	42630	42855	43054	41046	39326	39448	35797	34470	549587
Fee	4566	3371	3349	3325	3345	3317	3334	3349	3193	3059	3069	2785	2682	42745
	======	=======	=======	=======	=======	=======	=======	=======	=======	=======	========	=======	========	========
Tot Cost with Fee	63400	46710	46393	46066	46348	45947	46189	46404	44240	42386	42517	38583	37151	592333
% Completion	10.70%	7.89%	7.83%	7.78%	7.82%	7.76%	7.80%	7.83%	7.47%	7.16%	7.18%	6.51%	6.27%	100.00%
Cumulative Cost	63400	110110	156503	202569	248917	294865	341053	387457	431697	474082	516599	555181	592333	
Cumul Completion	10.70%	18.59%	26.42%	34.20%	42.02%	49.78%	57.58%	65.41%	72.88%	80.04%	87.21%	93.73%	100.00%	

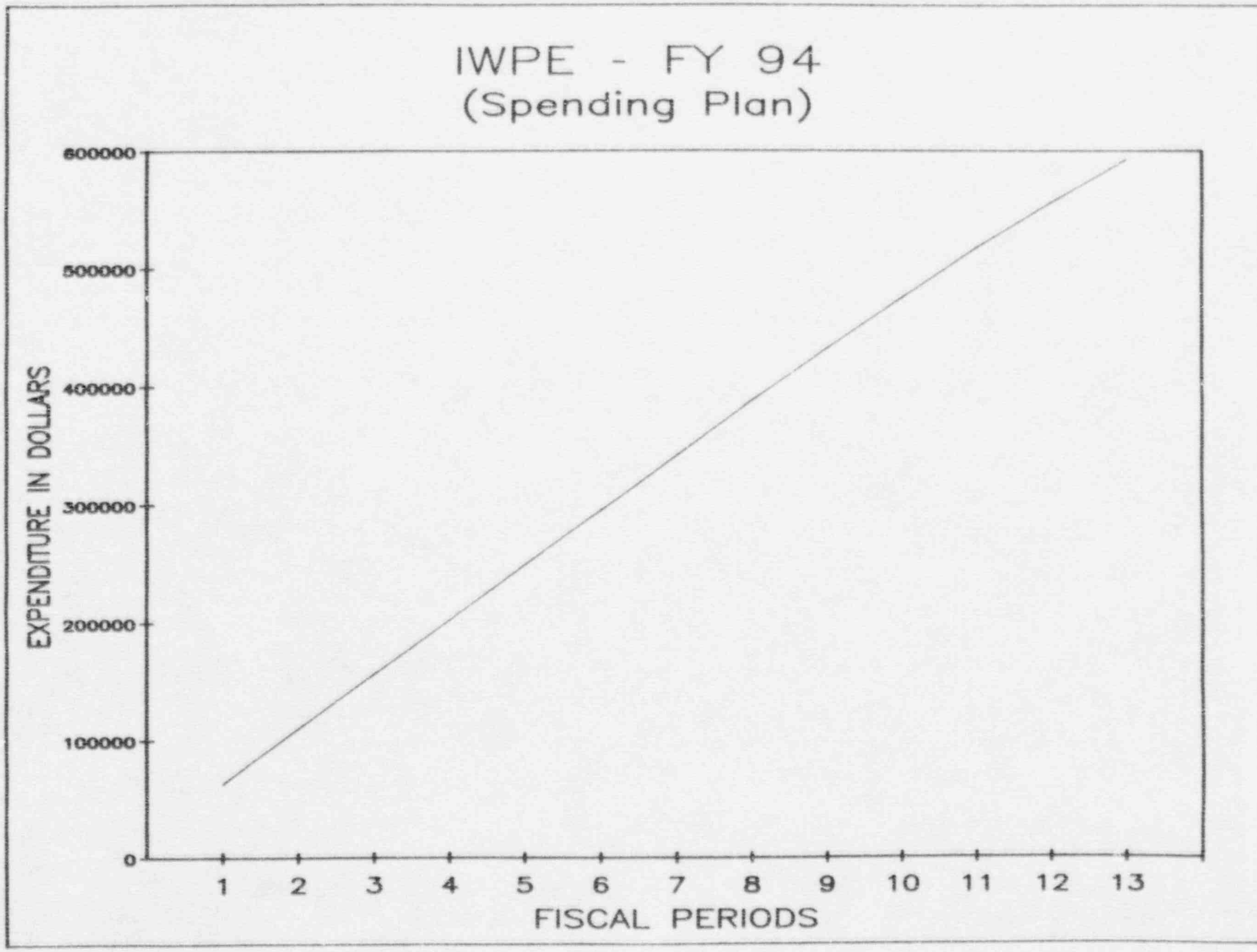

Figure 6.21 Composite Spending Plan, FY 94

Table 6.26 Manpower Plan, FY 94

Manpower Plan F/Y 94

17 Dec 90

3704-040 INTEGR. WASTE PACKAGE EXP.

Center Labor	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-4	4	4	4	4	4	5	4	4	4	5	4	1	0	47
Center Pl-3	188	126	122	123	122	122	122	124	119	116	117	104	101	1606
Center Pl-2	267	159	159	157	157	156	158	156	148	134	139	127	122	2039
Center Pl-1	136	167	168	167	169	165	168	167	158	150	149	150	147	2061
Center Clerical	103	125	125	125	126	125	126	129	126	127	126	100	90	1553
Total Center Labor	698	581	578	576	578	573	578	580	555	532	535	482	460	7306

Swri Labor	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Swri Pl-3	13	4	5	4	5	4	4	5	4	5	4	4	5	66
Swri Pl-2	18	1	0	0	0	0	0	0	0	0	0	0	0	19
Total Swri Labor	31	5	5	4	5	4	4	5	4	5	4	4	5	85

Table 6.27 Task 1 Spending Plan, FY 94

Spending Plan F/Y 94

17 Dec 90

3704-041 CORROSION

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	3567	939	809	767	850	767	809	809	767	850	809	767	744	13254
Center Pl-2	5789	1579	1381	1381	1381	1381	1381	1381	1381	1381	1381	1381	1250	22431
Center Pl-1	1023	1200	1220	1220	1220	1200	1220	1220	1220	1220	1200	1220	1161	15539
Center Clerical	344	458	458	458	458	447	458	458	458	458	458	458	458	5833
Center Labor	10723	4178	3868	3826	3910	3795	3868	3868	3826	3910	3848	3826	3612	57058
Center Burden	4557	1775	1644	1626	1662	1613	1644	1644	1626	1662	1636	1626	1535	24250
Center Overhead	12988	5058	4685	4635	4736	4597	4685	4685	4635	4736	4661	4635	4378	69111
Swri Pl-3	359	0	0	0	0	0	0	0	0	0	0	0	0	359
Swri Pl-2	547	30	0	0	0	0	0	0	0	0	0	0	0	577
SWRI Labor	906	30	0	0	0	0	0	0	0	0	0	0	0	936
SWRI Burden	385	13	0	0	0	0	0	0	0	0	0	0	0	398
SWRI Overhead	1549	52	0	0	0	0	0	0	0	0	0	0	0	1601
Material/Supply	548	547	548	547	548	547	547	548	547	548	547	548	465	7035
Travel	561	748	748	748	749	748	748	748	748	748	748	749	748	9539
Est excl. CFC,Fee	32216	12399	11493	11382	11604	11300	11492	11493	11382	11603	11440	11384	10736	169927
Center CFC	859	335	310	307	313	304	310	310	307	313	308	307	289	4571
SWRI CFC	197	7	0	0	0	0	0	0	0	0	0	0	0	204
Tot Estimate Cost	33272	12740	11803	11689	11917	11604	11802	11803	11689	11916	11749	11691	11026	174702
Fee	2577	992	919	911	928	904	919	919	911	928	915	911	859	13594
Tot Cost with Fee	35849	13732	12723	12600	12846	12508	12722	12723	12600	12845	12664	12602	11884	188296
% Completion	19.04%	7.29%	6.76%	6.69%	6.82%	6.64%	6.76%	6.76%	6.69%	6.82%	6.73%	6.69%	6.31%	100.00%
Cumulative Cost	35849	49582	62304	74904	87749	100258	112979	125702	138301	151146	163810	176412	188296	
Cumul Completion	19.04%	26.33%	33.09%	39.78%	46.60%	53.24%	60.00%	66.76%	73.45%	80.27%	87.00%	93.69%	100.00%	

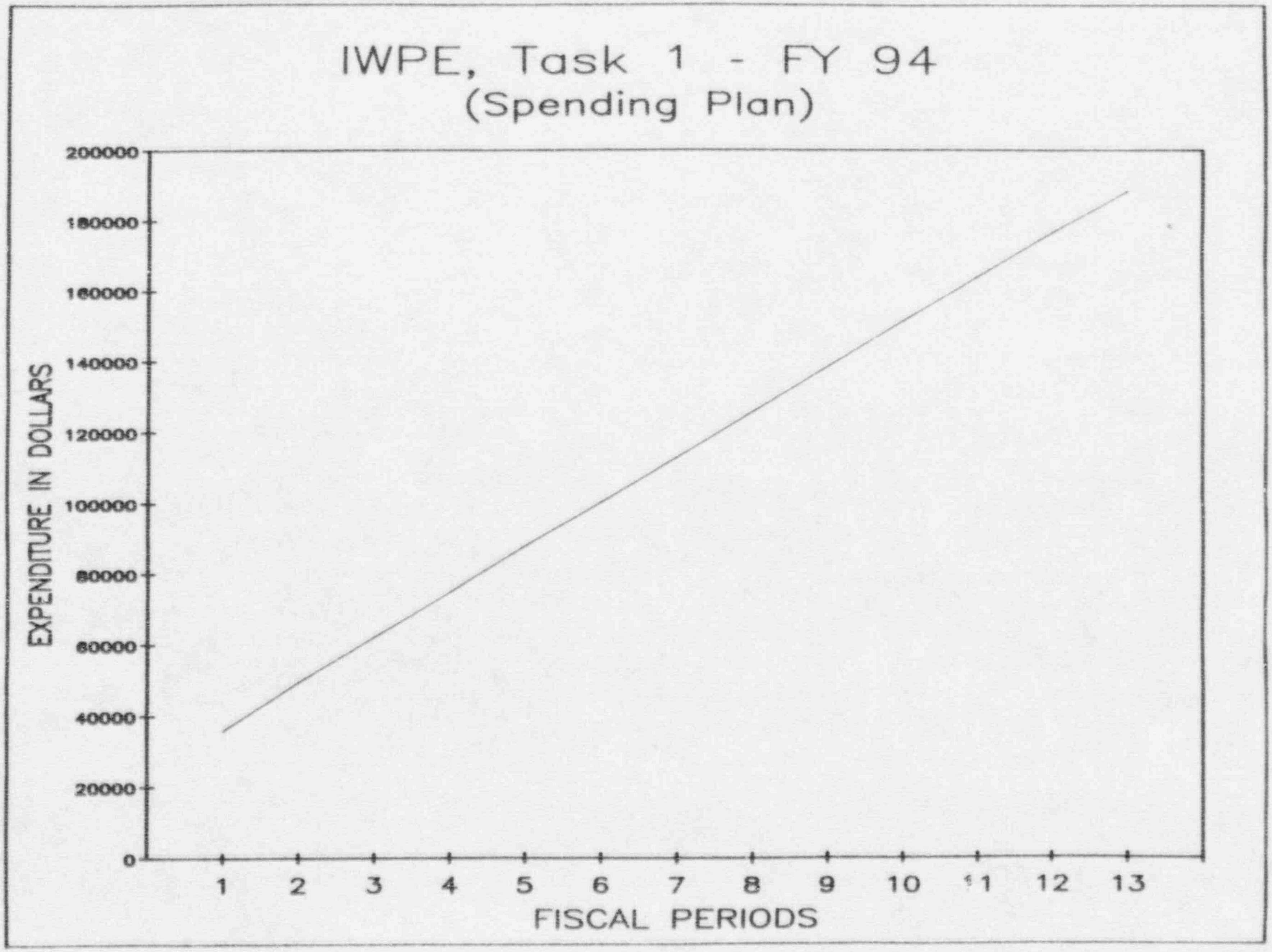

Figure 6.22 Task 1 Spending Plan, FY 94

Table 6.28 Task 2 Spending Plan, FY 94

Spending Plan F/Y 94

17 Dec 90

3704-042 STRESS CORROSION CRACKING

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	1525	2153	2176	2185	2153	2185	2111	2185	2185	2153	2144	2153	2185	27495
Center Pl-2	1151	1908	1973	1941	1941	1941	1941	1908	2006	1875	1973	1941	1941	24437
Center Pl-1	846	1279	1279	1279	1279	1279	1279	1259	1279	1279	1279	1279	1279	16189
Center Clerical	401	573	573	584	573	573	573	596	573	573	573	584	573	7323
Center Labor	3923	5912	6001	5989	5945	5977	5903	5948	6043	5879	5969	5956	5977	75424
Center Burden	1667	2513	2551	2545	2527	2540	2509	2528	2568	2499	2537	2531	2540	32055
Center Overhead	4752	7161	7269	7254	7201	7240	7150	7204	7320	7121	7230	7215	7240	91357
Swri Pl-3	160	160	200	160	200	160	160	200	160	200	160	160	200	2274
SWRI Labor	160	160	200	160	200	160	160	200	160	200	160	160	200	2274
SWRI Burden	68	68	85	68	85	68	68	85	68	85	68	68	85	967
SWRI Overhead	273	273	341	273	341	273	273	341	273	341	273	273	341	3889
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel	450	450	450	450	450	450	450	450	449	450	450	450	450	5849
Est excl. CFC,Fee	11293	16536	16896	16739	16748	16708	16513	16755	16881	16574	16685	16653	16834	211814
Center CFC	314	474	481	480	476	479	473	477	484	471	478	477	479	6042
SWRI CFC	35	35	43	35	43	35	35	43	35	43	35	35	43	495
Tot Estimate Cost	11642	17044	17420	17253	17267	17222	17020	17275	17400	17089	17198	17165	17356	218352
Fee	903	1323	1352	1339	1340	1337	1321	1340	1350	1326	1335	1332	1347	16945
Tot Cost with Fee	12545	18367	18772	18592	18607	18559	18341	18616	18750	18415	18533	18497	18702	235297
% Completion	5.33%	7.81%	7.98%	7.90%	7.91%	7.89%	7.80%	7.91%	7.97%	7.83%	7.88%	7.86%	7.95%	100.00%
Cumulative Cost	12545	30912	49684	68277	86884	105443	123784	142400	161150	179565	198098	216595	235297	
Cumul Completion	5.33%	13.14%	21.12%	29.02%	36.93%	44.81%	52.61%	60.52%	68.49%	76.31%	84.19%	92.05%	100.00%	

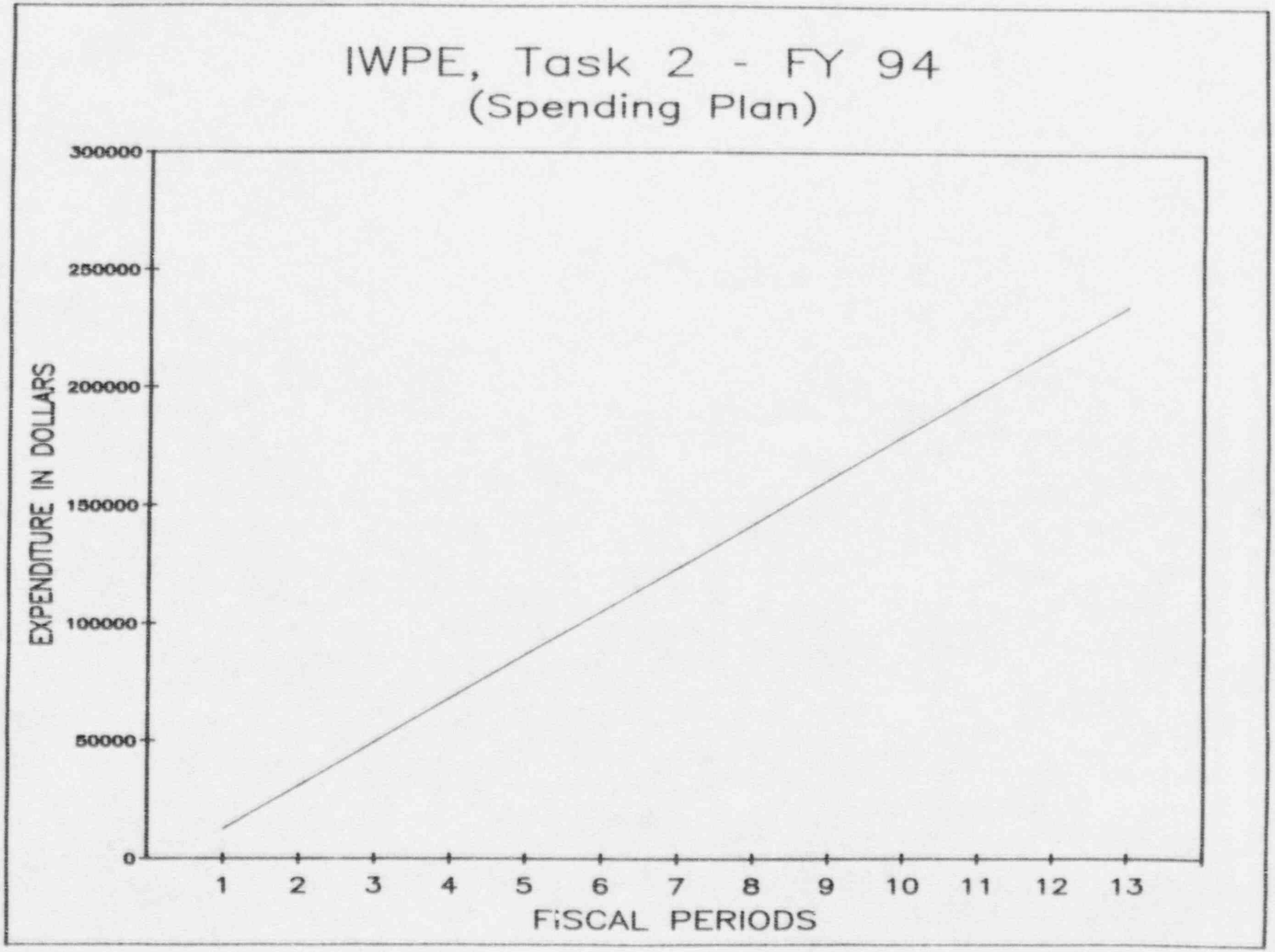

Figure 6.23 Task 2 Spending Plan, FY 94

Table 6.29 Task 3 Spending Plan, FY 94

Spending Plan F/Y 94

17 Dec 90

3704-043 MATERIALS STABILITY

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	228	228	228	293	228	228	260	260	130	65	98	65	65	2377
Center Pl-2	822	756	855	822	822	789	822	822	460	197	197	164	197	7729
Center Pl-1	669	649	669	649	669	629	649	669	452	315	295	315	295	6924
Center Labor	1719	1633	1752	1764	1719	1647	1732	1752	1043	577	590	544	558	17030
Center Burden	731	694	745	750	731	700	736	744	443	245	251	231	237	7238
Center Overhead	2082	1979	2122	2137	2082	1995	2098	2122	1263	699	715	659	675	20627
Swri Pl-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Labor	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Burden	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Overhead	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel	253	253	253	253	253	253	252	253	114	0	0	0	0	2137
Est excl. CFC,Fee	4785	4559	4871	4904	4785	4594	4818	4870	2864	1522	1556	1435	1470	47032
Center CFC	138	131	140	141	138	132	139	140	84	46	47	44	45	1364
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	4922	4690	5012	5046	4922	4726	4956	5011	2947	1568	1603	1478	1514	48396
Fee	383	365	390	392	383	368	385	390	229	122	124	115	118	3763
Tot Cost with Fee	5305	5055	5401	5438	5305	5094	5342	5400	3177	1690	1727	1593	1632	52159
% Completion	10.17%	9.69%	10.38%	10.43%	10.17%	9.77%	10.24%	10.35%	6.09%	3.24%	3.31%	3.05%	3.13%	100.00%
Cumulative Cost	5305	10360	15761	21199	26504	31598	36940	42340	45517	47206	48934	50527	52159	
Cumul Completion	10.17%	19.86%	30.22%	40.64%	50.81%	60.58%	70.82%	81.18%	87.27%	90.50%	93.82%	96.87%	100.00%	

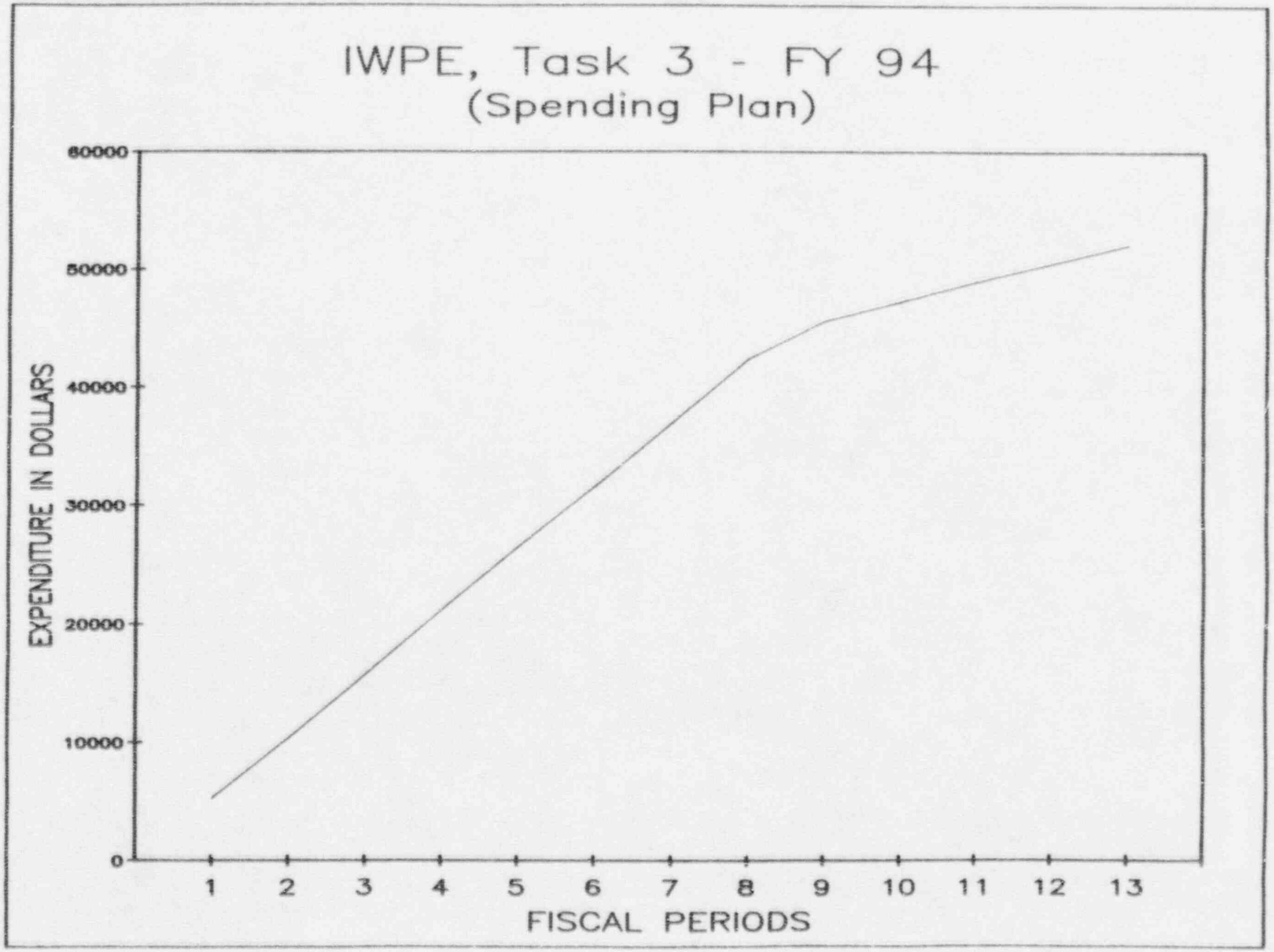

Figure 6.24 Task 3 Spending Plan, FY 94

Table 6.30 Task 4 Spending Plan, FY 94

Spending Plan F/Y 94

17 Dec 90

3704-044 MICROBIOLOGICALL INDUCED CORR.

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	358	358	358	358	326	358	358	358	358	358	358	358	358	4624
Center Pl-2	33	33	33	66	33	33	66	33	33	33	66	33	33	526
Center Pl-1	138	157	138	138	157	138	157	138	157	138	157	138	157	1908
Center Labor	529	548	529	562	516	529	581	529	548	529	581	529	548	7058
Center Burden	225	233	225	239	219	225	247	225	233	225	247	225	233	2999
Center Overhead	640	664	640	680	625	640	704	640	664	640	704	640	664	8549
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel	418	418	418	418	418	418	418	418	418	418	418	418	418	5434
Consultants	643	643	643	643	643	643	643	643	643	643	643	644	643	8[illegible]60
Est excl. CFC,Fee	2455	2507	2455	2542	2421	2455	2593	2455	2507	2455	2593	2456	2507	32400
Center CFC	42	44	42	45	41	42	47	42	44	42	47	42	44	565
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	2497	2551	2497	2587	2462	2497	2640	2497	2551	2497	2640	2498	2551	32965
Fee	196	201	196	203	194	196	207	196	201	196	207	196	201	2592
Tot Cost with Fee	2694	2751	2694	2790	2656	2694	2847	2694	2751	2694	2847	2695	2751	35557
% Completion	7.58%	7.74%	7.58%	7.85%	7.47%	7.58%	8.01%	7.58%	7.74%	7.58%	8.01%	7.58%	7.74%	100.00%
Cumulative Cost	2694	5445	8138	10928	13584	16278	19125	21819	24570	27264	30111	32806	35557	
Cumul Completion	7.58%	15.31%	22.89%	30.73%	38.20%	45.78%	53.79%	61.36%	69.10%	76.68%	84.[illegible]8%	92.26%	100.00%	

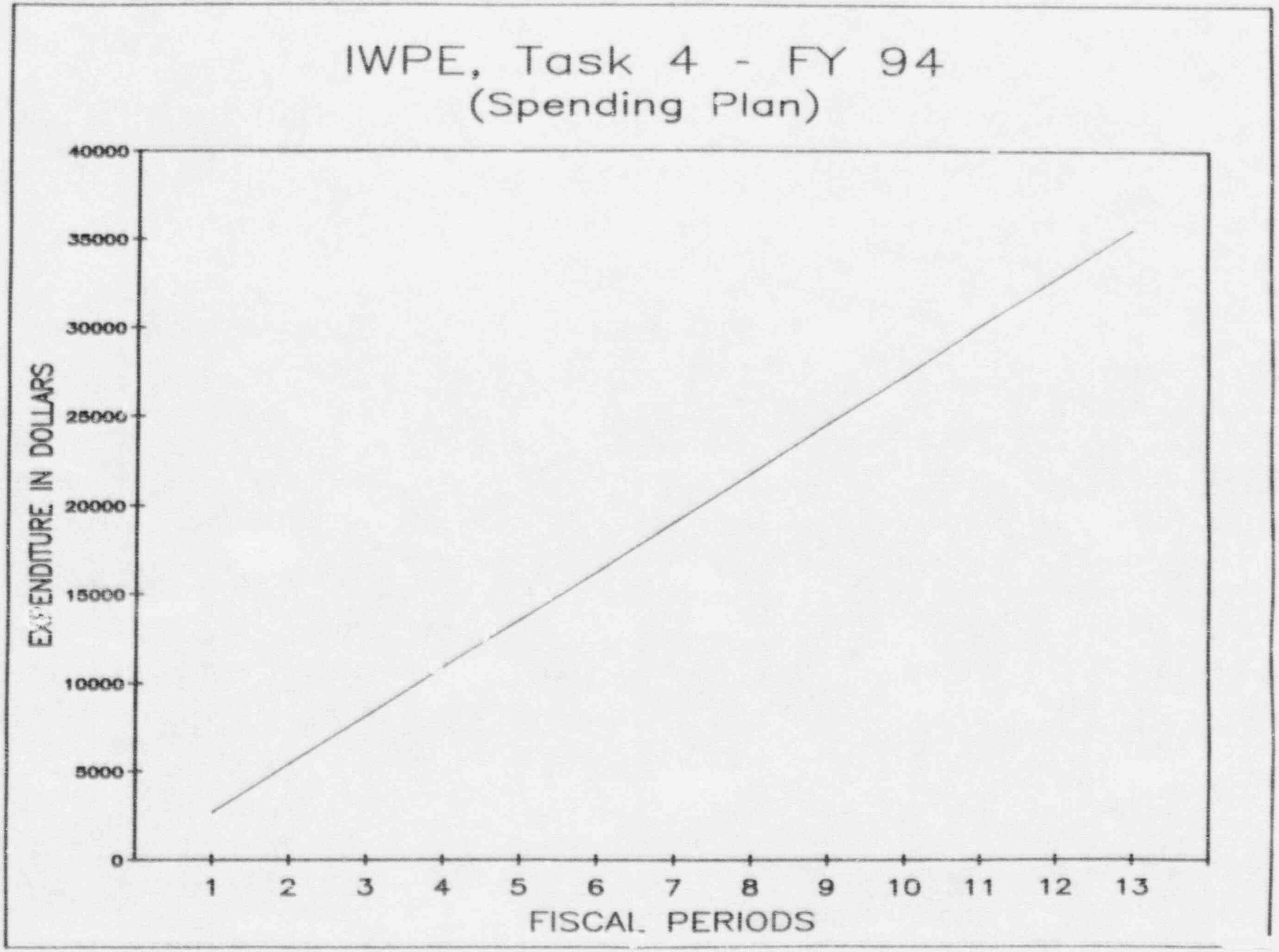

Figure 6.25 Task 4 Spending Plan, FY 94

Table 6.31 Task 5 Spending Plan, FY 94

Spending Plan F/Y 94

17 Dec 90

3704-045 OTHER DEGRADATION MODES

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-2	625	592	592	592	592	592	592	592	592	592	592	592	592	7729
Center Labor	625	592	592	592	592	592	592	592	592	592	592	592	592	7729
Center Burden	266	252	252	252	252	252	252	252	252	252	252	252	252	3285
Center Overhead	757	717	717	717	717	717	717	717	717	717	717	717	717	9362
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel	416	415	415	415	415	415	415	416	415	415	415	415	415	5397
Consultants	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subcontractors														
Ohio State	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Est excl. CFC,Fee	2063	1976	1976	1976	1976	1976	1976	1977	1976	1976	1976	1976	1976	25773
Center CFC	50	47	47	47	47	47	47	47	47	47	47	47	47	619
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	2113	2023	2023	2023	2023	2023	2023	2024	2023	2023	2023	2023	2023	26392
Fee	165	158	158	158	158	158	158	158	158	158	158	158	158	2062
Tot Cost with Fee	2279	2181	2181	2181	2181	2181	2181	2182	2181	2181	2181	2181	2181	28454
% Completion	8.01%	7.67%	7.67%	7.67%	7.67%	7.67%	7.67%	7.67%	7.67%	7.67%	7.67%	7.67%	7.67%	100.00%
Cumulative Cost	2279	4460	6641	8822	11003	13185	153[illegible]	17548	19729	21911	24092	26273	28454	
Cumul Completion	8.01%	15.67%	23.34%	31.00%	38.67%	46.34%	54.00%	61.67%	69.34%	77.00%	84.67%	92.33%	100.00%	

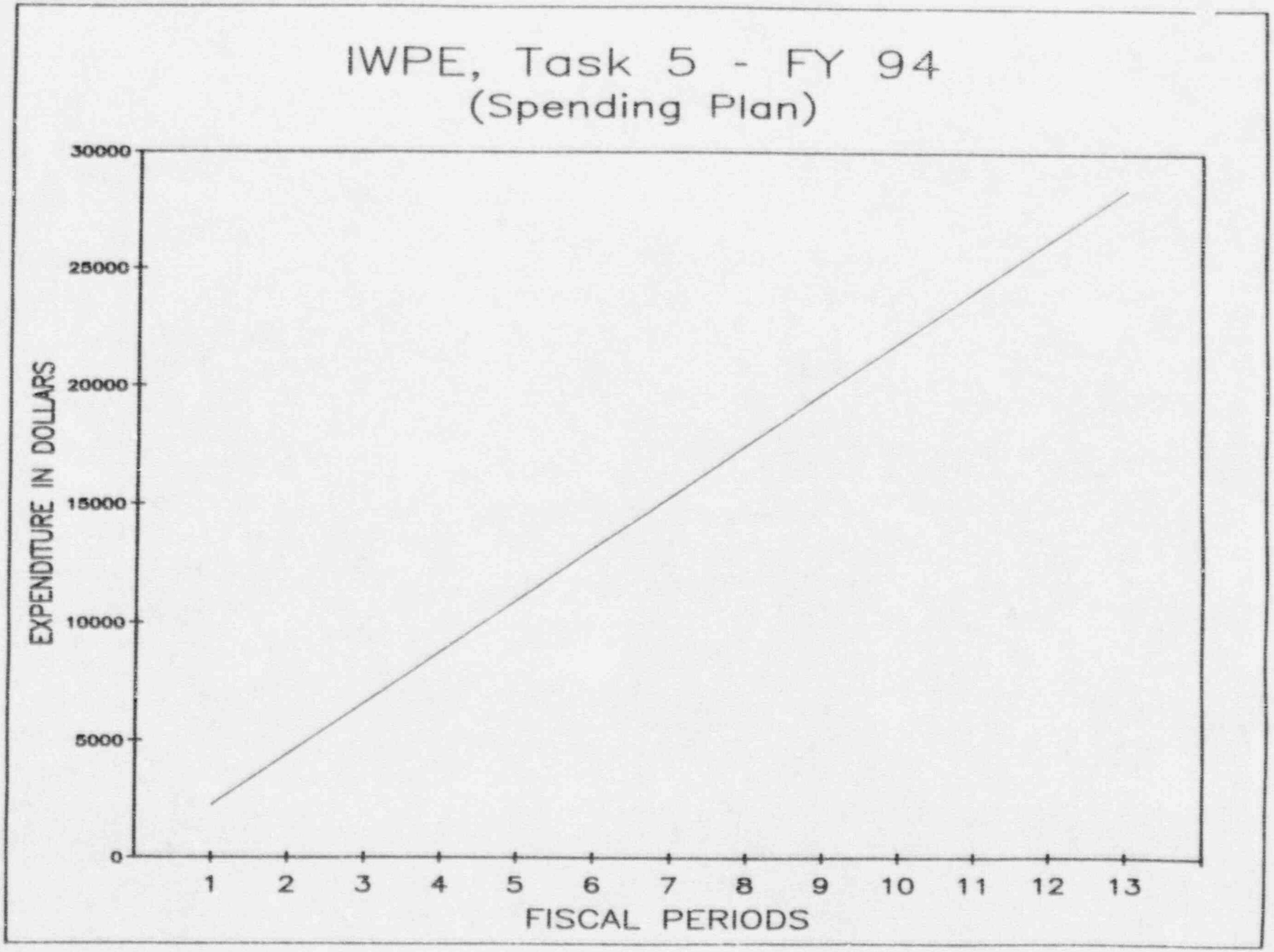

Figure 6.26 Task 5 Spending Plan, FY 94

Table 6.32 Task 6 Spending Plan, FY 94

Spending Plan F/Y 94

17 Dec 90

370< 046 PROGRESS REPORTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-4	213	213	213	213	213	267	213	213	213	267	213	53	0	2507
Center Pl-3	570	570	538	529	570	570	570	570	580	505	538	116	0	6227
Center Pl-2	362	362	395	362	395	395	395	395	395	329	362	66	0	4210
Center Clerical	435	401	401	390	413	413	413	424	413	424	413	103	0	4641
Center Labor	1581	1547	1547	1493	1591	1644	1591	1602	1600	1525	1525	338	0	17585
Center Burden	672	657	657	635	676	699	676	681	680	648	648	144	0	7474
Center Overhead	1915	1873	1874	1809	1927	1992	1927	1941	1938	1847	1848	410	0	21300
Report Services	93	89	87	86	89	91	91	91	90	91	91	23	0	1012
Est excl. CFC,Fee	4261	4166	4165	4023	4283	4426	4285	4315	4308	4111	4113	914	0	47371
Center CFC	127	124	124	120	127	132	127	128	128	122	122	27	0	1409
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	4388	4290	4289	4143	4411	4557	4413	4444	4436	4233	4235	942	0	48780
Fee	341	333	333	322	343	354	343	345	345	329	329	73	0	3790
Tot Cost with Fee	4728	4623	4622	4465	4753	4912	4755	4789	4781	4562	4564	1015	0	52569
% Completion	8.99%	8.79%	8.79%	8.49%	9.04%	9.34%	9.05%	9.11%	9.09%	8.68%	8.68%	1.93%	0.00%	100.00%
Cumulative Cost	4728	9352	13974	1843[illegible]	23192	28103	32859	37648	42429	46991	51555	52569	52569	
Cumul Completion	8.99%	17.79%	26.58%	35.08%	44.12%	53.46%	62.51%	71.62%	80.71%	89.39%	98.07%	100.00%	100.00%	

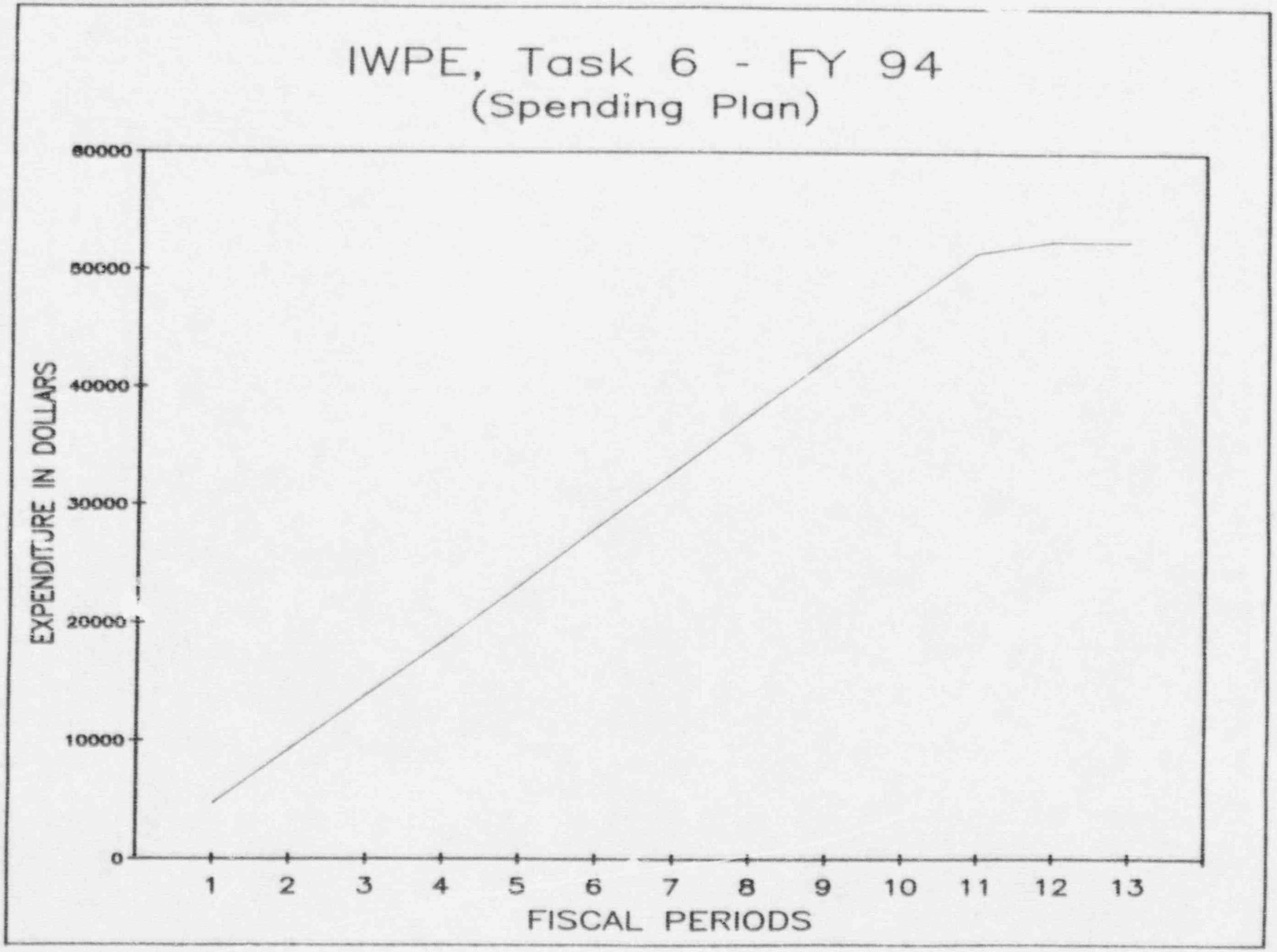

Figure 6.27 Task 6 Spending Plan, FY 94

Table 6.33 Composite Spending Plan, FY 95

Spending Plan F/Y 95

17 Dec 90

3704-040 INTEGR. WASTE PACKAGE EXP.

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Pl-3	2727	1651	1662	1739	1618	1662	1316	923	825	825	870	825	793	17439
Center Pl-2	3128	1703	1738	1773	1703	1147	973	487	348	348	348	382	313	14391
Center Pl-1	2453	1788	1705	1767	1767	1767	1455	707	457	437	457	457	437	15655
Center Clerical	1021	729	729	729	729	729	741	389	243	243	255	243	231	7011
Center Labor	9330	5871	5834	6008	5818	5306	4486	2505	1873	1853	1930	1908	1773	54495
Center Burden	3965	2495	2480	2553	2473	2255	1906	1065	796	787	820	811	754	23160
Center Overhead	11300	7111	7067	7277	7047	6427	5433	3035	2269	2244	2337	2311	2148	66007
Swri Pl-3	169	211	169	211	169	169	211	169	211	169	169	211	169	2404
Swri Pl-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Labor	169	211	169	211	169	169	211	169	211	169	169	211	169	2404
SWRI Burden	72	90	72	90	72	72	90	72	90	72	72	90	72	1022
SWRI Overhead	288	361	288	361	288	288	361	288	361	288	288	361	288	4110
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Report Services	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel	2031	2032	2031	2031	2031	1595	1193	674	450	450	450	450	427	15851
Consultants	643	643	643	643	643	611	0	0	0	0	0	0	0	3826
Subcontractors														
Ohio State	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Est excl. CFC,Fee	27798	18814	18583	19174	18540	16722	13685	7808	6050	5863	6066	6142	5630	170874
Center CFC	747	470	467	481	466	425	359	201	150	148	155	153	142	4366
SWRI CFC	37	46	37	46	37	37	46	37	46	37	37	46	37	523
Tot Estimate Cost	28582	19330	19087	19701	19043	17184	14090	8045	6246	6046	6257	6340	5809	175763
Fee	2224	1505	1487	1534	1483	1338	1095	625	484	469	485	491	450	13670
Tot Cost with Fee	30806	20835	20574	21235	20526	18521	15185	8670	6730	6517	6742	6832	6260	189433
% Completion	16.26%	11.00%	10.86%	11.21%	10.84%	9.78%	8.02%	4.58%	3.55%	3.44%	3.56%	3.61%	3.30%	100.00%
Cumulative Cost	30806	51641	72215	93450	113976	132497	147682	156352	163082	169599	176342	183174	189433	
Cumul Completion	16.26%	27.26%	38.12%	49.33%	60.17%	69.94%	77.96%	82.54%	86.09%	89.53%	93.09%	96.70%	100.00%	

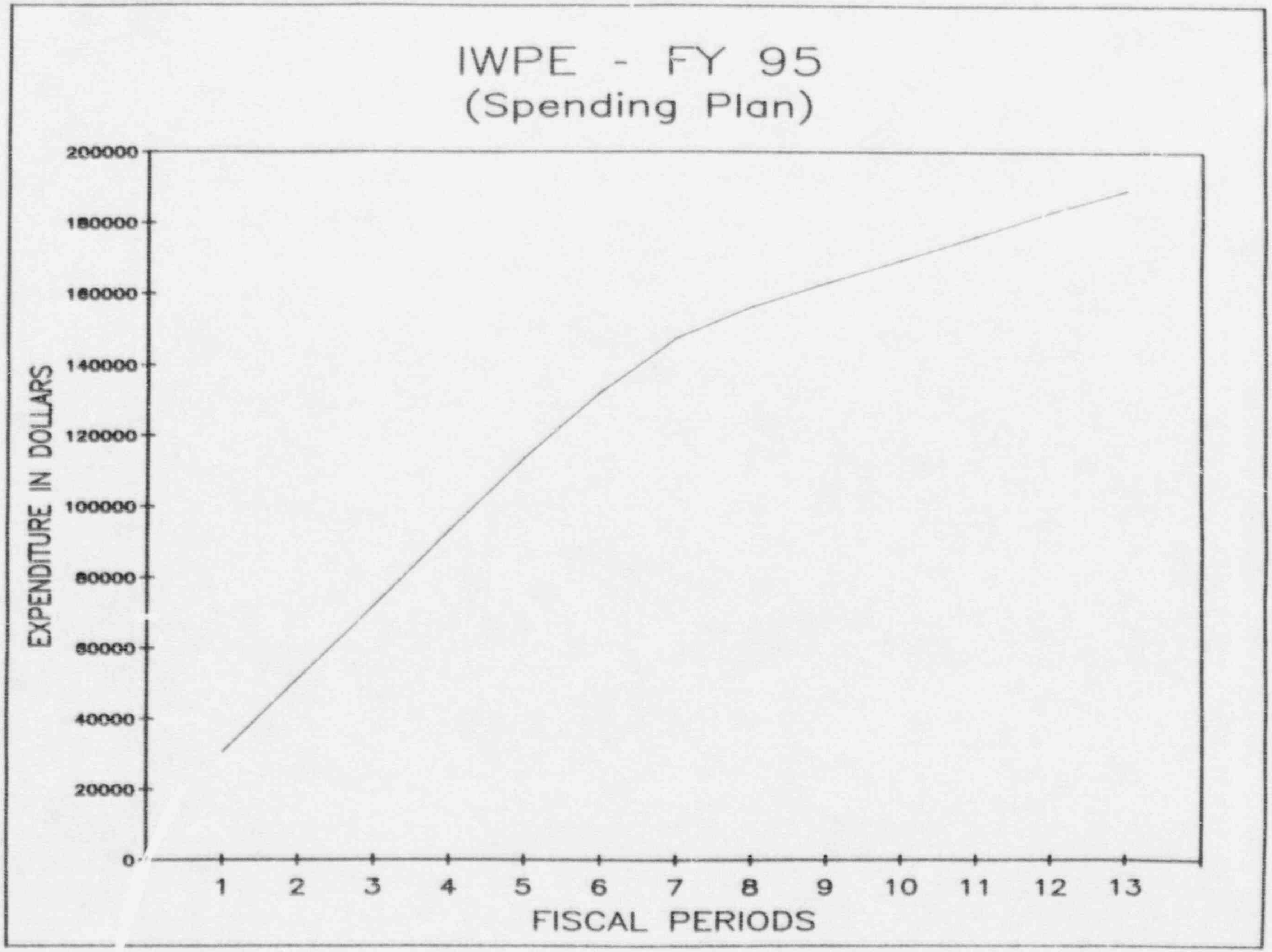

Figure 6.28 Composite Spending Plan, FY 95

Table 6.34 Manpower Plan, FY 95

Manpower Plan F/Y 95

17 Dec 90

3704-040 INTEGR. WASTE PACKAGE EXP.

Center Labor	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Pl-3	82	50	50	52	49	50	39	28	25	25	26	25	24	525
Center Pl-2	90	49	50	51	47	33	28	14	10	10	10	11	9	414
Center Pl-1	118	86	82	85	85	85	70	34	22	21	22	22	21	753
Center Clerical	84	60	60	60	60	60	61	32	20	20	21	20	19	577
Total Center Labor	374	245	242	248	243	228	198	108	77	76	79	78	73	2269

Swri Labor	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Swri Pl-3	4	5	4	5	4	4	5	4	5	4	4	5	4	57
Swri Pl-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Swri Labor	4	5	4	5	4	4	5	4	5	4	4	5	4	57

Table 6.35 Task 1 Spending Plan, FY 95

Spending Plan F/Y 95

17 Dec 90

3704-041 CORROSION

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	414	370	414	414	370	414	414	98	0	0	0	0	0	2905
Center Pl-2	521	521	521	521	521	521	521	139	0	0	0	0	0	3789
Center Pl-1	832	832	811	832	832	832	832	249	0	0	0	0	0	6050
Center Clerical	486	486	474	486	486	486	486	146	0	0	0	0	0	3536
Center Labor	2253	2209	2220	2253	2209	2253	2253	632	0	0	0	0	0	16280
Center Burden	957	939	943	957	939	957	957	269	0	0	0	0	0	6919
Center Overhead	2729	2675	2689	2729	2675	2729	2729	766	0	0	0	0	0	19719
Swri Pl-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Swri Pl-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Labor	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Burden	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Overhead	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel	748	748	748	748	748	748	749	224	0	0	0	0	0	5461
Est excl. CFC,Fee	6687	6571	6600	6687	6571	6687	6688	1890	0	0	0	0	0	48379
Center CFC	180	177	178	180	177	180	180	51	0	0	0	0	0	1304
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	6867	6747	6778	6867	6747	6867	6868	1941	0	0	0	0	0	49683
Fee	535	526	528	535	526	535	535	151	0	0	0	0	0	3870
Tot Cost with Fee	7402	7273	7306	7402	7273	7402	7403	2092	0	0	0	0	0	53553
% Completion	13.82%	13.58%	13.64%	13.82%	13.58%	13.82%	13.82%	3.91%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Cumulative Cost	7402	14675	21981	29383	33656	44058	51461	53553	53553	53553	53553	53553	53553	
Cumul Completion	13.82%	27.40%	41.04%	54.87%	68.45%	82.27%	96.09%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	

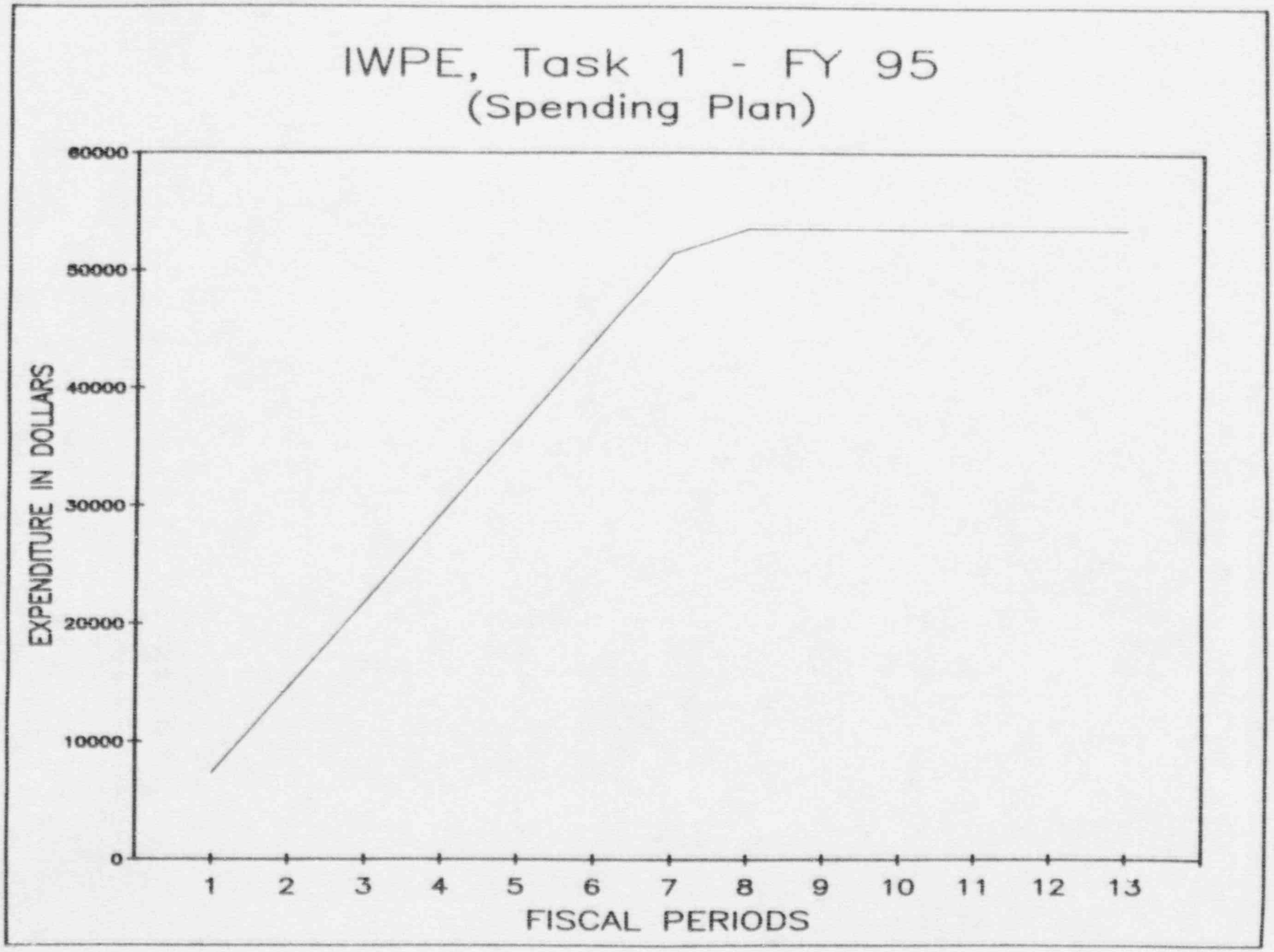

Figure 6.29 Task 1 Spending Plan, FY 95

Table 6.36 Task 2 Spending Plan, FY 95

Spending Plan F/Y 95 — 17 Dec 90

3704-042 STRESS CORROSION CRACKING

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	1890	825	825	902	825	825	870	825	825	825	870	825	793	11928
Center Pl-2	1703	348	348	382	313	382	348	348	348	348	348	382	313	5909
Center Pl-1	1164	457	437	457	457	457	457	457	457	437	457	457	437	6590
Center Clerical	535	243	255	243	243	243	255	243	243	243	255	243	231	3475
Center Labor	5292	1773	1865	1985	1839	1908	1930	1873	1873	1853	1930	1908	1773	27903
Center Burden	2249	796	793	844	781	811	820	796	796	787	820	811	754	11859
Center Overhead	6411	2269	2259	2404	2227	2311	2337	2263	2269	2244	2337	2311	2148	33797
Swri Pl-3	169	211	169	211	169	169	211	169	211	169	169	211	169	2404
SWRI Labor	169	211	169	211	169	169	211	169	211	169	169	211	169	2404
SWRI Burden	72	90	72	90	72	72	90	72	90	72	72	90	72	1022
SWRI Overhead	288	361	288	361	288	288	361	288	361	288	288	361	288	4110
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	[illegible]	0	0
Travel	450	450	450	450	450	450	450	450	450	450	450	45[illegible]	427	5827
Est excl. CFC,Fee	14931	6050	5895	6344	5826	6009	6198	5918	6050	5863	6066	6142	5630	86922
Center CFC	424	150	149	159	147	153	155	150	150	148	155	153	142	2235
SWRI CFC	37	46	37	46	37	37	46	37	46	37	37	46	37	523
Tot Estimate Cost	15392	6246	6081	6548	6010	6199	6399	6105	6246	6048	6257	6340	5809	89680
Fee	1194	484	472	507	466	481	496	473	484	469	485	491	450	6954
Tot Cost with Fee	16586	6730	6553	7056	6476	6680	6894	6578	6730	6517	6742	6832	6260	96634
% Completion	17.16%	6.96%	6.78%	7.30%	6.70%	6.91%	7.13%	6.81%	6.96%	6.74%	6.98%	7.07%	6.48%	100.00%
Cumulative Cost	16586	23316	29869	36925	43401	50081	56975	63553	70283	76800	83543	90374	96634	
Cumul Completion	17.16%	24.13%	30.91%	38.21%	44.91%	51.83%	58.96%	65.77%	72.73%	79.48%	86.45%	93.52%	100.00%	

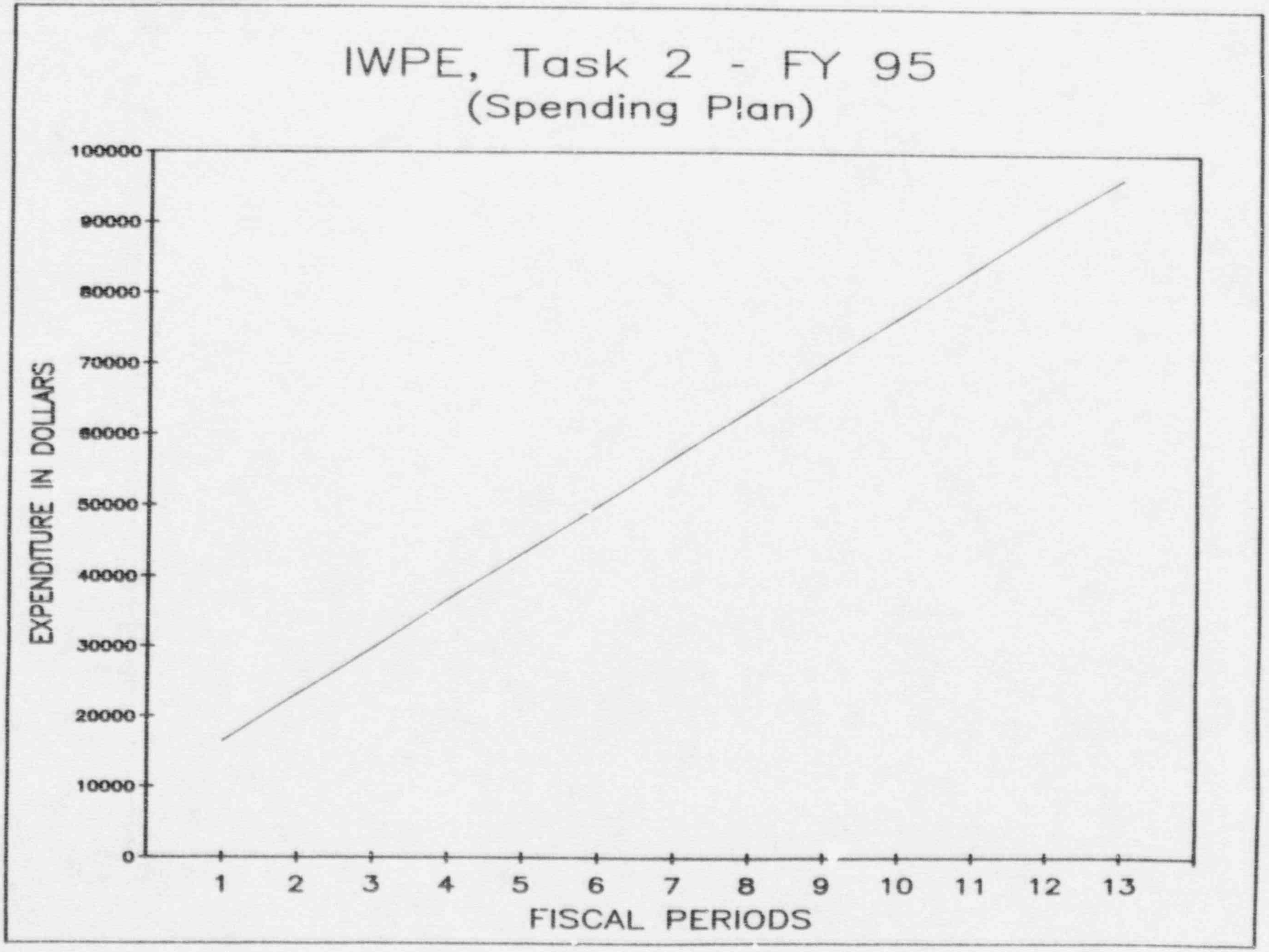

Figure 6.30 Task 2 Spending Plan, FY 95

Table 6.37 Task 3 Spending Plan, FY 95

Spending Plan F/Y 95

17 Dec 90

3704-043 MATERIALS STABILITY

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	65	98	65	65	65	98	33	0	0	0	0	0	0	488
Center Pl-2	209	174	209	209	174	209	104	0	0	0	0	0	0	1286
Center Pl-1	312	333	312	333	312	333	166	0	0	0	0	0	0	2100
Center Labor	586	604	586	606	551	639	303	0	0	0	0	0	0	3874
Center Burden	249	257	249	258	234	272	129	0	0	0	0	0	0	1647
Center Overhead	709	732	709	734	667	774	367	0	0	0	0	0	0	4693
Swri Pl-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Labor	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Burden	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI Overhead	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Est excl. CFC,Fee	1544	1593	1544	1598	1452	1684	799	0	0	0	0	0	0	10214
Center CFC	47	48	47	49	44	51	24	0	0	0	0	0	0	310
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	1591	1641	1591	1647	1496	1735	823	0	0	0	0	0	0	10524
Fee	123	127	123	128	116	135	64	0	0	0	0	0	0	817
Tot Cost with Fee	1714	1768	1714	1775	1612	1870	887	0	0	0	0	0	0	11341
% Completion	15.11%	15.59%	15.11%	15.65%	14.22%	16.49%	7.82%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Cumulative Cost	1714	3482	5196	6971	8584	10454	11341	11341	11341	11341	11341	11341	11341	
Cumul Completion	15.11%	30.71%	45.82%	61.47%	75.69%	92.18%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	

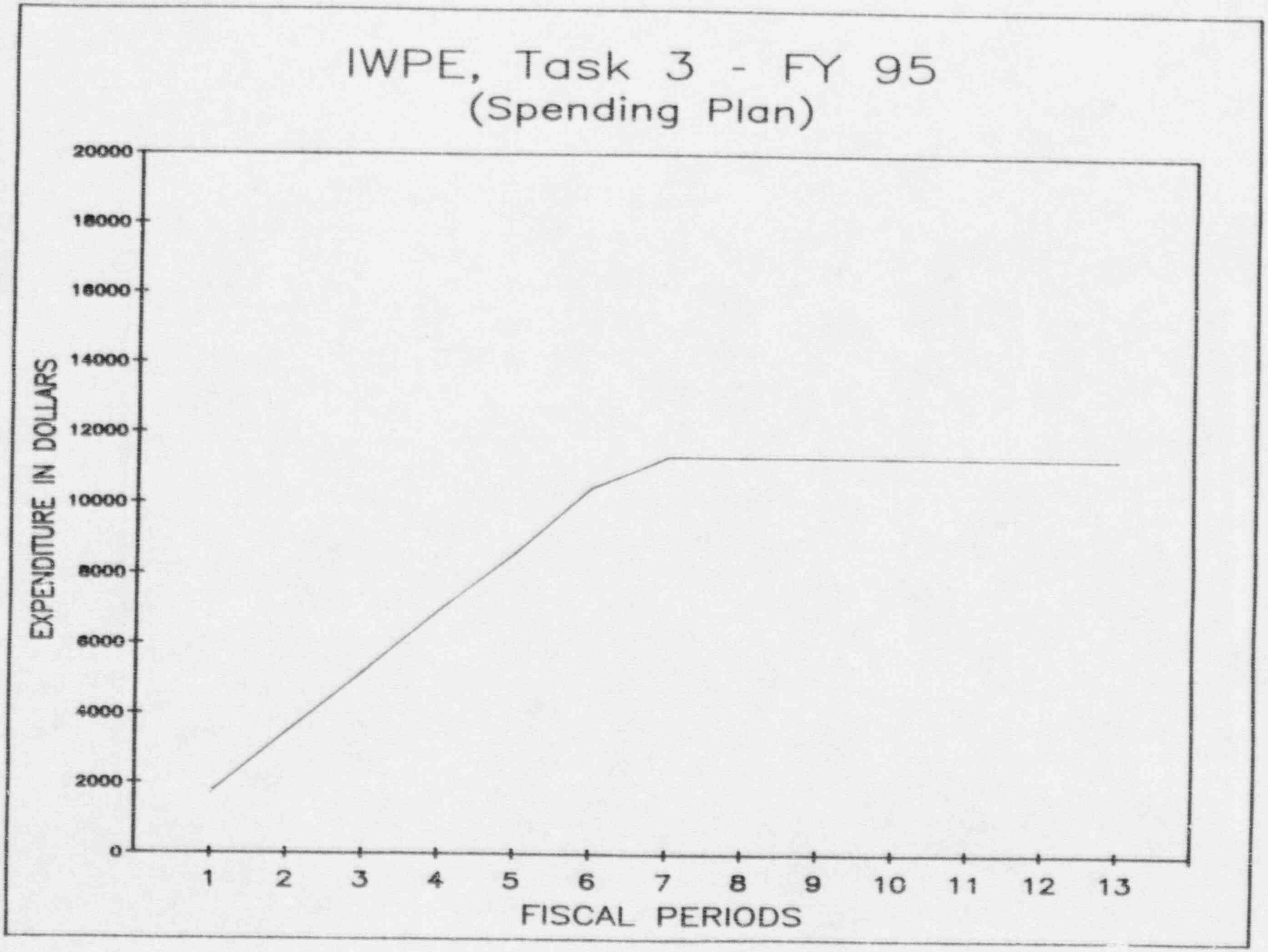

Figure 6.31 Task 3 Spending Plan, FY 95

Table 6.38 Task 4 Spending Plan, FY 95

Spending Plan F/Y 95

17 Dec 90

3704-044 MICROBIOLOGICALL INDUCED CORR.

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-3	358	358	358	358	358	326	0	0	0	0	0	0	0	2116
Center Pl-2	70	35	35	35	70	35	0	0	0	0	0	0	0	278
Center Pl-1	146	166	146	146	166	146	0	0	0	0	0	0	0	915
Center Labor	573	559	538	538	594	506	0	0	0	0	0	0	0	3309
Center Burden	244	238	229	229	252	215	0	0	0	0	0	0	0	1406
Center Overhead	694	677	652	652	719	613	0	0	0	0	0	0	0	4008
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel	418	418	418	418	418	397	0	0	0	0	0	0	0	2487
Consultants	643	643	643	643	643	611	0	0	0	0	0	0	0	3826
Est excl. CFC,Fee	2572	2535	2480	2480	2627	2342	0	0	0	0	0	0	0	15037
Center CFC	46	45	43	43	48	41	0	0	0	0	0	0	0	265
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	2618	2580	2524	2524	2675	2382	0	0	0	0	0	0	0	1530[illegible]
Fee	206	203	198	198	210	187	0	0	0	0	0	0	0	12[illegible]
Tot Cost with Fee	2824	2783	2722	2722	2885	2570	0	0	0	0	0	0	0	[illegible]05
% Completion	17.11%	16.86%	16.49%	16.49%	17.48%	15.57%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	1[illegible].00%
Cumulative Cost	2824	5607	8329	11051	13936	16505	16505	16505	16505	16505	16505	16505	16505	
Cumul Completion	17.11%	33.97%	50.46%	66.95%	84.43%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	

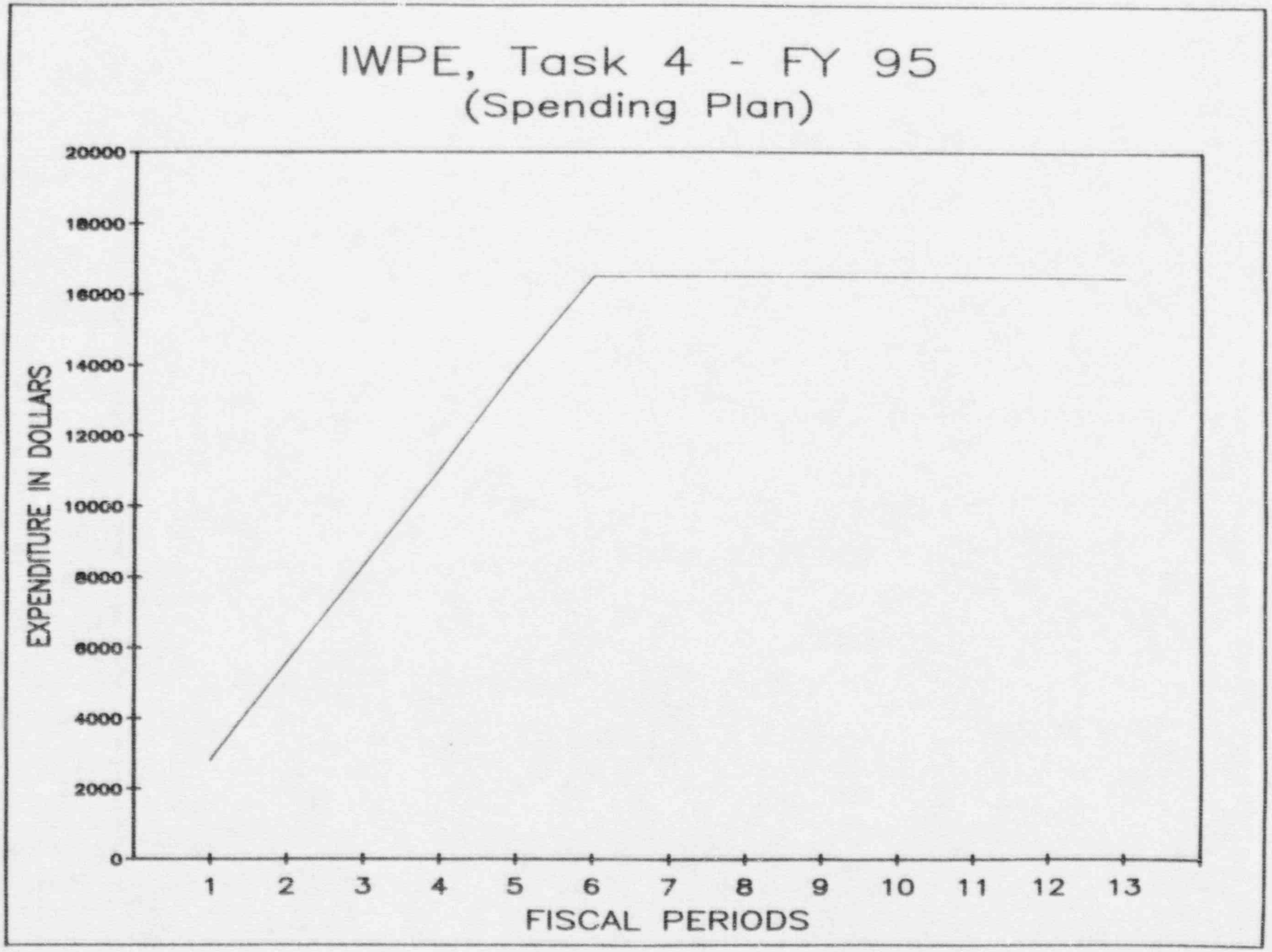

Figure 6.32 Task 4 Spending Plan, FY 95

Table 6.39 Task 5 Spending Plan, FY 95

Spending Plan F/Y 95

17 Dec 90

3704-045 OTHER DEGRADATION MODES

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-2	626	626	626	626	626	0	0	0	0	0	0	0	0	3128
Center Labor	626	626	626	626	626	0	0	0	0	0	0	0	0	3128
Center Burden	266	266	266	266	266	0	0	0	0	0	0	0	0	1330
Center Overhead	758	758	758	758	758	0	0	0	0	0	0	0	0	3789
Material/Supply	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Travel	415	416	415	415	415	0	0	0	0	0	0	0	0	2076
Consultants	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Subcontractors														
Ohio State	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Est excl. CFC,Fee	2064	2065	2064	2064	2064	0	0	0	0	0	0	0	0	10323
Center CFC	50	50	50	50	50	0	0	0	0	0	0	0	0	251
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	2115	2116	2115	2115	2115	0	0	0	0	0	0	0	0	10574
Fee	165	165	165	165	165	0	0	0	0	0	0	0	0	826
Tot Cost with Fee	2280	2281	2280	2280	2280	0	0	0	0	0	0	0	0	11400
% Completion	20.00%	20.01%	20.00%	20.00%	20.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Cumulative Cost	2280	4561	6840	9120	11400	11400	11400	11400	11400	11400	11400	11400	11400	
Cumul Completion	20.00%	40.01%	60.00%	80.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	100.00%	

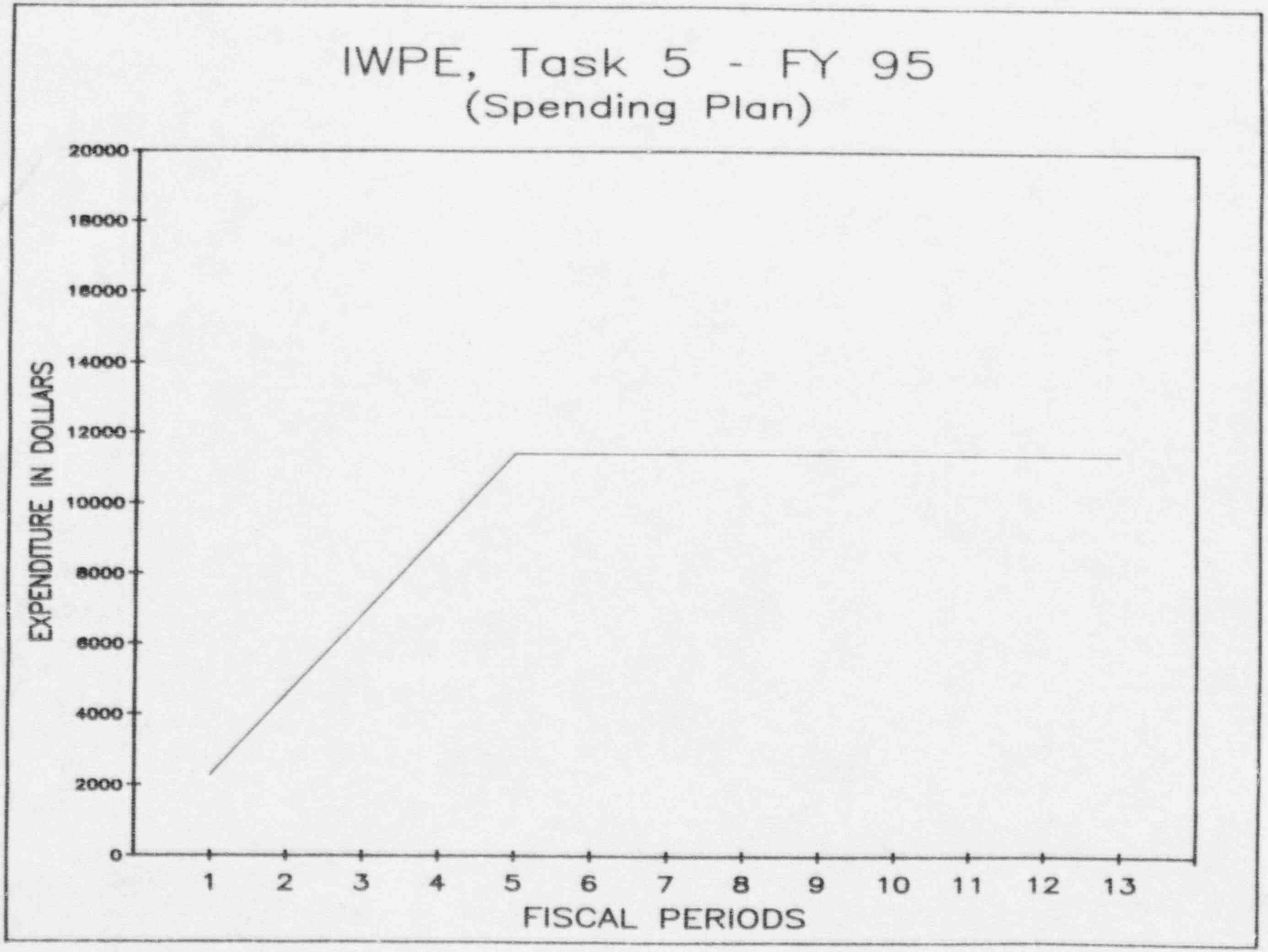

Figure 6.33 Task 5 Spending Plan, FY 95

Table 6.40 Task 6 Spending Plan, FY 95

Spending Plan F/Y 95

17 Dec 90

3704-046 PROGRESS REPORTS

	1	2	3	4	5	6	7	8	9	10	11	12	13	Total
Center Pl-4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Pl-3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Pl-2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Clerical	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Labor	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Burden	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center Overhead	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Report Services	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Est excl. CFC,Fee	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Center CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
SWRI CFC	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Estimate Cost	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fee	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tot Cost with Fee	0	0	0	0	0	0	0	0	0	0	0	0	0	0
% Completion	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	100.00%
Cumulative Cost	0	0	0	0	0	0	0	0	0	0	0	0	0	
Cumul Completion	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	