Independent Spent Fuel Storage Installations (ISFSI) Annual Report for FY 1978

G. E. Zima

March 1979

**Prepared for
the U.S. Nuclear Regulatory Commission**

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INSTALLATIONS (ISFSI)
ANNUAL REPORT FOR FY 1978

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ABSTRACT

The prime objective of the subject program is the identification of technical aspects of the design, operation and maintenance of independent spent fuel storage installations which could contribute to technical bases for Regulations and Regulatory Guides issued by NRC for these facilities. Activities on the various tasks of the program for the FY 1978 period are discussed in this report.

CONTENTS

ABSTRACT	ii
INTRODUCTION	1
TASK ACTIVITY	2
Task 1 - Identify Subjects for Survey and/or Study Related to ISFSI	2
Task 2 - Chemical/Mechanical Degradation Processes Affecting Fuel and Structural Materials of ISFSI	6
Task 3 - Fuel Crud Characterization with Reference to ISFSI Operations	7
Task 4 - ISFSI Design and Maintenance Review	8
Task 5 - Surveillance of Fuel and Primary ISFSI Structures	9
REFERENCES	12

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INTRODUCTION

The independent spent fuel storage installation (ISFSI) will be designed to provide a controlled water pool storage environment for spent nuclear fuel during some part of the time span between reactor pool residence of spent fuel and its reprocessing or ultimate disposal. It is expected that the ISFSI will be designed to accomodate fuel of ~1 yr age (post-reactor discharge time), or older.

The basic justification of the water pool interim storage concept is that the radioactivity contained in the spent fuel can be contained virtually indefinitely by the fuel cladding in a well managed pool environment. Furthermore, it is expected that the statistically small incidence of fuel cladding perforations developed prior to ISFSI receipt can be managed by well established pool water radiological monitoring and cleanup procedures and, if necessary, special handling of the affected fuel. To date, these ISFSI qualities appear to be generally confirmed by the experience with spent fuel storage here and abroad.

A prime objective of the subject program is the identification of technical aspects of the design, operation and maintenance of an ISFSI which could contribute to the technical bases for Regulations and Regulatory Guides issued by NRC for ISFSI. This objective necessarily entails a broad scope of technical interest. While several specific technical subjects were identified in the subject 189, generally this program is expected to remain responsive to current public interest in the ISFSI concept and to the general evolution in pool storage design/operation/maintenance practice. The latter program directives provide for considerable flexibility in the selection of review subjects and in the phasing of the respective activity.

TASK ACTIVITY

Paraphrases of the various tasks specified in the subject 189 (300A01131 Rev. 1) are given below, together with statements of progress on the respective tasks.

Task 1 - Identify Subjects for Survey and/or Study Related to ISFSI

The subject program was started after the summary report of the DOE sponsored survey on pool storage of spent fuel by A. B. Johnson, Jr.⁽¹⁾ Either through partial sponsorship by this program, or indirectly, this program has continued to benefit from Johnson's work pursuant to his involvement in spent fuel storage public hearings and his participation in technical interchange on spent fuel storage on a world-wide basis. The perspective on lay and professional opinions on various aspects of pool storage of spent fuel afforded by Johnson's work has been a valuable component of our sponsor liaison during the FY78 activities of this program. Formal and informal reports by Johnson on his activities pertinent to this program have been submitted to the sponsor in the course of the FY78 period and they will not be reviewed here.

As a result of our review of the current ISFSI technology, an informal report was submitted to the sponsor on proposed specialized study/review topics pertinent to pool storage of spent fuel to be considered for implementation in FY78 or FY79.⁽²⁾ This report was prepared in cooperation with a number of PNL departments and various General Electric personnel from the San Jose (CA) and the Morris (IL) locations. The topics presented in this report which are still of current interest are discussed briefly in the following.

Decay Thermal Power Study

It is believed that there is sufficient uncertainty in the ability to estimate the decay thermal power from spent fuel, as a function of in-reactor history and age (post-reactor discharge time) to warrant a program for measuring this characteristic of spent fuel. A correlative program would attempt to relate the radiation signature of a fuel assembly to its decay thermal power. While the decay power study might

eventually have some utility for benchmarking codes (e.g. ORIGEN) for calculating spent fuel characteristics, it was felt that a principal target of this work would be relation of utility-supplied fuel history data and the radiation signature to decay power. If a suitable correlation could be established between certain features of the fuel radiation and the gross decay power for a range of fuel ages and reactor exposure histories, then the decay power of an assembly could be characterized throughout its storage life by a relatively quick radiation scan at the time of ISFSI receipt of the fuel. In addition to gaining practical measures of the decay power and radiation impacts of specific fuel assemblies on a given storage facility, such information could be a powerful aid to fuel accountability at various stages in the spent fuel history. This program was proposed as a joint PNL/GE program using the Morris (IL) facility of the General Electric Company for experimental work involving spent fuel assemblies.

Gamma Flux Characterization for Individual Fuel Assemblies and Arrays

The objectives of this task are twofold: to characterize the gamma radiation from single fuel assemblies and arrays of assemblies under various conditions of water shielding to improve operational hazards assessments relating to end-of-spectrum loss of water scenarios for ISFSI; to benchmark code calculations of gamma radiation and/or to evolve alternative techniques for calculating the gamma flux characteristics of fuel arrays spanning a range of reactor histories and ages (post-reaction discharge time).

This was proposed as a joint PNL/GE study utilizing the Morris (IL) pool of the General Electric Company for experimental work.

Commentary on Various Aspects of ISFSI Design/Operation/Maintenance by Various Spent Fuel Managers

A commentary by General Electric Morris Operation (Morris, IL) was incorporated in the FY78 program under Task 4 of the subject 189. A tentative outline for this commentary is given under the Task 4 discussion.

Design Considerations for ISFSI Water Waste Treatment Systems

This task would make a general review of special requirements for ISFSI on the treatment of water contaminated by radionuclides with particular attention to the efficiency of cleanup and the minimizing of waste streams associated with water cleanup. This study would result in specific recommendations for ISFSI water waste treatment systems beneficial to design and the preparation of Guides and Standards.

Design Considerations for Radioactivity Monitoring of ISFSI

Radioactivity monitoring is a well established discipline in many respects. The mature ISFSI complex will, however, present various requirements with regard to scope and procedures for radioactivity monitoring, the centralization of monitoring information, and the coordination of this information with ISFSI operations and maintenance. To some extent, these requirements are expected to be unique to this facility considering the various sources and sinks for radioactivity, the potential magnitude of the radioactivity inventory and the need for long-term monitoring to detect significant changes in the containment of the stored fuel radioactivity. This task would address these various aspects, with the target being a 'manual of good practice on radiological monitoring at ISFSIs.'

Review of Surveillance Procedures for the Fuel and Primary Structures of the ISFSI

The purpose of this task is to identify practicable techniques for monitoring the structural integrity of fuel and primary structural materials of the ISFSI. Of the two structural categories, the state of the fuel cladding is of greatest interest and presents the most important challenge to current materials surveillance technology. The as-received state of the fuel is important to any assessment of long-term pool storage effects on the cladding. Under this task, the status of the knowledge of the fuel condition at time of reactor discharge would be reviewed, utilizing existing and supplemented data banks relating to those aspects of spent fuel characterization believed to be relevant to the pool storage technique. The feasibility of various degrees of computer assistance in the storage

and retrieval of this information would be studied. The various fuel inspection techniques now in use, or under development, for identifying actual or incipient clad penetrations would be evaluated for their possible use in an ISFSI surveillance system. The eventual target would be a system capable of comprehensive monitoring of fuel rod integrity over extended periods of storage.

Analysis of Release of Radioactive Species from Defective Fuel Under Pool Storage

The consequences of cladding perforation for fuel of various types over a range of reactor histories and ages, i.e., the amount and kind of radionuclides which could be released to the pool water under various degrees of cladding loss, is a subject of interest. Based on pool storage experience to date, the incidence of incipient defects brought to full cladding penetration by the pool environment and the aggravation of prior (reactor-induced) clad perforations by the pool storage is expected to be insignificant. These findings notwithstanding, it is an important duty of the fuel storage technologists to maximize their understanding of the radiological consequences of clad penetrations for the different kinds of stored fuel. This is, in our opinion, a prime requirement in developing general public acceptance of the various interim fuel storage strategies. This task was proposed to capitalize on current PNL work on the powerplant effects of clad penetrations, with the expectation that radionuclide release models developed for the in-reactor environment might be applicable as a base from which to consider the conceivable influences of the pool storage environment on radionuclide release to the ISFSI water system.

Some of the above specialized studies were considered to be outside the authority of the subject program. At this juncture, we regard the fuel surveillance and fission product release work to be of importance to public acceptance of the interim fuel storage concepts. The current general interest in minimizing the low level waste streams from fuel storage facilities brings the proposal on water waste treatment study into prominence. While the decay

heat and gamma characterization studies are primarily related to ISFSI design and operational considerations, the fuel accountability implications of these studies are also of some general interest.

Task 2 - Chemical/Mechanical Degradation Processes Affecting Fuel and Structural Materials of ISFSI

A review of the various information sources pertaining to the subject of this task, including the general technical literature, the minutes of international meetings and public hearings on spent fuel storage, has continued throughout the FY78 period. Several comprehensive reviews directly and indirectly related to various aspects of the ability of the pool environment to degrade materials have been published in this country and abroad.^(1,3,4,5) A. B. Johnson, Jr.'s paper in June 1978⁽⁶⁾ reviewed the impact of reactor-induced fuel defects on pool storage.

There are two essential questions of public interest which should be addressed to the spent fuel storage technologists. First, how long can fuel be stored under expected storage conditions before there is exposure of the fuel pellets to the water? Second, what are the public safety implications of such exposure as a function of the number of pellets so exposed and the service history and age (post-reactor discharge time) of the pellets?

At present, the first question can be answered as follows. World-wide experience with pool storage of spent fuel from light water reactors indicates an indefinite storage life for fuel with no prior (pre-ISFSI) clad penetrations. Furthermore, even fuel with prior penetrations has not exhibited a progressive deterioration under pool storage which would preclude an indefinite storage life. On the basis of current understanding of conceivable fuel and cladding degradation processes, there is no expectation of a time-delayed process whereby previously passive cladding exhibits a sudden deterioration in containment ability for radionuclides. Should such a process be possible, it might be expected to bear some sensitivity to the service history and age of the fuel. At any given time, the fuel inventory of an ISFSI will represent a spectrum of such fuel factors. As a result, such a process would affect only a fraction of the inventory. Furthermore, it is inconceivable that such a process could evade prior recognition by the fuel surveillance strategies for ISFSIs, which, while centered on monitoring the pool water radioactivity, will also include

destructive and non-destructive examination of selected spent fuel specimens representing various pre-ISFSI histories and pool storage experience.

The second question, the consequences of exposure of fuel to pool water, has been addressed by considerable laboratory study of radionuclide leaching under pool conditions.^(7,8) The results of water leaching studies to date demonstrate that the spent UO_2 matrix is remarkably stable to water within the temperature range of ISFSI pools. Furthermore, experience has shown that a well designed system for removal of soluble and particulate radionuclides from pool water would be capable of coping with the expected small release of radionuclides resulting from direct fuel-water contact. Tests with fuel representing extremes of reactor service (high burnup and large power rating) have been encouraging. There is at present no experimental evidence or theoretical support for a sudden deterioration of the nuclide retention qualities of the oxide fuel under water exposure which could result in a sudden release of radionuclides after years of passive behavior.

In summary, present experimental and theoretical knowledge support an indefinite pool storage life for good quality fuel. Pool storage experience with clad penetrated fuel has shown no evidence of a progressive worsening of such defects (with UO_2 fuel) under pool storage. Full, or partial, blocking of the penetration by various corrosion products, thereby reducing the rate of radionuclide leaching appears to be a likely action.

A brief topical report summarizing the comments under this task of the FY78 program is in preparation.

Task 3 - Fuel Crud Characterization with Reference to ISFSI Operations

A report was prepared under this task⁽⁹⁾ reviewing various aspects of the fuel deposited crud and the possible impact of fuel crud on ISFSI safety and operations. Following a review of observations of fuel crud amount, distribution, structure, elemental and chemical compound composition, there is a discussion of various factors affecting the importance of fuel crud to ISFSI operations. In the appendices of this report: a brief review is given of the factors affecting crud formation, deposition and removal; some of the

reported radioactivity characteristics of fuel crud are summarized and several simple indices are utilized to identify potentially significant parent elements and nuclides which could be involved in fuel crud; a comparison is made between the radioactivity inventories assignable to the fuel crud and to that contained in the fuel proper, with an indication of the importance of fuel age (post-reactor discharge time) to the significance of various nuclides which could be contained in fuel crud.

On the basis of the conceivable ISFSI radioactivity inventory assignable to fuel crud, and the ability to manage fuel crud received by the ISFSI, the public safety implications of fuel crud in the ISFSI environment are regarded as minimal. Some additional information which would be helpful in a further assessment of the importance of fuel crud to ISFSI operations and occupational safety is discussed in this report.⁽⁹⁾

Task 4 - ISFSI Design and Maintenance Review

The major contribution under this task for FY78 and FY79 funding will be a commentary prepared by the General Electric Morris Operation (Morris, IL) on various aspects of their experience with the Morris (IL) ISFSI facility to be submitted during the FY79 period. A tentative outline for this report is given below.

I. INTRODUCTION

II. THE MORRIS OPERATION SPENT FUEL STORAGE FACILITY

- Chapter 1 - The Fuel Storage System
- Chapter 2 - The Basin
- Chapter 3 - The Basin Filter
- Chapter 4 - The Basin Coolers
- Chapter 5 - Cask Handling Equipment
- Chapter 6 - Fuel Handling Equipment
- Chapter 7 - Support Equipment

III. RECEIVING AND STORAGE OF SPENT IRRADIATED FUEL

- Chapter 8 - Cask Turnaround Overview
- Chapter 9 - Receiving (End of Transportation Step)
- Chapter 10 - Preparation for Unloading
- Chapter 11 - Unloading
- Chapter 12 - Preparation for Shipping

There are plans to include a commentary on various aspects of the transportation of spent fuel to the Morris facility in this report. This latter work

would be included in the FY79 activities of the present program. A tentative outline of information to be supplied with this transportation addendum is given below.

For each shipment:

- Facility and location from which shipped
- Shipping distance and time
- Time in storage during transit
- Contamination level of coolant on receipt
- External radiation levels on receipt
 - on surface of cask
 - at one meter from cask
 - at two meters from vehicle
 - in cab of vehicle
- Any significant defects on receipt
 - in the cask
 - in the cask contents
- Characteristics of contained irradiated fuel
 - metric tons of fuel elements
 - core thermal power level (megawatts)
 - level of irradiation (megawatts days per metric ton) for each element
 - cooling time for each element
- Gross weight of cask
- Mode of transport
- Temperature on cask surface

The report incorporating this commentary will be prepared jointly by General Electric and Battelle, PNL.

Task 5 - Surveillance of Fuel and Primary ISFSI Structures

It is the purpose of this task to evaluate current operational and developmental surveillance techniques for their potential utility to ISFSI fuel and structures surveillance. The major part of this effort was deferred until FY79.

The central focus of non-fuel structure surveillance is on the major pools for fuel handling and storage, the water cooling and purification systems, and the equipment servicing the pool complex (fuel and cask handling equipment, etc.). In general, non-fuel structure surveillance has extensive industrial precedence which affords sufficient guide-lines for this work.

At present, among the considerations affecting the detailed planning of fuel surveillance for ISFSI are the following.

- On the basis of spent fuel storage experience to date, nominal LWR fuel (fuel which satisfies all current inspection criteria for non-leakers) will present no significant long-term pool storage problems. Specifically, apart from minor sources external to the cladding (e.g. fuel crud), such fuel should release no radionuclides to the pool system for an indefinite storage period.
- Actual fuel storage experience and fuel leaching studies indicate that fuel with perforated cladding (fuel identified as a leaker at some stage in its history) does not present a radionuclide release potential beyond the capacity of nominal pool water cleanup systems.

The principal techniques for fuel surveillance are expected to be comprehensive monitoring of the radioactivity of the general pool water and the various visual inspection techniques permitted by the clarity of the pool water. The extreme sensitivity of pool radioactivity monitoring to fission product leakage is indicated by the following exercise.

Assume: a net water volume of $1 \times 10^3 \text{ m}^3$ for a fully loaded 500 MTU pool storage module;⁽¹⁰⁾
 fuel age ranges between 1 and 10 years;
 fuel nuclide composition is estimated using the Diablo Canyon fuel model for LWR UO_2 fuel (33 GWD/MTU, 30 MW/MTU, 3.3% enriched);⁽¹¹⁾
 a nominal pool specific radioactivity of $4 \times 10^{-4} \text{ } \mu\text{Ci/ml}$.⁽¹²⁾

Further, assume that a quantity of ^{137}Cs is released to the pool (and uniformly mixed without dilution) sufficient to increase the pool specific radioactivity by a readily detectable factor of 10 (to $4 \times 10^{-3} \text{ } \mu\text{Ci/ml}$). Under the above assumptions, this perturbation to the specific radioactivity could be caused by about 0.05 gm of ^{137}Cs . This amount of ^{137}Cs represents only about $1 \times 10^{-5}\%$ of the fuel inventory of this radionuclide, or roughly the ^{137}Cs content of about 5 fuel pellets out of a total of 50×10^6 pellets in the inventory (assuming a pellet U loading of $\sim 1 \times 10^{-5} \text{ MTU}$).

As a concession to unexpected degradation in the ability of nominal and defective fuel to contain fuel radionuclides, somewhat more detailed surveillance of selected fuel assemblies may be undertaken. Such surveillance

could include: local pool water monitoring via use of canisters for separate assemblies or some degree of water partitioning for small arrays of assemblies; in-situ non-destructive inspection of assemblies. The survey of surveillance equipment and techniques under this task is intended to assist in planning the various fuel surveillance strategies appropriate to ISFSI. A spent fuel and fuel pool equipment integrity study, under DOE sponsorship (Savannah River Project Office), includes several tasks relevant to ISFSI surveillance, namely: monitoring of foreign spent fuel information; examination of spent fuel and pool equipment; assessment of degradation mechanisms under the pool environment.

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