NRC REPORT TO CONGRESS ON THE STATUS OF DOMESTIC AND INTERNATIONAL EVALUATIONS OF NUCLEAR REACTOR AND FUEL CYCLE SYSTEMS

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November 1979

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Executive Summary

The U.S. Nuclear Regulatory Commission was directed by Congress, in the 1979 authorization legislation (P.L. 601), to submit periodic reports on NRC's assessment of the status of domestic and international evaluations of nuclear fuel cycle systems and a summary of all research activities relating to such matters. This is the first semi-annual report which covers NRC activities in alternative reactor and fuel cycle evaluations prior to June 30, 1979. Events occurring after this date will be covered in subsequent reports to Congress in this series.

Because of the strain on available agency resources due to the Three Mile Island accident, NRC is able to provide only a limited analysis of the status of alternative reactor and fuel cycle systems evaluations. Nonproliferation Alternative Systems Assessment Program (NASAP) and International Nuclear Fuel Cycle Evaluation (INFCE) final reports will not be available until late this year or early next year, and as of mid-1979 NRC had made only preliminary reviews of certain NASAP and INFCE documents. NRC will provide additional comments on alternative reactor and fuel cycle systems in its subsequent reports to Congress.

In its analysis and review, NRC has examined information emanating primarily from four sources: (1) DOE NASAP documentation, (2) INFCE Working Paper documentation, (3) the GAO, and (4) the Congressional Research Service (CRS). NASAP was organized by DOE and is the technical program which provides U.S. alternative systems concepts input to INFCE. NRC staff members are independently reviewing DOE work related to the NASAP effort.

The majority of the NASAP material reviewed by the staff is contained in DOE's Preliminary Safety and Environmental Information Documents (PSEIDs). These PSEIDs exist in seven volumes. Six describe the mainline reactor types under consideration by DOE. The seventh describes the associated fuel cycle facilities. The six reactor types discussed are: Light Water Reactor (LWR), Heavy Water Reactor (HWR), Light Water Breeder Reactor (LWBR), High Temperature Gas-Cooled Reactor (HTGR), Gas-Cooled Fast Breeder Reactor (GCFR), and Liquid Metal Fast Breeder Reactor (LMFBR). The seventh PSEID provides information on candidate fuel cycle concepts for the reactor types. Three fuel cycles are discussed: Once Through Uranium Fuel Cycle, Uranium Fuel Cycle with Uranium and Plutonium Recycle, and Thorium Fuel Cycle with Thorium and Uranium-233 Recycle.

DOE has also provided several supporting NASAP documents discussing Nuclear Energy Characterization Data, Safeguards Considerations for the NASAP Alternative Fuel Cycles, and the Denatured U-233 Fuel Cycle. NRC has provided review comments on these documents as well.

INFCE began in October 1977. It now has 53 participating countries and is organized around eight working groups. The United States has offered about 50 papers to the working groups and has reviewed and commented on more than 200 papers contributed by other countries and organizations. NRC participation has been in the U.S. organizational support structure for INFCE. INFCE documents will not be released until the final reports are published and therefore NRC is limited in its discussion of them in this report.

NRC also has examined pertinent reports prepared by GAO and CRS. A brief discussion of these reports is also included in this report.

During FY 1979 Congress approved an $800,000 carry-over of FY 1978 funds for alternative reactor and fuel cycle research at NRC. However, with Congressional approval NRC delayed all but $125,000 of this research effort in order to meet resource needs precipitated by the Three Mile Island accident.

NRC has implemented a modest technical assistance program directed to a better understanding of some of the licensing issues unique to the NASAP reactor conceptual designs. NRC also has contracted with Brookhaven National Laboratory to provide background technical information for NRC's use in establishing future programs and policies relevant to the safeguarding of fuel cycles developed by the commercial nuclear industry.

During FY 1979, NRC will have devoted about four person years of staff time and expended about half a million dollars on technical assistance in support of the alternative reactor and fuel cycle effort. NRC also maintains a significant research program in fast breeder reactors and a limited program in advanced converter reactors, funded at $14 million and $3.2 million respectively in FY 1979 and supported by about 14 person years of NRC staff effort.

This report provides limited preliminary comments related to the six reactor concepts proposed by DOE under NASAP. In order to perform a systematic evaluation of the safety and licensing issues for the six reactor concepts, additional information and analysis in four general areas is needed: (1) facility system descriptions, (2) safety approach, (3) accident analysis, and (4) research and development program plan. For only the LWR do we have sufficient information in the four general areas. However, each of the six concepts, given appropriate engineered safety features, could be potentially licensable. The extended-life LWR may be the most readily licensable concept; also the U.S. has already had versions of the HTGR and LMFBR operating in this country.

The main proliferation concerns center on the back end of the fuel cycle, i.e., those operations associated with reprocessing and fabrication of recycle fuel, and waste management. All of the fuel cycles considered, with the exception of the once-through fuel cycles, require reprocessing and recycling of fissile materials. More information about the institutional and technological fixes that would be applied to these fuel cycles is needed in order for NRC to attempt an evaluation of the relative proliferation risks.

Presently, the NRC does not possess enough information to draw final conclusions regarding the relative safety, safeguardability, environmental impact, and licensability of the alternative reactor and fuel cycle concepts that have been reviewed. However, it is doubtful that NRC would draw final conclusions on such matters until an actual application is received, so as to not prejudice the outcome of the licensing review process.

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NRC REPORT TO CONGRESS ON THE STATUS OF DOMESTIC AND INTERNATIONAL EVALUATIONS OF NUCLEAR REACTOR AND FUEL CYCLE SYSTEMS

I. INTRODUCTION

The U. S. Nuclear Regulatory Commission was directed by Congress, in Section 9 of the 1979 NRC authorization legislation (PL-601), to submit a semi-annual report on NRC's assessment of the status of domestic and international evaluations of nuclear fuel cycle systems. The law directs the Commission to:

> "...report to the Congress semiannually through calendar year 1980 and annually through calendar year 1982 on the status of domestic and international evaluations of nuclear fuel cycle systems. This report shall include, but not be limited to, a summary of the information developed by and available to the Commission on the health, safety and safeguards implications of the leading fuel cycle technologies."

Section 9 of the Joint Explanatory Statement of PL-601 further states that, as part of the report to Congress, NRC shall provide:

> "...a summary of all research activities relating to such matters, identification of areas of deficiency in such existing information and ongoing efforts, and recommendations regarding matters which should be undertaken to minimize any potential adverse impact on matters within the Commission's jurisdiction;"

This is the first semi-annual report and covers NRC activities in alternative reactor and fuel cycle evaluations prior to June 30, 1979. Events occurring after this date will be covered in subsequent reports to Congress in this series.

Section II of this report references pertinent documentation. Section III provides a summary of NRC comments on alternative reactor and fuel cycle systems described in reports that were reviewed. Section IV summarizes applicable NRC research and technical assistance on alternative reactor and fuel cycle concepts. Section V provides additional comments.

Identification and description of alternative reactors and fuel cycles by DOE are still being developed and the leading technologies are yet to be delineated. Nonproliferation Alternative Systems Assessment Program (NASAP) and International Nuclear Fuel Cycle Evaluation (INFCE) final reports will not be available until late this year or early next year. To this date NRC has made only preliminary reviews of draft NASAP and INFCE documents.

The Three Mile Island accident has placed a severe strain on available agency resources; thus, at this time the staff is able to provide only limited analysis of the status of alternative reactor and fuel cycle systems evaluations. High priority demands on NRC resources will continue in FY 1980. Nevertheless, after completion of the NASAP and INFCE reports, the staff will consider means to apply sufficient resources to the review and assessment of these documents so that in subsequent reports to Congress the relative merits of alternative reactor and fuel cycle systems may be further analyzed.*

NASAP was organized by DOE and is the technical program which would provide U.S. alternative systems input to INFCE.** NRC staff members are independently reviewing DOE work related to the NASAP effort. The NASAP documents are comprised of the Preliminary Safety and Environmental Information Documents (PSEIDs), which provide information for each reactor and fuel cycle type, and several supporting documents. NRC staff has commented on these documents and the comments will be considered by DOE in the development of the NASAP final report. Meetings were held with DOE contractors to discuss the reactor and fuel designs for several reactor types.

Our participation in INFCE originated as a result of informal contacts between NRC and the Department of State in September and October of 1977. INFCE now has participation from 53 countries and is organized around eight working groups. Our staff members served as NRC contacts on the U.S. support groups for those INFCE working group areas in which NRC has significant interests and expertise and have coordinated informal staff reviews of U.S. and foreign country analyses and studies.

NASAP assessments and conclusions are to be completed this year and will be presented by DOE in a report to Congress and the President by December 1979. INFCE Working Group Reports are now being finalized. The INFCE final report is scheduled to be presented to the Final Plenary Conference in February 1980.

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* NRC has also agreed, in response to a GAO recommendation, to provide a staff report to the President and Congress on our preliminary findings of known or suspected licensing issues and problems associated with alternative technologies under serious consideration by DOE. This report could include a comparative evaluation of the alternative technologies studied from the safety, safeguards, environmental and licensing points of view. NRC would publish this report subsequent to the com pletion of the NASAP program and the INFCE studies.

**According to DOE, NASAP has the following objectives:

a. Assess the safety, environmental and safeguards issues that might impact development and licensing of the principal alternative technologies;
b. Obtain inputs for estimating R&D costs and times to accomplish, and
c. Compare alternative technologies for nonproliferation benefits and costs.

II. SUMMARY OF PERTINENT REFERENCES

In the analysis and review of alternative reactor and nuclear fuel cycle system concepts, NRC has examined documents emanating from four primary sources:

- DOE NASAP documentation,
- INFCE Working Paper documentation,
- GAO reports, and
- Congressional Research Service (CRS) Report.

NASAP Reports

The primary NASAP documentation is the Preliminary Safety and Environmental Information Documents (PSEIDs). The PSEIDs are composed of seven volumes. The first six volumes address six classes of alternative reactor and fuel cycle system concepts; these are Light-Water Reactors (LWRs), Heavy-Water Reactors (HWRs), Light-Water Breeder Reactors (LWBRs), High-Temperature Gas-Cooled Reactors (HTGRs), Gas-Cooled Fast Reactors (GCFRs), and Liquid-Metal Fast Breeder Reactors (LMFBRs). The seventh volume addresses Fuel Cycle Facilities for all the reactor concepts discussed. In addition, DOE provided supporting documents discussing Nuclear Energy System Characterization Data, Safeguards Considerations for the NASAP Alternative Fuel Cycles, and the Denatured U-233 Fuel Cycle. NRC has provided review comments to DOE on all these documents. A summary of NRC comments on these documents is provided in Section III.A of this report.

INFCE Reports

INFCE reports are papers contributed by the U.S. and other foreign organizations. With participation from 53 countries, INFCE is organized around eight working groups covering the topics of fuel and heavy water availability; enrichment availability; supply assurances; reprocessing, plutonium handling, and recycle; fast breeders; spent fuel management; waste management and disposal; and alternative fuel cycle and reactor concepts. The United States has offered about 50 papers to the INFCE working groups and has reviewed and commented on more than 200 papers contributed by other countries and organizations. The NRC has participated in the review of many of these papers. Since all reports prepared for INFCE are "Official -- For INFCE Use Only" and no INFCE documents are to be released until the final reports are published, NRC's discussion of them in this report is limited. A summary of NRC's participation in INFCE is provided in Section III.B of this report.

GAO Reports

The GAO report of primary concern is the March 7, 1978 GAO Final Letter Report regarding NRC's role in selecting fission technologies which was prepared for the Joint Economic Committee of Congress. A brief discussion of this report is provided in Section III.C of this report.

GAO has also prepared other reports on topics related to Nonproliferation and Alternative Fuel Cycles. NRC reviewed a draft version of such a report late in 1978. A final version of this report was received by NRC too late for coverage in the discussions of this report.

CRS Report

The Congressional Research Service (CRS) prepared a report entitled, "Alternative Breeder Cycles for Nuclear Power: An Analysis," October 1978, for the Subcommittee on Fossil and Nuclear Energy Research, Development and Demonstration of the Committee on Science and Technology, U.S. House of Representatives. A brief summary of NRC comments on this report is provided in Section III.D of this report.

III. SUMMARY OF NRC COMMENTS ON ALTERNATIVE REACTORS AND FUEL CYCLES

A. Summary of NRC Comments to DOE on NASAP

1. Preliminary Safety and Environmental Information Documents

This portion of the report summarizes our review and assessment* of the Preliminary Safety and Environmental Information Documents (PSEIDs) provided to us by DOE. These PSEIDs are in seven volumes, with six describing the six mainline reactor types under serious consideration by DOE and one describing the associated fuel cycle facilities. This review and assessment is a first step in the direction of providing a comparative evaluation of the alternative fuel cycle and reactor types from the safety, safeguards, environmental and licensing points of view. At this stage, it appears that each of the concepts is potentially licensable, given adequate engineered safety features would be provided.

Under an agreement with DOE, NRC provided to DOE on June 13, 1979 a set of comments and questions on the PSEIDs. The comments are summarized on the following pages.

In order to place this preliminary NRC review and assessment into perspective, it is important to understand what NRC would need in order to perform a systematic comparative evaluation of the safety, safeguards, environmental and licensing issues, and to compare these needs with what DOE has provided and what is generally known about these alternative reactors and fuel cycles. Ideally, NRC would like to have consistent and well defined (relative to the preliminary nature of a conceptual study) information in four general areas. The NRC comments on the six PSEID documents on reactor types are grouped in these four area, namely:

1) Facility System Descriptions - For reactors: a description of the mechanical, nuclear and thermal hydraulics aspects of the reactor core region; the heat transport system, including the decay heat removal system; the facility engineered safety features; instrumentation and control; containment; and the balance of plant. For fuel cycle facilities: a description of process, chemical, mechanical, criticality, ventilation, scrap and waste handling systems; confinement and radiation control systems; effluent treatment and handling systems; engineered safety systems; safeguard and physical protection systems; and proliferation resistance features;

2) Safety Approach, including a description of areas of conformance or departure from NRC's Code of Federal Regulations, the General Design Criteria, standards and regulatory guidelines;

*At this stage NRC's preliminary "review and assessment" comprises: an updating of our present licensing position regarding these reactors and fuel cycles; comments on safety aspects; and questions directed to DOE that will aid NRC in its continuing review process.

3) Accident Analysis, including the low probability, potentially high consequence accident assessment; and

4) Research and Development (R&D) Program Plan, in particular identifying the key safety areas with estimates of time and cost.

It is understandable that DOE could not provide all this information within their budget and schedule constraints, in particular for some of the less-developed reactor and fuel cycle concepts. As NASAP evolves, NRC, both by independent investigation that makes use of past experience with similar reactor and fuel cycle concepts, and through evaluation of further analysis and assessment provided by DOE, will continue to review and assess the mainline reactor and fuel cycle types in these four information categories.

The six reactor types and associated fuel cycle variations are:

a. (PSEID Vol.I) Light Water Reactor (LWR) with (a) extended burnup; (b) denatured (U-233/U-238) fuel; (c) spiked plutonium recycle; and (d) a plutonium/thorium cycle;

b. (PSEID Vol. II) Heavy Water Reactor (HWR) of the Canadian Deuterium Uranium (CANDU) type;

c. (PSEID Vol. III) Light Water Breeder Reactor (LWBR) with four Prebreeder/Breeder Pair Variations;

d. (PSEID Vol. IV) High Temperature Gas-Cooled Reactor (HTGR) with 2 fuel cycle variations;

e. (PSEID Vol. V) Gas-Cooled Fast Breeder Reactor (GCFR) with 2 fuel cycle variations;

f. (PSEID Vol. VI) Liquid Metal Fast Breeder Reactor (LMFBR) with 15 core type, fuel form, and fuel cycle variations; and

g. (PSEID Vol. VII) Fuel Cycle Facilities; for numerous variations of both uranium and thorium cycles.

The discussions of individual concepts that follow are intended to portray the present state of the dialogue between NRC and DOE relative to safety, safeguardability, and licensing issues. These issues have been communicated to DOE in the staff letter of June 13, 1979. For the most part, environmental issues (and the related issues of economics and fuel utilization) have not been addressed at this time.

a. The Light Water Reactor (LWR) - Variants (PSEID Volume I)

Four variations on a standard LWR-design are being considered as part of this NASAP study. These are: extended burnup, from 30,000 Megawatt Days/Metric Ton (MWD/MT) to 50,000 MWD/MT; a denatured fuel (U-233 or U-235 mixed with U-238) cycle; a plutonium/thorium cycle; and spiked plutonium recycle. For all four variations the deviation from a standard LWR design, in this case the Combustion Engineering System-80 PWR design, is slight and therefore the facility system description, safety approach, and accident analysis are all quite similar to the CE-System 80. In fact, other than the fuel-rod design itself, the reactors are virtually identical. From the view of reactor safety, these LWR variants have limited and well-defined problems. (Before NRC can make a similar statement on environmental impact, more information must be supplied.) Differences arise in fuel storage requirements and in fuel handling due to higher enrichments and higher radiation levels, in particular from the fresh spiked and fresh denatured fuels. Innovations in the areas of fuel fabrication and fuel reprocessing for the spiked and denatured fuel cycles are considered in section III.A.1.g, "Fuel Cycle Facilities."

1) Facility System Descriptions - Since they deviate only slightly from standard LWR designs, the descriptions are relatively complete. Only specific fuel rod design information, and fuel storage and handling strategies, need further amplification. For example it is not clear just how added fission gas inventory in the extended burnup pins will be accommodated.

2) Safety Approach - Since these variants differ only slightly from licensed LWRs, this item is clearly defined. An example of a potential change in regulatory requirements is in 10 CFR 51 (Licensing and Regulatory Policy and Procedures for Environmental Protection) where the applicability of Tables S-3 and S-4 is limited to 4 percent enrichment and 33,000 MWD/MT.

3) Accident Analysis - This assessment depends considerably on the steady-state and transient behavior of fuel rods. Comments have been made to DOE regarding the need for transient testing of extended burnup fuel pins and for a more comprehensive picture of fuel behavior in general for the denatured fuel cycle option.

4) R&D Program Plan - NRC requested information on DOE's R&D plans in the safety area for all the LWR variants but in particular regarding fuels for extended burnup and the denatured fuel cycle.

b. The Heavy Water Reactor (HWR) (PSEID Volume II)

The conceptual design for the HWR as submitted by DOE is a combination of an upgraded CANDU* core and reactor coolant system (RCS) coupled with a CE-System 80 standardized LWR design for the steam generators, power conversion system, and balance of plant. Thus, except for the system interfaces, the reactor core and the RCS, this conceptual design is well understood by the NRC. A thorough understanding of this HWR then requires an understanding of the Canadian reactor core and RCS design, the interfacing of the RCS with the rest of the plant, and the upgrading features determined by DOE. The upgrading basically is an increase

*CANDU: CANadian Deuterium Uranium.

in: (1) size of core and RCS, (2) temperature and pressure; (3) enrichment (from natural uranium to 1.2% enriched), and (4) the burnup (from 8,000 MWD/MT for CANDU to 20,000 MWD/MT for the DOE design). Although not a very familiar reactor concept to the U.S. industry and U.S. licensing, the Canadian HWR has extensive operational experience and the benefit of extensive Canadian safety review. DOE gave NRC a draft report on the CE-HWR design which was helpful in the initial assessment.

(1) Facility Systems Descriptions - The discussions are fairly detailed and complete. Either the system is part of the CE-System 80 standard design for a LWR plant or it is an upgrading of the existing CANDU design. Questions were asked of DOE regarding systems descriptions which were unique to the upgrading. For example, there were questions regarding the nuclear characteristics of the core for the extended burnup.

(2) Safety Approach - There are intrinsic characteristics of this HWR conceptual design which require a rethinking of traditional licensing regulations and practices. The HWR pressure boundary (pressure tubes) is in a high radiation environment and has rolled joints (as opposed to welded); these two features are at variance with LWR reactor coolant pressure boundary requirements. The HWR has a positive power coefficient which may be at variance with the LWR General Design Criteria. NRC has asked DOE a variety of questions regarding the conformance of the HWR to U. S. licensing practice for LWRs.

(3) Accident Analysis - The accident analysis area needs considerable attention for the HWR, as reflected in the NRC comments and questions. Little is known to the NRC staff regarding a Loss-of-Coolant Accident (LOCA), a Loss of Regulation Accident (LORA), a Loss-of-Heat Sink Accident (LOHSA), and natural convection cooling for this particular HWR design. One of the most crucial considerations for the HWR is the leak-before-break concept for the pressure tubes. If the NRC staff does not accept the leak-before-break concept, a number of accident scenarios involving rapid failure of pressure tubes will have to be considered.

(4) R&D Program Plan - Comments and questions on the safety R&D program for the HWR centered around the leak-before-break issue. Even with access to valuable Canadian data and experience with pressure tubes and pressure tube failures, NRC still envisions a rather extensive R&D program directed to a U.S. version of the HWR. Other R&D areas include seismic effects on pressure boundary including the fuel loading machine and fuel steady-state and transient performance.

Much of the effort to date has been to understand better the extrapolation of the Canadian a reactor concept that has had little licensing exposure in this country. This has led to requests for more information on the CANDU design itself and for analyses and R&D assessments of those upgrade features that are unique to this HWR conceptual design.

c. The Light Water Breeder Reactor (LWBR) (PSEID Volume III)

The LWBR conceptual design is basically a pressurized water reactor (PWR) with a seed-blanket core composed of fissile U-233 oxide and fertile thorium oxide replacing the standard low enrichment uranium oxide core. In a certain sense then the LWBR is similar to the LWR-variants, discussed above, where modified cores are essentially installed in existing PWRs. For the LWBR, however, the deviation from the standard PWR is more substantial -- involving not only fuel pins but also the overall core power rating, the reactivity control mechanisms, the core thermal hydraulics and the introduction of a seed-blanket concept. An additional aspect of the LWBR that must be kept in mind is that for every LWBR there must be a "prebreeder" reactor (i.e., prebreeder fuel cycle) designed to convert sufficient Thorium into U-233 in order to provide an initial fissile inventory to start up a LWBR (U-233 is not found in nature). This is because a LWBR only breeds enough fuel to compensate for the fuel it burns; it provides none for additional LWBRs (i.e., it is not a net breeder). Thus, in considering safety and licensing aspects of the LWBR, the prebreeder conceptual designs must be taken into account. This is done by always considering the LWBR in Prebreeder/Breeder pairs.

Past licensing history for the LWBR can be considered in two parts: (1) a considerable fraction of the reactor plant, excluding the core, is a standardized PWR which has had considerable licensing exposure; (2) the Division of Naval Reactors (DNR) of DOE presently has operating a small (60 MW(e)) experimental LWBR at Shippingport, Pennsylvania, which has had a favorable NRC safety review. (The Shippingport LWBR is not licensed since it is a government owned reactor, and therefore it has not had the benefit of a formal licensing review.)

DOE has submitted a LWBR PSEID that presents conceptual designs for four Prebreeder/Breeder pairs. NRC concerns have centered on the core design, the reactivity control system design (the Shippingport LWBR has moveable fuel, and advanced concept designs employ moveable fertile pins), and on the scaling up of the nuclear steam supply system (NSSS) and balance of plant (BOP), if undertaken, to match the total electrical power output of a standard PWR (alternatively, the standard PWR could be used, resulting in a reduced plant power output).

(1) Facility Systems Description - The only relatively complete facility systems description presented was for the Shippingport reactor. Although this has been very helpful in better understanding some of the LWBR concepts, there is considerable need for more detailed descriptions of the fuel pin designs, the reactor's mechanical, nuclear, thermal hydraulic features and performance, and the reactivity control system's features and performance. This is reflected in the questions asked of DOE.

(2) Safety Approach - The licensing position taken by DOE for all these Prebreeder/Breeder pairs is that there is complete conformance to the spirit of the General Design Criteria (GDC) established by NRC and that the features of these reactors that are unique and distinct from licensed PWR's are not major obstacles to licensing. NRC needs considerably more information before it can draw similar conclusions in areas reflected in (3) and (4) below.

(3) Accident Analysis - To date, there has been little accident analysis for any of the prebreeder or breeder types. Because there is little or no experience with a number of the proposed fuel-pin designs, the operational performance and transient behavior of these fuel pins is not well known. Closely coupled to this is the response of the whole core and enlarged NSSS to such severe accidents as a LOCA. In the unlikely event of a LWBR core meltdown, there is a possibility of recriticality for some of the fuel types proposed. This matter should receive careful consideration. Questions regarding accident scenarios have been sent to DOE.

(4) R&D Program Plan - The safety R&D program for the LWBR should concentrate on fuels qualification and transient behavior, thermal performance, and accident analysis. In addition, questions regarding the hydraulic pressure equilization scheme for the control rods will have to be addressed. A more comprehensive and better specified approach to a safety R&D program will be needed from DOE.

It would assist NRC's assessment of the LWBR considerably if the number of options (four) presently being considered by DOE could be reduced to one or two.

d. The High Temperature Gas-Cooled Reactor (HTGR) (PSEID Volume IV)

The original PSEID submittal for the HTGR was the standardized "GASSAR" HTGR design modified slightly to accommodate the medium enrichment fuel required so as to meet the non-proliferation fuel enrichment requirements (e.g., up to 20% enrichment for U-235). Thus, with the exception of any safety or licensing implications from the different fuel enrichment, the large NASAP HTGR has had the benefit of rather extensive licensing review both in GASSAR proceedings and the reviews of the Summit and Fulton reactors before these reactor applications were cancelled. Again, except for the change in fuel enrichment, we find that the facility systems description, the safety approach, the accident analysis, and the safety R&D program all are documented elsewhere and are familiar to the NRC. For this relatively standard HTGR with a steam (turbine) cycle, as summarized in the HTGR-PSEID, the initial informational needs are basically met. However, a major design modification was introduced in Addendum II to the HTGR PSEID, namely the direct cycle gas turbine. With this scheme the same helium gas that is heated in the HTGR core drives the gas turbines directly. The gas turbines have shafts coupled directly to the main electric generators, which produce the electric power.

The emphasis of NRC's questions to DOE were on the gas turbine (GT), and the thrust of NRC's continuing review of the NASAP-HTGR will be on the safety implications of a GT design.

(1) Facility Systems Description - In the referenced Addendum and in a meeting with General Atomic (the DOE contractor for the NASAP HTGR) the plant layout for and unique features of a HTGR with a gas turbine was covered only in very general terms. As this GT modification is in its very early stages of development, more detailed systems descriptions associated with the GT components are not available. Questions to DOE reflect these concerns.

(2) Safety Approach - It will be necessary to establish licensing criteria for the HTGR-GT, in particular to meet the unique aspects of the gas turbine design. The objective of these criteria will be to assure that at least a comparable level of safety is achieved in comparison with other commercial reactors. For example, NRC has asked DOE to provide its initial evaluation of differences in safety approach and licensing criteria between the Federal Republic of Germany's HTGR-GT and the U. S. version.

(3) Accident Analysis - The preliminary accident analysis for the HTGR-GT conceptual design will be important in sorting out problem areas and safety R&D emphasis. Accident analyses specifically related to the GT modification, such as failure of the turbomachinery housed in the reactor vessel, were requested, as well as those "generic" accidents common to all HTGR's such as adiabatic core heat-up caused by sustained loss of forced convection cooling, internal pressure equalization accidents, control rod ejection, and core support structure failures.

(4) R&D Program Plan - The safety R&D program before the introduction of the GT was, although extensive, well understood. With the GT modification there will have to be a considerable extension of the R&D directed to safety issues, into areas not so well understood today. NRC thus requested additional information on the HTGR-GT research, development and testing program, including the depth of involvement of foreign participants.

NRC also emphasized to DOE that it would be very helpful to have a firm commitment from DOE for either the GT or the conventional steam cycle.

e. Gas Cooled Fast Breeder Reactor (GCFR) (PSEID Volume V)

Of all the six mainline reactors under consideration by DOE and being reviewed by NRC, the GCFR is the only one for which there is no test, prototype, or comercial reactor experience. Yet, for three reasons NRC is acquainted with the GCFR concept and its licensing issues: (1) the AEC completed a conceptual design study review of a GCFR in 1974; (2) the GCFR, because it also is a fast reactor, has many core-region similarities with the LMFBR; and (3) because it is gas cooled, much of the HTGR technology is applicable.

Basically the GCFR PSEID describes a reactor system quite similar to the one studied by NRC's predecessor, the AEC, in 1974. At that time AEC considered the GCFR licensable but listed a number of major concerns, one of which was the reliability of core cooling which was dependent on a forced convection system. DOE has recently introduced an upflow* design, as part of the NASAP-GCFR study, in order to provide a natural circulation cooling feature to the design. While NRC welcomes these types of design modifications, it should be noted that any

*In the previous GCFR design, helium is forced down through the hot core in order to remove the core-generated heat. In the new GCFR design, helium is forced (pumped) up through the hot core. This latter arrangement is referred to as "up-flow" and has the potential advantage of shutdown heat removal by natural circulation (no pumps (circulators) running).

major design change introduces new unknowns with potential new safety and licensing issues.

(1) Facility Systems Description - This item is not as well established as for some of the more highly-developed reactors. Up to the point of the "upflow" modifications, however, there was adequate information to proceed with this stage of the NRC review. It is in the area of upflow modifications that considerably more information will be needed. It is also important to understand the impact of scaling up from the 300 MW(e) plant, for which there is considerable information, to the 1200 MW(e) plant proposed in the NASAP study.

(2) Safety Approach - Assuming that upflow is adopted, it will be important for DOE to redescribe the safety approach, specific safety characteristics and design features present for the prevention and mitigation of postulated accidents. In terms of licensing potential, NRC views the containment design criteria as important. Thus, we noted to DOE that similar criteria to those we summarized for the NASAP LMFBR ("Bases for Containment Design in Large LMFBRs") would be appropriate for a large GCFR.

(3) Accident Analysis - As with other reactor types, accidents which have the potential for adversely affecting the health and safety of the public usually involve core disruption and core melting. Thus accident analyses must eventually include the impact of core melt and disruption on the reactor vessel and containment integrity as well as thermal margins for natural convection cooling. In particular the accident analyses should take into account the effects of upflow.

(4) R&D Program Plan - There are a number of points which need clarification and development in the area of safety R&D. As noted above, the specific plan for the impact of upflow needs greater definition, as do some of the more generic, in-place programs, such as reliability of vented fuel pin designs. Over the past several years the GCFR program has relied on a combination of U. S. LMFBR and HTGR and foreign HTGR and GCFR R&D programs to considerably complement its own. NRC needs to understand the relative importance of these programs and the impact of their termination on the GCFR program itself.

f. The Liquid Metal Fast Breeder Reactor (LMFBR) (PSEID Volume VI)

The PSEID for the LMFBR is a description of core characteristics for 15 variations on a large 1000 MW(e) sodium-cooled fast breeder reactor. These 15 concepts include variations in core design (a homogeneous core vs a heterogeneous core); fuel form (carbide fuel vs. oxide fuel); and fuel and blanket type (Pu/U fuel, Pu/Th fuel, U-233/U fuel; U Blanket, Th Blanket). But, other than a description of the core characteristics for these 15 variants, there is virtually nothing presented in the PSEID that further describes the LMFBR.

It will be very difficult to factor the LMFBR into a comparative evaluation of NASAP reactor types without specific information on the NSSS and BOP and an understanding of the basic safety approach. For example, there is no indication whether the LMFBR will be a loop-type* plant or a pot-type* plant -- a decision which will have considerable safety implications. NRC believes that it will be unfair to the NASAP-LMFBR review for NRC to assume and use an extrapolation of the Clinch River Breeder Reactor (CRBR) design for making safety and licensing assessments. The CRBR, being a loop design of an early 70's vintage does not reflect recent design innovations and improvements. Also, a number of key safety issues associated with CRBR remained outstanding at the time of suspension of the safety review (spring 1977).

Nevertheless, NRC has gained valuable LMFBR experience in the licensing proceedings for CRBR as well as for the Fast Flux Test Facility (FFTF) which were completed, for the most part, in November 1978. Based on this experience and on the information provided in the PSEID, NRC asked questions and made comments to DOE in two broad areas:

- the general design and safety approach area; and
- the specific core and fuel design area.

1) Facility Systems Description - For the LMFBR descriptions were virtually non-existent. In order to complete an adequate review we need descriptive information on such systems as the primary heat transfer system (PHTS), the decay heat removal system, the plant protection system and the containment system.

2) Safety Approach - Other than a statement that the LMFBR will conform to the licensing requirements established for CRBR, there was little safety approach guidance from DOE. It is important for DOE to recognize that any one of the LMFBR-variant conceptual designs must be consistent with and conform to the spirit and intent of the staff licensing positions as reflected in the regulatory guides, criteria in the Standard Review Plan, the GDC, and other licensing regulations. In order to aid DOE in considering a safety and licensing approach for the NASAP LMFBRs, NRC provided, along with questions, a recapitulation of recent licensing staff positions in containment design entitled "Bases for Containment Design in Large LMFBRs."

3) Accident Analysis - The physics data presented in the PSEID for the variants is important, necessary input to an accident analysis and evaluation. For example, it is valuable to know how the sodium-void reactivity coefficient

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*An LMFBR has three heat transport loops: a primary sodium loop which removes heat from the reactor core, a secondary sodium loop, and a water/steam loop which drives the turbine generator. In the pot (or pool) arrangement all primary reactor components (core, pumps, intermediate heat exchangers (IHX's)) are immersed in the sodium coolant and located inside the reactor vessel. In the loop design, the primary loop pumps and IHX's are located outside the reactor vessel and connected to the core region by piping.

varies from one core design or fuel form to another. However, this is only a starting point for key accident sequence analyses. It was requested that DOE provide more information on accident analyses, especially the low probability -- high consequence core disruption and meltdown analyses which are key in establishing containment requirements.

4) R&D Program Plan - The NRC has been closely following the DOE safety R&D program for LMFBRs over the past 10 years and has a considerable confirmatory research program of its own. For the most part these programs have addressed safety issues for the conventional LMFBR design (homogeneous core, loop plant, Pu/U oxide fuel, U-blanket). Although many of the problem areas are generic enough that they are appropriate areas for these NASAP LMFBR types, there are safety problems unique to these variants. It will be important in the future to understand the DOE R&D program plan that will address these problems. Areas of importance include the steady-state and transient behavior of carbide fuels, the core disruption and meltdown sequence for a heterogeneous core, and the material interaction effects between molten thorium carbide or uranium carbide and sodium or concrete.

In order to facilitate the continuing review of the NASAP LMFBR, it would be helpful for DOE to reduce the options presently in place (15) to two or three.

g. Fuel Cycle Facilities (PSEID Volume VII)

This DOE document was written to provide information on the safety and environmental issues and permit NRC to, identify licensing issues for all those fuel cycle facilities that would be required to service any of the reactor concepts described above. These fuel cycles include:

- Once through uranium fuel cycle - this is the extant fuel cycle for LWR's.
- Uranium fuel cycle with (uranium and) plutonium recycle.
- Thorium fuel cycle with (thorium and) uranium-233 recycle.

All of the fuel cycles considered in the NASAP program, with the exception of the once through fuel cycles, require reprocessing and recycling of fissile materials. Operations for the front end of the uranium or thorium fuel cycles are similar to one another and involve mining and milling of ore, production of a pure uranium (or thorium) compound, enrichment of uranium in the U-235 isotope (enrichment of thorium is not required), and use of the uranium or thorium in fuel assemblies. In addition, thorium compounds have been produced in the past for limited use in reactors or other articles of commerce.

Because of the similarities between the front ends of the uranium and thorium cycles, and the fact that thorium compounds have been manufactured in the past, and since the main proliferation concerns center on the back end of the fuel cycle, NRC has focused the greater amount of attention on the back end of the fuel cycle, i.e., those operations associated with recovery (reprocessing), recycle (fabrication of recycle fuel) of fissile materials, and waste management.

Reprocessing

Chapter 5 of this PSEID, Reprocessing, contains a description of fuel reprocessing for five variations of uranium fuel reprocessing and seven variations of thorium fuel reprocessing. The descriptions are almost totally qualitative, with little detail given to many important subjects, such as effluent treatment, safety features, safeguards systems, etc. DOE notes correctly that:

- There is a requirement for additional development work on technology for reducing effluents from uranium fuel reprocessing to meet current health and safety regulations.

- There is little actual experience relevant to commercial reprocessing of thorium based fuel assemblies.

NRC's reviews of potential licensability of the reprocessing variations could not be detailed or in depth because the PSEID did not contain enough quantitative data to permit definition of appropriate licensing criteria.

Recycle Fuel Fabrication

In the PSEID, DOE aggregated the discussion of recycle fuel fabrication of twelve different fuel forms into four classes of fuel, losing much information at this level of aggregation. The data provided to NRC, to be useful, should adequately describe the differences between the processing of the fuel forms considered covering such items as emissions, radiological doses, etc. For this operation also, NRC was unable to develop licensability criteria from the small amount of data given.

Waste Handling and Treatment

The PSEID contains a statement that "current DOE National Waste Terminal Storage (NWTS) program calls for the selection by 1979 of two sites overlying suitable salt formations, followed by the construction and startup in 1985 of one NRC-licensed repository...." It appears that the program cannot be implemented on the schedule proposed. Current NRC estimates for the time required for preparation of a license application, processing a repository license application, and reaching a licensing decision are such that the startup of a licensed repository would not occur before 1992. Hence, DOE planning should be realistically based on a repository startup in that time frame.

International Fuel Service Centers (IFSC)

The documentation prepared for DOE on the bases for and potential problems in the design, construction, and operation of an IFSC are not available to NRC at this time. The description of the IFSC contained in the PSEID is too brief for NRC to comment knowledgeably on it.

Summary

In general, the PSEID on fuel cycle facilities touched on the principal safety and environmental and licensing issues that would be associated with various alternative fuel cycle systems. In addition, it also suggested some areas where more information would have to be developed through further studies or future research. It did not, however, make a quantitative comparison of safety or environmental trade-offs in areas such as occupational exposure, regional exposure, accident risk, or environmental, safeguards, or proliferation impacts. NRC believes that such comparisons, even though not available at this time, will have to be developed as part of the NASAP final evaluations if any conclusions or recommendations are to be reached about promising proliferation-resistant alternatives.

While the DOE PSEID identified systems and principal issues related to nonproliferation alternatives, it did not assess the proposed systems or facilities in sufficient depth to permit definition of appropriate licensing criteria or the potential difficulty of meeting such criteria. However, there is no reason to assume that the systems or proposed facilities could not be designed to meet the applicable local, state and Federal criteria at the time they may be proposed. Although many of the fuel cycle systems might never reach the demonstration phase -- since they may not have enough promise to warrant appropriate funding -- the proposed facilities (within the extent of present definition) all appear to be fundamentally licensable on a qualitative basis.

2. Nuclear Energy System Characterization Data

The draft DOE document, "Nuclear Energy System Characterization Data," presents voluminous numerical data, together with a limited amount of analysis. The data is primarily to be used as source material in the NASAP analyses.

General

Three overall uranium fuel cycles are delineated in the document:

- The once through fuel cycle is properly identified as being limited by uranium availability. An improvement of enrichment technology is noted as a potential enhancement for the once through fuel cycle. While this may be true from a resource availability standpoint, no mention is made of potentially significant considerations with regard to the important proliferation and safeguards aspects of such technological advances.
- The second fuel cycle outlined is the uranium recycle option, which might possibly involve the LWBR. While uranium recycle is theoretically a potential alternative, in other countries it is only being actively considered by those that plan large and aggressive breeder programs. Either in the U.S. or abroad, this cycle will require facilities for the long term storage of plutonium, which are not mentioned in the DOE document. The economic and proliferation-resistance implications of such requirements have not been covered in any documents reviewed to date.

- The third fuel cycle considered is the uranium and plutonium recycle case. All modes of recycle in this case seem to be based on two theoretical safeguards regimes. One regime assumes universal worldwide safeguards; the second regime assumes two safeguards regions, one region with no restrictions and one region where only denatured, spiked, or diluted fuel can be utilized. Thus, in this document, the concept of uranium and plutonium recycle seems to depend upon the acceptability of technological measures (denaturing, spiking, or dilution) as deterrents to proliferation resistance. Based upon progress to date in the INFCE work, NRC notes that it appears such technological measures alone are judged to have little potential for preventing national proliferation and are only considered helpful for preventing sub-national diversion.

Reactor Data and System Analyses

No new reactor types are projected to be introduced before early in the next century. On this basis, the effects of new types on proliferation resistance, resource utilization, and new facility requirements will be minimal for the next 20-25 years.

The report forecast that new reactor types could have a potential of capturing a maximum of 50% of the market for new and replacement reactors in about 11 years and 100% in about 30 years, based upon market penetration begining at the time of first commercial deployment. The current nuclear situation adds uncertainty to both the penetration rate and the time of new system introduction. Further, the introduction of any new reactor technology into the market will probably require substantial government support and resolution of institutional impediments.

Analytical results indicate that improved LWR fuel can be introduced into all reactors, both existing and projected, within a five-year period from 1985-1990. This would appear to imply complete industry penetration within five years. In view of development, demonstration and regulatory requirements, it appears that such a fast penetration rate is overly optimistic.

The data presented in this section of the DOE document include cumulative spent fuel storage requirements through the year 2025. From this presentation it appears that no Federal waste repository would be available to accept spent fuel until that year. This basic assumption on respository availability does not appear to be consistent with Federal policy nor with the assumptions in PSEID, Vol. VII, Waste Treatment and Handling.

Summary

The three basic LWR uranium fuel cycle options are discussed in this DOE document. However, in the case of each option, the discussion is flawed by the lack of consideration of key proliferation aspects which would be of significant importance in evaluation and selection of improved modes of operation. The discussion of reactor data and systems seems to take an overly optimistic view of the commercialization timing of improved LWR fuels and new reactor types in view of performance to date and the climate of increased design, development and regulatory requirements.

3. Safeguards Considerations for the NASAP Alternative Fuel Cycles

This section focuses on the potential safeguards issues that distinguish the DOE NASAP candidate fuel cycles from each other and from the reference uranium-plutonium fuel cycle. The accompanying table on page 23 presents an overview of the 17 candidate fuel cycles and the proposed means each would employ for safeguarding against proliferation -- namely, spiking, use of U-233/Thorium fuel, denaturing, and coprocessing. The chart also presents a summary of safeguards issues (e.g., material control and accounting, physical security, institutional/ international considerations, and storage) associated with each of these 17 candidate fuel cycles. Safeguards issues are those which might have an impact on licensability, fuel cycle research and development, commercial implementation or operations. These findings are preliminary and should not be interpreted as commiting the NRC to specific positions in future licensing actions.

a. Material Control and Accountability (MCA)

The following preliminary comments summarized the major NRC concerns with regard to potential MCA safeguards issues and problems.

1) Dynamic Real-Time Accounting

The NASAP reports assume that dynamic real-time accounting processes will be used in conjunction with periodic clean-out physical inventories and that automated MCA systems will be available. NRC has not yet determined the degree to which dynamic real-time accounting systems can supplement periodic clean-out physical inventories. Further, research and development will be needed to develop ways of assessing the adequacy of automated MCA systems before the NRC is prepared to make such a determination. Accountability problems of hold-up and clean-out in high throughput facilities, particularly in radioactively hot processes, need to be examined in detail before dynamic real-time accounting or automated MCA systems can be considered ready for licensing.

2) Spiking

Four methods for spiking are proposed by NASAP. These include the addition of radioactive material to nuclear fuel; partial reprocessing of spent fuel, retention of some portion of the fission product in the recovered plutonium; pre-irradiation of fuel assemblies prior to shipment to a reactor; and mechanically attached radioactive sources. Proposed minimum radiation levels (rem per hour at one meter), at a time two years after fabrication, range from 10 rem per fuel assembly to 1,000 rem per kilogram of heavy metal for PuO_2 and high enriched UO_2 powder or pellets.

For the first two concepts, the radioactive spikants would greatly complicate the taking of samples for chemical analysis and somewhat complicate the analysis itself. Most nondestructive assay (NDA) techniques would be rendered inoperable. Lacking such techniques, it would be very difficult to perform real-time or near-real-time accountability in bulk processing plants. In addition, the physical inventory process would be slowed, material balances would be less accurate than in the absence of spiking, and inspection activities, both domestic and international, would be hampered. The timeliness of both NRC and IAEA verification of material balances would be reduced.

A decision to proceed with significant research and development and commercialization of the NASAP alternate fuel cycles which require spiking would necessitate definition of spiking levels and threshold concentrations of special nuclear material (SNM) useful for producing a nuclear device. If spiking were adopted, NRC would have to develop regulations governing its use.

3) U-233/Thorium Cycles

There is little experience with the commercial reprocessing of highly irradiated thorium fuels. It is therefore impossible to judge whether present NRC material accountability regulations can be met in commercial size reprocessing and fabrication plants for U-233/Th fuels. A unique characteristic of U-233 fuels is the high radiation levels associated with U-232 and its daughters. These levels are high enough to require remote fabrication, and non-destructive analysis techniques will have to be developed for any fuel cycle using U-233. The feasibility of performing real-time accountability in U-233 fabrication plants will depend on the successful outcome of such efforts. As with spiked fuels, the taking of samples will be laborious and time consuming.

4) Denatured* U-233 Fuel

For some of the reactor concepts involving denatured U-233 fuels, such as the LWR, substantial quantities of plutonium appear in the spent fuel. The fuel will therefore have to be reprocessed by a combination of the Purex** and Thorex** processes. Very little, if any, experience in reprocessing denatured spent fuels exists, and

*Denaturing is defined as the addition of a non-fissile isotope to a fissile isotope in such proportions as to make the fast critical mass of the mixture impracticably large for a nuclear explosive weapon.

**The Purex process is the conventional solvent extraction process for recovering fissionable materials from uranium plutonium based fuels.

The Thorex process is the conventional solvent extraction process for recovering fissionable materials from thorium based fuels.

therefore it is impossible to project how well NRC's accountability requirements can be met in such a reprocessing plant without detailed study.

For denatured fuels, NRC would have to review the composition data for U-233 fuels before selecting enrichment thresholds for safeguards requirements for uranium containing this isotope and for uranium containing both U-233 and U-235. Another consideration that may enter into setting threshold enrichments for uranium containing U-233 is the greater ease of separating this isotope from U-238, compared with that of separating U-235.

5) Heavy Water Reactors

Two safeguards problems associated with the use of heavy-water reactors (HWRs) are the increased availability of heavy water in large quantities and on-line refueling.

Heavy water can be used to moderate reactors fueled with natural uranium, and these can be used to produce plutonium. A substantial commitment to the heavy-water reactor fuel cycle in the U.S. might require, therefore, the imposition of safeguards on heavy water, not now required by NRC regulations. Safeguards would likely consist mainly of material accounting, surveillance and containment.

The technology of safeguarding heavy water is not well developed. Current safeguards practices place considerable reliance upon optical surveillance, item counts, and periodic checks of operating records to detect any undeclared activities. For heavy-water production facilities of commercial size (at least 200 metric tons (Te) of D_2O per year), present accountability techniques appear to be too inaccurate to detect the diversion from the extraction process of the minimum quantity (~ 10 Te) of D_2O required to supply the initial inventory of a small plutonium production reactor (annual production rate 8 kg Pu). It appears that applying safeguards to a heavy-water production facility would involve problems different from those NRC has encountered in other types of safeguarded plants to date. Considerable development of criteria and methods for safeguarding large plants of this type would have to be undertaken if they were to become a reality in the U.S. licensed industry.

For the heavy water reactor concept, NRC would have to determine the minimum amount of heavy water of safeguards significance, and the threshold concentration of deuterium in water for safeguards to apply.

With respect to on-line refueling, the frequency of this operation, the large inventory, and its rapid turnover impose a need for more safeguards attention than required by current fuel cycles for light water reactors.

6) Coprocessed Fuels

The safeguards issues relative to coprocessing appear similar to those for the uranium/plutonium cycle, with the exception that pure plutonium would not be stored. The presence of uranium with plutonium would slightly complicate measurement of plutomium within coprocessing fuel cycles.

For coprocessed fuels, the concentration of plutonium in mixed oxides for thermal recycle fuels would probably be too low for direct use in a nuclear explosive. This may not be true for fast breeder reactor mixed oxide fuel, with its much higher concentration of plutonium. The percentage of plutonium would be based on considerations of the practical needs of the fabrication plants and reactor neutronics.

b. Physical Security

The present criteria defining "self-protecting" SNM (i.e., not readily separable from other radioactive materials and with a radiation dose rate of more than 100 Rem per hour at 3 feet) are under study within NRC. Based on these study results, NRC may need to consider any revisions to the existing protection requirements needed for fixed sites and transportation from the standpoints of both theft and sabotage for licensed SNM, spikants, spiked SNM, and high level wastes. DOE should coordinate with NRC to assure that NASAP review criteria remain consistent with future study results.

If the plutonium recovered from spent denatured fuel is recycled in energy centers, the safeguards technical problems are essentially the same as those discussed in the NRC GESMO proceeding, with the modifications associated with the physical and administrative nature of energy centers.

NRC and DOE have ongoing research programs to characterize the potential radiological source that could arise from sabotage (explosive breaching) of a loaded LWR spent fuel shipment and to estimate potential health consequences. Additional research may be required to characterize the source term and health consequences of explosive breaching of spiked fuel shipments, shipments to which a spikant sleeve has been mechanically attached, or fuel shipments associated with the remaining candidate fuel cycles.

c. Institutional and International Considerations

1) Spiking

A significant safeguards issue presented for NRC consideration in NASAP is the effectiveness of spiking fuel as a safeguards measure against nuclear weapons proliferation. It can be postulated that U.S. exports of unirradiated fuel that afford nuclear weapon potential could be spiked to emit radiation levels comparable to spent reactor fuel. If the importing country plans to use this material for the development of nuclear weapons, the fuel would first require processing by remote means, imposing processing requirements equivalent to those for reprocessing of spent reactor fuel.

Remote processing appears to be a relatively minor hurdle to overcome for any technologically advanced nation that decides it needs nuclear weapons. Thus, spiking does not appear to reduce the risk of national proliferation of nuclear materials for diversion to nuclear weapon development; it merely assures that such overt action is not made easier to accomplish than it would be from the spent fuel, which many nations already possess.

Spiking may have substantial adverse effects on the environment through the production of increased amounts of radioactivity (e.g., Co^{60}) beyond those normally required for the generation of electric power. An environmental impact statement may therefore be required prior to a national decision to implement spiking and an environmental impact proceeding probably would involve appreciable delays.

2) Heavy Water

If heavy water were to be safeguarded in the interests of non-proliferation, the definition of a safeguards significant amount of heavy water should be consistent with international commitments. Safeguards on heavy water are not required under the NPT-INFCIRC/153 system of the IAEA, but may be required under bilateral or trilateral agreements or voluntary submissions. Historically, the IAEA has accepted the responsibility for applying safeguards to heavy water when so requested. It is not regularly safeguarded under NPT because heavy water is not included in the definition of nuclear material by the IAEA.

d. Storage

A once-through fuel cycle implies the indefinite, perhaps permanent, storage of spent reactor fuel in repositories. NRC believes it already possesses legal authority to license the storage of spent fuel in Away-From-Reactor facilities because spent fuel is considered to be a high level waste for the purposes of Section 202(3) of th Energy Reorganization Act of 1974 (ERA). Explicit legislative confirmation of this authority in the proposed H.R. 2586, the Spent Nuclear Fuel Act of 1979, would preclude confusion on this point.

Disposition of the plutonium separated from spent denatured U-233 fuel is also significant from the standpoint of proliferation. If this plutonium is considered waste, NRC believes it would be subject to licensing authority under Section 202(3) of the ERA. Plutonium recovered from spent denatured fuel and separated U-233, from U-233/Thorium and, possibly, from denatured fuel cycles, may be either stored or recycled in "secure" energy centers. If storage is in licensed facilities, the safeguards problems will be, generally, those already considered in the GESMO proceeding.

EXISTING OR SUSPECTED SAFEGUARDS RELATIONSHIPS FOR THE NASAP FUEL CYCLES EXAMINED

PROPOSED ALTERNATIVE FUEL CYCLES 2/	TECHNOLOGICAL APPROACHES TO NONPROLIFERATION				POTENTIAL IMPACTS 1/ ON SAFEGUARDS			
	A. SPIKING	B. U-233/Th FUEL	C. DENATURING	D. COPROCESSING	A. MCA	B. PHYSICAL SECURITY	C. INSTIT/INTEL CONSIDERATIONS	D. STORAGE
Light Water Reactors								
1.1 PWR Once Through (OT)	-	-	-	-	-	-	-	X
1.2 PWR Modified OT	-	-	-	-	-	-	-	X
1.3 PWR U/Pu Recycle	X 3/	-	-	X	X	X	X	-
1.4 LWR Denatured U-233 Recycle	X	X	X	-	X	X	X	-
Light Water Breeder Reactors								
2.1 Backfit Pre-Breeder U/U-233 Recycle	X	X	-	-	X	-	X	-
2.2 Advanced Pre-Breeder U-233-Th/U-233 Recycle	X	X	-	-	X	X	X	-
2.3 Pre-Breeder U-Th/U-233 Recycle	X	X	-	-	X	-	X	-
2.4 Breeder UO_2-Th/U-233 Recycle	X	X	-	-	X	X	X	-
Heavy Water Reactor								
3.0 HWR Denatured OT	-	-	X	-	X	-	X	X
High Temp. Gas Cooled Reactors								
4.1 HTGR Denatured OT	-	-	X	-	-	-	X	X
4.2 HTGR Denat. Recycle U-235-Th/U-233	X	X	X	-	X	-	X	-
Gas Cooled Fast Reactor								
5.1 GCFR U-Pu/U-233 Recycle	X	X	X	X	X	X	X	-
Liq. Metal Fast Breeder Reactors								
6.1 LMFBR U-Pu/U Recycle	-	-	-	X	-	-	X	-
6.2 LMFBR U-Pu Recycle	X	-	-	X	X	X	X	-
6.3 LMFBR U-Pu/Th Recycle	X	X	X	-	X	X	X	-
6.4 LMFBR Th-Pu/Th Recycle	X	X	X	X	X	X	X	-
6.5 LMFBR Denat. U-235-Th/Th Recycle	X	X	X	-	X	-	X	-

1/ The potential safeguards impacts categorized here apply to the alternative fuel cycles and except for storage concerns do not apply to the current LWR fuel cycle.

2/ NASAP Reactor/Fuel/Cycle Systems for NRC Review.

3/ The X's portray existing or suspected relationships between the fuel cycles examined, the technological approaches to nonproliferation, and the potential impacts on safeguards.

e. Summary

As noted, the findings presented herein are preliminary in nature and should not be interpreted as committing the NRC to specific positions in future safeguards licensing actions. More definitive statements on safeguardability of alternative fuel cycles will be presented in future reports on the basis of review of the NASAP and INFCE final reports, further fuel cycle definition, research and development by DOE and NRC staff work.

4. The Denatured U-233 Fuel Cycle

The report, "Interim Assessment of the Denatured U-233 Fuel Cycle: Feasibility and Nonproliferation Characteristics," ORNL-5388, was reviewed as a NASAP support effort. While the impacts of U-233 usage on reactors were not considered, the document is an exhaustive study of the denatured U-233 fuel cycle and contains analyses of many denatured fuel systems. The analysis presents voluminous data on the uranium, uranium/plutonium and denatured uranium fuel cycles covering eight fuel cycle options with four cases being studied for each option, and two levels of uranium supply (high and intermediate) used in each case and option. A total of 64 cases were studied.

Nuclear Power Demand

The demand curve for nuclear power used in the analysis presented in this report required that nuclear power reactors be capable of supplying 1100 GWe in 2049. Not unexpectedly, for the high-cost U_3O_8 supply runs (constrained resource availability), only those fuel cycle options that include breeders are able to meet the demand. For the intermediate-cost U_3O_8 runs (larger resource availability), options using heavy water moderated converters are also capable of meeting the demand.

Although NRC recognizes the need to consider the ultimate capability of any resource base in terms of GWe produced/MT U_3O_8, it does not appear reasonable that a projection of installed nuclear power 70 years from now is a realistic decision criterion on which to base near-term (1980) decisions. NRC believes that the near-term decisions should include consideration of the transitional period (say 2000-2020) showing changes in the nuclear fuel cycle as new types of reactors, instead of LWR's, are built. NRC recommends that some detailed evaluations of the differences among the options over the nearer term transition period be developed and factored into the decision process.

"Secure" Centers

With the exception of the throwaway option, all other options considered in ORNL-5388 require fuel reprocessing of LWR and other types of fuel. Further, all options except the Pu throwaway option recycle plutonium to reactors built on a "secure" center together with fuel reprocessing facilities. The characteristics of the "secure" center are not completely delineated. The restriction of certain reactors to secure centers can be a potentially significant factor in the growth of nuclear power. The ratio of the installed nuclear capacity outside an energy center to the installed nuclear capacity inside the

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center, termed "energy support ratio," is a measure of the restrictions in nuclear power plant siting attributable to the requirement for secure centers.

NRC recognizes the desirability of obtaining the maximum amount of information from the complicated systems studies, and therefore considers the data on the energy support ratio valuable. However, data must be available to consider the nuclear power fuel cycle and reactor complex in the early years (say 2000-2020) of the next century. Options that appear to be very different in the mid-21st century may be quite similiar in the early years of the next century, and very likely near term considerations may dominate the selection of alternative fuel cycles. Hence, a discussion of the energy support ratio over the early years of the next century as well as an evaluation of the limiting ratio should be included.

In addition, the requirement for a"secure" center is an assumption in Chapter 6 of the ORNL document. Since this assumption does not affect the results of systems studies, in terms of numbers of reactors, development costs, etc., it would appear desirable to clearly indicate that this assumption does not impact on other study results. (The energy support ratio is, of course, dependent on the assumption.)

Summary

This support document projects the nuclear power industry 70 years in the future and considers over 60 alternative fuel cycles. Thus it is both too diffuse and long range in its perspective to provide much insight into near-term decision making. It is believed that the transitional phases of some long-term alternatives in the 20-30 year time frame would likely be very significant in the decision making process and should be analyzed in the NASAP effort.

III.B SUMMARY OF NRC PARTICIPATION IN INFCE

In October 1977, forty countries and four international organizations met in Washington and agreed to undertake an International Nuclear Fuel Cycle Evaluation (INFCE). INFCE, which now has fifty-three participating countries and is scheduled to conclude in February 1980, is organized around eight working groups and a Technical Coordinating Committee made up of representatives of the twenty-two countries chairing the eight working groups.

The eight working groups and their "co-chair" countries are:

1. Fuel and Heavy Water Availability (Canada, Egypt, India)

2. Enrichment Availability (France, Federal Republic of Germany, Iran)

3. Supply Assurances (Australia, Philippines, Switzerland)

4. Reprocessing, Plutonium Handling, Recycle (Japan, United Kingdom)

5. Fast Breeders (Belgium, Italy, U.S.S.R.)

6. Spent Fuel Management (Argentina, Spain)

7. Waste Management and Disposal (Finland, Netherlands, Sweden)

8. Alternative Fuel Cycle and Reactor Concepts (Republic of Korea, Romania, United States)

NRC's participation has been in the context of the U.S. organizational support structure for INFCE. Individual staff members have been named as contacts to work with the U.S. support groups for six of the eight INFCE working groups (numbers 3-8) and three special U.S. cross-cut review groups (safeguards; nonproliferation; technical and economic aspects).

These personnel have reviewed, along with specialists from the Department of Energy, the Department of State, the Arms Control and Disarmament Agency, the Environmental Protection Agency, and other interested organizations, various U.S. and foreign papers circulated by the U.S. INFCE Coordinator's Office.

The U.S. has offered about 50 papers to the INFCE working groups and has reviewed and commented on more than 200 papers contributed by other countries and international organizations. This combined total of 250 papers was preceded by several hundred preliminary drafts and discussion papers on sub-topics, most of which were also reviewed in whole or in part by members of the U.S. support structure.

NRC staff member comments have been of two types, those of a general technical nature and those concerning regulatory considerations. The latter comments have included licensability questions: when and under what circumstances might a given type of technology or control system be considered sufficiently well understood and supported by adequate data to permit it to be licensed and used in the U.S.? Such comments on alternative reactor and fuel cycle concepts have been provided by NRC in the NASAP context (see discussion above), but have been repeated in key areas as appropriate in INFCE. In this regard, it is noted that one purpose of NASAP was to provide technical support to INFCE, especially to Working Group 8 of which the U.S. is a co-chair country.

III.C. GAO REPORTS

In a letter report to the Joint Economic Committee of Congress, dated March 7, 1978, GAO recommended that the NRC (1) establish a program to systematically and independently monitor the development of alternative fission reactor and fuel cycle technologies for the future, and (2) identify and report to the President and cognizant Congressional committees known or suspected licensing issues and problems associated with the reactor and fuel cycle technologies under serious consideration by DOE before any are scheduled to be selected for future development. GAO also recommended that, to the extent possible, the Chairman of the Commission should rank the reactor and fuel cycle technologies for desired development in the United States from a licensing point of view, and clearly identify the relative safety, safeguards, and environmental advantages and disadvantages of each.

In letters to GAO and various Congressional Committees dated June 9, 1978 the Chairman of NRC responded to the GAO recommendations. NRC indicated that it has been monitoring the alternative fission reactor and fuel cycle technologies described in the Nonproliferation Alternative Systems Assessment Program (NASAP) as well as those in the International Fuel Cycle Evaluation (INFCE). Comments have been and will continue to be sent to DOE on their NASAP documentation. NRC has established a NASAP/INFCE working group to coordinate the Agency's activities in alternative fuel cycle assessments and research efforts. NRC has agreed to provide a staff report to the President and Congress on preliminary findings of known or suspected licensing issues or problems with alternative technologies under serious consideration by DOE. NRC plans to publish the report subsequent to the completion of the NASAP program and the INFCE study. A future edition of these semi-annual reports to Congress may serve as the vehicle for reporting to the President and Congress on these matters.

In late 1978, NRC reviewed a draft of a report produced by GAO entitled "Nuclear Reactor Options to Reduce the Risk of Proliferation and to Succeed Current Light Water Reactor Technology." In January, 1979, NRC provided GAO with comments on this draft report. Although the report contains no recommendations or conclusions directed at NRC, the Agency did provide GAO with comments to improve the accuracy and completeness of the report. For example, NRC staff pointed out technical inaccuracies and conclusions requiring additional supporting verification and offered additional pertinent information where appropriate. A final version of this report was published by GAO in May 1979.

III.D. SUMMARY OF NRC COMMENTS ON THE CONGRESSIONAL RESEARCH SERVICE REPORT: ALTERNATIVE BREEDING CYCLES FOR NUCLEAR POWER: AN ANALYSIS

NRC reviewers of this report found it to be of high quality and comprehensive in its treatment of the various alternative breeder concepts. Also, some of the views expressed in the report appear to be in general agreement with those of the NRC.

The NRC has reviewed this report in part to monitor the degree of technical accuracy in "companion" efforts to NASAP/INFCE and in part to provide perspective for NRC efforts as well as constructive comments to the authors of the CRS report. A meeting was held at NRC April 11, 1979, with a CRS representative during which such comments were exchanged.

The report does not deal as well with the ex-reactor portion of the fuel cycle as it does with the reactor concepts. Since it is the vulnerability of the special material while it is outside the reactor that gives rise to proliferation concerns, a more appropriate focus, therefore, would have been on alternative breeder fuel cycle systems.

It is noted in the report that there seems to be little "discernability" between the proliferation risks of one alternative breeder concept and another and that for all of the concepts the risks appear to be relatively low but not yet quantified or compared with other risks of public concern.

The report also noted that there is somewhat of a "gap" or lack of meaningful connection between nuclear power breeder reactors and nuclear weapons proliferation. That is, the scenarios describing diversion of special material and the creation of a threat have not been critically reviewed in depth or on a comparative basis. Although the report notes this problem, it does not set forth criteria for determining the risk from such scenarios relative to others, including non-reactor scenarios, nor does it discuss how to judge whether disproportionate applications of safeguards may occur with one of several routes to proliferation. These considerations still need to be given attention and review for adequate Congressional and public understandings.

To the extent allowed and useful, NRC will continue efforts to coordinate reviews and advice on safety concerns with the CRS as they progress in their efforts to clarify various proliferation scenario facts for Congressional decisions.

IV. SUMMARY OF APPLICABLE RESEARCH AND TECHNICAL ASSISTANCE

NRC has developed short-range research and technical assistance programs to help identify outstanding safety, safeguards and environmental issues associated with alternative reactor and fuel cycle concepts. During FY 1979 approval was requested and obtained from Congress to apply $800,000 of FY 1978 carryover funds to this work as a part of ongoing programs at several National Laboratories; however, with Congressional approval NRC delay this research effort because of resource needs precipitated by the Three Mile Island accident.*

NRC has implemented a modest (for FY 1979, $300 K) technical assistance program directed to a better understanding of some of the licensing issues unique to the NASAP conceptual designs. These areas include:

1. Failure dynamics of HWR pressure tubes and implications of break before leak;

2. The reactor physics characteristics of the HWR;

3. Accident sequences peculiar to the HWR;

4. The variation in core disruption consequences as a function of the variations in the LMFBR designs;

5. Accident sequences peculiar to the HTGR design with a gas turbine; and

6. Core melt and core retention characteristics for fuel forms and fuel cycles different than plutonium and uranium mixed oxide.

In FY 1979, NRC also contracted with Brookhaven National Laboratory (BNL) to provide a preliminary analysis and assessment of the requirements for safeguards and the difficulty of safeguarding the various alternative nuclear fuel cycles being considered by DOE in NASAP. The BNL study is intended to identify and evaluate safeguards regulatory issues and potential solutions which could occur given implementation of the NASAP alternative fuel cycles.

To date, the study has provided an overview and preliminary assessment of generic safeguards issues, potential safeguards problems, and alternative solutions for each fuel cycle. The study has explored the impact of the current regulatory structure upon the time required to implement each cycle. Remaining tasks address ranking of the major alternative fuel cycles by difficulty of safeguards, impact of legal obstacles that could restrain implementation of the fuel cycle options, impact on implementation of the US/IAEA safeguards agreement, and impact on operation of multinational fuel centers in the United States.

*Subsequent to the delay, Congress directed NRC to [illegible]000 for fuel cycle studies. This authorization was received in August 1979, after the end date of this Report (June 30, 1979).

When completed in early FY 1980, this $154 K study will provide background technical information for the NRC to use in establishing future programs and policies relevant to the safeguarding of fuel cycles developed by the commercial nuclear industry.

NRC also maintains a significant research program in fast breeder reactors and a limited program in advanced converter reactors, funded at $14 million and $3.2 million respectively in FY 1979 and supported by about 14 person years of NRC staff effort.

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V. ADDITIONAL COMMENTS

Section 9 of Public Law 601 (FY79 NRC authorization legislation) states that, as part of the Report to Congress, NRC shall provide:

> "...a summary of all research activities relating to such matters, identification of areas of deficiency in such existing information and ongoing efforts, and recommendations regarding matters which should be undertaken to minimize any potential adverse impact on matters within the Commission's jurisdiction;"

It has been noted elsewhere that this first semiannual report is based on only a preliminary review, over about a 6-month period, of the DOE PSEIDs. As such, a definitive "summary of all research activities", including a listing of deficiencies in present programs and recommendations for future work, cannot be part of this first report.

A. Reactor Types

As a first step, in Section III.A, we have indicated the status of information provided to us by DOE for each reactor type in four general categories -- facility system descriptions, safety approach, accident analysis, and the research and development program. The reader is referred to these portions of the summaries for the status of information provided for the specific reactor types. Until more information is provided by DOE in the first three information categories, the NRC can neither be more definitive in evaluating the merits of an in-place plan nor be more responsive in estimating safety R&D costs and durations. Nevertheless, we have provided estimates of trends, emphasis, and needs.

B. Fuel Cycle Concepts

As we noted above (Section III.A.), the information received from DOE in support of an NRC evaluation of the NASAP concepts did not assess the proposed systems in sufficient depth to permit definition of appropriate licensing criteria. For NRC to provide meaningful evaluations related to health and safety, safeguards, and environmental considerations, documents that approach the level of detail of an applicant's report would be required.

Since fuel cycle operations tend to be generic in nature, it is suggested that DOE choose a few typical fuel cycles that it would like NRC to comment on and define them in sufficient depth for evaluation purposes. To permit NRC to provide definitive opinions on alternative fuel cycles, DOE should provide detailed analyses of the safety, safeguards, and environmental effects of typical fuel cycle facilities, and a comparison of the effects of such facilities with those of the once-through LWR fuel cycle.

VI. GLOSSARY

ACRS - Advisory Committee on Reactor Safeguards
BOP - Balance of plant
CANDU - CANadian Deuterium Uranium
CE - Combustion Engineering
CFR - Code of Federal Regulations
CRBR - Clinch River Breeder Reactor
CRS - Congressional Research Service
D&D - Decommissioning and Decontamination
ERA - Energy Reorganization Act
FFTF - Fast Flux Test Facility
GASSAR - General Atomic Standard Safety Analysis Report
GCFR - Gas-cooled fast breeder reactor
GDC - General design criteria
GESMO - Generic Environmental Statement on Mixed Oxides
GT - Gas turbine
GWe - Gigawatts electric
HTGR - High temperature gas reactor
HWR - Heavy water reactor
IAEA - International Atomic Energy Agency
IFSC - International Fuel Service Centers
INFCE - International Nuclear Fuel Cycle Evaluation
LMFBR - Liquid metal fast breeder reactor
LOCA - Loss-of-coolant accident
LOHSA - Loss-of-heat-sink accident
LORA - Loss-of-regulation accident
LWBR - Light water breeder reactor
LWR - Light water reactor
MCA - Material control and accountability
MWD/MT - Megawatt days per metric ton
MW(e) - Megawatts electric
NASAP - Nonproliferation Alternative Systems Assessment Program
NDA - Nondestructive assay
NNPA - Nuclear Non-Proliferation Act
NPT - Nonproliferation Treaty
NWTS - National Waste Terminal Storage
NSSS - Nuclear steam supply system
ORNL - Oak Ridge National Laboratory
PHTS - Primary heat transfer system
PSEIDs - Preliminary Safety and Environmental Information Documents
PWR - Pressurized water reactor
RCS - Reactor coolant system
R&D - Research and development
SNM - Special nuclear material

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