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DIVERSION ANALYSIS AND SAFEGUARDS MEASURES
FOR LIQUID METAL FAST BREEDER REACTORS*

by

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Diversion Analysis and Safeguards Measures For Liquid Metal Fast Breeder Reactors

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ABSTRACT

The general objective of the study is to perform a diversion analysis and an assessment of the available safeguards methods and systems for verifying inventory and flow of nuclear material in accessible and inaccessible areas of liquid-metal fast breeder reactor, LMFBR, systems. The study focuses primarily on the assembly-handling operations, assembly storage facilities, and reactor operations facilities relating to existing and/or near-term planned experimental, demonstration and prototypal reactor plants. The safeguards systems and methods presented are considered to be feasible for development and for implementation within the resource limitation of the IAEA and are considered to be consistent with the objectives, requirements, and constraints of the IAEA as outlined in the IAEA documents INFCIRC/153 and INFCIRC/66-Rev-2.

I. INTRODUCTION

This preliminary report describes the technical safeguards required by the International Atomic Energy Agency (IAEA) for current and near-term fast breeder reactors (FBRs) and assesses the current and developing safeguards techniques and systems consistent with the eventual deployment of fast-breeder power systems.

Safeguards for nuclear fuel cycles should be considered in the context of a world deployment of various reactor types and a varying availability of fuel cycle services. This is particularly true of the current experimental, demonstration, and prototypal fast breeders, which must be fueled and safeguarded in the transition period.¹ The quantities of plutonium and uranium fissile materials, the fuel handling systems, and the storage methods for the fuel assemblies of fast breeders will have a significant impact on safeguards techniques. The plutonium and fissile uranium throughput, the high fissile content, and the use of sodium coolant for the liquid-metal fast breeder reactor (LMFBR) fuel cycles may require development of additional safeguards techniques beyond those for the thermal light-water reactor (LWR) fuel cycle.

The feasibility of, and the limitations and constraints on, the application of certain safeguards measures and techniques for the LMFBR are not in common with LWR systems. Important distinctions of the LMFBR fuel cycle are: the total quantity of nuclear material in inventory and in flow; the concentration levels of nuclear material in single items (assemblies); the assembly-

handling operations and storage facilities; the reactor operating modes. The total quantity of nuclear material in inventory and in flow for each demonstration and commercial breeder reactor system would be 3,000-10,000 kg of plutonium, which is in the range more of the annual flow rates of 6,000-12,000 kg for current and proposed large LWR reprocessing plants. The content of the fissile material, 6-15 kg of plutonium, in each of the fresh and spent fuel assemblies is on the order of the IAEA significant-quantity guideline of 8 kg. The automated assembly-handling and the storage facilities, both in-air and in-sodium, and reactor operations facilities should be understood in some detail to effectively develop and optimize safeguards consistent with the needs and the inspection resources of the IAEA.

A timely perspective for developing LMFBR safeguards is obtained by considering that the existing experimental reactors have plutonium flow rates and inventory quantities (ranging from 1/2 to 2 tonnes of plutonium) which is comparable to some current size reprocessing and mixed oxide fabrication plants having flow rates of about 200 tonnes of heavy metal (1 to 2 tonnes of plutonium) per year. Consequently, in the context of near-term nuclear power development, the deployment of LMFBRs and reprocessing facilities appear to be on a comparable time-scale with impact on safeguards system development needs closely coupled.

The general objective of the study is to perform a diversion analysis and an assessment of the available safeguards methods and systems for verifying inventory and flow of nuclear material in accessible and inaccessible areas of LMFBR systems. The study focuses primarily on the assembly-handling operations, assembly storage facilities, and reactor operations relating to existing and/or near-term planned experimental, demonstration and prototypal reactor plants. The safeguards systems and methods presented are considered to be feasible for development and for implementation within the resource limitation of the IAEA and are considered to be consistent with the objectives, requirements, and constraints of the IAEA as outlined in IAEA documents INFCIRC/153² and INFCIRC/66-Rev.#2³.

The current study phase of this task emphasizes: (1) selection of one or more reference LMFBRs and handling systems; (2) development of a diversion-path analysis for the current class of prototypal and demonstration reactors and for the design and handling features relating to the experimental class of reactors; (3) preliminary assessment of the potential implementation of currently available accountability methods and containment and surveillance techniques; (4) safeguards inspection effort needed to delineate the inspection activities and the IAEA's annual manpower requirements; and (5) procedures for implementing IAEA safeguards systems, with recommendations for application of available safeguards techniques and suggestions for development programs of more advanced cost-effective techniques.

II. REFERENCE LMFBRs AND FUEL HANDLING SYSTEMS

The facility design features of the generic LMFBR reference reactors and fuel handling systems are primarily based on two general classes of reactors -- (1) demonstration and commercial and (2) experimental -- currently in operation, under construction, or in the design stage. The former class includes SNR-300⁴ (Federal Republic of Germany, or FRG), Monju⁵ (Japan), Phenix⁶ and Super Phenix⁷ (France), BN-350⁸ and BN-600⁹ (USSR), and the CRBR¹⁰ (US). The

scale of the experimental reactors falls into two categories: power ratings (1) higher than 100 MWt and (2) lower than 100 MWt. In the first category are the FFTF¹¹ (US) and the PFR¹² (UK). In the second are EBR-II¹³ (US), the KNK-2¹⁴ (FRG), Joyo¹⁵ (Japan), FBTR¹⁶ (India), and the BOR-60¹⁷ (USSR).

The basic units of one fuel assembly and one blanket assembly have been adopted for item accountability with reactors in the normal operating mode. However, for the experimental reactors, experimental requirements and experimental-assembly designs necessitate the more restrictive item accountability by fuel element (pin). Generally, the fuel assemblies for the operating power reactors differ from those for the experimental reactors in dimensional design, dismantling capabilities, frequency and mode of handling, plutonium and ²³⁵U content, and burnup rate and average burnup. These differences necessitate investigating variations in requirements for diversion path analysis, safeguards measures, item accountability, and containment and surveillance (C/S) techniques.

Since the safeguards system will have some components that are plant-specific even within each class and category of reactor, the safeguards analysis has been structured to include three general considerations: (1) verification of the inventory of fresh fuel assemblies in handling and storage; (2) verification of the inventory of irradiated fuel assemblies in storage and in preparation for transport; and (3) handling systems for irradiated fuel assemblies. The third consideration involves some unique differences in the design of fuel handling systems that necessitates plant-specific safeguards. In some plants, experimental assemblies or fuel assemblies must be dismantled and given special handling and storage. The requirements for verifying inventory and flow of these dismantled assemblies as well as the intact assemblies have been assessed in terms of reference plant operations and handling programs, with item accountability adopted to the level of the individual fuel elements within the assembly when necessary.

The differences between the core and blanket design details for the demonstration and commercial reactors and the experimental reactors have been categorized and are summarized in Table I. The categorization allows

TABLE I. Data for Reference LMFBR Fuel and Blanket Assemblies

	Experimental Systems		Demonstration Systems	Commercial Systems
	<100 MWt	>100 MWt		
Number of Assemblies				
Inner Core	60	30-80	60-110	170-200
Outer Core		50	50-90	160-170
Blanket	200	50	90-170	200-400
Fuel Elements/Ass.	90	200-325	160-220	130-270
Uranium Elements/Blanket Ass.	30	80-90	80-90	40-90
Nuclear Fuel Content (Fresh/Irradiated)				
Material Form	PuO ₂ /UO ₂	PuO ₂ /UO ₂	PuO ₂ /UO ₂	PuO ₂ /UO ₂
Heavy Metal, kg/Ass.	2-14	30-50	30-55	20-95
Pu/ ²³⁵ U, kg/Ass.	1-3 Pu, 2-3 ²³⁵ U	8-13 Pu, 10-12 ²³⁵ U	6-14	3-18
Pu/ ²³⁵ U, kg/Element	0.03-0.07	0.03-0.04	0.03-0.06	0.025-0.05
Irradiated Blanket				
Pu, kg/Ass.	1	1-3	1-3	1-3
Pu, kg/Element	0.03	0.01-0.04	0.01-0.04	0.01-0.04

maintaining a cognizance of design differences that must be identified and addressed in planning a generic safeguards system. Although the objective of the experimental programs for all these reactor systems have much in common, the operating modes for handling and testing fuels differ sufficiently to require changes in IAEA safeguards approach.

Many types of fuel-performance irradiation tests and test devices have been developed for specific research and development (R&D) functions, specific reactor systems, and specific R&D radiation programs. The programs for assembling and preirradiation inspection and for dismantling and postirradiation inspection, as well as the plant capabilities, differ significantly for the two classes of reactor facilities. In some experimental reactor facilities, the core assemblies are being, or will be, assembled and dismantled on the site. In such a case, the safeguards plan must accommodate the flow of item accountability at the fuel-element level.

The design features of the metallurgical inspection cells, and of the assembly and dismantling cells, the IAEA accountancy verification measures, and the IAEA C/S techniques have been integrated into generic LMFBR fuel handling systems for the experimental-reactor facilities. The reference generic fuel handling system for the demonstration and commercial LMFBRs does not include the metallurgical inspection cell. None of the reactor systems studied included on-site facilities for analytical-chemistry investigations requiring destructive assays. Areas for these chemical assays have therefore not been considered in the safeguards plan developed in this study.

III. DIVERSION ANALYSIS

The significant safeguards concerns for LMFBRs and for LMFBR fuel handling systems are the accountability, surveillance, and unique assembly identification of fuel and blanket assemblies during the following fuel cycle sequential activities of: unloading the fresh fuel and blanket assemblies from the transport casks into storage cells with an air atmosphere, transfer into other cells for storage under sodium, loading the assemblies into the reactor vessel and reactor core, unloading the spent fuel and blanket assemblies from the reactor into temporary storage pools for planned decay-heat cooling periods, and finally removing the assemblies from the storage pools, and transferring the assemblies to the shipping cask.

The unique feature of this sequence of stages is that both the fresh and the irradiated fuel assemblies, each containing about equal masses of plutonium, are submerged in sodium in the reactor operations facilities. The sodium environment limits direct visual inspection and assembly identification to those times when the assembly is in the assembly handling operations and storage facilities during movement in the transfer areas (out of sodium or air storage), during movement through the transfer cell to conditioning cells, and during the in-water or in-air storage and eventual loading into the spent-fuel shipping cask. Additional safeguards concerns for the experimental reactors must include the on-site capability to partially disassemble an experimental assembly, reassemble it with fresh test fuel elements (pins), and reinsert the assembly into the reactor for further irradiation.

The total time interval from receiving fresh fuel and blanket assemblies to shipping the spent fuel and blanket assemblies may be on the order of 1-2 yr

for experimental facilities and 5-7 yr for demonstration and commercial power-generating systems.

The diversion analysis for the design of the safeguards approach must include two general extreme diversion strategies: (1) the abrupt diversion of at least one assembly, and (2) the protracted diversion of a significant quantity of nuclear material by the removal of some fuel elements from assemblies over an extended time period. The diversion analysis would therefore include items of nuclear material that may be diverted within the limits of IAEA verification requirements.

For the purpose of this study, the manner in which abrupt diversion could occur includes the following considerations (listed in the order of probable occurrence or estimated importance):

1. Substitution of unirradiated fuel assemblies with counterfeit or dummy assemblies not containing fissionable nuclear material. The substitution may be made by the reactor operator, the fabricator, or both the operator and the fabricator in collusion.

2. Substitution of unirradiated fuel assemblies with dummy assemblies containing fewer fissile-fuel elements (pins). The substitution may be made in the same way as in the preceding Item 2.

3. Interchange of fuel assemblies with blanket assemblies, which may be effected by the operator during loading and unloading. This possibility is enhanced when the fuel-cycle management programs include blanket assembly reshuffling for optimum breeding.

4. Interchange of fuel assemblies with assemblies having a lower concentration of nuclear fissile material.

5. Substitution of irradiated fuel assemblies with dummy assemblies. This may be done by the reactor operator working alone or in collusion with the operators of the fabrication and reprocessing plants.

Protracted diversion of fuel elements (pins) would be a safeguards concern only for experimental reactors with on-site dismantling facilities and examination facilities to evaluate fuel performance. In these facilities, the nuclear material flows and inventory can be in the form of fuel elements (pins) because of a need for direct examination of the pins or for dismantling and handling experimental or failed fuel assemblies.

Accountability by fuel element must be considered for all reactor systems in which cooling storage of individual fuel elements in air or gas is being planned.

The diversion-analysis approach used in the study includes selection of material balance areas (MBAs) and key measurement points (KMPs) for physical inventory and flow to verify: (1) nuclear material flow from receipts of fresh assembly and dispositions of intact and nonintact irradiated assemblies or fuel elements; and (2) physical inventory in storage areas such as receiving vessels, buffer storage tanks, preparation or conditioning cells, and sodium and nonsodium cooling storage tanks for unirradiated and irradiated

assemblies. To maintain continuity of knowledge for verification of the flow and physical inventory of assemblies and elements, appropriate and available C/S measures would supplement the item-accountability measures at the KMPs.

A. SAFEGUARDS OBJECTIVES AND GOALS

The objective of the IAEA inspection effort is the independent verification of assembly and/or fuel-element flow and storage inventory consistent with the goals and guidelines for timeliness and significant quantities outlined in INFCE/SEC/11.¹⁸ Within the IAEA, the meaning of "significant quantity," or SQ, is related to existing IAEA safeguards practices that involve periodic inventory verification and complementary C/S of nuclear material. The IAEA attempts to identify a timeliness of diversion detection (to be of the same order of magnitude as conversion time) before the material is processed for component fabrication. This detection time is a function of the physical and chemical form of the material. The current IAEA goals for SQ and the proposed guidelines for conversion time as applied to the range of reactor systems comprising the reference fuel handling systems in this study are outlined in Table II for the demonstration and commercial systems and Table III for the experimental systems. The fissile composition and quantities

TABLE II. IAEA Safeguards Goals and Guidelines: Nuclear Material, Significant Quantity, and Conversion Time for Demonstration and Commercial Systems

Nuclear Material	Significant Quantity (SQ)	Number of Assemblies	Number of Elements	Conversion Time
Non-Irradiated Fuel PuO_2/UO_2	8 kg Pu	1	110-320	order of 1-3 weeks
Non-Irradiated Fuel $^{235}\text{UO}_2/\text{UO}_2$	25 kg ^{235}U	2-5	220-1600	order of 1-3 weeks
Irradiated Fuel PuO_2/UO_2	8 kg Pu	1	110-320	order of 1-3 months
Irradiated Fuel $^{235}\text{UO}_2/\text{UO}_2/\text{PuO}_2$	8 kg Pu + (8/25) ^{235}U	2-5	220-1600	order of 1-3 months
Irradiated Blanket PuO_2/UO_2	8 kg Pu	2-8	220-800	order of 1-3 months

TABLE III. IAEA Safeguards Goals and Guidelines: Nuclear Material, Significant Quantity, and Conversion Time for Experimental Systems

Nuclear Material	Significant Quantity (SQ)	Number of Assemblies	Number of Elements	Conversion Time
Non-Irradiated Fuel PuO_2/UO_2	8 kg Pu + U [$^{235}\text{U} > 20\%$]	1-3	90-270	order of 1-3 weeks
Non-Irradiated Fuel $^{235}\text{UO}_2$	25 kg ^{235}U	8-12	720-1080	order of 1-3 weeks
Irradiated Fuel PuO_2/UO_2	8 kg Pu + U [$^{235}\text{U} > 20\%$]	1-3	90-270	order of 1-3 months
Irradiated Fuel $^{235}\text{UO}_2$	25 kg ^{235}U	8-12	720-1080	order of 1-3 months
Irradiated Blanket PuO_2/UO_2	8 kg Pu	8	720	order of 1-3 months

listed provide the base data for developing a safeguards approach in terms of IAEA significant quantities and timeliness goals and guidelines for diversion analysis.

The nuclear materials in Tables II and III are listed in the probable order of the ease of handling and/or processing for direct use of the contained fissile material. This preliminary ordering is subject to modification depending on the design specifics of the reactor system and the operating mode. For demonstration and commercial systems, Table II, with initial loadings of fresh PuO_2/UO_2 fueled assemblies containing 6-14 kg of plutonium, the assembly is considered a high-priority single-item-accounting unit containing a SQ of nuclear material. For this class of reactor systems using highly enriched uranium HEU ($> 20\%$) in the initial phases of the fuel cycle, the increase in the number of items necessary to accumulate a SQ of nuclear material places this mode of diversion at a slightly lower level of possible occurrence.

In the experimental class of reactor systems, Table III, the difference in the ordering of possible occurrence for assemblies initially fueled with PuO_2/UO_2 and those initially fueled with HEU ($^{235}\text{U} > 60\%$) becomes insignificant depending on the specific design and size of the assembly.

The blanket assemblies are given the lowest level of occurrence probability in both the demonstration and commercial systems and the experimental systems, because the annual item flow is usually small. The flow-through for blanket assemblies is about one-third that for the fuel assemblies.

For specific operating situations in the experimental reactors, such as failed fuel assemblies that may have to be partially or completely dismantled, the item accountability is to be measured in terms of fuel elements. The item flow would be monitored only at relevant strategic measurement points of the safeguards system. The safeguards approach for failed fuel assemblies in the demonstration and commercial reactors, however, assumes that the assembly will be handled as an intact assembly and prepared for shipment to an off-site facility for evaluation. If the facility has no capability for destructive metallurgical and chemical analysis, the ordering of diversion occurrence for the fuel elements is expected to follow closely those levels assigned the intact assemblies in Tables II and III.

B. POTENTIAL IMPACT ON THE IAEA INSPECTION EFFORTS

Part A of the IAEA Safeguards Technical Manual outlines the objectives, discusses possible diversion paths of nuclear materials, describes the present IAEA safeguards system, and presents guidelines for the State's system of material accounting and control (SSAC), in terms of meeting IAEA reporting requirements.

IAEA safeguards inspections for power reactors now rely on routine reporting by the State and periodic inspection by IAEA personnel for independent inventory verification. The procedures, frequency, and levels of inspection are negotiated with the State and are documented in accord with two basic types of documents: (1) agreements between the State and IAEA (in accordance with INFCIRC/153 and INFCIRC/66-Rev-2), and (2) Facility Attachments. Specific information on the site and agreements are included in the Facility

Attachments and the Design Information Questionnaire (DIQ). The DIQ for reactors contain detailed descriptions and drawings of facility layout, reactor operating and design data, nuclear material descriptions, nuclear-material flow, nuclear-material handling, and nuclear-material accountancy and control systems.

Generally, the agreements require the State to provide monthly reports. The accounting reports the State supplies for each material-balance area include inventory-change reports (ICRs) and material-balance reports (MBRs) with physical inventory listings (PILs). Special reports (SRs) are issued by the State under unusual circumstances where anomalies or potential anomalies in nuclear-material balance have been identified.

Periods between inspections by the IAEA can vary from one to twelve months depending on the type of power reactor. The negotiated inspection level and frequency are agreed to in terms of inspector-days per facility, with the IAEA having some discretion in the allocation of the effort. The total inspection may require one or more man-years of effort per year for the reactor facility and the assembly handling and storage facilities in the LMFBR systems being considered in this study. The continuity of surveillance is partially provided in some stages of the fuel cycle (e.g., fresh- and spent-fuel storage) by placing storage seals at access positions and using a camera-surveillance or access position monitoring system to detect undeclared movement of items.

For LMFBRs, the detection time criteria indicate the need for the highest frequency of inspection in the stages of the fuel-assembly handling system containing fresh fuel than in those containing irradiated fuel. However, the inspections for inventory verification in the fresh fuel stages may be coupled with the scheduled shipments of batch loads of unirradiated assemblies from the fabricator that are temporarily stored until the replacement core loading is completed, processed, and prepared for reactor operation. In estimating the IAEA's inspection effort for item identification, accountancy, and inventory verification, a prime consideration is the overall safeguards approach which includes optimizing the complementary safeguards measures of C/S. The inspection activities and frequency of inspection determined for each strategic point are to be made consistent with the guidelines of INFCIRC/ 153 and INFCIRC/ 66-Rev-2, and to be maintained within the limited resources of the IAEA. A reference preliminary safeguards approach for LMFBR'S is outlined in IAEA-STR-85.¹⁹

C. ITEM FLOW IN FUEL HANDLING SYSTEM

1. Item Accountability

The item-accountability measure of fuel and blanket assemblies in the fuel-handling storage and operations, or in the reactor-operations facility, is formed by adding all measured receipts to the initial inventory and subtracting all measured removals from the final measured inventory. During the normal flow of uniquely identified assemblies, nuclear-materials control emphasizes administrative controls supplemented by secure storage for the identified assemblies, tamper-indicating assembly seals or systems of seals, sealed containers or transport casks for receiving and shipping, etc. Although these methods of assembly inventory are effective for control of nuclear materials, there exist inherent limitations in both sensitivity and

timeliness. Limited measurement capabilities and the uncertainties of the nuclear-material content in the assemblies, may obscure the diversion of significant quantities of nuclear materials from a plant. Timeliness may be limited by practical difficulties such as accessibility, economics of operation, and consequent reduction in the frequency of item inventory verification. Use of nondestructive assays and special in-plant sensors such as gamma-ray detectors and neutron interrogation techniques would provide the technical basis for improved methods of item accountability verification.

The inventory closing balance of item accounting may be a necessary condition for some level of assurance that diversion has not occurred, but it is neither sufficient nor satisfactory for meeting the safeguards objectives of the IAEA. The fundamental attribute of items containing fissile material is the fissile-material content itself.

Item accountability and the accountability of the nuclear-material contained in the assembly can be equivalent only when there is assurance that nuclear-material is not missing from the assembly, i.e., assurance that the integrity of the assembly and its contents has been maintained. The use of neutron interrogation techniques for nondestructive assay (NDA) would provide direct assurance that the integrity of the nuclear-material content has not been compromised since the fabrication of the assembly.

The distinction must be maintained between NDA neutron-coincidence counting, NCC systems of measurements for nuclear-material accounting in the sense of nuclear material balance accountancy and NDA for the verification of nuclear-material content for accountability in an assembly. It is only in the latter sense that NDA is recommended in this report. For this mode of using NDA the accuracy of measurements is a second level consideration. To measure material content to 1%, or to 2%, or to 10%, etc., would be related to the level of assurance of material type and content in the assembly.

2. Containment and Surveillance (C/S)

The principal containment and surveillance function applicable to item accountability is monitoring of assembly storage areas, assembly flows, and assembly handling. The C/S measures would produce a record of any unplanned changes in the item inventory by application of closed-circuit TV (CCTV), radiation monitors, and loading sensors on assembly handling machines. C/S measures include the monitoring of strategic areas not specifically planned for storage of nuclear material. The integrity of IAEA instrumentation, devices, and seals would be supported by surveillance records.

A technical effective safeguards approach with item accountability for the fuel handling system will require development of devices to identify fuel assemblies and of tamper-indicating seals or systems of seals on designs of reactor-specific fuel assemblies. The devices and seals may have to be designed to operate under sodium.

The equivalence between accountability of items and the accountability of nuclear material content requires the added assurance that the structural integrity of the assembly and its contents have been maintained since fabrication. The use of tamper-indicating seals or a system of seals would provide part of this assurance.

3. Operator Fuel Handling System Control Points (OCP)

The operational stages of the fuel handling system are designed for moving assemblies within the reactor complex. The operation consists of transferring the assemblies into and out of the reactor and, by crane and transport casks, to adjoining supporting facilities for storage, inspection, decontamination, and shipment to off-site processing plants.

a. OCP Reference Plan for Demonstration and Commercial Reactors

Figure 1 represents the reference assembly-flow plan for the fuel handling systems of demonstration and commercial reactors. Each major stage in the handling sequence is identified with a listing of the operating functions at that stage and denoted as a numbered operator control point (OCP). The movement of assemblies inside the reactor vessel (OCP-4) includes shuffling or interchanging of assemblies between core and blanket positions, transfer of assemblies to and from a temporary storage position, and transfer of assemblies to an access port through which the fuel transfer machine moves the assemblies to external sodium-cooled storage positions. The fuel handling system must be capable of performing these operations in the least possible time for economical operation and in accordance with the rigorous safety practices required because of the environment of radioactivity and sodium.

The operations related to flow of fuel and blanket assemblies involve the inspection of fresh assemblies and temporary storage of the assemblies (OCP-2) before being transferred into the in-sodium storage cell (OCP-3). In addition to gauging tests and inspections at OCP-2, the operator may require a NDA measurement of nuclear-material content in the fresh assemblies. The operator's incentive for measurement may be based on either the economics of operational management and control of nuclear materials in resolving shipper/ receiver differences between fabricator and operator or on a need for an independent measure of quality control to enhance the safety of the reactor power operations. With good management of material control, assemblies that do not satisfy nuclear-material specifications will be rejected in the early stages of the fuel handling operations. For normal power operation, the time period between receipt and core loading of assemblies may be on the order of 1 to 2 yr. For non-normal power operation, this time period may extend to 3 or 4 yr, and more storage capacity for fresh-fuel may be required.

Operators' control point, 3, includes the storage area for irradiated assemblies, which is required to allow adequate reduction of decay heat before being transferred to the inspection and preparation cell (OCP-6) for off-site shipment or extended storage. The inspection and preparation cell may also contain equipment for dismantling of special assemblies to recover in-reactor measuring instruments or to recover experimental capsules for shipment to a metallurgical-examination laboratory.

The inspection and shipment-preparation cell (OCP-9) is the final operator control point before transfer of nuclear material to the shipping area. The final detailed verification measures and data acquisition for each assembly would be taken in OCP-9. The NDA measurement of the nuclear material content in each assembly would establish an independent base for resolving shipper/receiver differences between the reactor operator and the reprocessing operator.

Fig. 1. Reference Assembly-flow Plan for Fuel Handling Systems of Demonstration and Commercial LMFBR Plants

b. OCP Accounting of Assemblies

Operation of all fuel handling systems is automated except those involving unloading of fresh fuel assemblies from the transport cask and into a receiving storage cell (OCP-1). The automated systems control and record the operation of each handling mechanism. These programming operations include the positioning of the rotating reactor plugs, fuel handling grippers, fuel transfer mechanisms, and storage racks, including the vertical displacements of the racks. The movements, transfers, and positions for each assembly are recorded and stored in a computer based data-acquisition-and-retrieval system. The operator's computer has an accountancy data bank with a detailed and timely record of the assemblies in the reactor plant. The data bank contains the following information for each assembly: fabricators assembly identification; nuclear material and physical specifications; operators identification markings or serial numbers and relevant data for planned operation; results of gauging, physical measurement tests, and other inspection tests such as NDA measurements; position index by core row, sector, and number; computed or estimated burnup rate; transfer and movement from core; position index in storage cells or transfer buffer storage cells; and pertinent data on receipt and shipment dates. Under the planned safeguards approach, the assessability of the detailed data-bank information to the inspector should be incorporated into the inspection plan when needed for independent verification of assembly accountancy.

c. OCP Reference Plan for Experimental Reactors

Figure 2 represents the reference assembly-flow plan for the fuel handling systems of experimental reactors. The sequence of the fuel handling operation is basically similar in most stages to that for the demonstration and commercial reactors. The major differences are in the areas of OCP-6 and OCP-9, where on-site facilities exist for dismantling the experimental assemblies and examining the individual fuel elements. Reassembling of the experimental fuel assemblies with replacement fuel elements for further irradiation is a normal mode of operation. The handling sequence of the individual fuel elements for this stage of the system is an important consideration in the design of the safeguards approach.

4. Safeguards Approach: Material-balance Areas (MBAs) and Key Measurement Points (KMPs)

The diversion analysis and safeguards approach requires the selection of material-balance areas and key measurement points that would overlay and be consistent with the operational system of nuclear materials accountancy and control. The number of MBAs and KMPs will depend on the specific reactor-plant design, the plant operating mode, and the accessibility of the assemblies for implementing appropriate safeguards measures. The MBAs contain the closing inventory balance in the item accountancy of all identified assemblies except special experimental assemblies received from the fabrication plant. These assemblies are eventually shipped to the reprocessing plant or to off-site metallurgical laboratories for further investigation.

A preliminary study of the safeguards concerns at the interfaces between the output of the fabrication plant and the input to the LMFBR assembly handling operations, and between the output of the LMFBR assembly

Fig. 2. Reference Assembly-flow Plan for Fuel Handling Systems of Experimental LMFBR Plants

handling operations and the input to the reprocessing plant, indicates that safeguards considerations are interrelated. Nondestructive-assay and C/S methods at the LMFBR assembly handling facilities can be implemented only after detailed analysis has been given to the sequence of verification activities addressing the integrity of nuclear-material content at the fuel fabrication plant, the LMFBR facilities, and the reprocessing plant. Such an analysis must recognize the potential for diversion by a facility operator acting alone or in collusion with one or both of the other facility operators.

To effectively address the safeguards concern when the basic unit of item accountability is the assembly, the total LMFBR fuel handling facilities is divided into two MBAs: (1) the assembly handling and storage operations facilities (MBA-ABEF) and (2) the reactor operations facility (MBA-CD). Figure 3 represents the preliminary safeguards plan for the reference fuel handling system of demonstration and commercial reactors, and Fig. 4 represents the plan for the reference experimental reactors.

a. Assembly Handling and Storage Operations Facilities (MBA-ABEF)

The MBA-ABEF incorporates all in-air handling and storage operations (which are accessible areas) external to the in-sodium storage cell and the reactor vessel (both of which are inaccessible areas). For safeguards purposes, in-air handling and storage for fresh fuel and blanket assemblies are considered essentially as extensions of the handling and storage operations of the high-plutonium-throughput fuel fabrication plant, the only difference being in the exchange of assembly ownership and possible discrepancies between shipper and receiver on fuel content and specifications. Consequently, the IAEA's safeguards approach over this stage of the handling and storage operation is to extend to the MBA-ABEF the IAEA safeguards system (including inspection criteria and effort) applied at the fabrication plant.

The handling and storage operations for spent fuel and blanket assemblies in the MBA-ABEF are for processing and preparation of the assemblies for extended periods of storage before shipment off-site for reprocessing.

The difference between the safeguards plans for unirradiated and irradiated assemblies is the inspection frequency timeliness criteria consistent with the conditions of irradiation, and the inspection methods for inventory and transfer verification.

b. Reactor Operations Facility (MBA-CD)

The MBA-CD incorporates the handling and storage operations more directly relevant to the power operation of the reactor. The fuel and blanket assemblies are preconditioned for reactor loading and operations by thermal equilibration in the sodium environment. The MBA-CD comprises the under-sodium phase of the LMFBR handling and storage operations and defines the areas inaccessible for direct visual inspection and surveillance of fuel and blanket assemblies. The under-sodium environment of MBA-CD presents the advantage of a "quasi-containment" system, which would make it easier to supplement safeguards system accountancy measures by the use of C/S devices. The assembly flow in each transfer into or out of the MBA-CD may be determined by NDA and C/S devices. The reactor and storage cells in the MBA-CD is

Fig. 3. Preliminary Safeguards Plan for Reference Demonstration and Commercial LMFBF Plants

MBA-ABEF: ASSEMBLY HANDLING AND STORAGE OPERATION FACILITIES

MBA-CD: REACTOR OPERATIONS FACILITY

Fig. 4. Preliminary Safeguards Plan for Reference Experimental LMFR Plants

expected to have the capacity for the appropriate number of unirradiated assemblies for a single core loading and an equivalent core unloading of irradiated assemblies.

c. Key Measurement Points (KMPs)

The KMPs are selected at locations where the assemblies may be identified and accounted for to determine physical inventories and flows of the items (assemblies or elements). The KMPs for physical inventory include the assembly storage cells in each of the MBAs. The KMPs for flow include the verification of inputs and outputs (including measured discards) at each of the MBAs. The KMPs for physical inventory are denoted KMP-(A,B...); those for flows are denoted as KMP-(1,2...). The system of KMPs has been selected to form a safeguards structure with the sequence of operating stages coincident with the sequence of OCPs. With this approach, the safeguards impact on the plant operating mode is at a minimum, and the potential for IAEA inspectors to monitor the standard plant operating and process-control systems for nuclear material verification is at a maximum.

The selected KMPs for inventory are:

- KMP-A: In-air Storage
- KMP-B: In-sodium Storage
- KMP-C: Reactor Vessel
- KMP-D: In-sodium Extended Storage
- KMP-E: In-water or In-gas Extended Storage
- KMP-F: Buffer Storage for Shipment Preparation

The selected KMPs for flow are:

- KMP-1: Receiving Area
- KMP-2: Transfer from In-air Storage to In-sodium Storage
- KMP-3: Inspection and Preparation Cell
- KMP-4: Shipping Area

d. Strategic Points (SPs)

The strategic points (SPs) for the use of C/S devices are selected to determine information necessary and sufficient for safeguards measures, including the verification of the nuclear material in assembly flows and in storage inventories. All the SPs are in the access routes to and from the storage cells and reactor vessel.

The SPs selected are:

- SP-1: Assembly In-air Storage
- SP-2: Fuel Transfer Machine
- SP-3: Reactor Vessel and Charging Machine
- SP-4: In-sodium Extended Storage
- SP-5: In-water or In-gas Extended Storage
- SP-6: Buffer Storage for Shipment

All SPs are identified in Figs. 3 and 4.

5. Description of Safeguards Plans for MBAs and KMPs

a. KMP-1: Receiving Area

In the receiving area (KMP-1), the primary safeguards function is verification of the fabricator's shipment inventory (item count) of the transport cask and of the fabricator's fuel-assembly identification and fuel-content specifications. The containment and surveillance measures would include inspection of the IAEA's cask seal for its integrity and inspection of the shipped items for physical integrity.

Current shipping casks and canisters for transporting fresh and irradiated fuel to and from reactor power plants are being designed to handle 6-9 assemblies. The frequency of inspection is influenced by the operating mode of the specific reactor plant and on the reactor operator's program for accumulation and management of a core loading.

b. KMP-A: In-air Storage

The in-air storage cell (KMP-A) is the first phase in the item-flow cycle where extensive and detailed safeguards measures may be applied for independent verification by means of item-identification such as fabricator's identification markings, characteristic welding-line signatures (by close-up photography), item-identification sensors (FAIDs), and item structural-integrity devices if developed and adopted. These measures may be applied at this stage with minimal constraints due to the in-air environment, and due to the minimum impact on the efficient and economic operation of the reactor plant.

Safeguards-related NDA instrumentation would be introduced at this stage of the assembly handling sequence to identify anomalies which may exist between the fabricator and the reactor operator. NDA measures may be required to meet the timeliness and the significant quantity aspects of IAEA safeguards (INFCIRC/153, para 28 and 29, and INFCE/SEC/11).

The fissile isotope concentrations in the fresh LMFBR assemblies and elements are high enough that the NDA techniques for item accountability that are currently available or at advanced stages of development and implementation may be applied directly at this stage of the item-flow cycle. The high-resolution gamma spectroscopy system (HRGS), the high level neutron coincidence counter (HLNCC), and the active-well neutron coincidence counter (AWCC), or modifications thereof, appear to be most effective in establishing, for each assembly, the uranium and plutonium gamma-ray spectra, the ^{240}Pu content by passive coincidence counting of spontaneous fission neutrons, and the active neutron interrogation by coincidence counting of induced-fission neutrons in the fissile isotopes. The last two measurements are fundamental for the success of the safeguards system in verifying the inventory and item flow of fissile nuclear material in the LMFBR fuel handling system. All the measurements, however, will provide the basic data that will be compared with data from similar measurements after the assembly has been irradiated.

Use of the NDA measurements at this stage serves two fundamental safeguards functions simultaneously: surveillance and material accountancy.

For surveillance, it provides assurance that the integrity of the nuclear-material content in the assembly has been maintained. For accountancy, it establishes the basic data of nuclear-material accountancy for the complete fuel handling operation.

In the subsequent stages of the fuel handling operation, however, the timeliness criteria for detecting anomalies in item flow may be performed effectively by item accountancy supplemented by C/S devices designed for assembly identification and structural integrity monitoring.

c. KMP-2: Transfer from In-air Storage to In-sodium Storage

The flow KMP-2 is where independent verification can be made of the inventory change reports (ICRs) of transfers from MBA-ABEF to MBA-CD.

d. KMP-B: In-sodium Storage

The operators measurements for nuclear-materials control and the IAEA inspector's verification measurements performed and recorded for the fresh fuel assemblies in flow KMP-1 and -2 and for the physical-inventory KMP-A would be supplemented in the KMP-B stage by the records produced by the automated position indexing controller for the fuel transfer machine. Storage locations before the core loading, and storage locations after irradiation are recorded. Measures of interest to IAEA safeguards include records from the transfer machine loading and motion sensors and records correlating assembly signatures with storage-position index. The CCTV surveillance system would give assurance of the integrity of the automated item accountability and storage transfer operations. IAEA CCTV surveillance would be installed at SP-2 to register any transfer of items into or out of the sodium environment.

After an appropriate decay cooling period and before transfer to the extended storage cell KMP-D or KMP-E, spent fuel assemblies in the KMP-B storage area may be examined to determine the plutonium content for comparison and correlation with the preirradiation data, and for verifying the period. The primary measurement of interest would be passive neutron coincidence counting (with HLNCC), which would establish the spontaneous fission rates for normalization to the preirradiation data. The differential in the spontaneous fission count rate before and after irradiation would be due to ^{242}Cm and ^{244}Cm , and can be related directly to the irradiation history of the assembly. This allows an independent verification of the operators predetermined fuel management program reports of core loading, position shuffling, and operating power levels.

Active neutron interrogation measurements (by AWCC) of induced-fission neutrons could be correlated with similar data on the assembly before irradiation. Those measurements would establish the content of fissile fuel (plutonium or $\text{Pu}/^{235}\text{U}$) in the assembly. An additional comparison of interest for the IAEA safeguards verification would be the ratio of induced-fission neutron counts to the spontaneous-fission (SF) neutron counts before and after irradiation.

e. KMP-C: Reactor Vessel

The primary safeguards interest in the KMP-C stage is the correlation between (1) assembly positioning and the automated movement-and-

positioning index of the rotating-plug systems, and (2) the indications of the loading and motion sensors of the charging machine (SP-3). The data records must reflect the preplanned in-core loading and unloading configuration, the sequence of assembly transfers between in-vessel storage and core positions, and the reshuffling of assemblies in core and blanket. These records, which are contained in the operation computer data bank, are accessible to the IAEA for inspection procedures which provide the agency with an independent verification check when compared with IAEA safeguards data for the stages preceding and following KMP-C.

The KMP-C operational records include the reactor power operating history, records of the position index of the control rods, and the history of the control rod settings throughout the operating power cycle. Some reactor designs allow items to be transferred from the reactor vessel when the reactor is at full power. The CCTV surveillance of the charging machine at SP-3 or the fuel transfer machine at SP-2, or both, would monitor the out-of-sodium movement of assemblies in the sodium storage vessels. Under certain abnormal reactor operating conditions, information on control rod settings and transfer-machine-movement indexing may be required by the IAEA.

f. KMP-3: Inspection and Preparation Cell

Functions at the inspection and preparation cell staging area KMP-3, include cleaning the sodium from assemblies in preparation for direct shipment, extended storage before shipment, or metallurgical inspection and measurements before shipment. In experimental-reactor systems, the cell operations also prepare experimental or failed fuel elements for metallurgical inspection, and possibly dismantling, to establish the further disposition of the fuel elements.

IAEA safeguards measures are needed at the flow KMP-3 to provide independent verification of the inventory changes from MBA-CD to MBA-ABEF.

g. KMP-D: In-sodium Storage; KMP-E: In-water or In-gas Storage

In the case of extended storage and subsequent shipment to facilities external to the reactor plant, the assemblies would be stored under sealed conditions, with the IAEA seals supplemented by C/S methods to ensure the integrity of item-accountability, or to record movements involving the reconfiguration of the items. Surveillance devices to supplement CCTV would be crane loading sensors; under-sodium viewing (USV) systems for the in-sodium storage; and Cerenkov-glow vision devices and underwater optical viewing (UWOV) systems for the in-water or in-gas cooled storage. These devices are under development, and their potential for use should be reviewed periodically. For near-term needs, the IAEA safeguards approach would depend primarily on surveillance methods using CCTV and crane loading sensors.

h. KMP-F: Buffer Storage for Shipment Preparation

Function of the inventory measurement point KMP-F, involves the preliminary inspection phase of the irradiated assemblies in preparation for shipment. The IAEA's primary safeguards concern is the final item-accountability stage for the nuclear-material flow in the reactor plant before shipment off-site. It is the staging area at which the materials-balance for the

MBA-ABEF cycle is completed. Therefore, the safeguards approach should consider the use of a series of inspection measures to give data corresponding to the data base information developed in the initial phase of the item inventory at KMP-A.

The IAEA safeguards function at KMP-F (see Fig. 4) is to effect a rigorous item-accountability balance on the level of the assembly subunit fuel elements for the case of experimental assemblies requiring metallurgical examination or in the case of failed fuel assemblies requiring dismantling of the assembly. The safeguards approach would use the total range of item-accountability and C/S methods outlined. In some experimental systems, on-site examination may involve the cutting-up of individual fuel elements. Item accounting at the fuel element level may therefore require supplementary C/S measures which would give assurance of only declared access to nuclear material. Since the dismantling operation and the flow of items in units of fuel elements would be confined and limited to KMP-F, that measurement point may be selected as a subset of the total MBA-ABEF. The effectiveness of assigning a MBA category to the KMP-F is reactor-plant-specific and would require information on the plant design and operating modes for handling individual fuel elements.

i. KMP-4: Shipping Area

In the operation of the flow KMP-4, preparation and loading of items into transport casks for shipment off-site are to be performed under surveillance of the CCTV system at SP-7, with video images examined for correlation with loading-sensor data and item-identification data. The final cask sealing is to be done in accordance with the IAEA's inspection requirements and plan. The current transport-cask designs have capacities ranging from 3 to 7 spent fuel assemblies. The frequency of on-site inspections for verification of item accountability would be specific to the plant and its operating mode.

IV. SAFEGUARDS MEASURES

The introduction of fuel assemblies with a high content of $\text{Pu}/^{235}\text{U}$ into the receiving and shipping areas of the fuel cycle does allow a more direct near-real-time assay profile of the disposition of $\text{Pu}/^{235}\text{U}$. Information on the timely disposition of assembly flow is obtained from the direct applicability of material accountancy by NDA methods (HLNCC)^{20,21} and from the selective application of effective C/S technique.²² The proposed safeguards measures for the fuel handling system, as indicated in the reference item-flow schematics (Figs. 3 and 4), attempt to include safeguards instrumentation that are currently available to the IAEA or are in the laboratory-testing phase of development.

A. C/S METHODS

The safeguards techniques for containment and surveillance use a combination of instrumentation at the site, CCTV monitoring, fuel-assembly identification, and tamper indicating methods such as close-up photography to record the unique signatures of characteristic weld lines. The devices considered for the monitoring fresh and spent fuel and blanket assemblies in transit,

storage, and handling are radiation monitors, load sensors on cranes and fuel handling machines, acoustic monitors, and assembly identification devices based on ultrasonics.

1. Types of C/S Instruments

a. Fuel-assembly Identification Device (FAID)²²

The FAID system provides unique information of identification and integrity for independent verification of each assembly in the inventory. The concept being developed is to place an ultrasonic FAID on each fuel assembly that can be interrogated with an ultrasonic scanner. The data from this sensor would be collected by a data-collection module through tamper-indicating data links. The concept now is being developed for application on PWR and boiling-water-reactor (BWR) fuel assemblies. No concepts or feasibility studies for applying similar devices on LMFBR assemblies have been initiated. The application of FAIDs on existing LMFBRs may pose additional problems because of the sodium environment.

b. Underwater Optical Viewing (UWOV)²³

The conceptual laser-surveillance-system, which could be installed at in-water storage cells for spent fuel, would detect movement of fuel assemblies. The laser system creates a horizontal plane surface of light below the water surface and directly above the fuel assemblies. The light surface is generated by two separate laser beams sweeping in a horizontal plane. The position of any fuel assembly intercepting the light surface is determined by triangulation. The applicability of a similar device for viewing in a plane above sodium surfaces in storage areas should be explored for the LMFBR system.

c. Cerenkov-glow Vision Device²⁴

This technique is based on imaging and measuring the intensity of the Cerenkov glow that results from the interactions of the fission-product radiation with the water in the storage pool. Tests seem to indicate a correlation between the intensity of the glow and the exposures and cooling times of fuel assemblies.

d. Under-sodium Viewing System (USV)²⁵

This system uses ultrasonic-transducer techniques to provide both imaging and ranging capabilities. Although developed for showing location and orientation position of assemblies, the system may be used for safeguards purposes to determine the identity of the assemblies, their positions, and their orientations by forming images of coded notches or indentations. Further development of this technique for use on under-sodium storage systems would be reactor-plant-specific.

e. Crane and Fuel Handling Machine Sensors²⁶

A system of sensors would provide information concerning crane and handling-machine activity in the storage and reactor facilities. The sensor-system concept uses a combination of strain gauges to establish

direction of travel and loading strains on the machines. All components except the gauges would be placed in tamper-indicating sensor modules.

f. Pool Acoustic Monitors (PAM)²⁶

The PAM would monitor underwater and under-sodium acoustic activity in the storage pool. The primary objective of the PAM would be to provide an intrusion-alert record whenever acoustic signals in the pool are characteristic of fuel-assembly handling, particularly the fuel-assembly handling associated with transfer of assemblies from storage locations.

g. Portal Monitors²⁶

Monitors to control the movement of nuclear materials through access portals use radiation detectors to detect the spontaneous emission of gamma rays or neutrons. Such a monitor can be used as part of a C/S system to assure only declared access to nuclear material.

2. Selection of C/S Instruments

Factors governing the choice of C/S instruments are (1) the availability of commercial hardware for each monitor and (2) guidelines developed from facility constraints and performance requirements. Ideally, the C/S system should:

- a. Detect both reported and unreported movements
- b. Provide assessment information for both reported and unreported movements.
- c. Provide inventory verification data.
- d. Operate with a high degree of reliability.
- e. Allow timely reporting of data.
- f. Provide tamper-indicating capability throughout the system.
- g. Operate as simply and cost-effectively as possible within constraints.
- h. Minimize the impact on facility and transportation operations.
- i. Minimize the required number of inspectors and inspections.

B. DIRECT ACCOUNTABILITY OF FISSILE MATERIAL IN FRESH, SPENT, AND BLANKET ASSEMBLIES

Both the IAEA safeguards approach for the long-term handling and interim storage of fresh and spent fuel assemblies, and the international transfer of ownership of the fuel with resolutions of shipper/receiver balances, require direct identification of fissile content and accountability of nuclear-material balance. The safeguards approach for the fuel handling system will involve a combination of sensor information, inspector observations, and measurement data obtained by NDA techniques.

The currently available NDA techniques for item accountability can distinguish only between different classes of assemblies, e.g., fuel, blanket, and dummy replacement. No distinction can be made between the individual

assemblies of one class. It is not clear how effective NDA techniques may be if the NDA information is not supplemented by subsequent confirmatory information that a replacement or partial replacement has been made. An added level of assurance in flow verification and nuclear-material accountancy is provided by establishing that the difference between preirradiation and postirradiation isotopic measurements reflects the irradiation history of a specific assembly.

A number of instruments which have been assessed for application as NDA safeguards for item accountability include: high resolution gamma spectroscopy (HRGS) for passive gamma-ray spectrometry of plutonium; the high level neutron-coincidence counter HLNCC for passive measurement of spontaneous fission neutrons from ^{240}Pu , and the active-well neutron-coincidence counter AWCC interrogation system for measuring induced-fission neutrons in fissile isotopes.

1. Instruments and Methods for Determining Nuclear-material Content

a. High-resolution Gamma Spectrometry (HRGS)²⁰

In view of the high plutonium content in LMFBR mixed-oxide fuel, the plutonium assay by HRGS appears to be more effective for fresh fuel elements than for complete fresh fuel assemblies. The self-shielding effects in fuel elements are expected to be minimal, and consequently the gamma-ray spectra may be used as a quantitative measure of the plutonium content. The self-attenuation of the gamma rays in an LMFBR assembly, with or without sodium, would introduce uncertainty in the quantitative measure of the plutonium-content in a fresh fuel assembly. However, for purposes other than plutonium-content determinations, HRGS may be useful in certain assembly-identification modes. The direct assay of plutonium in an irradiated assembly by HRGS does not appear to be an effective measurement technique except to establish the existence of fission products.

b. High-level Neutron Coincidence Counter (HLNCC)²¹

Preliminary studies on neutron yield rates from the spontaneous fission of the ^{238}U , ^{240}Pu , and ^{242}Pu have indicated that the HLNCC is effective in the verification of nuclear-material flow in assembly form throughout the entire reactor fuel handling cycle, i.e., from the fresh-fuel through the spent-fuel stages.²⁷ Because of the high plutonium concentration throughout the fuel-irradiation period in an LMFBR, the spontaneous-fission (SF) neutron yield from the ^{242}Cm and ^{244}Cm does not dominate the SF neutron yield from the plutonium isotopes in the spent-fuel stage. This is significant when compared to the problem with LWR spent-fuel interrogation where the ^{244}Cm neutron yield rate is several orders of magnitude greater than the plutonium yield rate at the same level of burnup and after the decay of the ^{242}Cm contribution.

Initial computations of total neutron yield rates [S.F. and $(\alpha, n)^{18}\text{O}$] for the prominent isotopes are plotted as a function of fuel burnup in Figs. 5-7. The computations are results from a study of isotopic-safeguards techniques in LMFBR fuel cycles.²⁷ Figures 5a, 5b, and 5c represent different core regions where possible differences in enrichment and spectral effects were studied. In all regions, the results indicate that, for mixed-oxide fuel with a burnup of 35,000 MWd/T, about half the total neutron yield rate is contributed by plutonium after a cooling period of 1-2 yr and subsequent decay of the

Fig. 5. Neutron Yield versus Burnup in Three Core Regions

Fig. 6. Neutron Yield versus Burnup in Blanket Region

Fig. 7. Plutonium Isotopic and ^{241}Am Neutron Yield as a Function of Burnup

^{242}Cm isotope. From Table IV which lists specific isotopic neutron yields, and Fig. 7, which plots the burnup versus neutron yield for plutonium isotopes in the core axial-center region 26 (Fig. 5a), it is determined that the plutonium SF neutrons emitted primarily by the ^{240}Pu , with some contributions from the ^{242}Pu and ^{238}Pu , are 25-35% of the total SF neutrons emitted from the fuel.

TABLE IV. Principal Sources of Neutrons in Irradiated UO_2 Materials

Isotope	Half-life, yr	Neutrons Produced per gram-second		
		(α, n) Reaction	Spontaneous Fission ^a	Total
^{235}U	$7.038 \pm 0.005 \times 10^8$	$7.21 \pm 0.72 \times 10^{-4}$	$3.86 \pm 0.99 \times 10^{-4}$	$1.11 \pm 0.12 \times 10^{-3}$
^{238}U	$4.4683 \pm 0.0024 \times 10^9$	$8.43 \pm 0.84 \times 10^{-5}$	$1.36 \pm 0.02 \times 10^{-2}$	$1.36 \pm 0.02 \times 10^{-2}$
^{238}Pu	87.71 ± 0.03	$1.56 \pm 0.16 \times 10^4$	$2.60 \pm 0.11 \times 10^3$	$1.82 \pm 0.16 \times 10^4$
^{239}Pu	$2.4131 \pm 0.0016 \times 10^4$	$4.25 \pm 0.43 \times 10^1$		$4.25 \pm 0.43 \times 10^1$
^{240}Pu	$6.570 \pm 0.006 \times 10^3$	$1.56 \pm 0.16 \times 10^2$	$8.85 \pm 0.10 \times 10^2$	$1.04 \pm 0.19 \times 10^3$
^{242}Pu	$3.763 \pm 0.009 \times 10^5$	2.27 ± 0.23	$1.743 \pm 0.015 \times 10^3$	$1.743 \pm 0.015 \times 10^3$
^{241}Am	432.0 ± 0.2	$3.17 \pm 0.32 \times 10^3$		$3.17 \pm 0.32 \times 10^3$
^{242}Cm	0.4456 ± 0.0001	$4.48 \pm 0.45 \times 10^6$	$2.25 \pm 0.08 \times 10^7$	$2.70 \pm 0.09 \times 10^7$
^{244}Cm	18.099 ± 0.015	$8.82 \pm 0.88 \times 10^4$	$1.081 \pm 0.007 \times 10^7$	$1.090 \pm 0.007 \times 10^7$

^aReference value for spontaneous values.

$\bar{\nu}_{\text{sp}} = 3.756$ for ^{252}Cf .

The plutonium isotopes will make a significant contribution to the SF neutron yields at all the levels of burnup and decay-cooling times that are anticipated in the next two decades of LMFBR operation. This maintains even for a burnup of 100,000 MWd/T, where the plutonium isotopes are estimated to contribute 5-7% to the SF neutron yield, depending on decay cooling times. At burnups in the range of 75,000 MWd/T, the estimates indicate that the plutonium isotopes contribute 5-12% of the total SF neutrons after a 2-yr cooling period. For the core region with the higher concentration level of plutonium (region 56, Fig. 5c), the fraction of the plutonium SF neutrons is higher than in the core axial-center region 26 and the core axial-edge region 23 of lower enrichment. At burnups below 33,000 MWd/T, the plutonium SF neutrons dominate the neutron yield rate. These significant contributions to the neutron yield by the plutonium isotopes make passive-neutron-assay techniques a viable method for item accountability and identification of the spent fuel and blanket assemblies in the LMFBR cycle.

The unique characteristic of the LMFBR system that relates to the verification of nuclear-material flow in core assemblies is the almost constant plutonium concentration in reactors with core conversion ratios of approximately 0.7 and greater. Although the relative concentrations of the plutonium isotopes may vary over extended periods of burnup, the SF neutron yields from the plutonium are almost constant over an irradiation period extending to about 100,000 MWd/T. Table V gives the SF neutron yields for a reference core assembly containing approximately 35 kg of heavy metal. The variation is within 10% between the nonirradiated and irradiated fuel over this burnup range, and the apparent slight increase is found to be linear within an error of 0.3%.

TABLE V. Spontaneous Fission Neutron Yield
Reference (35 kg HM) Core Assembly
(10^6 Neutrons/s)

Average Burnup (MWd/T)	Plutonium				Curium	
	238	240	242	Total	^{242}a ($t_c = 0$)	244
0	0.18	1.2	0.30	1.68	-	-
12,000	0.17	1.23	0.30	1.72	1.51	0.30
35,000	0.16	1.29	0.33	1.78	12.38	2.69
77,000	0.13	1.39	0.36	1.87	58.63	14.12
96,000	0.12	1.42	0.36	1.91	70.74	22.90

^aHalf-life = 162.8 days

The significance of the neutron source strength is that the curium-isotope concentrations can be determined from a difference measurement of SF neutron source strengths between the fresh fuel and the spent fuel in a given assembly. The resulting curium concentration gives a direct measure of the irradiation history of the assembly. This difference-method of determining the curium concentration has the advantage of allowing use of the time decay of ^{242}Cm as a consistency check in the physical-inventory verification of the stored assemblies. The high concentration of ^{242}Cm at high burnups is unique to LMFBRs, and presents the opportunity for the inspector to make a timely in-the-field assessment as to a possible anomaly in the flow of nuclear material in the assembly handling operations of the reactor.

Figure 6 indicates that the plutonium should dominate the SF neutron yield rate over the burnup periods anticipated for the blanket assemblies in all classes of reactor systems.

The HLNCC measurements are of major safeguards importance in verifying plutonium flow accountancy data well within the time period before the reprocessing operation. Strategic measurement points in the fuel handling system are the inventory-measurement points KMP-A and KMP-F. The HLNCC systems would have to be modified in order to minimize the interference of the high gamma-ray radiation background of the spent fuel. This may be done through selection of neutron detectors and/or interspersing a gamma-ray attenuation material such as lead between the assembly and the detection system. The placement and operation of the HLNCC measurement system at the KMP's are plant-design-specific, and modifications in designs would be required to accommodate the specific plant features. A measure of the nuclear-material content in an assembly with an uncertainty of about 10% (when complimented by C/S and assembly identification and structural integrity measures) may be preferred by inspectors compared to a system without such information on a per assembly basis. The difference between the measured and expected values of the nuclear material content of an assembly, should add to zero over a number of assemblies (assuming no measurement bias). Consequently, the inspector attains a measure of assurance against protracted divergence.

c. Active-well Neutron-interrogation System (AWCC)²²

An IAEA safeguards measurement of complementary importance to the HLNCC measurements is the direct determination of total fissile $\text{Pu}/^{235}\text{U}$ concentrations in the fresh and spent fuel assembly. For verification of material flow and physical inventory, the induced fission neutron rate measurements can be obtained by using an external neutron source of sufficient strength to effect a neutron multiplication above the total neutron yield rate. Fissile content in the assemblies may be determined by the AWCC system. The $^{241}\text{Am-Li}$ source system may be modified for use on spent fuel assemblies and designed for use as a dual purpose HLNCC. A possible alternative or supplementary technique is to introduce a neutron moderating sleeve between the assembly and the gamma-ray shielding region with the AWCC operating in a self-multiplication mode. For this operating mode, lower strength $^{241}\text{Am-Li}$ sources may be sufficient.

The determination of the fissile $\text{Pu}/^{235}\text{U}$ content of the fuel assembly before and after irradiation is also a surveillance measure for maintaining assurance of item-flow and of physical-inventory accounting data for assemblies. As with the HLNCC surveillance system, the strategic measurement positions are the inventory measurement points KMP-B and KMP-H. The placement and modification for AWCC equipment would be similar to those for the HLNCC system. It should be established whether the design and/or placement constraints would allow integrating these systems into a single common design with flexibility in operating modes.

C. AUTOMATED DATA-ACQUISITION SYSTEM

IAEA inspection activities are basic to the international safeguards system. This follows directly from the need for independent inventory verification, and also from the number of activities which can only be performed by an inspector. These activities may include safeguards equipment maintenance, verifying proper operation of tamper-indicating features, observation of nonscheduled operations, nuclear-materials shipment and receipt, and monitoring of unusual activities, such as movement of very large equipment into and out of an area containing nuclear materials. Advantages of on-site inspection activities include improved timeliness of detection, assessment of the cause of alarms, surveillance for unauthorized activity, and independent inventory verification.

Safeguards systems currently used have been based on material accountancy supplemented by C/S measures. Although experience has indicated a general capability of providing effective international safeguards, current procedures may be found inadequate to meet the significant-quantity and timeliness goals of the IAEA, for the anticipated deployment of large scale nuclear facilities.

A necessary, but not sufficient, condition to satisfy the timeliness goals is the development of nondestructive assay methods for the measurement of nuclear material in a near-real-time mode. The sufficiency condition will be satisfied by the development of containment/ surveillance methods to complement materials accountancy. The objective of timely detection will require monitoring of nuclear-materials inventory by containment/surveillance measures located at strategic measurement positions and operating in a near-real-time mode.

Because of the limited resources of the Agency, the possibility of remote monitoring by automated data acquisition systems with tamper-indicating data links and data collection modules, either independently or in a verification mode with the SSAC system, should be considered.

V. SAFEGUARDS INSPECTION EFFORT

The measurement equipment and C/S devices currently available to the IAEA's Operations Division are very limited and inadequate for assembly identification or for verifying material inventory and flow in the reactor assembly handling and storage systems. Seals for LMFBR assemblies are not available, therefore comparative technical and cost-effectiveness assessments with other techniques are difficult. The need for IAEA safeguards systems to be applied to LMFBRs is near-term (a decade or so). Present programs to develop devices and techniques for improved safeguards do not address special near-term LMFBR safeguards needs of the IAEA.

Estimates of IAEA inspection efforts have been made based on several factors relating to the near-term implementation of IAEA safeguards systems. The assessment for inspection requirements emphasizes the safeguards measures that are currently available or may be available for field implementation by the IAEA's Operations Divisions within the next 3 to 5 yr. Safeguards techniques available for the current and near-term operating LMFBRs are visual identification of individual fuel and blanket assemblies, visual verification of the structural integrity of the assembly (when out of sodium), and NDA assay of plutonium content in the assembly by the neutron assay and interrogation techniques. At the present time, the neutron coincidence counting (NCC) system provides some verification assurance of the nuclear-material content in the fuel and blanket assembly, but will require further development before application as a material balance accountancy measurement.

Although the preliminary inspection efforts estimated for the generic reference LMFBR systems may emphasize near-term safeguards measures, the potential development of advanced concepts for the unique identification of individual assemblies (in or out of sodium) and of devices or systems of devices for a measure of assurance that the structural integrity of the assemblies has been maintained (in or out of sodium) are reflected in these estimates. However, as these advanced concepts are developed, the systems should be evaluated and technically assessed against a uniformly consistent set of performance measures, some of which are: (1) feasibility of implementation in the near-term operating LMFBR systems, (2) cost-effectiveness of assembly design or redesign on the operation of the reactor systems and supporting facilities, (3) level of safeguards assurance provided by the systems to the Operations Divisions in terms of cost-effective application of inspection resources.

Application of NDA for verification of nuclear material content in the assemblies as the primary attribute of safeguards assurance is supported by the direct field experience of the Operations Divisions and the Division of Development and Technical Support. The level of effort assumed in the listed inspection measurement activities was based, in particular, on the NCC systems for the assay of plutonium in LMFBR assemblies and was assessed in terms of the experience of the Operations Divisions with the recent field testing of the passive NCC measurement techniques on fresh assembly loadings of fast breeder reactors.

NCC apparatus possible for field implementation within the scope of this study is considered for two modes of field operations: (1) a partially portable system and (2) a completely in-place installation. From the IAEA's field operations experience both of these options may have applications. The partially portable system, in which only the neutron detectors and possibly some of the electronic circuitry are portable, does have advantages in terms of assuring the IAEA's independence of verification. The maintenance and calibration of the neutron sensors may be placed under the control of the IAEA. Independent verification may be difficult if the in-place system is adopted. Measurement accuracies for the passive NCC have not as yet been determined for spent LMFBR fuel and blanket assemblies. Radiation background problems associated with the applicability of NDA measurements on irradiated fuel and blanket assemblies should be investigated. The gamma-ray radiation interference with NCC could be reduced by introducing a sleeve of high-Z material but this approach should be field tested.

An analogous series of testing is needed for the active neutron-interrogation measurement system. For both the passive and active neutron methods, the measurement accuracy for the plutonium content that would be acceptable should be assessed in terms of the alternatives available for verifying assembly identification, assembly structural integrity, or nuclear-material content in the spent fuel and blanket assemblies. The effectiveness of these alternatives should be assessed for application to current LMFBR assemblies and reactor operating conditions and for future implementation in commercial systems. Detailed design and operating features of these techniques would be necessary in order to select the safeguards approach giving the highest level of assurance to:

- detect the diversion of significant quantities (abrupt and protracted);
- satisfy the goals of timeliness of detection, and
- optimize the cost-effectiveness of the IAEA inspection effort.

The inspection time for applying seal and identification reading sensors to the assemblies (in or out of sodium), the sensitivity of the signal to the positioning of the reading sensors, and the actual mechanical manipulation required for identifying the assembly and verifying its integrity was assumed to require no more than the inspection time associated with the NCC systems. These time requirements may be revised in the future as the C/S systems are developed and field tested.

Records and/or data relating to core-loading configurations, storage positioning index, and reactor operating data are considered as required input data and will be needed by the inspector to make a field assessment of consistency in the verification of assembly inventory and of nuclear-material content in the assembly.

A. INSPECTION ACTIVITY MBA-ABEF: ASSEMBLY HANDLING AND STORAGE OPERATION FACILITIES

The frequency of inspections and the inspection activities for physical-inventory verification or assembly-flow verification at the key measurement points may differ for each of the inventory and flow KMPs and for each of the two classes of fuel handling systems (for demonstration and commercial reactors and for experimental reactors). The estimates of the inspection efforts that

are assigned to each KMP are therefore presented as general guidelines from which more-definitive inspection efforts would be planned for each specific reactor systems. The inspection activities, the frequency of inspections, and the inspection efforts are outlined in the sequence of the assembly flow within each of the MBAs.

In determining the frequency of inspection, the timeliness-of-detection guidelines -- which are on the order of 1-3 weeks for unirradiated fuel and 1-3 months for irradiated fuel and blanket assemblies -- will be assumed as an average 2 weeks and 2 months, respectively. A man-day of effort is based on an average 8-h working day.

1. KMP-1: Receiving Area

This strategic point is the initial flow KMP and will require inspection activities for each receiving operation. The minimum inspection frequency will be determined by the design capacity of the transport cask.²⁸ A cask with a 9-assembly capacity would require 11 receiving operations, and 11 inspections per year for an average 100-assembly-per-year refueling schedule. Assuming the operator needs one day for unloading at each receiving operation, the inspection effort should be planned to cover about 11 man-days for this stage of the fresh-fuel handling sequence.

The fabricator's shipment records and the operator's receipt records should be made available to the inspector for independent verification of consistency. The IAEA requirements would include the verification of the operator's ICR for this flow KMP.

The inspection activities at this point would consist of:

1. Checking the integrity of the IAEA seal, if seals are applied to the transport cask or assembly canister, at each receiving operation.
2. Examining fabricator's shipment records and operator's receipt records at the receiving area for self-consistency in assembly accounting, assembly identification, assembly physical integrity, and stated nuclear material specifications.
3. Verification of assemblies by counting items, reading identification serial numbers, and visually inspecting physical integrity of the assembly.
4. Examining records, positioning, and servicing of surveillance and containment devices such as CCTV.

2. KMP-A: In-air Storage

The primary function of the IAEA inspector at this inventory KMP are verification activities in the in-air storage of the fresh fuel and blanket assemblies. A very limited buffer or auxiliary storage area may be used for inspection activities -- inspecting the seal of the assembly canister, counting assemblies, observing the removal of assemblies from the canister or transport cask, visually verifying assembly integrity, and checking the

assembly identification numbers of the fabricator and operator -- before the assemblies are transferred into the fresh-fuel inspection cell and into the in-air storage facility for fresh fuel and blanket assemblies. The inspection effort is comprised of independent verification of the operator's accounting and assembly identification serial number, assembly integrity by close-up photography and/or verification of assembly seals (if these have been developed), and direct NDA (NCC) measurements on every assembly. This KMP position is located adjacent to the equipment cell for transferring the assembly to under-sodium storage. Consequently maximum inspection efforts in detailed measures should be applied at this stage, where accessibility to the assembly is feasible.

Confirming assembly identification serial numbers, assuring assembly integrity measured by assembly surveillance devices, and verification of material content in each assembly as determined by NCC methods would be priority inspection activities. The frequency of inspection is estimated to average 26 times per year in order to satisfy the IAEA safeguards goals and guidelines with respect to significant quantity and timeliness of detection for nonirradiated nuclear material.

To minimize the impact on the operator's handling operation and simultaneously on the IAEA's inspection resources, the inspection effort should be based on the following considerations:

- (1) The assemblies should be transferred from the receiving area into the in-air storage area for fresh fuel soon after they are received from the fabricator.
- (2) The safeguards measures of verifying the unique identity and the physical integrity of the assembly should be performed at each of the 11 or so receiving operations.
- (3) The NDA measurements (using NCC techniques) for verifying the integrity of the nuclear-material content should be made at each of the receiving operations.
- (4) Most of the storage designs for fresh fuel appear to be able to accommodate the placement of the assembly identification and integrity-sensoring devices and the NCC systems such that, in the transfer from MBA-ABEF to MBA-CD, the assembly flow path could be channeled through these devices and systems. The optimum flow route would be determined by the operator for economy of operations.
- (5) The safeguards cost-impact may result from the time required to set up the assembly-surveillance devices and take the sensor readings, and to set up the NDA system and attain good counting statistics.

Within the scope of this report, it is assumed that the assembly identification and integrity checking devices and the NDA measurement systems can be developed to take readings within the normal fuel-handling system flow of assemblies and that, when the assemblies are in storage, the sensing or measurement operation will involve only a vertical lifting and lowering of the assembly, with no lateral translational movements.

a. NDA Systems

In recent field verification measurements of nuclear-material content in fresh LMFBR fuel assemblies by passive neutron assay (the NCC method), accuracy was in the range of 2% for a 10-min counting period. Similar accuracy may be assumed for the active (^{241}Am -Li source) neutron interrogation mode. For a 10 minute counting period per assembly and a one-day set-up time for the inspector's calibration and independent verification of instrumentation readings, an inspection effort of approximately 1.5 man-days per receiving operation (9 assemblies) or 17 man-days per year for both interrogation modes is to be expected.

b. Assembly Identification and Integrity Devices and Sensoring Systems (AIIDSS)

The amount of the inspection effort for identifying assemblies and verifying the physical integrity of the assemblies will depend on the particular type of sensors and the time necessary for applying and reading the sensors. With the exception of visual aids and close-up photography, neither adequate seals or seal systems to indicate the structural integrity of the assembly nor unique identification systems for LMFBR assemblies have been or are being developed for near-term field implementation. It is therefore difficult to assign the time period an inspector would need to set up the sensing system and take an actual reading under field conditions which may involve in-air, in-sodium, in-water and in-gas environments. The time requirements would depend on the operational procedure required by specific AIIDSS concepts. If the sensing-system design allows the assembly to flow on its normal passage through the sensors as part of the fuel handling system, the only time required would be that for sensor reading. If the sensing system requires that the assembly flow path be interrupted, or, for the assembly in storage, that the assembly be laterally transported to the sensor, then the time necessary for these actions should be added to the inspection time estimates. These timing considerations apply to all safeguards verification systems, AIIDSS, and NDA measurement systems.

The inspection time related to application of AIIDSS will be assumed to consist only of the (1) sensor-reading period and (2) set-up times not greater than those associated with the NCC systems.

For the KMP-A area, the time required for taking assembly sensor readings in the field is assumed to be 20 min per assembly (10 min identification and 10 min for integrity measurement), with a one-day set-up period for the inspector's calibration and/or independent verification of instrument operations. The estimated inspection effort is approximately 1.5 man-days per receiving operation, or 17 man-days per year.

The inspection effort may range up to about 34 man-days per year, if the sensor readings for assembly identification and for verification of the assembly integrity are combined with the NCC measurements. Therefore, if the safeguards measures are taken simultaneously or in some combination, the inspection effort at this stage of the KMP-A may range from 17 to 34 man-days per year.

During the period of accumulating and storing the required number of assemblies for the subsequent core loading operation, the physical inventory

(in addition to the inventory changes which occur at each of the receiving operations) may be done by counting assemblies, and by identifying assembly serial numbers and storage cell positioning index. The accessibility of the assemblies in the in-air storage area suggests that a one man-day of effort per inspection for physical-inventory verification would be adequate for a storage-cell capacity of 100 or more assemblies. For a frequency of inspection of 26 times per year, of which 11 inspections are combined with the receiving operations, an additional 15 man-days (one man-day for each of 15 inspections) of inspection effort are required to satisfy the average timeliness guidelines of 2 weeks for the fresh fuel assemblies.

The IAEA requirements would include the verification of inventory by the IAEA inspector, and comparison with ICR's furnished by the operator for this inventory key measurement point.

The inspection activities at KMP-A would consist of:

1. Examining the positioning-index records for the in-air storage of the fresh fuel and blanket assemblies.
2. Verifying the consistency between the operator's records and the actual storage positioning and number of assemblies.
3. Verifying assemblies by visual counting the number of assemblies, reading assembly identification serial numbers, checking assembly physical integrity by visual or AIIDSS methods, and using NDA measures for subsequent consistency verification.
4. Examining records, positioning, and servicing of surveillance and containment devices such as CCTV.

3. KMP-2: Transfer from In-air Storage to In-sodium Storage

The design of most FBR storage facilities and handling rooms for fresh fuel assemblies should allow using the AIIDSS sensors and the neutron measurement methods just before the transfer of the assemblies from in-air storage (MBA-ABEF) into the area of under-sodium storage (MBA-CD). A series of NCC measurements and AIIDSS readings similar to those performed at the input to the fresh-fuel storage cell, KMP-A, would update and complete the bank of basic and strategic data for each assembly before the assemblies are transferred into nonaccessible areas in which there would be limitations on some safeguards measures. The strategic data bank completed at KMP-A forms the reference base against which the subsequent physical inventory and inventory changes involving AIIDSS measures, which are performed during the sequential stages of assembly handling, including in-situ irradiation, may be verified for consistency.

The inspection effort at this flow KMP required to verify the ICR's from MBA-ABEF to MBA-CD is anticipated to be approximately 6-8 man-days per inspection for the transfer of 100 assemblies. This estimate is based on NDA measurements and AIIDSS sensor readings being performed simultaneously or in some combination (for a total measurement time of 20-40 min per assembly), with a one- or two-day set-up time for instrumentation and verification of

instrument operating integrity, and with one transfer operation per year. The inspection requirements depend on the operations management plans for assembly handling and the rate and frequency of transferring the assemblies into the in-sodium environment (KMP-B in MBA-CD) for the preparation before reactor loading. Under normal operation, the entire core loading is precisely positioned in the sodium storage cell and allowed to thermally equilibrate to the sodium condition before the reactor is shut down for loading or unloading.

The rate and frequency of transferring the assemblies into the sodium environment is expected to be greater for the experimental reactors than for the demonstration and commercial power reactor systems. Based on an average twice-a-year transfer schedule to cover exigencies in both categories of experimental reactors, a preliminary inspection effort of 12-16 man-days per year will be adopted for the purpose of this study.

For minimal impact on the operations of the facility and on the IAEA's inspection resources, the safeguards approach should be planned for specific reactor-plant systems. The IAEA's requirements would include the verification of the ICRs furnished by the operator for this flow key measurement point.

The inspection activities at KMP-2 would consist of:

1. Examining the operator's positioning-index plans and identify assemblies for the in-air storage (KMP-A of MBA-ABEF), and the in-sodium storage (KMP-A of MBA-CD) for cross-correlation in the inventory change operation.
2. Verifying the consistency between records, ICRs, plans, and actual storage positioning.
3. Verify the numbers of assemblies by visual counting, reading assembly identification serial numbers, checking assembly integrity by visual or AIIDSS methods, and using NDA measurements for consistency verification in establishing the basic information data bank.
4. Examining records, positioning, and servicing of surveillance and containment devices such as CCTV.

4. KMP-3: Inspection and Preparation Cell

The transfer of irradiated assemblies from the in-sodium decay cooling storage cell KMP-B (MBA-CD) to KMP-F (MBA-ABEF) for shipment off-site, or to KMP-D or KMP-E (MBA-ABEF) for extended storage, would flow through KMP-3. The assemblies are cleansed of sodium and would probably be inspected by the operator before being transferred to the next sequence of operations. To ensure a smooth-flowing operation, some facilities may have a limited auxiliary storage for one or two assemblies in KMP-3. Therefore, the inspection effort for this flow KMP is closely coupled with the inspection effort associated with inventory areas KMP-D, KMP-E, or KMP-F. The IAEA safeguards inspector function for KMP-3 would be primarily a visual verification of assemblies in the transfer operation. The frequency of inspection would correspond to and be integral with the frequency of inspection at any of the subsequent KMPs for

inventory or inventory-change verification inspections. The inspector would through the visual observation of the irradiated assemblies gain a measure of assurance in the consistency of the inventory changes reported by the operator.

The inspection activities at KMP-3 would consist of:

1. Verifying assemblies by visual counting, visual assembly identification, and visual check of assembly physical integrity.
2. Verifying the consistency between operator's records and actual storage locations.
3. Examining records, positioning, and servicing of containment and surveillance devices such as CCTV.

5. KMP-D: In-sodium Extended Storage

For those facilities designed for in-sodium extended storage, the inspection approach would depend to a large extent on containment and surveillance, such as verification of storage seal integrity. The inventory verification would consist of assembly counting, assembly identification, and storage-position index as reported by the operator. The principal instruments for performing this inventory verification would be the combination of the USV, if developed, and /or modification of the UWOV for implementation in a sodium environment.

The physical operations for random-sampling accounting would require lifting the assembly from its storage rack until its top passes through the plane of the sodium surface and into the inert-cover-gas region. The triangulation technique for determining the assembly position in a planar-coordinate system would allow correlating the storage-position index with the sensor readings of assembly-identification and the transfer-machine position index. The assembly would then be lowered into its original rack position. Depending on the design and operational mode of the assembly-identification sensing devices, the assembly may not need to be subjected to lateral translational movements.

For an assumed 20 min sensor-reading operation per assembly (~20 assemblies per day), a capacity of 200-400 assemblies would require about 10-20 man-days for inspection (including allowance of one day for the independent verification of instrumentation and AIIDSS performance). The total inspection effort should be planned to range from 60 to 120 mandays per year in order to satisfy the averaged two months detection-timeliness guideline for irradiated assemblies. The inspection effort may be less if an independent verification of the storage-seal integrity is accepted as an alternative for many of the inventory inspections.

The inspection activities at KMP-D would consist of:

1. Obtaining and checking the operator's reported plan for storage-position index for each identified assembly before actual transfer of assemblies into KMP-D.

2. Examining the operator's records of movements of the fuel transfer machine, crane, and transfer cart and identified assembly positioning for cross-correlation verification with operator's reported records in KMP-B (MBA-CD).
3. Obtaining records relating to irradiation history, fuel content, and decay-cooling time for each identified assembly.
4. Examining records, positioning, and servicing of surveillance and containment systems such as CCTV, USV, and storage-seal-integrity checking devices.

6. KMP-F: In-water or In-gas Storage

The inspection effort anticipated for this method of extended storage should not differ greatly from that for the in-sodium extended storage (KMP-D). The primary difference is the visual access to the assemblies afforded by the air or gas environment and the instrumentation or principles of instrumentation available for use in a water or gas storage facility. For example Cerenkov-glow devices may supplement the UWOV system in the in-water storage cell. The estimated inspection effort would not differ greatly from the 60-120 man-days per year assigned to KMP-D, depending, in part, on the storage capacity. The inspection effort would be less if an independent verification of the storage-seal integrity is accepted as an alternative for many of the inventory inspections.

The inspection activities at KMP-E would consist of:

1. Obtaining and checking the operator's plan for storage-position index for each identified assembly before actual transfer of assemblies into KMP-E (MBA-CD).
2. Examining the operator's records of movements of the fuel transfer machine, crane, and transfer cart and identified assembly positioning for cross-correlation verification with operator's reported records in KMP-B (MBA-CD).
3. Obtaining records relating to irradiation history, fuel content, and decay-cooling time for each identified assembly.
4. Verifying inventory by direct visual confirmation of assembly serial number and by Cerenkov-glow monitoring devices if used.
5. Examining records, positioning, and servicing of surveillance and containment systems such as CCTV, UWOV, and storage-seal-integrity devices.

7. KMP-F: Buffer Storage for Shipment Preparation

The inspection effort in KMP-F is required to independently verify irradiated fuel and blanket assemblies placed in temporary storage in preparation for eventual off-site shipment. The assemblies would be transferred directly from MBA-CD or from the extended storage cell within MBA-ABEF. The assemblies would be placed in sodium-filled canisters and accumulated to at

least the capacity of the transport casks. Current cask designs have planned capacities of 6 or 7 irradiated fuel assemblies. A complete assay of the nuclear-material content in the assemblies at this phase of the assembly handling operations would provide a timely measure of fissile-fuel for credit to the reactor operator and an effective IAEA independent verification of the closing balance by assembly unit accountancy and by the nuclear-material content in each assembly. This would provide a measure of assurance in precluding possible collusion for diversion by the State involving both the reactor operator and the reprocessing-facility operator.

The NDA measurements may be made upon receipt of the assemblies or just before placing the assemblies into canisters for shipment off-site. Most facility designs can accommodate the NCC measurement systems. The independent verification activities by the inspector would include assessment of assembly physical integrity by close-up photography for cross-correlation with photographs obtained and reported on the input flow to MBA-ABEF at KMP-A. The correlation between assembly identification serial number and nuclear-material content for each assembly as determined by NCC methods should be the prime focus of the inspection effort.

The frequency of inspection as required by the detection timeliness guideline of an average of 2 months is 6 inspections per year. To minimize the impact on the operator's assembly handling operations as well as on the IAEA's inspection resources, the inspections at KMP-F should be planned for those times when the number of stored irradiated assemblies accumulated for shipment is about 2-3 times a single transport-cask load. For the current cask capacities of 6-7 irradiated assemblies per cask, the number of stored assemblies for inspection would be about 12-21. For a yearly throughput of 100 irradiated assemblies, the number of inspections would be expected to range between 5 and 8, which is consistent with the inspection frequency of 6 per year required by the timeliness guidelines. For an assumed 1.5 to 3 man-days per inspection, the total annual inspection effort should range between 8 and 24 man days.

If the assembly handling operations are scheduled to accumulate only a single transport-cask load for immediate shipment, the inspection plan may have to be expanded to increase the frequency of inspections to 14 or 17 per year. This inspection frequency would also cover the contingency that the IAEA would require a verification of an inventory change due to shipments at each shipping operation.

For this report, the reference inspection effort estimate is based on the number of irradiated assemblies accumulated in storage not to exceed 2-3 times a single transport cask load. The inspection effort would be less if an independent verification of the storage-seal integrity is found to be an acceptable alternative for many of the inventory inspections.

The inspection activities at KMP-F would consist of:

1. Examining the positioning-index and shipment records for the storage of the irradiated fuel and blanket assemblies.
2. Verifying the consistency between the operator's records and plans for shipment and the actual storage positioning and number of assemblies observed.

3. Verifying assemblies by visually counting the number of assemblies, reading assembly identification serial numbers, checking assembly physical integrity by visual or AIIDSS methods, and using NDA measures for subsequent consistency verification with respect to receipt data obtained in KMP-A.
4. Examining records, positioning, and servicing of surveillance and containment devices such as CCTV.

8. KMP-4: Shipping Area

Flow KMP-4, is closely coupled with KMP-F and should verify inventory changes with the same frequency of inspection as that assigned to KMP-F. The minimum inspection effort will be determined by the design capacity of the transport cask and the operator's management program for the assembly handling operations. The inspection verification effort for a transport-cask shipment would be about the same as the 1 man-day effort assumed for loading. Consequently, inventory-change verification will require either 5-8 man-days per year or 14-17 man-days per year, depending on the selected frequency of inspection. (See preceding section on KMP-F.)

The inspection activities for KMP-4 would consist of:

1. Examining the records of the assemblies being shipped for cross-correlation with the operator's original plans and with the entry records for each identified assembly as had been inventoried at the input to KMP-1 and/or KMP-A.
2. Checking the final placement and integrity of the cask seals or canister seals, whichever is applicable.
3. Examining records, positioning, and servicing of surveillance and containment devices such as CCTV.

B. INSPECTION ACTIVITY MBA-CD: REACTOR OPERATIONS FACILITY

The in-sodium storage cell (KMP-B) will handle and store the fresh fuel and blanket assemblies planned for loading into the core and the irradiated fuel and blanket assemblies unloaded from the core. The frequency of inspection at KMP-B should be planned to include all the planned inventory changes. In addition to the reactor loading and unloading operations, the inspector must verify the transfer of fresh fuel and blanket assemblies from in-air storage (KMP-A) to in-sodium preparation storage (KMP-B) and verify the transfer of irradiated and decay-cooled fuel and blanket assemblies from in-sodium storage (KMP-B) to the inspection cell (KMP-3) before shipment to off-site facilities or to extended storage.

In this part of the fuel handling system, the hostile sodium environment is a significant barrier to direct accessibility of assemblies. This barrier may be considered an inherent additional safeguards and may balance some of the disadvantages resulting from the inaccessibility of the assemblies to certain safeguards measures. As referred to in Section III.C.3.b, the fuel handling systems are highly automated, so physical inventory and verification of inventory change would rely primarily on the application of storage

positioning, item identification, and assembly accounting with (1) direct containment and surveillance based on positioning and loading sensors of the loading/unloading machine and (2) emphasis on surveillance methods for detecting and recording any unplanned intersection of the plane of the sodium surface. The latter surveillance methods may include the use of the UWOV and/or the USV as described in Section IV.A.1.

1. KMP-B: In-sodium Storage of Fresh Fuel and Blanket Assemblies

For the storage of fresh fuel and blanket assemblies, KMP-B would require an inspection effort to reflect the IAEA's timeliness guideline of an average 2 weeks conversion time. However, the inspection effort may be limited in time depending on the in-sodium storage period prior to the reactor loading operations. For this report, it is assumed that the in-sodium preparation period would be 1-2 months. This suggests that one inspection during this period may suffice. A second inspection activity may be made to establish a cross-correlation verification of consistency of the records and to update the information data bank just before the reactor is loaded.

The physical-inventory verification would consist of assembly counting, assembly identification, and confirming the storage-position index. The principal instruments used for this inventory verification would be the combination of USV and/or a modification of UMOV for a sodium environment if developed. The physical-inventory accounting would be taken by lifting the assembly from its storage rack and intersecting the sodium plane and/or the light-surface plane to determine assembly identification and storage position index. The assembly would then be lowered into its original rack position. The assembly need not be subjected to lateral translational movement for this accounting operation.

Two considerations may be explored for impact on inspection effort. The first relates to easing the IAEA manpower requirements. It may be advantageous to transfer assemblies from KMP-A of MBA-ABEF to KMP-B of MBA-CD as soon as possible, because the inspection effort for under-sodium storage may not be as manpower demanding as that for required in-air storage. The basis for this statement is that the hostile environment of sodium may be considered as a barrier for easy access to the assemblies, and the unique direct confirmation of nuclear content within the assemblies and the verification of the integrity of the fuel content by the NCC measurements. These NCC measurements may be performed subsequent to the removal of an assembly from the in-sodium environment and just prior to the transfer operation into the reactor vessel.

The second consideration is that if safeguards assurance is better established for assemblies in an in-air storage environment, then a short in-sodium preparation period (2 months) would be advantageous. However, this may require a higher level of inspection effort (2 to 3 mds per inspection). The estimates of the level of inspection effort to be assigned to the in-sodium storage of fresh fuel and blanket assemblies would appear to depend on the operating mode of each reactor system and, as such, does become plant-specific. Based on a short in-sodium preparation period with 2 inspections per year (exclusive of the transfer operations), the range of inspection effort is estimated to be between 4 to 6 mds per year.

The inspection activities related to storage of fresh fuel and blanket assemblies at KMP-B would consist of:

1. Checking the operator's plan and records to verify the storage-positioning index for each identified assembly (before the actual transfer from KMP-B to KMP-C).
 2. Examining the operator's records for transfer from storage and checking the identified assembly positioning as recorded by the operator's transfer machine for self-consistency verification and for comparison with the operators records in KMP-B, in terms of the anticipated reactor loading configuration.
 3. Examining records, positioning, and servicing of C/S devices such as CCTV, and of sensors for verifying assembly serial number identification, and storage seal integrity.
2. KMP-B: In-sodium Storage of Irradiated Fuel and Blanket Assemblies

The storage of irradiated fuel and blanket assemblies at KMP-B requires an average inspection frequency every 2 months. A general design criterion for storage of the irradiated assemblies from demonstration and commercial reactors is to allow 90-180 days for decay cooling before reprocessing. It appears that 1 or 2 inspection periods would have to be planned for this stage of the fuel handling operations in addition to the inspection effort that must be applied during the changes of inventory (into and out of KMP-B).

A delay in reprocessing of the LFMBR fuel may be planned, depending on the near-term operating mode of some facilities. In such a case, there are two safeguards considerations that may influence the level of the inspection effort, depending on where the increased decay cooling will occur. If the increased cooling is scheduled for KMP-B, the number of inspections per year may have to be increased proportionately at that point. However, if the increased cooling is planned for an expanded storage facility other than KMP-B, the increased frequency of inspection would be applied at the expanded storage facility (e.g., KMP-D or KMP-E). In this latter situation, it is suggested that the inspection effort should include applying NDA measures at the time of transfer out of KMP-B. In the former, the NDA measures may be postponed to a later stage in the sequence of the fuel handling operations (e.g., to KMP-F).

The physical inventory verification would consist of assembly counting, assembly identification, and storage position index. The principal instruments for making this inventory would be the USV and/or the UWOV modified for a sodium environment. Physical-inventory accounting would consist of lifting the assembly from its storage rack and intersecting the sodium-surface plane and/or the light-surface plane to determine assembly identification and storage-position index. No lateral translational movements need to be made for this accounting operation.

For an assumed 2-3 inspections per year and an effort of 2-3 man-days per inspection, the inspection effort is estimated to be 4-9 man-days per year for this phase of KMP-B.

The inspection activities related to storage of irradiated fuel and blanket assemblies at KMP-B would consist of:

1. Checking the operator's plan for storage-position index of each identified irradiated assembly.
2. Examining the operator's records for the transfer machine. Identify assembly positioning as recorded by the operator for comparison with the operator's records in KMP-A and for comparison with the reactor loading configuration within KMP-C.
3. Obtaining and checking the operator's records relating to the irradiation history for each removed assembly, reactor power history, and the operator's estimated plutonium content in each assembly.
4. Examining records, positioning, and servicing of surveillance devices such as CCTV, and of sensors for verifying assembly serial number identification, and storage-seal integrity.

3. KMP-C: Reactor Vessel

The frequency of inspection for the reactor should be planned to coincide with the operator's fuel-management schedules for reloading. The schedule for the inspection effort may vary from 1 to 2 months for some experimental reactors to 1 yr for demonstration and commercial power reactors.

The inspector verification activity at inventory KMP-C has a two-fold purpose: (1) consistency verification of the loading and unloading core configuration within and between the power runs, and (2) establishing a base data set for consistency verification with data obtained in the other material-balance areas and flow and inventory key measurement points. This consistency verification covers the complete fuel handling operations from receipt of an identified assembly to the shipment of the assembly.

Assuming that a 1 h time period per assembly is necessary to complete a replacement and interchange (i.e., a reloading operation) of fresh and irradiated assemblies in a demonstration or commercial reactor, the corresponding inspection effort for a 100-assembly reloading should be not less than 13 man-days. Adding 1 or 2 man-days for preparation and orientation on site, an estimated total of 15 man-days for the effort is assigned to a reloading operation in demonstration and commercial reactor systems.

In an experimental reactor, the loading schedules are determined by the experimental program, with perhaps 3-6 reloading operations required per year. However, with increased frequency of reloading, the number of assemblies involved in such an operation are usually less. The higher frequency may involve 12-16 assemblies per operation, and the lower about 30-40 assemblies. In general, the total number of assemblies involved on a yearly basis is expected to be again about 100, the same as in a demonstration or commercial system.

In an experimental reactor, however, current designs of fuel handling mechanisms have not been optimized for minimum fuel handling time as economic constraints would require in commercial power reactors. This study assumes that a complete fuel assembly interchange requires 2 h per assembly. Consequently, the inspection effort for the reloading operation in experimental

systems is estimated as 25 man-days per year. Assuming 1 or 2 man-days are required for preparation and orientation on site for each reloading operation, the inspector effort to be assigned to experimental reactors may range from 30 to 36 man-days per year for those systems requiring 3 and 6 annual reloadings, respectively. These estimates are based on the assumption that the inspector set-up time for each reloading operation will be about the same for 12 assemblies as it is for 40 assemblies.

These estimates of inspection effort have been applied to cover the broad class of reactor systems currently in operation or anticipated to be operational in the next one or two decades. A more-effective estimate of the level of IAEA inspection effort must be plant-specific in design, operating mode, and the safeguards approach selected for the system.

A general remark that should guide the planning of inspection activities is that the consistency-verification role of the inspector for the reactor reloading stage of the fuel handling sequence must be passive with respect to the actual mechanics of the operation. The operator's responsibility is primarily to accurately reload the reactor core to a predetermined specified configuration, with maximum adherence to safety concerns, and in the most economical manner. The safeguards activities during this operation should be planned so as not to interfere with these objectives.

The inspection activities related to KMP-C would consist of:

1. Checking the loading configuration of the completed power run (before reloading) as recorded by the operator and made available to the IAEA inspector.
2. Examining for self-consistency the operator's records relating to the internal charging machine (ICM) movements, rotating-plug-position indexing, and identified assembly positioning.
3. Checking the operator's record of planned loading configuration, and maintaining this record for future consistency checks.
4. Examining for self-consistency the operator's records for the internal-charging-machine movements position-indexing, identified fresh assembly positioning, and interchange of blanket assemblies. (In the subsequent reloading period, this set of data may be used as another level of consistency checking).
5. Obtaining and checking for consistency verification the operator's: (1) records of rotating plug position indexing corresponding to identification of fresh and irradiated fuel assemblies and (2) data from the charging-machine loading sensors.
6. Obtaining and checking for consistency verification the operator's: (1) records of rotating-plug-position indexing, corresponding to identification of blanket assemblies interchanged, (2) identification of irradiated blanket assemblies removed and identification of fresh blanket assemblies loaded, and (3) data from the charging-machine loading sensors.

7. Obtaining and checking for completeness the operator's records relating to irradiation history data for each removed assembly, reactor power history and control rod setting. These data will be needed by the IAEA inspector for subsequent verification of burn-up isotopics, and NDA (NCC) measurements.
8. Examining records, positioning, and servicing of surveillance devices such as CCTV.

C. SUMMARY REMARKS ON THE SAFEGUARDS EFFORT

In the estimates of the IAEA's inspection effort for the LMFBR systems, the following practices were included: optimizing surveillance-inspection activities, reviewing data acquired by sensing instruments; reviewing reactor power plant operation records for cross-correlation and consistency and, at appropriate stages in the fuel handling system, to independently verify the materials inventories by item accountability and by direct measurement of material content in each item through use of NDA techniques by neutron coincidence counting. The safeguards approach emphasized review and evaluation of data relating to reactor power operation, fuel loading and unloading schedules, verification of unit assembly flows and storage dispositions, identification of operating anomalies, records of nuclear material shipment and receipts, and data relating to movement of operating equipment in the fuel handling system (including the indexing pattern of the nonconcentric rotating-plug system). The inspection activities and the frequency of inspection determined for each strategic point were optimized with the guidelines and goals for detection within the timeliness criteria of anomalies in the flow of material and within the limited resources of the IAEA.

Tables VI and VII, respectively, summarize the estimates of the safeguards inspection effort for the MBA-ABEF and the MBA-CD of the generic LMFBR reference systems. The total annual IAEA inspection effort, based on an 8-h working day excluding travel time to and from a facility, may range from 151 to 258 man-days for the demonstration and commercial reactors to 166 to 279 man-days for the experimental reactors. It should be noted, however, that the actual inspection effort and the method of implementing the safeguards approach is specific for the reactor-plant design and dependent on operating mode. For example, if the extended storage of spent fuel and blanket assemblies is planned for off-site facilities, then the inspection effort would be reduced by 60 to 120 man-days for this stage of the fuel handling system. A safeguards option that, if accepted, would reduce the inspection effort for extended storage in on-site facilities is to emphasize reliance on storage-seal integrity.

The safeguards approach and inspection activities for a specific reactor plant will depend on trade-offs between many factors, two of which are IAEA resources and timeliness of detection.

VI. IMPLEMENTATION OF THE AGENCY'S SAFEGUARDS SYSTEM

The safeguards systems for the LMFBR will be developed, in an evolutionary and studied manner, by gradual implementation of available safeguards measures at operating reactor systems and supporting facilities. Improved safeguards effectiveness will depend primarily on the coupling of the developments in the

TABLE VI. Safeguards-inspection Effort for Material Balance Area MBA-ABEF in Reference LMFBR Plants: 100-assembly/yr Flow Rate

Material Balance Area (MBA) ABEF: Assembly Handling and Storage Operations Facilities

Key Measurement Points	Inspection Activity	Number of Inspections per year	Man-days per Inspection	Total Man-days per year	
KMP-1 Receiving Area	Examination of shipment/receiver records and reports. Check integrity of transport cask seal or assembly canister seal. Examine containment and surveillance system records and servicing.	11	1	11	
KMP-A In-Air Storage	Examination of records. Cross-correlation of records and reports for consistency. Independent verification of assembly inventory, accounting, identification, and physical integrity. NDA measurements and calibration. Examine containment and surveillance system records and servicing.	11	1.5-3	17-34	
		15	1	15	32-49
KMP-2 Transfer from In-Air Storage to In-Sodium Storage	Examination of records. Cross-correlation of records and reports for consistency in transfer of fresh fuel and blanket assemblies from MBA-ABEF to MBA-CD.	2	6-8	12-16	
KMP-3 Inspection and Preparation Cell	Examination of records. Cross-correlation of records and reports for consistency in transfer of irradiated fuel and blanket assemblies from MBA-CD to MBA-ABEF.				
KMP-D In-Sodium Extended Storage	Examination of records. Cross-correlation of records and reports for consistency. Independent verification of assembly inventory, accounting and identification. Examine containment and surveillance system records and servicing.	6	10-20	60-120	
KMP-E In-Water or In-Gas Extended Storage	Examination of records. Cross-correlation of records and reports consistency. Independent verification of assembly accounting, identification, and physical integrity. Examine containment and surveillance system records and servicing.	6	10-20	60-120	60-120
KMP-F Buffer Storage For Shipment Preparation	Examination of records, cross-correlation of records and reports for consistency. Independent verification of assembly accounting, identification, and physical integrity, NDA measurements and calibration. In the Experimental Reactors, the independent verification is to be maintained on the fuel element level of accounting, identification and physical integrity, and NDA measurements.	5-8	1.5-3	8-24	
KMP-4 Shipping Area	Examination of shipment records and reports. Independent verification of assembly accounting and identification. Apply and check transport cask or assembly canister seals. Examine containment and surveillance system records and servicing.	5-8	1	5-8	
		Total Man-days per year MBA-ABEF		128-228	

TABLE VII. Safeguards-Inspection Effort for Material Balance Area MBA-CD in Reference LMFBR Plants: 100-assembly/yr Flow Rate

Material Balance Area (MBA) CD: Reactor Operations Facility

Key Measurement Points	Inspection Activity	Number of Inspections per year	Man-days per Inspection	Total Man-days per year	
KMP-B In-Sodium Storage					
Fresh Fuel and Blanket Assemblies	Examination of records. Cross-correlation of records and reports. Independent verification of assembly accounting and identification. Examine records of transfer machine movements and positioning for cross-correlation with related KMPs. Examine containment/surveillance system records and servicing.	2	2-3	4-6	
Irradiated Fuel and Blanket Assemblies	Examination of records. Cross-correlation of records and reports. Independent verification of assembly accounting and identification. Examine records of transfer machine movements and positioning for cross-correlation with subsequent KMPs inventory and reactor history data and loading configuration.	2-3	2-3	4-9	8-15
KMP-C Reactor Vessel	Examination of records: core loading configurations, internal charging machine movement, reactor operating data, and operator's burn-up data.	1 ^a	15 ^a	15 ^a	15 ^a
		3-6 ^b	10-6 ^b	30-36 ^b	30-36 ^b
		Total Man-days per year		-	
		Demonstration and Commercial Reactors		23-30	
		Experimental Reactors		38-51	

a - Demonstration/Commercial Reactors

b - Experimental Reactors

instrumentation R & D programs with the experience gained by the Operations Divisions in the field implementation of the safeguards systems. Under the near-term program plan, currently available safeguards techniques, or modifications for specific applications, will be used, and these techniques will be gradually supplemented with more-advanced safeguards techniques as they are developed and field-tested by the Operations Divisions.

There are several safeguards techniques which may be needed for implementation in the near-term period. The adoption of these improved measures would necessarily have to include the following considerations: the safeguards techniques that are available for use in LMFBRs and the limitations of these techniques; the inspection time required to get effective readings for item accounting, assembly identification, verification of the integrity of nuclear-material content, and verification of the assembly structural integrity; the relative levels of safeguards assurance that these techniques can be expected to give the IAEA; the impact on assembly costs of applying seals for verification of the structural integrity; the impact of inspection on reactor designs and operations; the impact on the head-end (chopping stage) of the reprocessing plant resulting from a safeguards-influenced assembly design; and the impact of inspection on the operations of the current fuel handling systems.

Programs for developing improved safeguards techniques include:

A. PASSIVE NCC METHOD FOR SPENT FUEL AND BLANKET ASSEMBLIES

The current state of development and field implementation of neutron coincidence counting (NCC) for independent verification of the integrity of the nuclear-material content in LMFBR assemblies suggests that, for the near-term period, NCC may be used at many of the KMPs for surveillance and accountancy of the nuclear material flow in the fuel handling system of an LMFBR.

Design and testing of the NCC technique for application to irradiated fuel and blanket assemblies is recommended for near-term development and field implementation. The radiation background fields of irradiated assemblies can have severe problems in measurements technique and implementation. The introduction of NCC measurements of nuclear material content in irradiated assemblies would increase the level of safeguards assurance in the reactor fuel handling system. With NCC, the inspector could independently verify the nuclear-material accounting with a direct measure of the nuclear-material content in the assemblies throughout the fuel handling operations.

B. ACTIVE NCC SYSTEM FOR SPENT FUEL AND BLANKET ASSEMBLIES

The development, design, and testing of an active neutron interrogation system is recommended to supplement or provide a technique alternative to the passive NCC measurement on irradiated assemblies. The required external neutron source strength would introduce additional design and shielding problems in applying the NCC technique for irradiated assemblies and would impact on the practical application to current LMFBR systems. If developed, however, the system would allow the inspector to obtain a direct measure of the nuclear-material content in the assemblies if applied both at the input stages for fresh fuel and blanket assemblies and the output stages for irradiated assemblies in the fuel handling operations facilities.

C. CLOSE-UP PHOTOGRAPHY

Development of close-up photography of assembly welds as possible assembly identification signatures is recommended for near-term field implementation on fresh and irradiated assemblies. This would be a supplementary measure to the visual method of verification of assembly identification by observing serial numbers and physical attributes. The need for special photographic equipment and delays due to film development time would be a factor in the assessment of the safeguards effectiveness of this method.

D. IDENTIFICATION OF FUEL AND BLANKET ASSEMBLIES

Assembly identification systems for possible implementation at in-air and/or in-sodium storage areas need to be defined for near-term development to supplement the currently limited visual identification of assemblies. The feasibility of implementation for current LMFBR systems, the level of safeguards assurance that may be attained, and the cost-effectiveness of the IAEA's inspection resources should be the primary considerations in assessing the optimum system for the IAEA.

E. UNDER-SODIUM VIEWING (USV) AND UNDER-WATER OPTICAL VIEWING (UWOV)

It is recommended that a development program be started for the near-term implementation of the USV and UWOV systems by the triangulation method for

in-sodium and in-water, and in-gas storage facilities. The program should include the long-term objective of developing these systems for unique assembly identification signatures that may be used by the IAEA inspector in verifying the physical inventory.

F. IN-SODIUM, IN-WATER, AND IN-GAS STORAGE SEALS

The possibility of segmenting the storage areas into modules for partial sealing of individual modular facilities should be investigated. Such segmenting may require development of advanced seals that include the capability of operating under sodium or under water. The potential reduction these seals could effect in the inspection effort for inventory verification of stored assemblies should be assessed for each stage of storage in the fuel handling operations. The cost-effectiveness in the inspection effort may justify the development of sealing systems for implementation in current or near-term operating reactor facilities.

G. DEVICES FOR VERIFYING STRUCTURAL INTEGRITY OF FUEL AND BLANKET ASSEMBLIES

Development programs are recommended for devices (seals) or a system of devices for in-sodium application to verify the structural integrity of an assembly. Short-term needs can be satisfied by the currently implemented neutron measurement system (NCC) for direct verification of the nuclear-material content in an assembly. However, devices for checking assembly-integrity may be found which would reduce the IAEA's inspection effort. The feasibility of implementation in the near-term operating reactor systems, the cost-effectiveness in the inspection resources, and the level of safeguards assurance provided by the devices should be continuously assessed in terms of the limitations of these devices to directly verify the integrity of the nuclear material content in an assembly.

H. DESIGN OF LMFBR ASSEMBLIES

A long-term development program is recommended to investigate the design or redesign of the LMFBR assemblies to enhance the containment features and consequently increase the level of assurance of the integrity of the nuclear-material content. A cost-effectiveness study would include the cost impact to the operator if the design or redesign indicates an increase in the costs of fabricating and handling the assembly. The impact on the design of the head end of the reprocessing plants should be included in the cost-effectiveness study.

I. DESIGN OF FRESH-FUEL STORAGE FACILITIES

The design considerations for storage facilities for fresh fuel assemblies should include the feature of combined or partial sealing capabilities for sections of assembly storage positions.

J. DESIGN OF SHIPMENT CASKS

Shipment-cask designs should accommodate the safeguards need for seals and C/S devices.

K. GENERAL DESIGN OF FUEL HANDLING SYSTEMS

The design of the fuel handling systems should incorporate features that address the safeguards requirements for ease of measurements. These features would include (1) buffer and auxiliary assembly storage space for use by operators and inspectors in order to establish inventory-balance accountancy with minimal impact on normal operations, and (2) space allocations for accommodating safeguards NCC and HRGS measurement systems and C/S devices.

The general design features of the fuel handling system would be influenced by the requirement for safeguards systems that use a combination of instrumentation; CCTV monitoring, fuel-assembly-integrity checking devices, fuel-assembly identification and storage placement systems. Provision for physical inspection by various personnel with suitable physical-protection mechanisms is needed. Some sensors that may be considered for monitoring fuel assemblies in storage and handling operations are portal radiation monitors, crane-loading monitors, pool acoustic monitors, USV and UWOV systems, and Cerenkov-glow vision devices.

The designs of the loading-unloading machines and of the transfer-conditioning cells should allow for accommodating direct visual and identification instrumentation for IAEA surveillance and accountability purposes.

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