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NON-PROLIFERATION ISSUES FOR THE DISPOSITION OF FISSILE MATERIALS USING REACTOR ALTERNATIVES

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ABSTRACT

The Department of Energy (DOE) is analyzing long-term storage and disposition options for excess weapons-usable fissile materials. A number of the disposition alternatives are being considered which involve the use of reactors. The various reactor alternatives are all very similar and include front-end processes that could convert plutonium to a usable form for fuel fabrication, a MOX fuel fab facility, reactors to burn the MOX fuel and ultimate disposal of spent fuel in some geologic repository. They include existing, partially completed, advanced or evolutionary light water reactors and Canadian deuterium uranium (CANDU) reactors. In addition to the differences in the type of reactors, other variants on these alternatives are being evaluated to include the location and number of the reactors, the location of the mixed oxide (MOX) fabrication facility, the ownership of the facilites (private or government) and the colocation and/or separation of these facilities. All of these alternatives and their variants must be evaluated with respect to non-proliferation resistance.

Both domestic and international safeguards support are being provided to DOE's Fissile Materials Disposition Program (FMDP) and includes such areas as physical protection, nuclear materials accountability and material containment and surveillance. This paper will focus on how the non-proliferation objective of reducing security risks and strengthening arms reduction will be accomplished and what some of the non-proliferation issues are for the reactor alternatives. Proliferation risk has been defined in terms of material form, physical environment, and the level of security and safeguards that is applied to the material. Metrics have been developed for each of these factors. The reactor alternatives will be evaluated with respect to these proliferation risk factors at each of the unit process locations in the alternative.

INTRODUCTION

The DOE established the Fissile Materials Disposition Program (FMDP) to address the disposition alternatives applicable to the long-term storage and disposition of surplus fissile material. Within this program, a team was formed to focus on the non-proliferation, security, and safeguards needs of the various long-term storage and disposition alternatives being considered. The primary program goal is to render weapons-usable fissile material inaccessible and unattractive for weapons use while protecting human health and the environment. The National Academy of Sciences (NAS) recommended the Pu disposition efforts attain the "spent fuel standard". This standard would require that the final disposal form be as difficult or unattractive as the recovery of residual Pu from spent commercial nuclear fuel. When this standard has been achieved, the proliferation risk is generally considered the same as that associated with the much larger inventory of residual Pu in commercial spent fuel. Technologies that go beyond the spent fuel standard are not currently being considered in this program.

The 1994 NAS report on the disposition of excess weapons Pu stated that reduction of risk of proliferation by unauthorized parties, reduction of risk of reintroduction of materials into arsenals and the strengthening of national and international control of fissile materials are necessary. After the initial screening process, eleven Pu disposition alternatives were selected as reasonable alternatives for further evaluation during the FMDP decision phase. They included two alternatives concerning the emplacement in deep boreholes, four alternatives concerning immobilization of the Pu and five reactor related alternatives. This paper discusses the reactor alternatives. The five reactor alternatives include:

- Burning in existing U.S. LWRs with ultimate repository disposition.
- Burning in CANDU heavy water reactors with spent fuel disposal by the Canadian utility.

- Burning in evolutionary or advanced LWRs with ultimate repository disposal.
- Burning in partially completed LWRs with ultimate repository disposition.
- Transfer to the Euratom market for mixed oxide (MOX) fuel and reactor burning.

There could potentially be a very large number of variants for these reactor alternatives. For the reactor alternatives, differences exist in the reactor type (BWR, PWR, CANDU); reactor status (existing, partially completed, new); number of reactors (2-4), location of reactors (in U.S., Canada, Europe); reactor owner (private, government owned contractor operated, Canada), location of fuel fabrication facility (U.S., Europe); and possible co-location of the MOX and Pu processing facilities.

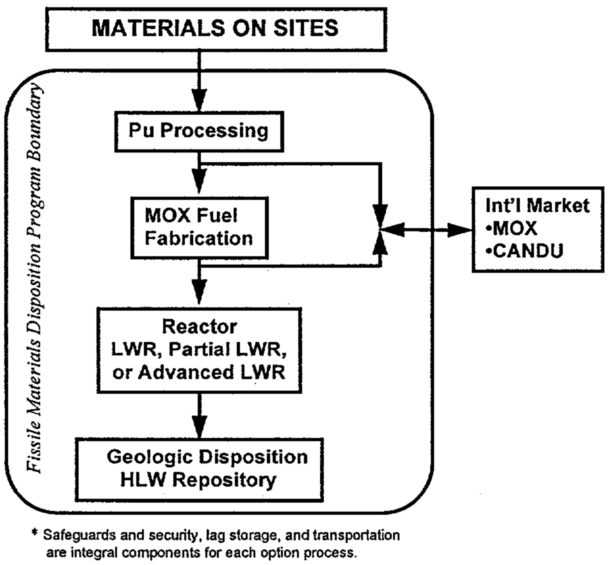

FIGURE 1. Reactor Alternatives

All of the reactor alternatives (Figure 1) consist of a Pu processing facility, MOX fuel fabrication facility, reactors, and high-level waste repository. The Pu processing facility receives a variety of Pu feed material and converts this material into Pu oxide. The MOX fuel fabrication facility purifies, blends and prepares MOX pellets. These pellets are then loaded into fuel rods and made into fuel bundle assemblies. The various reactors generally include fresh MOX receipt and storage, burning in the reactor core and spent fuel storage in a storage pool and/or dry spent fuel storage. The repository consists of a surface facility for the receipt and handling of the material and a subsurface facility for the permanent isolation of the material.

SECURITY AND SAFEGUARDS

The evaluation of proliferation risks associated with the reactor alternatives must be done from both the domestic and international perspectives and is based on two important factors, the "threats" and the "regimes" that exist to address these threats. The areas of responsibility can be separated naturally into national and international. The responsibility of the host nation government is to prevent unauthorized access to its material either by groups within its own organization such as disgruntled workers or by other national or international terrorist groups, criminal organizations, etc. The responsibility of the international group is to prevent the host country from diverting or retrieving material that has been declared surplus. This gives a very clear delineation of the threats associated with each perspective.

Threat

The threats can be defined as:

- theft (unauthorized removal of material by a group outside of the host nations nuclear organization),
- diversion (unauthorized removal of material by a member of the host nations own nuclear organization or unauthorized removal of material by the host nation itself in violation of the international regime before final disposition has taken place),
- retrieval (unauthorized access by the host nation in violation of the international regime after final disposition or unauthorized access by outside groups after final disposition), and
- conversion (the converting of retrieved material back into weapons form either by the host nation or other outside groups).

Domestic Safeguards

Both DOE and Nuclear Regulatory Commission (NRC) guidelines may apply depending on the facility. NRC licensed operations (e.g. commercial reactors) are expected to remain under NRC jurisdiction. Domestic S&S is comprised of two subsystems, nuclear materials control and accounting (MC&A) and physical protection required for protection of special nuclear material (SNM) and nuclear weapons against threats of diversion and theft. Domestic safeguards is primarily concerned with unauthorized actions by individuals and/or subnational groups. The S&S requirements for this alternative are primarily driven by the attractiveness of the material as defined in DOE Order 5633.3B (Table 1).

TABLE 1. DOE Nuclear Material Attractiveness and Safeguards Categories for Plutonium

	Attract. Level	PU/U-233 Category (Quantities in kgs)			
		I	II	III	IV[a]
WEAPONS	A	All Qtys	N/A	N/A	N/A
PURE PRODUCTS	B	≥ 2	≥ 0.4 < 2	≥ 0.2 < 0.4	< 0.2
HIGH-GRADE MATERIAL	C	≥ 6	≥ 2 < 6	≥ 0.4 < 2	< 0.4
LOW-GRADE MATERIAL	D	N/A	≥ 16	≥ 3 < 16	< 3
ALL OTHER MATERIALS	E	N/A	N/A	N/A	Note a

a/ The lower limit for category IV is equal to reportable limits in this Order

International Safeguards

The International Atomic Energy Association (IAEA) is the primary agency for international safeguards (ISG). ISG is also comprised of two subsystems, nuclear materials accountancy and materials containment and surveillance (C/S) required to satisfy international inspection agreements. The applied C/S provides continuity of knowledge during inspector absences and provides supplemental information to assure inventory values when measurement uncertainties might lead to the conclusion of inventory discrepancies. Since the potential adversary for ISG is the host nation, all C/S systems and data must be protected from tampering and alteration by the host. Therefore all monitoring equipment must be tamper protected and all data from the monitoring systems must be authenticated. Similarly, all measurement equipment used by the international inspectors must be calibrated by them and protected from tampering by the host between uses. The focus is on the independent verification of material use through material accountancy programs and C/S systems. IAEA inspections are conducted to verify the facility's declared nuclear inventory values to within a significant quantity (SQ) of material. Currently, a significant quantity of material is defined to be 8kg of Pu or 25kg of U-235. Other definitions apply to other fissile materials, such as U-233 and Thorium.

Nuclear material for this alternative falls under the IAEA categories of unirradiated direct use material (e.g. Pu metal and compounds, MOX powder and pellets, MOX fuel rods and assemblies) and irradiated direct use material (e.g. MOX fuel in the reactor core, spent MOX fuel). To achieve consistency among all long-term storage and disposition alternatives being considered in this program, the following specific *assumptions* have been made:

- Material under IAEA safeguards will remain so.
- Material not declared excess to stockpile and the strategic reserve will be exempt from IAEA safeguards.
- Excess unclassified material may be offered by DOE to the IAEA for IAEA safeguards and will remain under those safeguards.
- Excess classified materials will not be offered for IAEA safeguards until classified/restricted information has been properly protected.

PROLIFERATION RISK

Proliferation risk is or has been defined in terms of material form, physical environment, and the level of security and safeguards applied to the material (Figure 2). A number of measures have been developed for each of these factors to evaluate the various alternatives. The evaluation will address requirements, measures and identify the proliferation risk at each of the various steps in the alternative and the non-proliferation discriminators for the alternatives.

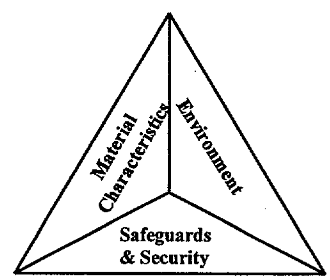

FIGURE 2. Proliferation Risk Factors

The risk of theft of weapon-usable nuclear material is considered during transportation, storage, and processing, as well as after disposition is completed. The environment includes processing steps, throughput, inventory, location, and transportation. Throughput for bulk operations and location are particularly important. The material characteristics are based on form attractiveness, which includes the physical, chemical, or nuclear (isotopic and radiological) makeup of the nuclear material, and on the presence of other fissile materials. The need to protect classified information, the nuclear material accountability system, the uncertainty of nuclear measurements, and the accessibility of the material are all measures of security and safeguards.

POTENTIAL FACILITY IMPACTS & ISSUES

It is assumed that all facilities will meet the necessary S&S requirements and that these measures will help mitigate any risks. Still, the threats to facilities will be different depending on the form of the material, the activities at the facility, and the barriers to theft and diversion (both intrinsic to the material and also to the facility). For each of the facilities in the reactor alternatives, there exists a potential risk to theft and/or diversion. The remainder of this section will briefly discuss each of the facilities/activities for the reactor alternatives. Table 2 at the end of this paper summarizes some of the information discussed in this section. The inherent risks to proliferation, attributes which affect proliferation resistance, facility impacts, and issues will be discussed.

Plutonium Processing

For this facility, most of the material is in a very attractive form with minimal intrinsic barriers and range in attractiveness from IID to IB (Table 3). Based on the quantity and attractiveness of the material, the facility will need to be a category I facility.

TABLE 3.
Plutonium Processing Material Attractiveness

Form	Input Attractiveness	Output Attractiveness
Pits	IB	IC
Oxides & High Grade Material	IC	IC
Low Grade Material	IID	IC

Material received into this facility (e.g. pits and containers with tamper indicating devices (TIDs)) would utilize item accountancy. Once the material has been removed from the "container", then bulk accountancy would be necessary. In addition, many of the processes involve bulk material and therefore, bulk accountability measurements which would utilize destructive assay and other non-destructive assay (NDA) techniques.

Except for the pits and containers with TIDs, many of the operations will involve hands-on activities where the material is accessible. The items being handled are not particularly large and do not require any special handling equipment (SHE). Most of the operations will be performed inside a glovebox. In most cases, the material is in a very pure form, such as a metal or oxide, and its isotopic composition makes it readily usable for a nuclear device. Increased use of operations to minimize access to nuclear material is needed. This could include the use of automated or robotic devices, remote handling and other barriers to minimize the accessibility to the material. There are a large number of complex processing steps with a relatively high bulk throughput. This combination provides increased opportunities for covert theft and diversion. Bulk material which is not in bulk process operations should be stored in sealed, containers to help minimize the opportunities for diversion. Waste streams containing fissile material will be generated and thus require monitoring to detect possible diversion.

This facility will involve large quantities of bulk material and very high throughputs making it very difficult to detect the diversion of a significant quantity of material using material accountability alone. It will be necessary to have ISG and other S&S measures to ensure that material is not being diverted. Material balance areas (MBAs) and nuclear measurement points need to be located in bulk processing areas to minimize the uncertainty of material accountability. All movement of fissile material across security or MBA boundaries must be monitored (i.e. bulk and item movements and waste streams).

In the case of an overt theft attempt, the targets of greatest concern would be the pits and pure metal and oxides which are transportable. There will be no intrasite transport movements (e.g. outside of the MAA). Safe secure transports (SSTs) will be necessary to deliver and pick up the material.

Because pits and some other weapons material are being processed, some of the material will be classified. The presence of classified material further complicates safeguards with respect to international inspection since material will not be under ISG unless restricted data can be protected. This may also apply to waste streams. Therefore, at least part of this facility may not be under ISG and verification by the IAEA is not possible until agreements between the IAEA and the U.S. can be accomplished. A number of different alternatives are being considered to address this problem including processing weapons related components and material into declassified forms and only then making it available for the IAEA and the use of modified IAEA safeguards until the material is unclassified.

MOX Fuel Fabrication

This facility will be a category I facility with a high bulk throughput. As in the case of the Pu processing facility, the initial feed materials (e.g. oxide and unirradiated fuel) are very attractive material (IC). The intrinsic attributes of this material are the same as described above for the Pu processing facility. Once the material has been blended, it becomes a less attractive target because it would be slightly more difficult to convert to a weapons usable form because the concentration of the Pu is lower and more material would be required to acquire a significant quantity. Once the MOX is placed into fuel rods and then fuel assemblies, its chemical, isotopic and radiological attributes would not change, but the mass/dimensions of the "containers" would increase. This makes the material more difficult to move and more difficult for diversion and overt theft. Waste streams containing fissile material will be generated.

The facility operations involve a large number of processing steps, and handling of bulk material which is relatively accessible. The initial process steps for the MOX fuel fabrication facilities have similar risks to those mentioned for the Pu processing facility and therefore similar measures are needed. Stringent materials accountability measures are needed to ensure that, during the blending processes and fuel rod and assembly fabrication, all nuclear material is accounted for. During the initial processing operations, bulk accountancy would be conducted until the material is placed into the fuel rods.

Nondestructive nuclear measurements for fresh MOX fuel rods and assemblies would help ensure materials accountability after destructive assay is no longer possible. Although devices are being developed to perform NDA on fuel rods and assemblies, this is still a very time consuming activity. Once the material is placed inside the fuel rods it is no longer accessible and item accountancy is used. The possibility for diversion is reduced because the fuel rods and assemblies are quite large and require SHE with appropriate measures in place to monitor and control access to this equipment to more easily detect diversion attempts.

For rods and/or assemblies that are relatively transportable, barriers and controls are necessary to mitigate the threat of theft. No intrasite transport will be required outside the MAA and again, SSTs will be used to both deliver and pickup the material.

Reactors

Within the reactor facility, material ranges from category IC SNM to category IVE. Table 4 summarizes the transition of states and theft attractiveness for the material.

TABLE 4. Reactor Material Attractiveness

Fuel Assemblies	Attractiveness Category	Overt Theft Attractiveness
Fresh	IC	Moderate
Irradiated	IVE	Low
Aged Spent	IID	Moderate

Once the fuel assemblies are placed into the reactor core, they are not only inside the reactor containment building, but their intrinsic barriers increase significantly once they have been irradiated. The low concentration of the Pu in the fuel, Pu isotopics, and the high radiological barrier makes handling the material more difficult and makes diversion and conversions to a weapons useable form more difficult. If the fuel assemblies are placed into dry spent fuel storage, they still have a significant radiation barrier. When placed in the storage containers, the fuel assemblies are very difficult to move without being detected. If, after sufficient time, the fuel assemblies are no longer self-protecting (100 rem/hr at 1 m), the material could become category IID. They still are not a particularly high theft target because of the significant external barriers in place.

Item accountancy is used to account for fuel assemblies. The application of C/S measures reduces the likelihood for covert diversion. Markings and seals on the assemblies can also be used to account for material. The fuel assemblies are discrete items that reside for long periods at a single location (e.g. reactor core, spent fuel pool, dry storage area). SHE is required to move these assemblies. Once they have been irradiated, remote handling is necessary. The material is generally not very accessible. For spent fuel, some NDA measurements are possible, but at the present time, they are generally used to confirm the presence of the spent fuel and not to accurately account for the material. Using the initial material information and the records from the reactor facility, the quantity of material can be indirectly estimated.

The large mass and dimensions of the fuel assembly require the use of SHE which provides increased delay against an overt attack and also helps in detecting any covert adversary activities.

The presence of fresh MOX fuel assemblies is the primary factor affecting S&S reactor operations. It may affect procedures, personnel qualifications, clearances, and response force requirements. It will be necessary to have a secure area where the SSTs can off-load the fresh fuel assemblies and areas where the necessary nuclear accountability and measurements can be performed. It may be necessary to store fresh fuel assemblies in a vault-like area or possibly storage pool where enhanced delay and access control measures are in place. It is very desirable to minimize the presence of fresh MOX fuel at the reactor site. This may not always be operationally feasible. If fresh MOX fuel is only present during core reloading, then additional temporary S&S measures could be implemented to protect this material and perhaps new costly fresh fuel storage areas could be avoided. After the fuel has been irradiated and removed from the core, it will be placed in a storage basin. Item accountability and C/S measures will be in place. If the fuel is eventually placed into dry storage, appropriate measures are still needed.

Repository

The spent fuel is received in shipping casks and the assemblies are removed and placed into disposal casks. Initially, the material is a low attractiveness target for both covert and overt theft. It is highly to moderately radioactive and each cask is very massive. From 10 to 100 years, the radiological barrier would decrease by an order of magnitude, thus making it more attractive. Although a large amount of material will be entering the repository the process operations are relatively simple and few in number. Again, the operations are on very large discrete items that remain in the drifts where they are placed. Once a drift has been filled, it will be sealed. Item accountability is used for the casks. No access is available to the material itself, although, access to the casks is possible. All movements of the casks requires special handling equipment.

Since the radiological barrier is time dependent, it is necessary to utilize other measures to help minimize the threat of diversion. Placement of the material in an underground repository makes retrieval of this material more difficult. The radiological barrier decreases over a long period of time to the point that the material will not be self-protecting. Therefore, it is necessary for long-term disposition to make the material as inaccessible as possible and provide protection for a long period of time. Additional long-term safeguards and C/S measures should be utilized to help protect this material. It is also important that accurate accountability of the material be maintained so there is a high degree of confidence that the material was not diverted and was, in fact, placed into the repository. The casks will be sealed, item accountancy performed, and C/S measures implemented.

Transport

For all category I material, SSTs will be used to move the material between facilities. Only after the MOX fuel has been irradiated will the requirement for SST movement be removed. The transport of SNM has inherently greater risks for overt theft scenarios and a lower risk for covert theft attempts. Minimizing the number and/or duration of the transport steps is desirable. Much of the risk for transportation is related not so much with the actual SST movements, but rather with the shipping and receiving activities at the various facilities. There are no known major impacts on transportation which will result from IAEA safeguards being applied. In the case of shipments by SSTs, "casual" inspection (e.g. an inspection which does not permit measurements or disclosure of sensitive design information about the SST) would be permitted. Tracking and monitoring of shipments by IAEA while enroute would not currently be allowed. In order to meet IAEA safeguards requirements it is likely that IAEA seals would be placed on the individual containers and also on the doors of the SST without interfering with the operational security procedures.

IAEA

The philosophies and implementation of ISG (commonly referred to as IAEA safeguards) are substantially different from domestic S&S. The most important difference is, of course, that the host country is the adversary that must be protected against. IAEA inspections also involve different techniques and different goals than domestic S&S inspections.

Nuclear measurements play an important role in verifying material accountability. Differences from "book" values and holdup are particularly important for high-throughput processes when statistical measurement uncertainties can lead to discrepancies larger than a significant quantity of material. C/S systems can be used to supplement measurements when this occurs.

Currently the IAEA does not have a policy that allows extended inventory frequencies due to the application of compensatory safeguards measures (e.g. defense-in-depth, item monitoring) like those that have been allowed by the DOE. Of course, additional domestic S&S measures will have no effect on ISG inventory frequencies since they do nothing to protect the material from diversion by the host country unless the IAEA can be convinced that the data coming from the systems is authentic.

Classified information (as in the Pu processing facility), must be protected. Protection of proprietary information will have to be negotiated with the IAEA on a facility basis. It is assumed that all facilities except possibly pit storage and a portion of the Pu processing facility, will be subject to IAEA safeguards. It is likely that ISG compliance will require additional accountability verification (e.g. identification, weighing, sampling and analysis and NDA), increased inventories and item checks, C/S measures installed throughout the facilities (e.g. surveillance, seals, monitors, tags), space for inspectors, and equipment for independent measurements by international inspectors. If provisions for these additional requirements are not made in the initial design of the facilities, the cost of placing the facility under ISG can be extremely high.

SUMMARY

It is assumed that all facilities will meet necessary S&S requirements and that appropriate protective measures will be taken. Integration of domestic S&S and ISG to reduce cost and operational impacts would be beneficial. The final disposition form of the reactor alternatives meets the spent fuel standard. Facilities which handle large quantities of bulk material, have high throughputs, and involve very complex operations have a greater risk that material can be diverted. The Pu processing and MOX fuel fabrication facilities, which are common to all reactor alternatives, are such facilities. In addition, the material is relatively accessible and measurement uncertainty may mean that theft/diversion of a SQ of material may be more likely. As the material is made into items (e.g. fuel assemblies), the likelihood for diversion decreases. After the fuel has been irradiated, the radiation barriers, along with the location and mass of the assemblies, makes theft, diversion and/or retrieval more difficult. The increased number of moves, miles, and handling steps involved with the transport operations increases the risk for theft and diversion. In general, this proliferation risk can be reduced by minimizing the handling and processing of the material and by applying appropriate S&S measures.

In this paper we have presented a technical approach for evaluating a nuclear facility for proliferation risk. This approach compliments the traditional vulnerability assessment (VAs) done by facilities and provides insight into the inherent proliferation risks for the individual processes and the facility. This information can then be used to help in developing the design or measures to help mitigate these risks. All nuclear facilities have an inherent proliferation risk due to their environment, processes, material forms, and available S&S measures. The evaluation of the various dispositions alternatives is in the early stages. The methodology continues to be developed and results of its application will be available in the future.

ACKNOWLEDGMENT

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TABLE 2. Facility Attributes for Proliferation Risk

Factors	Plutonium Conversion	MOX Fuel Fabrication	Reactor	Repository	Transport
Environment # of processing steps Max Pu inventory Bulk Pu throughput # SST trips/miles Fissile material(FM) wastes Location	• large # of complex processing steps • large Pu inventory • large bulk throughput • FM waste streams • glovebox operations • no intrasite transport	• initially high # complex proc steps and large bulk throughput • for rods/assemblies there are fewer steps and no bulk throughput	• fewer and simpler steps for most reactors • no bulk throughput • low FM waste streams	• very few and simple process steps • no bulk throughput • fuel located in casks and eventually underground	• large number of transactions • # of SST trips and miles • co-functional facility eliminates transport leg • secure SST loading area needed • crossing intl boundaries and materials acct
Material Form Form DOE material attractiveness Other separated FM present	• pure metal, oxide • matl attractiveness IB -IID • high conc pure metal and oxides • other separated FM is present • low intrinsic barriers • easily transportable	• direct use material in fresh fuel, powder, pellets • matl attractiveness IC • high conc oxide initially and blended to lower conc • initially transportable, rods/assemblies - large size/mass	• irrad fuel - irrad direct use located in dry or wet storage • matl attractiveness IC to IVE upon irradiation • self-protecting rad barrier • low Pu2 conc • large, massive assemblies	• highly irradiated material (time dependent) • matl attractiveness IVE • @ 100 yrs radiation less by an order of magnitude • @ 100 yrs % Pu239 higher • very large massive casks	• direct use material before irradiation • SSTs move all Cat I material • IVE moved via other means (truck, rail)
Safeguards & Security Accessibility Nuc matl meas accuracy MBA density Type of nuc acct sys Classification	• generally very accessible • primarily bulk nuclear accountability • *higher meas uncertainty* resulting in difficulty in meeting IAEA reqr for SQ • classified material • no special handling equip (SHE) needed	• less accessibility for rods and assemblies • initially bulk acct and *then item acct for* rods/assys • special handling equip reqr for rods/assys	• item accountability • SHE for moving assemblies • *limited access to fresh fuel* • NDA very difficult • radiation barrier for spent fuel	• item accountability • access to casks but not to the spent fuel • SHE *needed to move* casks	• item accountability • increased handling of containers • *increased nuclear meas* required to confirm material acct • nuclear meas required for each change of custody

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