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A Framework and Methodology for Nuclear Fuel Cycle Transparency

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A Framework and Methodology for Nuclear Fuel Cycle Transparency

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Abstract

A key objective to the global deployment of nuclear technology is maintaining transparency among nation-states and international communities. By providing an environment in which to exchange scientific and technological information regarding nuclear technology, the safe and legitimate use of nuclear material and technology can be assured. Many nations are considering closed or multiple-application nuclear fuel cycles and are subsequently developing advanced reactors in an effort to obtain some degree of energy self-sufficiency. Proliferation resistance features that prevent theft or diversion of nuclear material and reduce the likelihood of diversion from the civilian nuclear power fuel cycle are critical for a global nuclear future.

IAEA Safeguards have been effective in minimizing opportunities for diversion; however, recent changes in the global political climate suggest implementation of additional technology and methods to ensure the prompt detection of proliferation. For a variety of reasons, nuclear facilities are becoming increasingly automated and will require minimum manual operation. This trend provides an opportunity to utilize the abundance of process information for monitoring proliferation risk, especially in future facilities.

A framework that monitors process information continuously can lead to greater transparency of nuclear fuel cycle activities and can demonstrate the ability to resist proliferation associated with these activities. Additionally, a framework designed to monitor processes will ensure the legitimate use of nuclear material.

This report describes recent efforts to develop a methodology capable of assessing proliferation risk in support of overall plant transparency. The framework may be tested at the candidate site located in Japan: the Fuel Handling Training Model designed for the Monju Fast Reactor at the International Cooperation and Development Training Center of the Japan Atomic Energy Agency.

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NOMENCLATURE

EVTM: Ex-Vessel Transfer Machine
FFA: Fresh Fuel Assembly
FHM: Fuel Handling Machine
IVTM: In-Vessel Transfer Machine
SFA: Spent Fuel Assembly

1.0 Introduction

Nuclear fuel cycle transparency is a high-level concept, defined as a confidence building approach among political entities, possibly in support of multi-lateral agreements, to ensure civilian nuclear facilities are not being used for the development of nuclear weapons. Additionally, nuclear fuel cycle transparency involves the cooperative sharing of relevant nuclear material, process, and facility information among all authorized parties to ensure the *safe and legitimate use* of nuclear material and technology.

A system is considered *transparent* when the parties involved can evaluate for themselves whether or not the *proliferation risk* is at an acceptable level. For this to occur, proliferation risk should be monitored in a continuous fashion.

The intent of this research is to develop a framework capable of continuously assessing proliferation risk to support overall plant transparency. A continuous, or real-time, analysis is important to increase the rapidity with which diversion might be detected. Currently, it is difficult to assess proliferation risk on a continuous basis; for example, by updating risk as different plant processes are used.

Figure 1 below describes a framework of nuclear fuel cycle transparency. Data is collected from the nuclear facility and sent to a secure data base. The transparency analysis software generates a proliferation risk to support transparency of the facility.

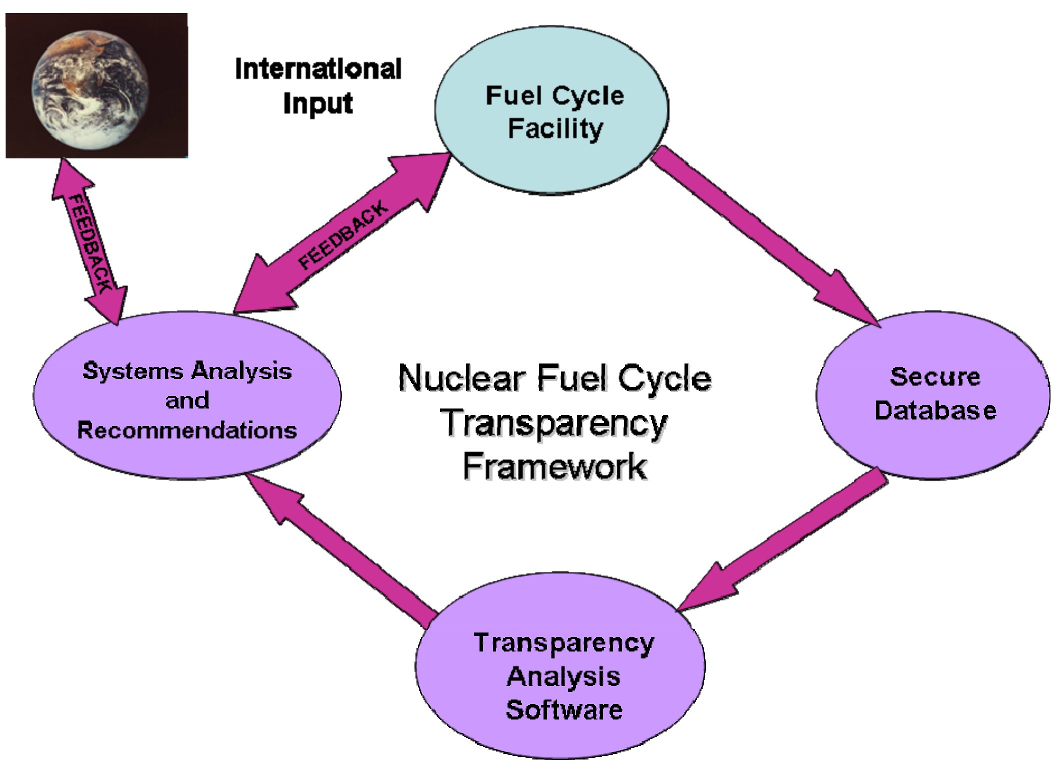

Figure 1. Nuclear Fuel Cycle Transparency Framework

The projected outcome of this research is the ability to determine inconsistencies in the operation of a nuclear facility through rapid analysis of plant process and monitor information. It is important to note that following the analysis, the values obtained can be used to recommend changes to reduce proliferation risk. Also, the analysis provides results and feedback to the site as well as all other authorized parties. The framework is designed to support and maintain an acceptable level of proliferation risk.

The International Atomic Energy Agency (IAEA) serves as an important international forum for scientific and technical cooperation in the peaceful use of nuclear technology. The agency serves as the world's intergovernmental forum, applying nuclear safeguards and verification measures to civilian nuclear programs. Nuclear technology for peaceful uses continues to expand under the IAEA safeguards pertaining to the Non-Proliferation Treaty (NPT), although membership to IAEA does not necessarily require membership to the NPT. Under the treaty, and in compliance with Nuclear Supplier Group guidelines, nuclear technology can be exported for peaceful purposes. Development of transparency methods based on automated remote monitoring may support exports for peaceful purposes, consistent with a global nuclear future.

This research suggests the methodology and technology developed may augment IAEA verification tools by providing a scientific approach to monitoring facilities and will provide a common framework for monitoring the operation of exported nuclear technology. Additionally, it will provide feedback to cooperating parties and will allow for full transparency of a nuclear fuel cycle; thus creating an environment in which all international parties are confident that nuclear power is safe, secure, and free of proliferation. The framework may also support multi-lateral nonproliferation agreements.

As transparency increases confidence among nations, it also facilitates the transfer of technology. The current international political climate indicates a need for increased methods of non-proliferation. As President Bush clearly states in the following quote, nuclear technology may be exported to developing countries.

> "The world must create a safe, orderly system to field civilian nuclear plants without adding to the danger of weapons proliferation."
>
> ~U.S. President George W. Bush, February 11, 2004

However, a system would be desirable to promptly detect diversion of nuclear material, because misuse of enrichment or reprocessing activities may indicate a non-peaceful use of nuclear technologies.

Additionally, the concepts developed by this research are useful in examining transparency issues of future technologies, such as the Fast Reactor Nuclear Fuel Cycles developed in Japan and the Generation IV Nuclear Energy Systems being developed internationally. As a result of the enhanced transparency of nuclear technologies and the associated confidence built among nation-states, the export of newly developed nuclear technology for peaceful purposes may be facilitated.

2.0 Nuclear Fuel Cycle Transparency Framework

2.1 Project Scope

The scope of this research is to advance the concept of nuclear fuel cycle transparency as capable of collecting plant process data and real-time monitor information for the purpose of assessing the proliferation risk in a continuous manner to enhance transparency of nuclear facilities.

2.2 Project Goals

The goal of this research is to develop a transparency framework capable of using plant process and monitor data to assess proliferation risk at a nuclear facility as it operates.

In the near future, the transparency framework may be demonstrated at a candidate site. The demonstration will establish a Transparency Test Bed to demonstrate application of the nuclear fuel cycle transparency framework for verification and validation of material process flow. This test bed will provide the basis for adding safety and other features also important to transparent operation.

Long term goals of this project include building the transparency concept into the design of nuclear facilities before they are deployed throughout the world. Additionally, it is our expectation that the transparency framework will be utilized to integrate other aspects of nonproliferation control, such as IAEA safeguards.

2.3 Project Objectives

Objectives of this research project include the following:

- Collaborate with the Japan Atomic Energy Agency to develop techniques that will enhance international confidence in safe, secure operations and handling of nuclear material.
- Foster international collaborations leading to workable, effective, globally accepted standards for the transparency methodology of nuclear material.
- Focus on the secure operation of nuclear facilities and the secure handling of nuclear material.
- Develop a quantitative framework to evaluate proliferation risk in support of facility transparency within the nuclear fuel cycle in real-time. (*Transparency Analysis Software*, described below.)
- Incorporate plant process information and procedures to utilize the existing data to the fullest extent (*Transparency Toolbox*, described below).
- Survey the field of detectors, sensors, and communication technologies currently in use or under development to improve the transparency of the nuclear process (*Transparency Toolbox*, described below).

Figure 2 describes the transparency framework and includes the Transparency Toolbox and the Transparency Analysis Software. As data is pulled from the secure data base, it enters the transparency toolbox where it is aggregated. Data is then sent to the Transparency Analysis Software. In this stage, a value of proliferation risk is determined.

The Transparency Toolbox and Transparency Analysis Software are described below.

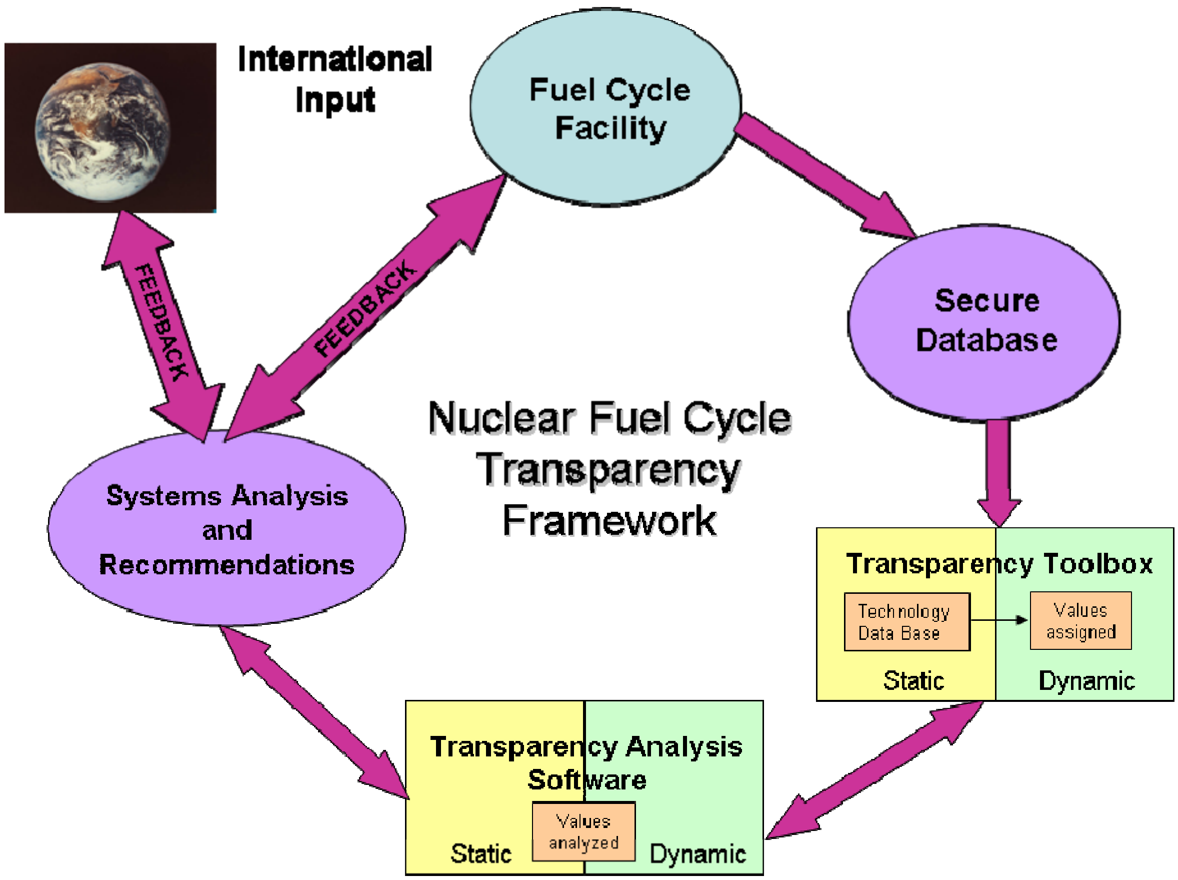

Figure 2. Nuclear Fuel Cycle Transparency Framework

2.3.1 Transparency Toolbox

The Transparency Toolbox contains the system by which data is collected and aggregated. It contains the information necessary to support the analysis. These tools include information from the available field of detectors, sensors, and communication technologies currently in use or under development. Additionally, plant process design information is housed in the Transparency Toolbox.

In this portion of the framework, raw data is continuously collected and placed in a secure data base. The data is aggregated and processed before passing it to the analysis software.

The Transparency Toolbox has the following primary functions:

- Utilizes Plant Process Data in the context of ***defined*** Plant Operating Procedures
- Provides information on additional technology support, including:
  - Automation technologies
  - Specialized monitoring techniques
  - Commercially available technologies
  - Advanced sensors
- Houses a database which lists usable technologies and performance data
- Divides data streams into three categories:
  - Monitoring data – surveillance data, images, etc.
  - Sensing data – door switches, motions detectors, radiation sensors, etc.
  - Security data – intrusion alarms, etc.
- Based on technologies and raw data, formulates processed data needed by the Transparency Software to calculate proliferation risk.

2.3.2 Transparency Analysis Software

The Transparency Analysis Software contains the system by which the proliferation risk of a nuclear facility can be calculated. Additionally, the Transparency Analysis Software performs the following tasks:

- Provides a structure for the design of the application at nuclear facilities.
- Provides a structure where plant observations are analyzed in real-time and compared to expectations.
- Analyzes data and performs analyses based on processed data obtained from the Transparency Toolbox.
- Provides a process or method to aggregate information into a useful measurement of the change in proliferation risk.
- The final measurement compares two quantitative analyses of overall proliferation risk at a nuclear facility in a timely fashion:
  - Static risk: This analysis of proliferation risk *is not* time-dependent. It is considered a "fixed value" or a "baseline" and is generated as a result of expected signals, plant process information, and plant design information.
  - Dynamic risk: This analysis of proliferation risk *is* time-dependent. It ultimately measures the change in proliferation risk relative to the static risk. The dynamic calculation is made from observed signals that are constantly being updated.

In the future, the Transparency Analysis Software may recommend procedures to further reduce proliferation risk, model historical trend information, and initiate response actions.

The Transparency Analysis Software is necessary to apply a methodology to quantitatively assess the proliferation risk at a nuclear facility. The continuous information provided by the Transparency Analysis Software will yield a timely non-proliferation assessment under global conditions which can change quickly and without warning. This analysis is necessary to design, support, and maintain transparent systems.

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3.0 Nuclear Fuel Cycle Transparency Concepts

In recent years, there has been an increased need for additional protocols with other descriptive and quantifiable methods to ensure transparency (IAEA-INFCIRC/540, 1997). Although international safeguards are critical, it is also important to characterize explicitly the uncertainty associated with each step in the process of the nuclear fuel cycle.

Currently, evaluations of nuclear fuel cycle transparency involve **qualitative** analyses of nuclear facilities, such as volunteer sharing of process information and publicly accessible video cameras. This qualitative judgment can be difficult to analyze or reproduce.

This section of the report describes the current efforts to **quantify** nuclear fuel cycle proliferation risk in order to achieve transparency.

3.1 Transparency Factors

A nuclear fuel cycle is transparent when the parties involved can assess the proliferation risk for themselves and determine that it is acceptably low. Thus, a detailed calculation of proliferation risk must be performed. Probabilistic risk assessment is often used as a way of computing the risk of a particular system or failure mode. Often this risk is expressed as the product of the probability or frequency of an event and the consequences of the event. However, by using the transparency framework discussed earlier in this report, a specific and timely calculation of risk may be performed.

This section will define a few of the quantitative factors relative to a proliferation risk calculation. The top-level mathematics associated with these factors will be discussed in subsequent sections.

3.1.1 Expectations

Expected signals, or data from plant processes or equipment as designed, used in this methodology are "baselines" used to determine the expected, or static, risk. As the analysis progresses, expected signals are aggregated with other expected information, such as plant process and plant design information; for instance, a certain material involved in a certain process will yield an expected risk. By comparing the expected signals to the real-time information generated by subsequent analyses, an evaluation of the change in proliferation risk can be made. If the continuous data collected meets or falls below expectations, proliferation risk is nominal or reduced.

Expected Signals + Process Information + Plant Designs → Static Risk

3.1.2 Observations

Observed signals are the measured, real-time, constantly changing conditions in the plant. As these data are analyzed, results observed are aggregated with other expected information, such as plant process and plant design information. The data is then processed to yield a real-time, or dynamic, risk. By continuously comparing the static risk to the dynamic risk generated by the analysis, an evaluation of proliferation risk can be made. If the observed signals do not meet expectations, proliferation risk is increased.

Observed Signals + Process Information + Plant Designs → Dynamic Risk

Since the transparency toolbox already contains plant process information and plant designs, only the observed signals need to be accumulated in a timely fashion.

A more detailed description of Expectations and Observations may be found in section 4.0.

3.1.3 Material Attractiveness

Many methods are available for calculating proliferation risk (Jones, 2003). However, for illustration, the framework developed includes material attractiveness as a key aspect of proliferation risk.

Material attractiveness represents the quantification of several factors concerning the diversion potential of nuclear material throughout the process flow of the nuclear fuel cycle. This factor determines a value representative of how attractive a certain material would be for purposes of proliferation.

3.2 Process Flow

Process flow refers to the movement, activity, or any processes associated with the nuclear material in the fuel handling cycle at a specific facility. Process flow information is crucial for the analysis, since each step in the process involves a separate comparison of observations to expectations. This information is well defined, structured, and organized and placed into the secure facility database.

This research examines an automated fuel handling process designed for Monju Fast Breeder Reactor. As an example, Table 1 describes some of the process flow information relevant to Monju. This information is specific to the movement of nuclear material from the Ex-Vessel Storage Tank to the Reactor Core and back at the Fuel Handling Training Model designed for the Monju Fast Breeder Reactor.

In the table below, each bullet in the process flow represents a node of information that could be collected to verify the movement or activity of the nuclear fuel in the nuclear fuel cycle facility. Information in this table represents some of the expectations that would be collected to calculate a static risk.

Table 1: Monju Fuel Handling Model Process Flow.
(Acronyms defined in the glossary of terms.)

FHM Positioned over selected Spent Fuel Assembly
□ FHM Limit Position Switch over the spent fuel assembly
□ FHM-Spent fuel assembly (SFA) attachment sensor
□ FHM-SFA lift sensor
□ FHM-SFA position switch over the IVTM pool
FHM transfers the SPF to the IVTM
□ FHM-SFA lowering sensor
□ FHM-SFA detachment sensor
□ FHM stow position switch
EVTM is positioned over EVST at desired position for Fresh Fuel Assembly
□ EVTM limit position sensor
EVTM extracts Fresh Fuel Assembly (FFA) from EVST
□ EVTM crane lower sensor
□ EVTM attachment sensor to FFA
□ EVTM crane lift sensor
□ EVTM crane position switch in the coffin A
EVTM moves to reactor
□ EVTM movement sensors
□ EVTM position sensor over reactor core
EVTM transfers FFA to IVTM
□ EVTM crane lowering sensor
□ EVTM crane lowering stop sensor
□ EVTM crane detachment sensor
□ EVTM crane retraction sensor
□ EVTM crane position sensor in the coffin A

If this transparency framework is to be implemented internationally, subsequent studies will require examining process flow information for each individual reactor type on a plant-wide basis. This specificity and flexibility of the framework allows for ease of implementation in all aspects of the nuclear fuel cycle.

3.3 Secure Transfer of Information

The client-server database serves as the intermediary for the transfer of information between the nuclear fuel cycle facility and the organization conducting the transparency analysis. The Client-Server functions are as follows:

- Collects pertinent information for the transparency analysis from the internal nuclear fuel cycle facility database or electronic logging system.

- Packages and encrypts the information for secure transfer through a virtual private network.
- Acts as a second line of defense for access to nuclear fuel cycle facility information.

The following diagram depicts the flow of process data from the facility through the Client-Server through the Virtual Private Network to the remote site for analysis.

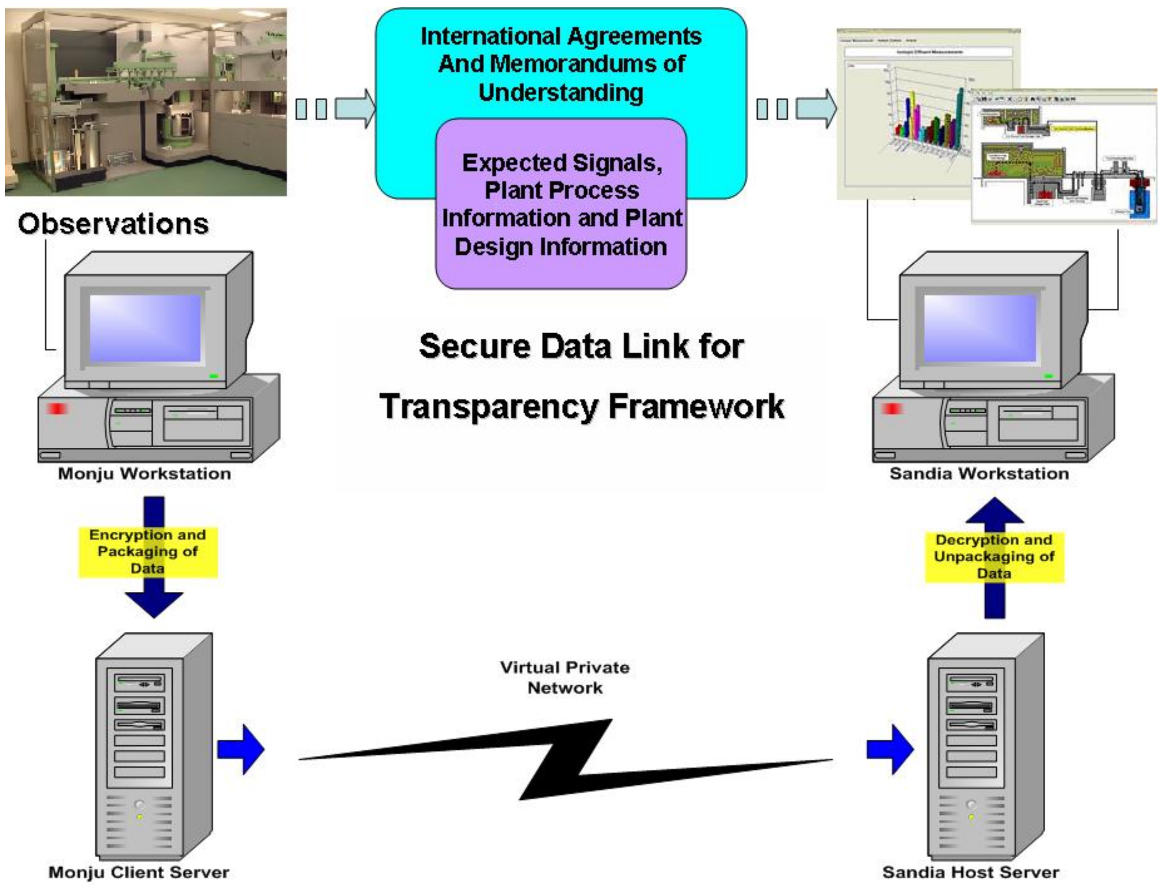

Figure 3. Secure Transfer of Information

4.0 Nuclear Fuel Cycle Transparency Mathematics

This section provides a high-level overview of the mathematical equations involved in performing the transparency analysis. It has been previously stated that proliferation risk, and ultimately fuel cycle transparency, is a function of the following:

- Material attractiveness: obtained from quantification of factors relating to proliferation of a specific material.
- The static (baseline) risk: obtained from standard process and monitor information. This value is calculated from **expected signals** from a particular process, plant process information, and plant design information.
- The dynamic (changing) risk: obtained from real-time processes and measurements. This value is calculated from **observed signals** from a particular process, plant process information, and plant design information.

4.1 Material Attractiveness (m)

Material attractiveness is a pre-determined value based on the following factors:

- *Material Weapons Capability*: How easily a specific material could be converted into weapons material.
- *Material Detectibility*: How easily the material could be detected by standard monitoring equipment.
- *Material Handleability*: How easily an adversary could handle the material; a function of the material's activity.
- *Material Accessibility*: How accessible the material is to adversaries (for example, in-core material would be less accessible than material in the receiving area).
- *Material Quality*: The type of radiation the material emits, and the activity of the material.
- *Material Quantity*: The amount of material.

Material attractiveness is also determined based on the type and size of reactor. At this time in the research, engineering judgment will be used to evaluate possible values of material attractiveness for a Fast Reactor. This judgment incorporates the assumption that spent fuel is more attractive to an adversary than fresh fuel, but less attractive than irradiated blanket fuel, due to the fuel cycle of a breeder reactor.

4.2 Static Risk (s)

Static risk is calculated from the "baseline" expected signals, plant process information, and plant design information. It is the result of an analysis of expectations for each plant process. Known values, such as type of material, material attractiveness, and material transfer information are aggregated in the transparency toolbox and are then analyzed. A static risk, which can be described as a "baseline value", is determined for further comparison.

static risk (s) = the normal operational risk obtained from expected signals, process information, and plant design

4.3 Dynamic Risk (d)

Dynamic risk is calculated based on observed signals, plant process information, and plant design information. Real-time raw data from monitors and sensors is aggregated in the transparency toolbox to detect deviations from expected signals and a value of "d" is calculated. A dynamic risk is determined for each plant process based on real-time data and is a non-zero value if there exist deviations from expected signals (i.e., a suspect activity is occurring). Dynamic risk has a value of zero when there are no deviations from expected signals (i.e., activities are normal). It is then analyzed by the transparency software.

dynamic risk (d) = the real-time risk obtained from observed deviations from expected signals

4.4 Proliferation Risk (R)

The following symbols are used in subsequent equations:
N = Proliferation Risk under Normal operations
R = Proliferation Risk
s = Static Risk
m = Material Attractiveness
d = Dynamic Risk (deviations from expected signals)

Proliferation Risk under Normal operations = the normal operational risk obtained from expected signals

(1) $N = s$

In the event that declared plant process data is not being followed, there exists an increase in proliferation risk, such that:

Change in proliferation Risk = material attractiveness multiplied by the real-time risk obtained from observed deviations from expected signals

(2) $\Delta R = md$

Since "d" is defined as either a zero or non-zero value, if plant process data is producing observed signals that do not deviate from expected signals, $d = 0$. However, if diversion of material is occurring, there exists a deviation of observed signals from expected signals. This will alert that incorrect procedures are being followed; either incorrect transfers of material are occurring, or the incorrect material is being used in a particular process. "d" then becomes a non-zero value. Thus ΔR is increased by a factor of m, the material attractiveness.

Proliferation risk = Proliferation Risk under Normal operations added to the Change in Proliferation Risk

(3) $R = N + \Delta R$

Thus:

Proliferation Risk = the normal operational risk obtained from expected signals, plant process information, and plant design information, added to the material attractiveness multiplied by the real-time risk obtained from deviations from expected signals

(4) $R = s + md$

Equation (4) applies to a single plant process. For a site-wide value of proliferation risk, R must be aggregated in the Transparency Analysis.

As shown in Equation (4), when proliferation is not occurring, $d = 0$, thus $R = s$. When proliferation might be occurring, $d \neq 0$, thus $R = s + md$. Material attractiveness becomes an important factor during the latter case. Figure 4 describes this process.

4.5 Transparency

In this framework, transparency is a high-level concept that is not measured on a quantitative scale. When all parties can evaluate that the proliferation risk is acceptable (thus, the static risk is at an acceptable level and there is a method to continuously calculate the dynamic risk) the system can be considered to be transparent.

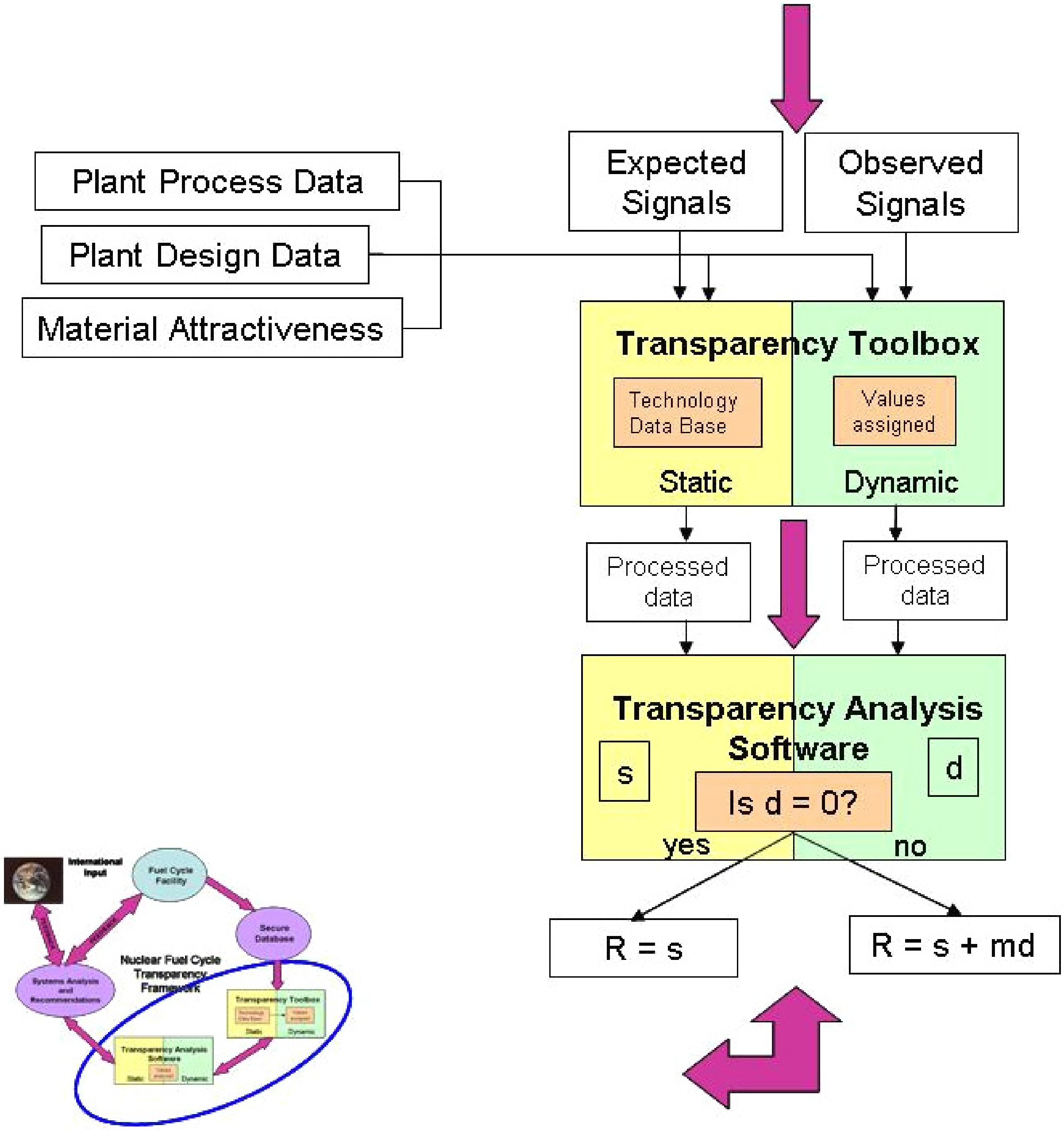

Figure 4. Data Flow Through Transparency Toolbox and Analysis Software

5.0 Conclusion

This research will proceed in two additional phases. In Phase I, described by this report, a collaborative effort between Sandia National Laboratories and Japan Atomic Energy Agency advanced a transparency framework and implemented an example methodology for measuring proliferation risk. This provided the conceptual framework for a remote verification and validation process for monitoring proliferation risk in support of transparency at a nuclear fuel cycle facility.

In the next step, Phase II, a demonstration of the nuclear fuel cycle transparency framework is needed to confirm the utility of the framework. It is expected that Phase II will provide improvements to the concept of transparency, the development of new technology, and the capability for extensive analysis at the facility-level. This demonstration is discussed further in Section 6.0.

The concept of the nuclear fuel cycle transparency framework requires an operational demonstration on a test bed to further establish the contribution to reducing the proliferation of nuclear weapons and support the evolution of nuclear fuel cycles. At the completion of Phase II, a Transparency Test Bed may be established to demonstrate the use of real-time plant process data and implement the nuclear fuel cycle transparency framework. It will become the objective of this research to begin testing these improvements and developments at an operating nuclear facility, ideally the Monju Fast Breeder Reactor.

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6.0 Proposed Demonstration Of Framework And Methodology

The purpose of the proposed demonstration is to extend the Phase I work into a demonstration of nuclear fuel cycle transparency between Sandia National Laboratories (SNL) and the Japan Atomic Energy Agency (JAEA). The Monju Fast Breeder Reactor (FBR) has been selected as the candidate site. Utilizing the unique training facilities at the Monju FBR, the framework may be tested at the Fuel Handling Training Model at the International Cooperation and Development Training Center, operated by the JAEA.

6.1 Demonstration Scope

The demonstration consists of two key aspects:

1. Collection and transfer of data from the Training Model to Sandia National Laboratories.
2. Data analyses made to determine: validity and importance of the data collected, proliferation risk, and transparency.

6.2 Demonstration Goals

The goal of this demonstration is to apply the Phase I work, the development of a transparency framework, to a working demonstration at the Fuel Handling Model developed for the Monju FBR. Work will be performed to provide a computer synchronized to the visible movements in the model to mimic facility operations and supply process data, transmit this data to a secure data base at the International Cooperation and Development Training Center, and then to transmit this data to a secure data base operated by analysts at Sandia National Laboratories. A real-time analysis of simulated proliferation risk will be demonstrated using the analysis software.

6.3 Demonstration Objectives

Key demonstration objectives include the following:

- With the assistance of the Training Model at the candidate site, the Monju FBR, develop, test, and demonstrate transparency measures and technologies for an automated nuclear fuel cycle component.
- Collaborate with the Monju FBR staff to develop tools that will enhance international confidence in safe, secure operations and handling of nuclear material.
- Foster international collaborations leading to workable, effective, globally accepted standards for the transparent analysis of nuclear facilities.

Figure 5 displays the Fuel Handling Training Model to be used in the proposed demonstration.

6.4 Roles of SNL and JAEA

Reflecting that both parties have cooperated to develop the concept in Phase I, the Phase II effort will continue to emphasize mutual efforts:

- SNL and JAEA will jointly develop specifications for the simulated process data for the Phase II demonstration.
- JAEA will make arrangements to acquire the agreed signals.
- SNL will support JAEA in establishing the secure data transmission system.
- SNL will receive the data from JAEA and perform the data analysis.
- SNL and JAEA will jointly develop the proliferation resistance evaluation methodology.
- Both sides will cooperate to observe information control and proprietary interests as mutually agreed.

Figure 5. Fuel Handling Training Model at the International Cooperation and Development Training Center

7.0 Glossary Of Terms

Dynamic Risk: The real-time risk obtained from observed deviations from expected signals. Dynamic risk is based on observed signals, process flow information, and plant design information.
Expectations: Data that is expected during the analysis, often based on plant process and plant design information. If the real-time data collected meets expectations, proliferation risk is nominal. Expectations are used to calculate static risk.
Material Attractiveness: A quantified, pre-determined value regarding the potential for diversion of different nuclear materials throughout the process flow of the nuclear fuel cycle, based on their usefulness to construct a nuclear weapon.
Methodology: The practices and procedures necessary to implement the Transparency Framework.
Nuclear Fuel Cycle Transparency: A confidence building approach among political entities to ensure civilian nuclear facilities are not being used for the development of nuclear weapons; a high-level concept.
Observations: Data that is observed during the analysis; the measured, real-time, constantly changing conditions in the nuclear facility. Observations can be based on plant process and plant design information. Observations are used to calculate dynamic risk.
Process Flow / Plant Process Information: The documented movement, activity, or any process associated with the nuclear material in the fuel handling cycle at a specific facility. This information is used to calculate static and dynamic risk.
Proliferation Risk: A numerical value representative of the risk that proliferation of nuclear materials might occur at a nuclear facility.
Static Risk: The “base-line” or normal operational risk obtained from expected signals, process flow information, and plant design information.
Transparency Analysis Software: A process of the Transparency Framework that analyzes static and dynamic risk to calculate proliferation risk.
Transparency Framework: The fundamental structure of the transparency concept advanced by this research.
Transparency Toolbox: It contains the information necessary for performing the analysis, including information from detectors, sensors, and communication technologies and plant process and plant design information.

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