DEVELOPMENT OF THE PHYSICAL MODEL

Z.LIU and S.MORSY
Department of Safeguards
International Atomic Energy Agency
Wagramer Strasse 5, P. O. Box 100, A-1400, Vienna
Austria

Abstract

A Physical Model was developed during Programme 93+2, which was an attempt to identify, describe and characterize various components of the nuclear fuel cycle, providing a technical tool to aid enhanced information analysis. It has become an integral part of the on-going State evaluation process in the Department of Safeguards. This paper describes the concept of the Physical Model, including its objectives, overall structure, contents and the development of indicators with designated strengths, followed by a brief description of how the Physical Model is used in analysing information on a State's nuclear and nuclear-related activities, and in developing integrated safeguards approaches.

1. BACKGROUND

Information has been a cornerstone of the Agency's safeguards system since its inception over forty years ago. Increased amounts and new types of information are becoming available to the Agency, especially from Member States with comprehensive safeguards agreements and additional protocols in force.

It has been recognized that an enhanced information analysis would play a central role in strengthened safeguards, allowing the Agency to assess the correctness and completeness of a State's declarations about its nuclear material and activities. Task 5 of the Programme 93+2, "Improved Analysis of Information on States' Nuclear Activities", was established to develop a coherent and comprehensive approach to the processing and analysis of the information available. With expert assistance from Member States, an *Acquisition Path* was developed to identify all known pathways that would be involved for a State to acquire weapons-usable material and subsequent weaponization. In seeking technical tools for implementing the enhanced information analysis, a *Physical Model* was developed by Agency staff and a small group of experts from Member States. It describes and characterizes the technologies and processes represented at all levels of the *Acquisition Path*. It was reviewed and endorsed by a Consultant's Meeting (Peer Review) with participants from ten Member States and now is available in hard copy and accessible in electronic form through the TOPIC information searching system. Currently, it is an integral part of the on-going State evaluation process as well as a useful tool in developing and implementing integrated safeguards approaches.

The *Physical Model* was originally developed in nine volumes: Mining/Milling, Conversion 1, Uranium Enrichment, Conversion 2, Fuel Fabrication, Nuclear Reactors, Deuterium/Heavy Water Production, Reprocessing of Irradiated Fuel and Development of Nuclear Explosive Devices. The need to expand the *Physical Model* was recognized soon afterwards. Expansion was initiated in 1999 and will be completed by the end of this year, through which three additional activities will be incorporated: Spent Fuel Management, Radioactive Waste Management and R&D Activities in Connection with Hot Cells. Methodology studies have also been carried out with support of Member State Support Programs (MSSPs), including R&D on the strengths of the Physical Model indicators when considered in combination, and guidelines for making use of the Physical Model. The *Physical Model* is anticipated to be subject to periodic review and update based on, inter alia, technical advances in nuclear fuel cycle activities, experience gained through its application practice and new requirements for implementing strengthened safeguards. Review and update of individual volumes of the *Physical Model* has been planned and will begin later this year with supports of MSSPs.

2. THE PHYSICAL MODEL CONCEPT

2.1 Acquisition Path

The development of the *Acquisition Path* was an attempt to identify every known technology and process that would be involved in the nuclear fuel cycle from source material production to the acquisition of weapons-usable material, i.e., highly enriched uranium (HEU) and separated plutonium (Pu), and then beyond the civilian fuel cycle to the development of nuclear explosive devices. It was developed to provide a systematic means of categorizing and recording relevant information from various sources to enable the effective and efficient analysis of the information available to the Agency.

The *Acquisition Path* is designed in a multi-level structure. Included at the top level are all the main steps (technologies) for the acquisition of weapons-usable material. Each step is interconnected with the preceding and/or succeeding steps by nuclear material flows. The top level of the *Acquisition Path* is given in Fig. 1 representing the *State-level acquisition path*.

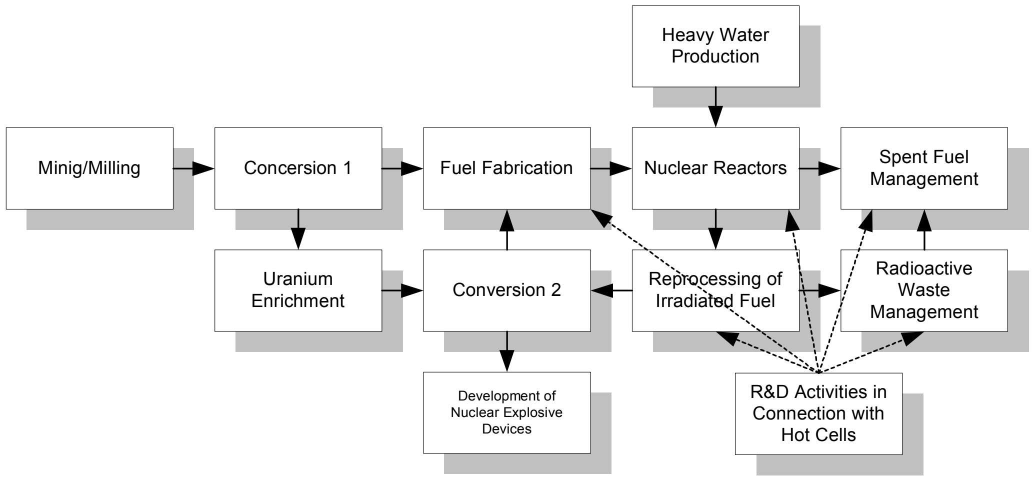

Fig.1 Acquisition Path (Top Level) in the Physical Model

Each step is then broken down into more specific routes or processes at lower levels of the *Acquisition Path*, i.e., every known process that is associated with the fuel cycle technologies represented at the top level is included at lower levels. For example, the technology of uranium enrichment is broken down into three branches at the second level, i.e., enrichment of UF_6, UCl_4 and U-metal respectively; and then further broken down at the third level into nine processes: gaseous diffusion, gas centrifuge, aerodynamic, electromagnetic, molecular laser (MLIS), atomic vapour laser (AVLIS), chemical exchange, ion exchange and plasma. The multi-level structure of the *Acquisition Path* is depicted in Fig. 2 taking uranium enrichment as an example.

Each level of the *Acquisition Path* is composed of eight basic elements, i.e., especially designed or prepared equipment, dual-use equipment, nuclear materials, non-nuclear materials, technology/training/R&D, end-products, other observables and environmental signatures. Shown in Fig. 3 is the schematic composition of a process at the bottom level of the *Acquisition Path*, which represents the *facility-level acquisition path.*

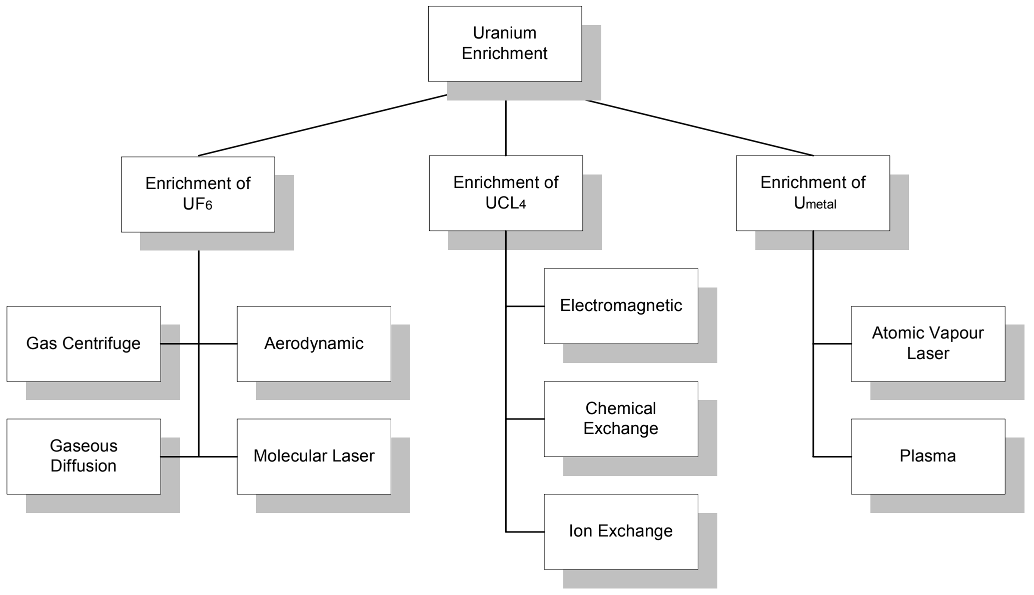

Fig.2 Acquisition Path for Enriched Uranium

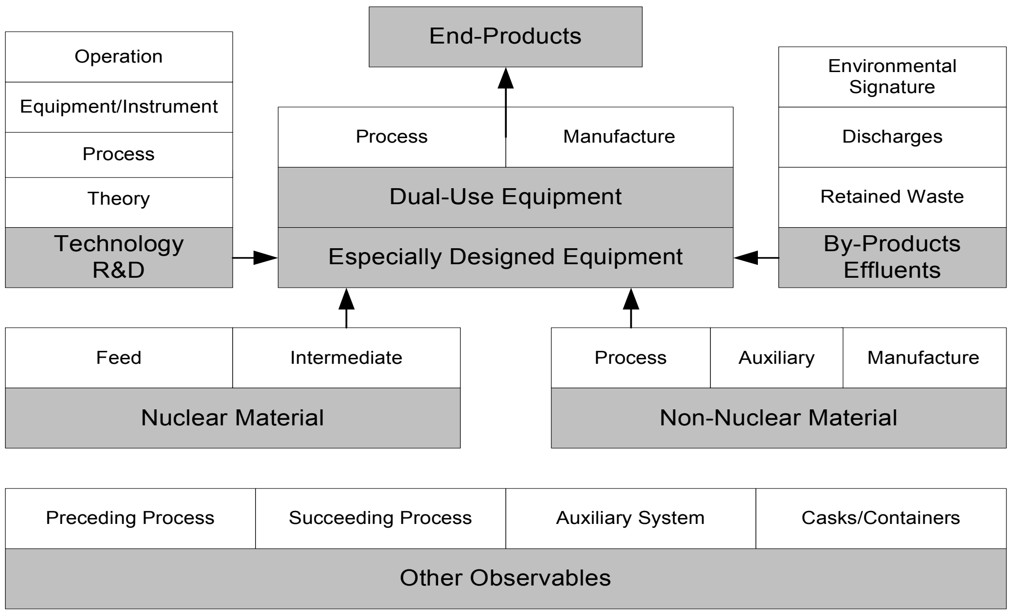

Fig. 3 Schematic Composition of a Process in the Acquisition Path

2.2 Physical Model

2.2.1 Contents

The *Physical Model* was developed to provide a well-documented technical basis to guide the work of analysis. It contains detailed narratives and illustrations for the technologies and processes represented at all levels of the *Acquisition Path*, beginning with a general description, and then proceeding with detailed descriptions on every basic element as illustrated in Fig. 3. Proliferation aspects of each activity are also included to address the misuse issue.

2.2.2 Indicators with Designated Strength

The *Physical Model* characterizes each technology and process in terms of *indicators*, specifying the existence or development of specific technologies or processes. It identifies essential equipment, materials and techniques that are associated with each nuclear activity, for which all items included in both INFCIRC/254/Part I (especially designed equipment and materials) and INFCIRC/254/Part II (dual-use equipment and materials) are incorporated. More items have been also identified by nuclear experts from Member States and are categorized as “other observables”, “end-products” and “by-products/effluents” (environmental signature), which may serve as further indications of a nuclear activity. Detailed descriptions and illustrations are provided as appropriate on the characteristics and utilization of each indicator.

The specificity of each indicator for a given nuclear technology or process was assessed by the Agency’s staff and consultants to determine the *strength* of an indicator as *strong*, *medium* or *weak* with the following criteria applied:

- if process A implies and is implied by indicator x, then x is a *strong* indicator for process A;
- if process A implies indicator y and indicator y *may* imply process A, then y is a *medium* indicator for process A;
- if process A *may* imply indicator z and indicator z *may* imply process A, then z is a *weak* indicator for process A.

2.2.3 Objective and Intended Use

The objective of the *Physical Model* is to:

- provide a general and easily accessible reference for fuel cycle activities;
- provide a model for a State's nuclear activities which would be a subset of the overall Physical Model;
- provide a simple (one-dimensional) mapping function from indicators to the existence or development of specific nuclear activities.

The *Physical Model* was developed to serve as a fundamental technical basis in the Agency's improved analysis of information. It is intended to be used as a technical tool for evaluating States' nuclear activities. It may also assist safeguards inspectors in preparing for routine and ad hoc inspections, design information verification visits and complementary access. Its main function, however, is to help the evaluator in performing State evaluations. The Physical Model may also be a useful tool in performing an acquisition path assessment, providing a technical basis for developing and implementing integrated safeguards approaches.

3. USE OF THE PHYSICAL MODEL

3.1 State Evaluations

The State evaluation needs to be performed in a comprehensive and systematic manner in order to test the hypotheses that "there is no diversion of nuclear material", and that "there are no undeclared nuclear activities" in a State with a comprehensive safeguards agreement and the additional protocol, i.e., the State's declarations are correct and complete. The basic problems encountered in performing the State evaluation are (1) organization, i.e., to place all the information into a coherent structure, permitting association of indicators with the existence or development of nuclear material and activities; and (2) recognition, i.e., to recognize the proliferation significance of questions or inconsistencies once they become part of the information at hand. The *Physical Model* can be used as an evaluation tool to deal with the organization and recognition problems.

3.1.1 Overview of States' Nuclear Programs

The overall structure of the *Acquisition Path* as adopted in the *Physical Model* provides a template to organize and to technically present an historical and current overview of a State's nuclear program in order to get a clear understanding of the State's nuclear program as a whole. It also provides a basic structure for the storage, retrieval and processing of information collected for implementing the evaluation. An appropriate format has been developed according to the overall structure of the *Acquisition Path* and is used in State evaluation reports.

3.1.2 Information Evaluations

Information evaluations are performed through various consistency checks to examine the internal consistency of a State's declarations and the consistency of the State's declarations with information collected by the Agency through safeguards verification activities and from external sources. As described above, a State's nuclear fuel cycle would be a subset of the overall *Physical Model*. The structures of the *Physical Model* in different levels, therefore, can be followed to organize the consistency checks at the State level and the facility level; and the narratives and indicators can be referred to for assessing consistency.

For example, at the State level, the evaluation can proceed by following the top-level structure of the *Physical Model.* The narratives and indicators at this level will help to assess the general consistency of a State's nuclear program as a whole, including internal consistency of the declared present and planned nuclear program; consistency of overall production and imports as well as flows and inventories of nuclear material with the utilisation inferred from the declared nuclear program; consistency of nuclear fuel cycle-related research and development (R&D) activities with the declared present and planned nuclear program; and consistency of uses, manufacture or imports of specified equipment and non-nuclear material with the needs inferred from the declared nuclear program.

At the facility level, the evaluation can be organized according to the bottom-level structure of the *Physical Model*. The narratives and indicators will help to examine the detailed consistency of each specific activity, e.g. whether the type of feed material matches the need of the declared activities; the type of product is in conformity with the declared activities and matches the declared use at the receiving facilities; the use of specified equipment and non-nuclear material fits with the declared activities; the type of nuclear waste and discharge is compatible with the declared activities; the environmental sample result matches the declared activities; and the status of closed-down or decommissioned facilities or LOFs is consistent with the State's declarations.

If a question or inconsistency exists, it is critical to recognize it. The *Physical Model* characterizes each technology and process in terms of indicators, providing a means to associate indicators with the existence or development of specific nuclear activities. Making reference to an indicator relevant to the question or inconsistency would enable to associate it with a specific nuclear activity. Indicators can also be used as "key words" in searching open source information.

The *Physical Model* indicators are designated with relative strengths reflecting a consensus view of nuclear experts from Member States, which is helpful for assessing the proliferation significance of individual questions or inconsistencies. For example, presence of both enriched and depleted uranium at the same location revealed by a swipe sample analysis would be a strong indicator pointing to the existence or development of uranium enrichment activities; presence of fission products and actinides in off-gas discharges would be a strong indicator for the existence or development of irradiated fuel reprocessing activities; procurement of a filament winding machine or maraging steel of high strength would be assessed as a medium indicator for the development of the gas centrifuge enrichment process, and so on.

3.1.3 Conclusions and Recommendations

The *Physical Model* can be used as guidance to preparing proposals for clarifications or follow-up measures. For example, when inconsistency is identified with regard to the import of a filament winding machine, the evaluator would be advised that it is possibly associated with the manufacture of fibrous rotor cylinders, and that it may need to be further clarified by the State for its intended end-use. The evaluator would also be advised, when preparing recommendations for follow-up measures, to look for other indicators in the category of "dual-use equipment" that are relevant to the manufacture of fibrous rotor cylinders, e.g., procurement of fibrous or filamentary material of high strength, rotor straightening equipment, or dimensional inspection systems. More indicators may possibly be referred to in other categories of the centrifuge enrichment process such as “especially designed equipment”, “nuclear material” and “by-products/effluents”.

3.2 Acquisition Path Assessment

It is recognized that integrated safeguards approaches would be developed by considering features of a State’s nuclear fuel cycle and results of information analysis. An acquisition path assessment is expected to provide a technical basis for the development and implementation of integrated safeguards approaches. As described before, all acquisition paths of weapons-usable material are identified, described and characterized in the *Physical Model*, which will therefore be a useful tool for the acquisition path assessment.

Firstly, by using the *Physical Model*, features of a State’s nuclear fuel cycle can be identified. For instance, nuclear fuel cycles in those States with comprehensive safeguards agreements can be categorized into a few basic types, e.g., a fuel cycle containing reprocessing and/or enrichment; a fuel cycle involving direct-use nuclear material, for instance, fabrication and/or use of MOX fuel or HEU fuel; and a LEU fuel cycle which does not include above-mentioned activities. Generic State-level safeguards approaches would be developed accordingly.

Secondly, with the help of the *Physical Model*, all plausible acquisition paths by which a specific State might seek to acquire weapons-usable material, i.e., State-specific acquisition paths, can be identified. For example, the activities that were most likely to be incorporated in a clandestine nuclear program if the State were to attempt to acquire weapons-usable material would be predictable, which may involve diversion of nuclear material or misuse of declared facilities under safeguards, modification or upgrading of existing capabilities, restoration of historical capabilities, construction of clandestine capabilities using retained technologies and available infrastructure, or development of new technologies to fill in capability gaps, and so forth. The coverage of State-specific acquisition paths by safeguards measures can thus be evaluated. The corrective actions may also be determined as for “where to go” and “what to look for” if the conclusion on the absence of undeclared nuclear material and activities for a State as a whole could not be maintained, which may involve a range of options including actions to resolve questions and inconsistencies, complementary access, or even restoring safeguards activities in the State to the level of traditional safeguards when necessary.

Another useful application of the *Physical Model* is in assessing the potential for a State to acquire weapons-usable material when development activities were likely going on in that State with respect to sensitive technologies such as reprocessing or enrichment. As described before, the *Physical Model* indicators have been developed to specify not only the existence but also the development of a specific technology or process. Making reference to indicators in different categories would help to examine the state of the development which may be marked as beginning with R&D activities without nuclear material involved, progressing into further R&D involving nuclear material, infrastructure development as necessary to support the development and completing the development. For example, indicators in the categories of Technology/Training/R&D are mostly associated with the R&D activities in the initial stage of the development. Those indicators under the categories of

Especially Designed or Prepared and Dual-Use Equipment can be used to examine status of the industrial infrastructure development. Some indicators are more often related to operations, such as Nuclear and Non-Nuclear Materials, By-products/Effluents and Other Observables. These indicators will help to determine if a reprocessing or enrichment process has been in operation. The potential for the acquisition of weapons-usable material in that State would be raised as the development is progressing, and might become high when a reprocessing or enrichment process is likely in place.

4. CONCLUSIONS

As a result of the initial development and subsequent expansion, the *Physical Model* provides a disciplined approach to defining what information should be collected and how it is most appropriately structured for analysis. The development of indicators with relative strengths is one of the main features of the *Physical Model*, providing a means to associate indicators with existence or development of nuclear material and activities. It can be used to deal with the organization and recognition problems in performing State evaluations and in developing integrated safeguards approaches. The *Physical Model* has been an integral part of the on-going State evaluation process and a useful tool in developing integrated safeguards approaches. It has become part of the basic understanding of safeguards analysts, inspectors and, particularly, country officers. To maintain knowledge of the Physical Model and the indicators thereof, a training course "The Nuclear Fuel Cycle and Proliferation Indicators" has been incorporated into the Department's regular training program. Individual volumes of the Physical Model will be reviewed and updated in the near future to reflect the technical advances and users requirements.

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