
Collaborative Human-Machine Nuclear Non-Proliferation Analysis

**F. L. Greitzer
R. V. Badalamente
T. S. Stewart**

October 1993

**Prepared for the U .S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U .S .Department of Energy
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SUMMARY

As a result of the discoveries in Iraq during the last two years, the International Atomic Energy Agency (IAEA) is attempting to strengthen the safeguards regime. Among the measures that have been proposed are:

- special inspections
- early provision and use of design information
- reporting of the export or import of certain equipment
- environmental monitoring
- enhanced analysis of nuclear materials and activities.

By enhancing the analysis of safeguards-relevant information, the IAEA seeks to provide early warning of possible nuclear-related activities that are inconsistent with a state's peaceful-use obligations. This research attempted to explore the application of automation technology to aid the IAEA Country Officer (CO).

Considerable attention has been devoted to the identification of software tools for preprocessing, analyzing, and synthesizing large volumes of information. The trend toward increased automation means the role of the user is shifting from perceptual tasks (for example, finding key words in a document, comparing photographs taken over time) to more cognitive ones (such as recognizing patterns in data or drawing conclusions). Unfortunately, system designs often fail to support the new roles of the user, perhaps because the automated feature is unrealistically expected to obviate human intervention. Due to poor interfaces with the operator-turned-evaluator, the full potential of new technology may not be realized.

The approach of the research was to examine user-system relationships that exploit the capabilities of the human as well as that of the machine. This approach has a goal of creating collaborative human-machine systems, built upon well-integrated functions at the task level, to yield better overall system performance. To guide the design of such systems, emphasis is placed on knowledge of the user's tasks, goals and intentions; available tools; procedures; and contextual information. This process is a balanced exercise in designing appropriate, intelligent user interfaces and identifying or defining appropriate software tools and resources. The following broad areas for intelligent support for the IAEA CO were identified:

- Portfolio management
- Information filtering and retrieval
- Analysis
- Decision making.

Specific support functions within each of these areas were implemented within a demonstration or concept prototype. This prototype, entitled Proliferation Analysis Support System (P ASS), was developed to help examine intelligent support concepts and to communicate the findings to experts and users.

The conclusion was that collaborative human-machine concepts should be incorporated into an automated information system environment at the IAEA. The expected benefits include:

- improved operability of the system
- enhanced analysis through more consistent usage and outputs of the process
- decreased training requirements through more effective and user-friendly interfaces.

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GLOSSARY

Acronyms:

CO	Country Officer
EMIS	Electromagnetic Isotope Separation
IAEA	International Atomic Energy Agency
INSIST	International Nuclear Safeguards Inspection Support Tool
MS	Microsoft
MUF	Material Unaccounted For
NEFIS	Nuclear Energy and Facilities Information System
NNWS	Non-Nuclear Weapon State
NPT	Non-Proliferation Treaty
PASS	Proliferation Analysis Support System
PC	Personal Computer
PF	Proliferation Framework
PINS	Proliferation Information Network System
PRIS	Power Reactor Information System
WMD	Weapons of Mass Destruction

Terms:

Accelerators:

A simple set of keystrokes that can substitute for interacting with menus using the mouse. Typically, the accelerator uses a mnemonic, such as the first letter of the menu selection, to invoke the action.

Associative Links:

In a hypertext or hypermedia system, the concept and implementation of human-machine interface features that provide direct access between related information through *direct manipulation*.

Collaborative Human-Machine System	A system design that integrates human and machine capabilities to exploit the strengths and accommodate limitations of each component, with a goal of attaining better performance than either human or machine can attain alone.
Concept Analysis	Concepts and their relationships can be extracted from discourse elements and categories for manipulation at a higher level of analysis (inference or reasoning) or for complex queries.
Concept Category	Recognized words or phrases that are mapped to categories for further processing as symbols or as a higher order "key word." Concepts align into a hierarchy framework.
Concept Prototype	A stage in system development concerned with developing a sufficiently deep understanding of the problem, through information gathering and prototyping, to define the scope of the problem and demonstrate concepts.
Data Fusion	Integration of information across various sources.
Direct Manipulation	A human-machine interaction method that treats information displayed on the screen as objects that may be acted upon using a pointing device (such as a mouse). This design approach contrasts with more complex command-language interfaces that require keyboard entry with properly-formatted commands to invoke actions.
Discourse Analysis	Passages can reference previous or predicted events, provide background information, or describe new lines of thought. These discourse elements describe a higher abstraction of information that can be used to focus the filtering process, or to support higher order semantics.
Document Retrieval	Refers to a single seeking process for a specific query. Although the source database may change, for filtering it is considerably more stable than the incoming stream.
Filtering	A method to separate relevant data from large volumes of incoming unstructured or semi-structured data based on a specific profile. The implied process is an ongoing one applied to a stream of data. Data that do not fit the profile are discarded.
Hypertext	Non-sequential writing with free user movement (Nelson, 1987). Software that attempts to transcend the fixed sequential presentation of information (exemplified by the printed page) by providing a visual display of information with which the user may interact to reveal related information.
Hypertext Browsing	The ability for the user of a hypertext system to follow any of numerous possible paths through a hypertext document by

interacting with objects (text, buttons, icons) that are linked to other parts of the document.

Information Treatment

Used within the Department of Safeguards at the IAEA to describe data processing and information management functions.

Interaction Object

A human-computer interface feature that may be manipulated directly by pointing and clicking a mouse or other pointing device positioned over the feature.

Key Word Recognition

Simple string matching to identify words or phrases of interest. This may satisfy the problem or be used as a first step. Key words are highly subject-matter dependent

Natural Language Processing

The investigation of computationally effective mechanisms for communications, both human-to-human and human-to-computer, using natural language. The terms text and document are used to represent items derived from a naturally occurring human language source. Written language or spoken language samples can be interchanged with these terms without loss of meaning for the collaborative concepts described.

Semantics

Words have multiple meanings; intended meaning must be determined in the context of the particular passage to reduce ambiguity errors in later analysis. Semantics is subject-matter and language-dependent.

Syntax

Meaning can be extracted from a word or phrase's grammatical use and can be partially identified by word order and context within a sentence. Syntax is also language dependent.

What-If Analysis

A problem-solving method in which alternative hypotheses or courses of action are examined and compared by exercising them using simulation or modeling techniques.

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1. INTRODUCTION

“The end of the Cold War era ... has not only eliminated, but has not even diminished, the possibility of destabilization of the international situation on the regional level. Proliferation of weapons of mass destruction [WMD]—nuclear, biological, and chemical—presents a special danger in this regard. The spread of WMD, like the metastasis of a cancerous tumor, can destroy the entire fabric of international relations and dash hopes for creating a just and lasting world order.”

--Russian Intelligence Report on Proliferation (1993)

1.1 Purpose of the Paper

The purpose of this paper is to report on the results of a project investigating support concepts for the information treatment needs of the International Atomic Energy Agency (IAEA, also referred to as the Agency) and its attempts to strengthen international safeguards. The aim of the research was to define user/computer interface concepts and intelligent support features that will enhance the analyst's access to voluminous and diverse information, the ability to recognize and evaluate uncertain data, and the capability to make decisions and recommendations.

The objective was to explore techniques for enhancing safeguards analysis through application of (1) more effective user-computer interface designs and (2) advanced concepts involving human/system collaboration. The approach was to identify opportunities for human/system collaboration that would capitalize on human strengths and still accommodate human limitations. This paper documents the findings and describes a concept prototype, Proliferation Analysis Support System (PASS), developed for demonstration purposes. The research complements current and future efforts to enhance the information systems used by the IAEA, but has application elsewhere, as well.

1.2 Background

The discovery of a clandestine nuclear weaponization program in Iraq has led the IAEA to undertake a significant effort to strengthen safeguards. Iraq was a signatory to the Treaty on the Non-Proliferation of Nuclear Weapons, or Non-Proliferation Treaty (NPT), and is a member state of the IAEA. As such, it had signed a comprehensive safeguards agreement with the IAEA and was subject to periodic inspections by the Agency. Despite those inspections, Iraq was able to construct an extensive weaponization program through the use of undeclared nuclear material and facilities. The Agency has determined that several measures are necessary to provide additional assurance that states do not engage in nuclear activities that are inconsistent with their peaceful use obligations under the NPT and safeguards agreements. Measures approved by the IAEA Board of Governors include: the use of special inspections; the early provision and use of facility design information; and reporting on the export or import of nuclear materials, certain equipment, and non-nuclear materials. In addition to these measures, the Agency is undertaking additional measures aimed at acquiring and analyzing more comprehensive data on nuclear activities of member states. One of the principal problems facing the Agency is how to make effective use of the data to provide early warning of activities contrary to the NPT and safeguards agreements. This problem serves as an appropriate case study for the research described in this report.

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2. INFORMATION TREATMENT NEEDS AT THE IAEA

Peace is never long preserved by weight of metal or by an armament race. Peace can be made tranquil and secure only by understanding and agreement fortified by sanctions. We must embrace international cooperation or international disintegration.

--Bernard M. Baruch (1946)

2.1 Information Needs and Uses

The term used to encompass the typical data processing and information management functions within the Department of Safeguards at the IAEA is information treatment. The department is attempting to enhance the way in which it treats information on states' nuclear activities to facilitate detection of cases where there may be cause for concern about a state's peaceful use undertakings.

In the past, the collection and analysis by the IAEA of safeguards or safeguards-related information was limited to information about declared nuclear activities in states with comprehensive safeguards agreements. This information is obtained by the Agency in the course of safeguards implementation-inspections and other verification activities. The recent experience with Iraq highlighted a need to obtain additional information from a variety of sources and to make better use of information already available.

To monitor the nuclear activities of member states, the Department of Safeguards accesses and processes an enormous volume of data from widely varying sources. Some of the data is available from existing IAEA databases, such as the Nuclear Energy and Facilities Information System (NEFIS) and the Power Reactor Information System (PRIS). Other data, such as that provided by states pursuant to safeguards agreements, may be resident on magnetic media or in hardcopy. The Agency intends to review various publications for relevant data and to incorporate these data in their analyses. In addition, the Agency will be using geographically-referenced data, photographs, and video tapes.

A need is recognized for an enhanced analysis capability, incorporating expert systems techniques to support the information monitoring, analysis, and decision-making functions of the IAEA. Application of artificial intelligence technology and expert systems may be used to enhance the analyst's awareness of potential problems, ability to recognize inconsistencies in the data, and to fill in an individual's gaps in knowledge of certain technical areas. The concepts of human-machine collaboration proposed in this paper are designed to complement, rather than duplicate, the role of expert systems in safeguards effectiveness evaluation.

2.2 Role and Characteristics of the IAEA Country Officer

The basic question that an Agency analyst is attempting to answer: *Are the state's nuclear activities consistent with its peaceful-use undertakings under the NPT and its safeguards agreement with the Agency?*

The individual responsible for answering this question is the Country Officer (CO), an inspector in one of the three operations divisions of the Department of Safeguards. A CO and an Alternate for each state are nominated by the Director of the Division of Operations. Both the CO and the Alternate have the same level

of responsibilities. The basic responsibilities of the COs are to have an up-to-date knowledge about safeguards- and other proliferation-relevant situations, and nuclear and nuclear-related activities that are directly relevant to the implementation of safeguards for each designated state. Such information may give an early indication of nuclear and nuclear-related activities in the state. The CO should be conversant with the current and anticipated safeguards implementation, as well as nuclear and nuclear-related activities using all available data sources. The CO follows Departmental and Divisional instructions and guidelines in conducting activities to fulfill these functions. Figure 2-1 summarizes the information treatment, analysis, and reporting functions of the IAEA CO.

The IAEA is staffed by persons from all 114 member states of the IAEA. Consequently, the inspectorate of the Department of Safeguards is made up of individuals from all over the world. The differences in culture, education, training, language, and computer literacy are myriad

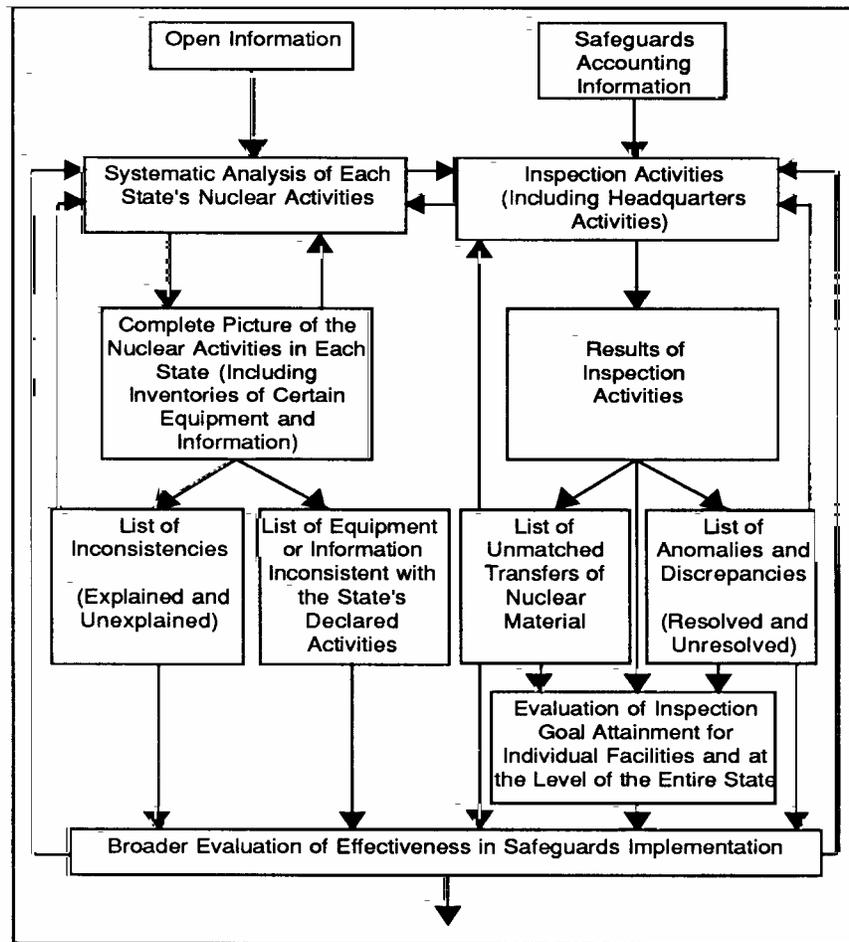


Figure 2-1 Summary of the Analysis Process of a State's Nuclear Activities

2.3 Country Officer Responsibilities

The IAEA has used COs to provide a single point-of-contact for information regarding a country. In 1992, the IAEA revised the responsibilities for a CO to include:

- Preparation and maintenance of the country file
- Informing line management about activities that may be inconsistent with the state's safeguards and non-proliferation undertakings, and other problems related to safeguards implementation
- Preparation of reports, including contributions to the divisional Country Status Reports.

In fulfilling these responsibilities, the CO:

- Monitors, reviews, analyzes, documents, and follows-up information available from non-safeguards sources, and, where appropriate, compares this information with that available through routine safeguards implementation activities.
- Compiles and analyzes information collected during inspections or submitted by the state that might indicate possible inconsistencies with the state's undertakings, including material accounting, transit matching, timeliness of reporting, nuclear material accounting, inspection goal attainment, and information gathered by inspectors in the field.
- Maintains records concerning anticipated facilities, locations, material accounting, and other items that may be subject to safeguards.

In January of each year, the CO prepares a comprehensive country status report for the previous year. This report is updated routinely throughout the year and must be available on short notice for the Director. Where inconsistencies and problems have been identified, a report by the CO is made immediately.

Since this concept was formulated earlier this year, a great deal of negative feedback has been received by the Department reflecting a perception on the part of Departmental personnel that these duties and responsibilities of the CO are unrealistic given the workload involved and the CO's on-going responsibilities as an inspector (typically, inspectors spend 90 days/year in the field).

2.4 Structure and Content of a Country File

For purposes of standardization, all information selected for documentation is grouped into 14 data categories on a country basis. The first 11 categories consist of open information on nuclear and nuclear-related activities: nuclear regulations, energy requirements, nuclear and nuclear-related programs, new nuclear technologies, facilities, exports and imports, nuclear capabilities, international cooperation, companies and firms, media reports, accidents and incidents. Category 12 (Safeguards Information) is safeguards confidential and is reflected in the CO's file for analytical purposes. Category 13 (State System of Accounting for and Control of Nuclear Material) contains information collected by inspectors or reported by the state. Category 14 (Analysis Results) is safeguards confidential and comprises possible inconsistencies and non-compliances, possible undeclared activities or facilities or materials, and analysis conclusions.

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3. HUMAN-MACHINE INTERFACE

Technological developments alone have changed the nature of the man-machine interface from emphasizing man's physical tasks to emphasizing his cognitive tasks, and thereby made a purely technological approach to man-machine systems obsolete.

--Hollnagel and Woods (1983)

3.1 Sources of Difficulty in Complex Systems

Considerable attention has been devoted to the identification of software tools used to preprocess, analyze, and synthesize the large volumes of information needed to perform effective safeguards assessment. The trend toward increased automation is shifting the role of the user from perceptual tasks (for example, finding key words in a document, comparing photographs taken over time) toward more cognitive ones (such as recognizing patterns in data or drawing conclusions). Unfortunately, system designs often fail to properly support the new roles of the user, perhaps because the automated feature is unrealistically expected to obviate human intervention. Another source of difficulty in complex systems is an implicit design philosophy that focuses on the form and literal content of isolated user-computer transactions, rather than on their function in the larger system (Greitzer, Hershman, and Kaiwi, 1985). One effect is that the full potential of new technology is not realized, due to poor interfaces with the operator-turned-evaluator. Indeed, the displaced user, lacking sufficient understanding of the automated function, may discard it and be left with resources inferior to those available before the introduction of automation.

The construction of complex systems should take into account the power of current technology to solve real-world problems. These systems should also provide features that are desirable and easily used by humans. The focus of the present research was to explore the application of automation technology in a way that exploits the capabilities of the human, as well as that of the machine. This approach has a goal of creating joint cognitive systems (Fitter & Sime, 1980; Woods, 1986) or collaborative human-machine systems that will perform better than either man or machine alone. Although this approach seeks to apply advanced technologies, such as knowledge-based systems, it contrasts sharply with the mainstream direction of artificial intelligence research and development that seeks to build autonomous systems.

Because of the key roles of humans in complex information systems, performance of the overall system depends to a large extent on the characteristics, capabilities, and limitations of humans and on how effectively the roles of humans and machines are integrated. Table 3-1 summarizes human information processing characteristics and indicates areas that may be supported or complemented through human-machine collaboration. The philosophy underlying the table is: The critical contribution of the human lies in the ability to draw upon knowledge and experience, to view information in novel ways, to synthesize seemingly unrelated information, and to grasp implications that may not be evident through automated methods. The proposed application of automation focuses on defining, identifying, and integrating appropriate software tools and resources that:

- facilitate access to and processing of large amounts of data
- establish electronic linkages reflecting the human's view of the problem and emerging solutions
- help track the status of many tasks conducted simultaneously over long periods of time
- provide information that fills gaps in a human's knowledge through automated assistance.

Table 3-1. Human and Automated System Capabilities

Human Information Processing Characteristics	Automated Support System Features
Perception	
<ul style="list-style-type: none"> • Limited ability to detect, discriminate • Depends heavily on pattern recognition 	<ul style="list-style-type: none"> • Can preprocess information • Can present proper amount of information in suitable format
Attention	
<ul style="list-style-type: none"> • Goal-oriented • Limited scope of attention • Performs multitasking • Prioritizes subtasks • Often experiences difficulty in subtask prioritization • May fail to correctly resume interrupted subtasks 	<ul style="list-style-type: none"> • Goal-oriented • Relatively unlimited scope of attention • Performs multitasking • Can help prioritize subtasks • Can monitor progress towards goal • Can remind user about unfinished tasks • Can help user focus attention on important tasks
Memory	
<ul style="list-style-type: none"> • Uses factual, procedural knowledge • May organize knowledge into complex structures • Has limited memory capacity • Has limited memory duration • Often experiences retrieval difficulty 	<ul style="list-style-type: none"> • Can store/retrieve factual information • Can store/retrieve procedural information • Can supplement human memory • Remembers what has been done and why
Decision Making	
<ul style="list-style-type: none"> • Uses knowledge, inference, pattern recognition, judgment, creativity • Often has difficulty analyzing • Can recognize and correct errors • Sensitive to information format, structure • Easily overwhelmed by large amounts of information • Performance may be degraded by repetitive subtasks 	<ul style="list-style-type: none"> • Can supplement human knowledge, inference, pattern recognition, judgment • Can help human explore alternatives • Can recognize and correct errors • Can format and structure information for user • Can perform subtasks automatically • Can filter information • Can make suggestions and recommendations • Can help identify important missing information

3.2 Ingredients of Collaborative Human-Machine Interfaces

A key goal of advanced information system design is to provide appropriate, effective user interface designs. Our proposed approach adds the goal of designing a system that fosters human-machine collaboration. This section describes some desirable ingredients of such systems and, in Table 3-2, identifies potential application of these concepts to an IAEA CO's information system environment.

Table 3-2. Collaborative Human-Machine Interface Concepts

Design Feature	Possible IAEA Advanced Information System Applications
Problem-Driven Design	Identify critical problem needs based on observed/inferred human information processing limitations, then provide tools to facilitate, guide, or constrain (rather than dominate) human decision-making: Devise interactive support for organizing and diagnosing the status of safeguards information collected about a country.
Direct Manipulation	Window-oriented, mouse-driven interface design that instills confidence in users to explore system capabilities, learn to navigate within, and use the system with minimal effort.
Graphical User Interface	Use of icons and graphical representations of objects or processes to provide task-oriented interactions and a valid design metaphor to facilitate usability and user understanding.
Routine Task Automation	Exploit hardware/software technology by automating menial tasks (such as file backup). Provide automated checklists where the user may direct automated <i>agents</i> to perform selected subtasks (text analysis, filtering, information retrieval).
Multitasking	Enable the user to perform discretionary manual tasks while the system manages automated tasks. Accommodate multiple windows.
Easy Access To Tools	Use context-sensitive knowledge of tasks to display only those buttons, icons, or menu options that represent tools applying to the current task context.
Goal Formation Support	Provide diagrams, illustrations, flowcharts, and other graphical aids to help the user identify appropriate goals and strategies.
Process Management	Support information management and portfolio maintenance requirements for country safeguards data.
Status Information	Use color and alerts messages to inform the GO of status changes.
Task Reminders	Enable user to create and attach electronic notes to displayed information. Provide capability for users to program macros or similar functions as a reminder to perform future required tasks.
Advice on Alternative Actions	Provide <i>what-if analysis</i> capabilities through simulation of nuclear fuel cycles.
Online Assistance	Develop context-sensitive help and online documentation that supports <i>hypertext browsing</i> .
Adaptation and Flexibility	Allow flexibility in screen attribute preferences (such as window border colors) through standard windowing system capabilities. Consider providing icon design alternatives using user preferences.

Effective joint cognitive system design requires a problem-driven, rather than technology-driven, approach (Woods, 1986). In a problem-driven approach, the designer uses knowledge about the task to provide tools supporting the user's cognitive demands and mitigating error-prone links in the human-machine system. The nature of the relationship between the human and the machine in a joint cognitive system depends upon the domain of application. One form of the relationship assumes a human generalist who manages and integrates input from various machine specialists. At the opposite extreme, the human may be one specialist who interacts with the knowledge of other (automated) specialists. In many real-world applications, the true position lies somewhere between these extremes. This is certainly the case with IAEA

COs, who may have specialized expertise, but will, in general, need to integrate and manage information from diverse domains.

To support the complex relationships inherent in a joint cognitive system, flexibility and user control are required. Direct manipulation interfaces (Hutchins, Hollan, and Norman, 1985) provide ingredients that support user control of the interaction and a safe, exploratory environment that fosters flexibility. Graphical user interfaces, when combined with direct manipulation, can be used to provide a relevant, intuitive conceptual framework that supports the user's information processing and problem-solving orientation. Given the increased use of multimedia in complex systems, user interface designs that are intuitive and easily navigated are particularly important. The multimedia approach tends to increase the amount and diversity of information that must be managed and accessed: The quantity and complexity of display options alone can produce information overload for the human user. Thus, interfaces for systems employing multimedia approaches to data fusion and analysis must provide contextual cues and a rich system of associative links to the user's tasks.

Collaborative human-machine interfaces require many features associated with the concept of intelligent interfaces: knowledge of user goals and intentions, available tools, procedures, and contextual information. At a minimum, an intelligent interface should perform menial tasks, automate routine functions, allow multitasking, and provide easy access to tools (Risland, 1984). At a more cognitive level, this type of interface should support goal formation, tool selection, and process management. This requires a degree of contextual knowledge—particularly knowledge about task goals that allow the system to inform the user about the status of tasks, remind the user to perform certain tasks, advise the user in selecting alternative actions, and provide online assistance (Greitzer, Hershman and Kaiwi, 1985). Finally, adaptation is an ingredient of intelligent interfaces that can provide flexibility with regard to user preferences or styles (Croft, 1984; Andriole, 1982). This flexibility is particularly important in the design of international user interfaces that must accommodate cultural differences.

3.3 Multicultural Considerations

The design of an information system for the IAEA has an important aspect that has not yet been addressed: designing user interfaces for international use. The impact of interface designs in cross-cultural, international contexts can be significant, but research on the topic is sparse. Nielsen (1990) has reported relevant work on issues relating to usability testing and problems specific to translation (for instance, translating text, date, and number formats). Additional issues relate to the cross-cultural use of graphical representations (such as icon designs, images, symbols) and of color. According to Taylor (1992), "... properly localized software applications, just like properly localized automobiles, toasters, beverages, and magazines, reflect the values, ethics, morals and language (or languages) of the nation in question."

Russo and Boor (1993) provide examples of some pitfalls in the use of images, symbols, and colors in cross-cultural applications. For example, signs of acceptance and disapproval (such as crosses or checks that are common in check boxes used in Western cultures) may not have universal meaning. In Egypt, for example, the cross is not interpreted as prohibitive. Similarly, the interpretation of colors varies greatly across cultures (Thorell and Smith, 1990). The use of red for error messages or yellow for warning messages is appropriate for Americans, but might convey confusing messages to Chinese, who associate happiness with red; or to Egyptians, who associate prosperity with yellow.

In addition to issues of text translation, images, and colors, the appropriateness or acceptability of product flow and functionality may be affected by cultural differences. The left-to-right and top-to-bottom organization of information (such as information display format within a window; icon placement; window placement) that is common in the United States may be counter-intuitive to Arabic or Chinese users. The functionality of modern windowing systems with pull-down, pop-up or sub-menus is enhanced for

experienced users through implementation of menu item accelerators or mnemonics: a simple set of keystrokes (such as CIRC-Q) can substitute for the operation of pulling down a menu and clicking on an item (such as Quit). However, most countries in Europe use different keyboards than those used in North America. These keyboards not only have different character positions, but also have excluded some characters or added others. Because mnemonic accelerators usually are based on the first letter of the command or menu item (for example, Q for Quit), the translation of the application can introduce problems in multicultural applications (del Galdo, 1990).

Because the IAEA application will be used by a comparatively small set of users, its design is not subject to many of the broad-ranging issues that commercial international software products must consider. In particular, the language-related issues noted previously are not as great a concern because English will be the primary language. Nevertheless, the proposed design of the p ASS prototype, described in the next section, stresses the use of icons and graphics. This emphasis is due to the fact that icons are economical in their use of screen space and can help alleviate problems of providing information for users whose first language is not English. The design of icons is an important issue that would be of concern even for homogeneous user populations. The icons used for the p ASS prototype have not been selected from a group of internationally recognized icons, and they have not been tested for recognizability or memorability; more attention to these details needs to be addressed in the design of an operational system. For the demonstration prototype, this study has attempted to follow the general guideline of consistency in the use of icons and in the placement of icons and buttons. The concept of an iconic index (Baird, 1990) was employed in an online glossary of icon definitions (Figure 3-1). The display formats are structured in such a way that users quickly learn where to expect recurring features, such as menu options, icons, and buttons. This structure facilitates the learning process for all users and is particularly valuable for non-native English speakers who will tend to look for familiar landmarks.

To summarize, guiding principles discussed in this section are:

- intuitive, direct manipulation interfaces to enhance the user's sense of control and navigational orientation, and to mitigate human memory requirements
- navigation support through consistent design of displays and control features across components to reinforce an appropriate mental map of the system
- seamless integration of information, specialized support functions, and media with the user's tasks to promote data fusion
- accommodation of individual differences in experience, knowledge, and technical expertise
- flexible interface features that accommodate cultural differences

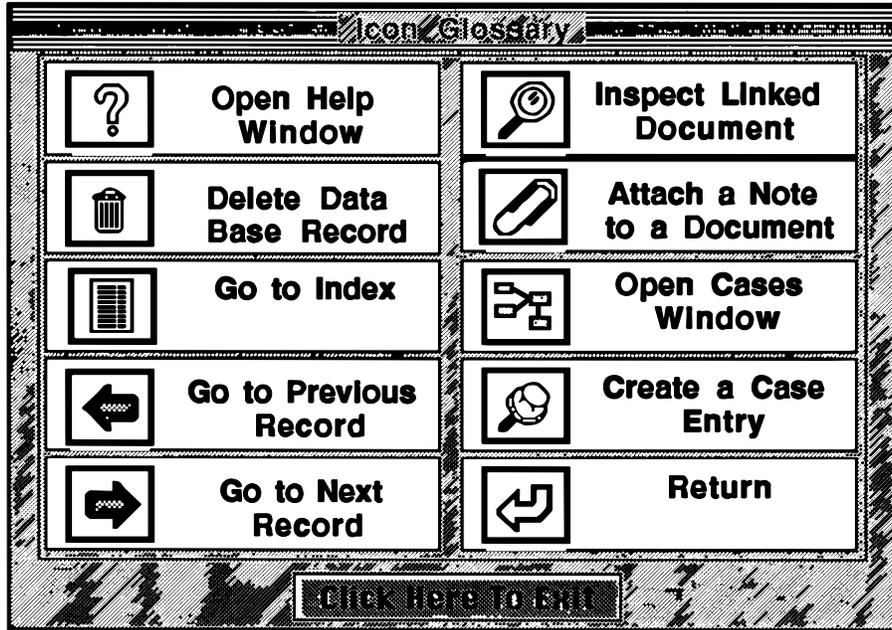


Figure 3-1. Sample Icon Glossary Window

4.0 PROLIFERATION ANALYSIS SUPPORT SYSTEM

In the course of their activities, Cos must collect, review, and analyze information on safeguards and non-proliferation undertakings, as well as the nuclear and nuclear-related activities, of the state(s) over which they have IAEA responsibility. The enormous volume of data, widely varying sources of data, and the extended periods of time (months or years) over which these determinations must take place, make this task extremely difficult even for highly experienced analysts.

4.1 Key User Support Functions

The key technical focus for developing the conceptual design of an advanced information system for IAEA COs, and its implementation in the PASS concept prototype, is to identify opportunities for and demonstrate human-machine collaboration. The functional areas in this context are broadly identified as

- Portfolio management
- Information filtering and retrieval
- Analysis
- Decision making

The following subsections provide more specific descriptions of support functions for the IAEA CO. The approach used to define, examine, and refine these concepts makes extensive use of rapid prototyping. The intent of this effort is to examine concepts and suggest directions for future research and development. Continued use of prototyping and extensive user involvement in design decisions is recommended to further define operational system requirements.

4.2 Overview

The PASS concept seeks to provide a collaborative information management and decision support system for the IAEA CO. The intended hardware and software environment for PASS is a PC platform running Microsoft Windows (MS- Windows), with network access to various electronic databases. The concept prototype is implemented on a Macintosh computer.

To use PASS, the user must login with a user ID. Given the ill, the system will be able to recognize the user and set up an appropriate work environment. This environment should include user preferences made within MS-Windows and relevant databases associated with the CO's state and topics of interest. The main work area would look something like the illustration in Figure 4-1. A tentative pulldown menu hierarchy is shown in Figure 4-2. The functions and processes described in the following subsections will be accessible using this menu hierarchy, as well as through direct manipulation links (icons or buttons) between the various components.

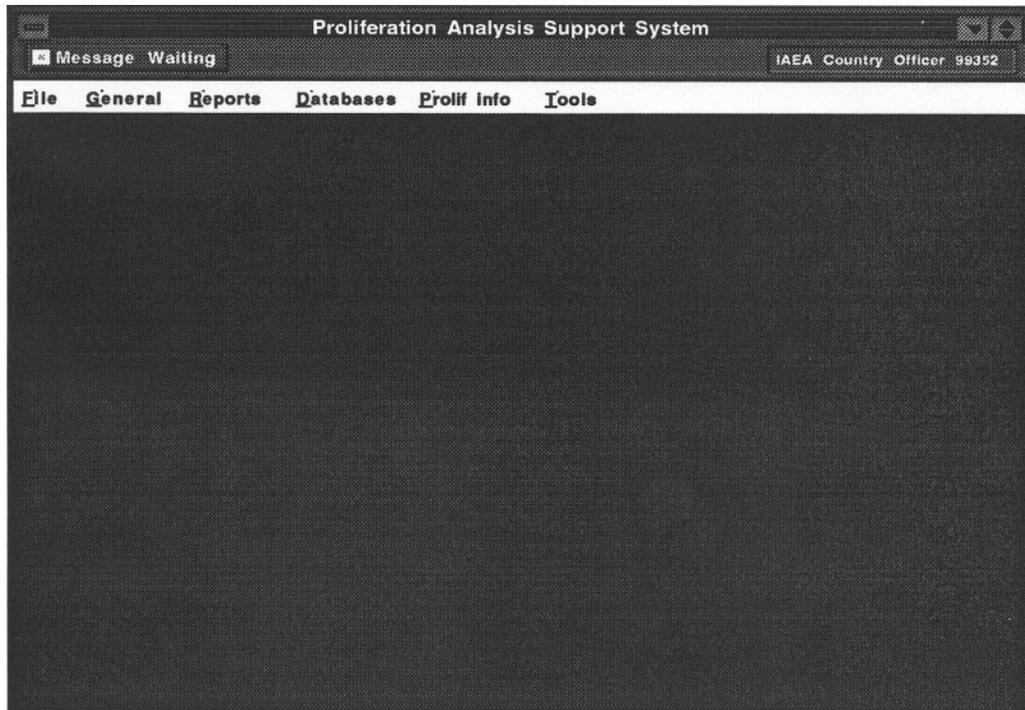


Figure 4-1. Main Window

Figure 4-2 Pulldown Menu Hierarchy for Main Window

4.3 Portfolio Management Support

The quest for continuous improvement has led many organizations to examine their business processes for improvements in productivity and quality (Harrington, 1991). Automated information systems can support quality and efficiency improvement of office tasks that depend upon expert knowledge for proper completion. In the IAEA office environment, automated support for portfolio development and maintenance will help the CO organize information for better access and retrieval, increase consistency of portfolios among individuals, and improve the management and reporting process.

The notion of portfolio management addresses the day-to-day administration and maintenance of the CO's file. Information is obtained through a variety of sources, including open source databases and responding instruments from the state itself as a signatory of the NPT. This large body of information must be cataloged and organized so that the CO will be able to access required data. Commercial, off-the-shelf software can be used to help organize various types of information, reports, and critical requirements and information needs. Data maintained by the CO will include general information, such as population and geographic features, industrial production statistics, and commerce information on imports or exports. Specialized tools can be developed to provide functions that are not met by commercial office applications.

Categories of safeguards information in the CO's filing system will correspond to the diverse types of indicators and observables that drive the analysis and decision making process. Representative categories include the following list (Paternoster, 1992):

- general information about the state
- nuclear materials production
- extraction and chemical conversion
- fabrication processes
- technology developments
- nuclear laboratory experiments
- physics design
- nuclear testing
- personnel and publications
- inspections.

At present, much of the data collected about a state is stored on paper and maintained in the CO's filing system. In the future, electronic databases are expected to replace the paper filing system. However, even before a complete electronic office is realized, automated support for the file maintenance function can save time, improve productivity, reduce filing errors, and help standardize CO files.

The efficacy of the electronic office environment advocated here will depend as much on the design of the human-machine interface as on the identification and implementation of software tools. The user interface must provide a seamless and consistent integration of software tools. Commercial tools that will be needed include, at a minimum: word-processor, text analysis and retrieval database systems, project scheduler, and an electronic spreadsheet. Specialized tools that support information access, analysis, and decision-making will provide the foundation for the collaborative human-machine system.

4.4 Information Filtering and Retrieval

Information filtering and retrieval is an active area of research. Automated systems are needed for filtering or retrieving information based on key word recognition or more sophisticated semantic features (in the case of textual documents); and systems for identifying and categorizing nontextual information (such as geographic information systems). Will and Reeker (1993) predict that the relatively immature state of natural language processing technology will significantly limit the applicability of fully automated systems for the foreseeable future. A considerable potential exists for integrated human-machine systems to improve performance over human-only systems and reduce the required level of human effort. This potential derives from the impressive capabilities of machine processing for some tasks and the recognized capabilities of humans for distinctly different tasks.

4.4.1 Document-Filtering Versus Information-Filtering and Retrieval

Document filtering and retrieval systems have been in regular use for a long time. This technology, however, differs from that of information filtering and retrieval, which is still a fairly immature area of natural language research. These technologies address different problems and use different approaches and assumptions to service the user's requirements. In document retrieval, the problem is selection of a document from a large search space; the problem is simplified by requiring the user to supply relevant key words in some combination (a representation scheme) and limiting retrieval to those documents that contain the key words either within their text or associated descriptive information. System execution is expected without

human intervention to take advantage of the speed and consistency with which a computer can perform predefined identification and comparison steps.

In information retrieval, the problem is to extract relevant information from the contents of a document. In this case, the computer performs at a higher level than that which is required for document identification, thereby relieving some of the human's cognitive burden. Key words are still necessary, but not sufficient for the desired level of performance because of the way words are used in natural language to convey meaning. The meaning of a word changes when seen in the context of a particular sentence (or position within a sentence), a passage within a document, or a specific document's subject matter. The same meaning could be represented by an entirely different word or phrase. To determine document relevance in this case, text analysis must be applied to the user's information request (to determine its meaning), data-based documents (for the same reason), and both must be put into a form convenient for comparison. The results of the comparisons are extracted passages that match document meaning with the user's information request. These passages can maintain reference links to their source documents so users may confirm their relevance within their original context.

Besides key words and phrases, methods to resolve meaning ambiguity used by natural language researchers for information retrieval systems include syntax and semantic clues, concept categories, and discourse analysis (see Figure 4-3). Meaning can be determined and extracted from a word or phrase based on grammatical usage (syntax) or by resolving the sense of a word from the context of a passage of text (semantics). The use of concept categories transcends syntax and semantics by mapping words or phrases to relevant groups for further processing as a higher-order "key word." Note that knowledge of the domain of interest is embedded in the retrieval system by designating groups as representing important concepts. This implies that an information retrieval system will not be a general purpose tool, but must be tailored or have boundaries assigned that describe its capability limits.

These first three methods assist in interpreting direct references, but much of the very important descriptive or detail information is written with indirect reference to its topic. This logically-connected supporting information might not be identified without discourse analysis, and once discourse elements are identified, they may be used to focus the filtering process or to increase the accuracy of retrieval or filtering systems.

Natural language processing and their domain-specific components are not normally seen as evolving during operational use through interaction with human users, but it is apparent that this approach might be used effectively in a joint human-machine collaborative relationship envisioned for PASS.

Example	Ambiguity Resolution Method
The decay left a foul odor... The isotope will decay...	Syntax: decay <noun> decay <verb>
They went to the bank for money ...and jumped in the river	Semantics: bank <business> (sense) bank <location>
It will arrive in July... It will arrive in pieces...	Semantics: in <time> (case) in <configuration>
The plant was secured with a locked fence... This building was monitored by camera...	Concept Category: plant, building => FACILITY
He took the vase off the table to clean it. The crumbs from dinner fell on the floor.	Discourse: it => table (co-reference)
I saw the boy get hit... The kid broke his leg...	Discourse: kid => boy (co-reference)

Figure 4.3. Text Analysis Methods

4.4.2 Text Analysis Support for the Country Officer

For the IAEA CO, a document and information filtering/retrieval system would provide a key underlying component of a tool like PASS. This component would need knowledge acquisition capabilities to allow for fine-tuning as well as the ability to execute multiple tasks concurrently. As a side benefit, it could be used to provide user training opportunities. Key features of the text analysis component are:

- Context-sensitive text analysis
- Capability for interactive reorientation
- Exploitation of human cognitive abilities through collaboration
- Ability to provide user training to maximize effective use of the system.

A joint cognitive system approach to text analysis would not only allocate the tasks between computer and human to exploit their respective strengths and offset weaknesses, but cause a rethinking of the problem bounds and implementing assumptions previously assigned to filtering and retrieval tasks. System functionality and design-previously constrained by computer resource limits and autonomous operations-would be open to developments in natural language processing technology, to accommodate human strengths and limitations, and to changes addressing application-specific constraints.

For the PASS application, some queries may run continuously on incoming data sources (a filtering function), but others would be launched automatically in a context-sensitive fashion. In other words, queries using specific subsets of domain information to resolve ambiguity would run based on the menu options and conditions selected by the user. These query results would provide selected documents or passages for the user to review and assess for relevance to the current investigation. The queries themselves could be designated as candidates for ongoing filtering criteria if a passage from a resulting document was tagged to support analyses and conclusions. See Sections 4.5 and 4.6 for descriptions of tools for organizing and linking analytic and decision-making tasks to source information through the use of note cards and case templates. This approach allows for focusing the natural language component to the context of the user's current task, as well as leveraging human competence in determining information relevance not only for the current question, but also for updating the filtering system profile criteria. The result would be a more tightly-integrated tool and more efficient distribution of tasks between the human and the machine.

The analysis that an IAEA CO would perform is an iterative process of refining queries as a result of previous retrieval results. When query results are presented as findings in an investigation context, the CO may recognize implications by associating information in some new or novel way and, as a result, refocus or generate several new concurrent lines of investigation. These excursions could in turn spawn other excursions, resulting in query topics several layers removed from the initial concepts. In a single session, a sufficient number of compound excursions distant from base concepts (the knowledge and domain categories designed into the text analysis component) may exist to cause performance of the retrieval system to no longer be reliable without augmenting its concept base to accommodate locally important queries. The need for two system capabilities is apparent in this scenario: the ability to detect when the user's investigation is stretching the reliability of the system, and the capability for dynamic text analysis system training for specialized situations or short-term application.

To detect when the user's investigation is stretching the reliability of the system, some type of text component performance data would have to be collected and analyzed automatically, with periodic (or on demand) reports to the user. Such a capability would have to be able to discriminate between system shortcomings (negative results from a query because the text analysis system could not perform as needed) and human shortcomings (negative results because the query was not well-aligned to the investigation). This is an area with a variety of research challenges.

Defining and then relating those local concepts to the existing set of text analysis concepts requires the world knowledge a human possesses. This could be facilitated through an interactive software tool, but knowing how and what to augment would be up to the user. Initiating a separate copy of the text analysis component to be modified with the human's grasp of local-to-global relationships to the particular context would be a reasonable approach to system operation. Based on subsequent use and performance, the user could determine whether to integrate the new information in all its searches or to reserve the copy for designated conditions.

To be used effectively by the IAEA CO, the text analysis system must be easily modified to improve the key words or concepts and their relationships as the CO gains specialized expertise and experience. As a by-product of a tool with the capability to review concept structures and relationships, a user unfamiliar with the implications of certain events could be trained by exploring the current base system. Similarly, a reviewer could critique the CO's assessment by browsing through the rich set of associative links set up by the CO in the process of building arguments and documenting conclusions.

4.5 Analysis Support

In conducting their analyses, COs attempt to forecast nuclear material and facilities and to estimate production of plutonium and highly enriched uranium at the facilities. COs are expected to recognize patterns of data that may point to activities in a Non-Nuclear Weapon State (NNWS) that are inconsistent with that state's peaceful-use obligations (that is, the existence of clandestine nuclear weapons development activities). Support for the analysis task requires tools that help the ca recognize patterns in safeguards data and identify safeguards-relevant features and trends.

Two concepts for analysis support are outlined in the following subsection:

4.5.1 Weaponization Paths Capability Matrix

A critical need for effective safeguards analysis is the ability to discriminate between peaceful and non-peaceful uses of technologies and material. To do this effectively, the analyst must integrate information from diverse sources and discern relationships among ostensibly unrelated facts and partial information, often designed to mislead the investigator. The Capability Matrix concept entails a strategy for enhancing

visualization of these relationships and providing automated assistance for bringing important data (or gaps in the known data) to the CQ's attention. Visualization support is obtained using the display of information in matrix form, with technologies (that is, pathways) represented in the rows and equipment types represented in the columns (see Figure 4-4). Data available about the designated state are tracked by the system and updated in the displayed matrix. The analyst can make visual comparisons of a state's known data with a weaponization path capability matrix containing required or typical data for a suspected path. Required or typical matrices may be defined, based on rules of thumb and established knowledge or criteria.

Data in the Weaponization Paths Capability Matrix can be updated automatically by tracking import and export logs. Matching tables can form the basis of an expert system that checks newly acquired data against lists of sensitive equipment, such as the Nuclear Supplier's Group list. The display of the matrix can use colors to highlight critical cells associated with a particular pathway, thereby cuing the analyst to focus on key indicators in future investigations or searches in available information sources.

Equipment Path	High Voltage Power Supplies	Vacuum Systems	Large Electromagnets	Marring Steel	Graphite Fiber	HF Power Supplies	Balancing Machines	Graphite	Heavy Water	Natural Uranium	Cooling Capability	Reactor	Irradiated Fuel	Excess Fuel Fabrication	Reprocessing Facility
EMIS	■	■	■												
Centrifuge Enrichment				■	■	■	■								
Clandestine Reactor								■	■	■	■				
Diversion from Low-Enriched Reactors												■	■	■	■

Figure 4-4. Weaponization Paths Capability Matirx

The capability matrix is one way of representing the status of the CO's ongoing analysis activity. Another representation uses a graphical format that depicts the flow of process and materials within a weaponization path (one row of the Weaponization Path Capability Matrix). For example, the path depicting diversion from low-enriched reactors (Row 3 of Figure 4-4) is shown in flowchart form in Figure 4-5. This display may serve as a reference or a help function for less experienced analysts, but it can also be used to provide direct-manipulation, *hypertext* links to the analyst's supporting material. The example shown in Figure 4-5 illustrates the diversion path in the nuclear fuel cycle for low enriched reactors. Icons in the display represent *interaction objects* that may be clicked on with the mouse to reveal more information or navigate to associated data. The bomb icon, for example, produces a pop-up text box with more detailed information about the diversion path. The push pin, paper clip, and document icons in the window refer to associated information linked to the currently displayed information using automated or user-initiated processing. These links, discussed in more detail in the next section, indicate to the CO the existence of supporting documentation for hypotheses or arguments that are being tracked, and provide immediate access to that information through a mouse click.

Figure 4-5. Weaponization Path Flowchart

4.5.2 Computer Simulation

Computer simulation and sensitivity analyses can be used to conduct what-if analyses and test hypotheses about clandestine weaponization activities, based on material flow data or material unaccounted for (MUF). This procedure may be accomplished by providing simulation models of declared fuel pathways. For example, given the number of power plants, research reactors, and power usage, the model would predict the material flow needed to provide a given amount of fuel. If the predicted amount of material differs from the observed (reported) value, the analyst's suspicions about a clandestine weaponization program would increase. Similarly, simulation models can be used to support sensitivity analyses to predict MUF.

4.6 Decision-Making Support

For the IAEA, decision-making support should include tools to help the CO organize evidence collected from a variety of sources over extended periods of time. The need to track information over long periods of time is critical for proliferation analysis. This type of decision-making differs markedly from others (such as command and control decision-making) that require split-second responses, often under stress. Because of extended time periods and incomplete and often misleading information, a key need exists for automated support in areas such as information integration (*data fusion*), and expert systems to help recognize non-peaceful use or diversion of nuclear or other technologies for clandestine weaponization.

4.6.1 Indicator Recognition

To perform the information processing and decision-making functions required for proliferation analysis, the CO must be able to recognize unusual data or situations. Key indicators must be tracked for this purpose. Some of these indicators are:

- Sophisticated chemical plants
- Sophisticated machine shops
- Analytical chemistry
- Maintenance of equipment-signs of special request procurements
- Plasma reactions and processing with plasmas
- Highly sophisticated electronics
- University programs
- Any unusual industrial activity that does not make economic sense
- Inventory of professionally trained people in high-tech areas
- Railroads, highways in areas with no apparent need for them
- Facilities (urban or remote) with associated design features
- Routing of electrical power
- Construction of co-generation plants
- Heat sink that is inappropriate for the location
- Unusual interest in nuclear medicine
- Reactor operations.

For example, if a country is known to be assembling clusters of trained personnel with specialties in technologies required for known enrichment schemes (such as large power supplies, high-speed bearing

design, etc.), it should increase the level of suspicion about the uranium enrichment as part of a weaponization path.

Support systems can be developed to inform the decision maker when incoming information contains pertinent indicators. For example, one indicator pertinent to power reactors is frequent shutdowns of the reactor, which may indicate production of weapons-grade plutonium. Another indicator is increased movements of material in and out of the spent-fuel pool. If both of these indicators are present, attempts may have been made to divert material for weaponization purposes (Patennoster, 1992). Examples such as these can provide the material required to develop a collaborative human-machine system to help the decision maker integrate diverse pieces of data (evidence) into a cohesive picture. This concept is further elaborated in the following paragraphs.

4.6.2 Collaborative Note Card and Case-Builder Support

An electronic Note Card system can help annotate and associate bits of related documents using a note card filing system metaphor. The Note Card database would provide links back to source documents, as well as forward links to the arguments or *cases* that the CO is in process of developing. Each such case would also be organized in a database that presents the logical process in a consistent fashion, along with annotations by the user and links back to the Note Card database and the original source information (see Figure 4-6).

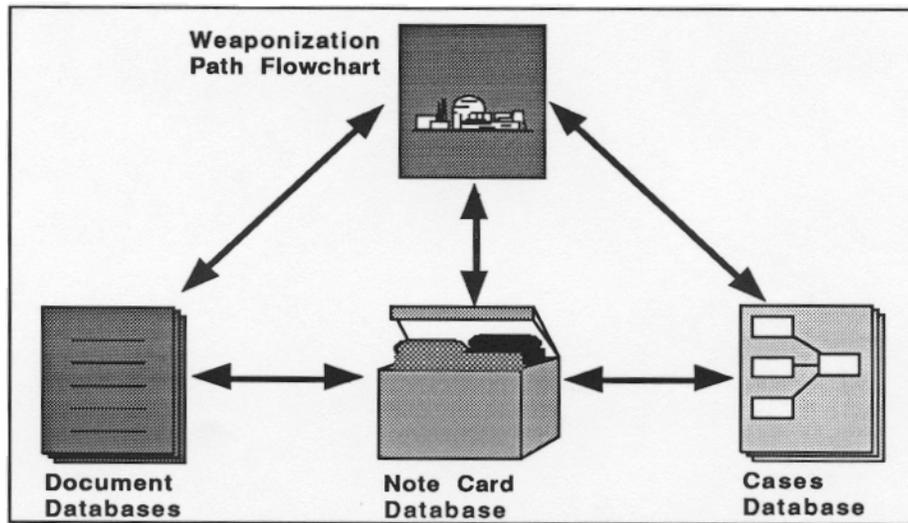


Figure 4-6. Collaborative Support Functions

The operational concept is as follows. Through various means of text search, preprocessing, or analysis (see Section 4.4), the CO finds a document of interest. A passage in the document is particularly relevant (suppose it refers to a state's spent fuel inventory). The CO selects the passage by highlighting it with the mouse, then clicks on a Note Card button (see Figure 4-7) the note card button is identified by a paper clip icon), that automatically brings up the Note Card window and prepares a new entry (database record) for the selected passage. A sample Note Card record is shown in Figure 4-8.

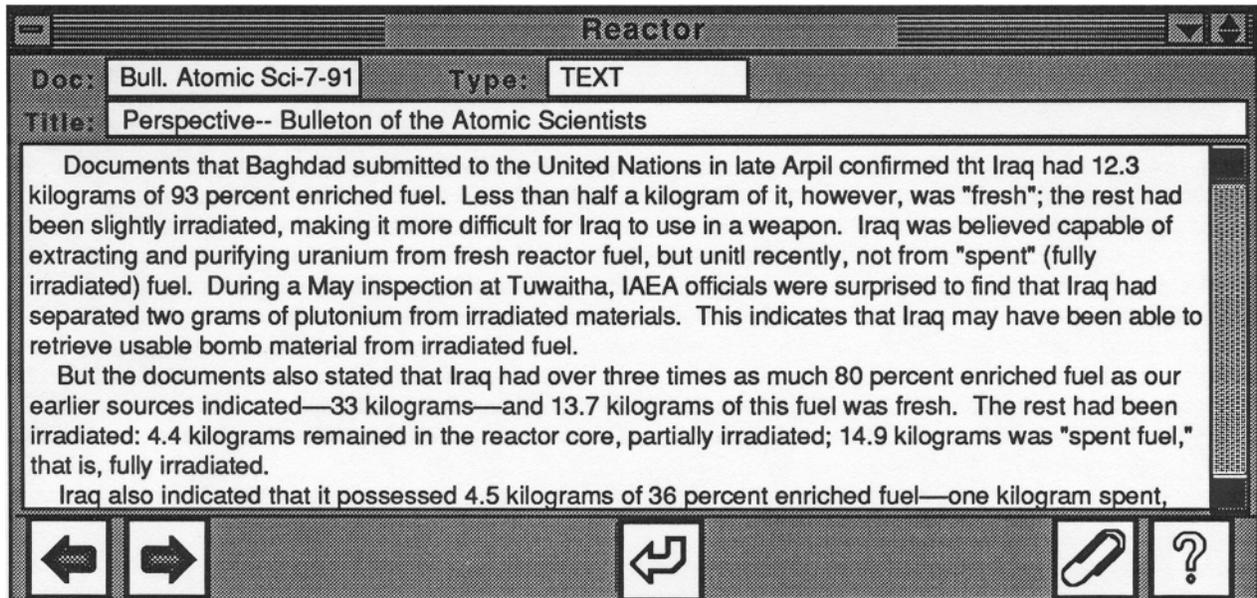


Figure 4- 7. Example of a Source Document with Links to Note Card System

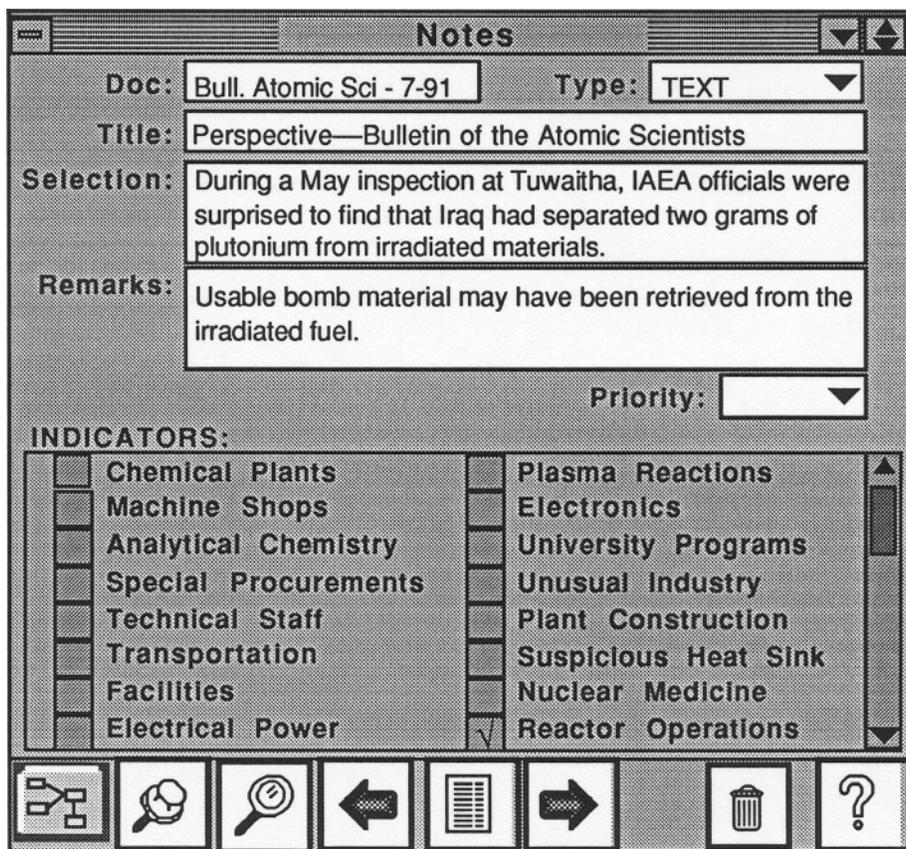


Figure 4-8 Note Card Database Window

Identifying information is pre-filled in the Note Card record display. In this way, the CO collects and keeps track of a number of pieces of evidence on possibly diverse proliferation topics. Each piece of evidence may be flagged with one of a set of pre-specified indicators (in this case, the indicator might be reactor operations). At the bottom of the Note Card window are icons representing buttons for navigation and information processing. From left to right, these are: a link to the Cases database (described below); a push pin representing a command to add the current record (as supporting evidence) to a specified case; a magnifying glass icon representing a command to go back to the source document to see greater detail; three browsing/navigation icons; a trash can for deleting a record; and a help icon. The browsing icons support navigation: left and right arrows mean go to previous and next note, respectively; and the list icon in the middle displays the note card index, which lists all note card records.

When a sufficient number of such pieces of evidence has been accumulated to begin building a case about an hypothesized diversion path or proliferation method, the CO may document a case in the Cases database (see Figure 4-9). The Cases database comprises pre-existing case templates, as well as user-created cases that graphically represent the logical argument leading toward a particular conclusion.

The development of cases may proceed in two ways. A CO may work forward, in a data-driven approach, to build a case from the evidence contained in the notes. Alternatively, the CO may work backward, in a top-down approach, to determine if evidence is sufficient to support a particular hypothesis. Typically, both approaches would be used in investigating the same information.

The key collaborative functions comprising this support concept are automated handling of the basic elements-notes representing accumulated evidence over long periods of time, cases representing hypotheses and logical arguments that the CO works on over extended periods, and management of electronic links among these and also back to source documents. The electronic links serve to document the process, both for the CO and for other staff members who might review or refer to the information. In Figure 4-9, an icon representing a link to the Note Cards database (paper clip) serves two functions:

- (1) It indicates that specified evidence is in hand
- (2) It provides a hypertext link to the evidence in the Note Card file.

The tool box associated with the Cases window (at the bottom of the window) supports navigation and case-building operations. The three leftmost icons allow the CO to create case templates from scratch or edit pre-existing templates. These icons contain the basic building blocks of evidence, conclusions, and the lines linking them that indicate cause/effect relationships (implication). The three middle icons support navigation (left arrow means go to previous case; right arrow means go to next case; and the list icon between these two icons displays the Cases window Index, which lists all cases currently being tracked. The letter A in the tool box represents a text tool that enables the analyst to type comments into the display. The paper clip icon enables the user to create links back to the Note Card database. The question mark icon is used by the analyst to set up an automated inquiry task in which the system will alert the analyst if relevant evidence (associated key words) are found. The icon in the tool box with a line drawn through a circle indicates that disconfirming evidence has been found for a specified element in the case. This icon has not been used in the case illustrated in this figure.

In addition to supporting activities underlying the accumulation of evidence and case- building, this network of information and linkages can be used to help the CO prepare reports and assemble supporting material. Output of current status is periodically required, often on short notice. The associative links existing within the analysis and case development components may be exploited to produce as output a standardized status document, which may then be edited and embellished by the CO for final disposition.

To summarize, a concept for human-machine collaboration in nuclear nonproliferation analysis tasks has been described. A key element of the concept is the integration of human and machine functions at the task level, supported by a rich network of associative links among data, hypotheses, and conclusions that helps the analyst maintain focus and provides a consistent framework for reporting and reviewing findings. Major features of the proposed system have been implemented in an interactive prototype to demonstrate the concepts.

Figure 4-9. Cases Window *[figure not available]*

5.0 APPLICATION OF THE RESEARCH RESULTS

5.1 Expected Benefits of the PASS Concept

The benefits of a well-integrated support system for the IAEA Country Officer divide into five categories:

- **Informative Support** -Using graphical representations whenever feasible, provide information about what is known, what is not known, and what must be done in a situation. This support is referred to as enhancing the CO's situation awareness. Enhanced situation awareness will lead to better performance of required duties.
- **Routine Support** -Perform routine sorting of information, update status of information acquisition tasks, and assemble data and analyses required for routine reports. Alleviation of requirements to perform routine, repetitive tasks allows more time for the CO to devote to more creative, exploratory activities.
- **Analytical Support** -Analytical support for the CO, in the form of standard sets of analyses and templates describing weaponization scenarios, will facilitate recognition of potential safeguards violations.
- **Decision Support** -Decision templates (Cases) help the CO construct arguments using the linkages to supporting Notes and Source Documents. The structure provided in this way helps standardize the record-keeping process and provides an audit trail that may be used to review the logic and evidence.
- **Communication** -Through graphical representations and direct manipulation, the design of the human-machine interface promotes ease of use by non-technical analysts and reviewers. This design also has the potential to decrease the amount of training required to learn the system compared to systems that are predominantly text-based and command-language driven.

5.2 Relationships to Other Work

This research complements other ongoing work at Pacific Northwest Laboratory and at other DOE national laboratories. Two projects that are particularly noteworthy are described briefly as follows.

5.2.1 Proliferation Framework

Nuclear proliferation analysts are required to search and process large volumes of information pertaining to many countries known to be or suspected of engaging in programs involving the development of nuclear weapons. This information, originating from both open and classified sources, is extremely difficult to manage efficiently. Many of the information management and analysis tasks related to these data are currently performed manually.

The aim of the Proliferation Framework (PF) is to enhance the proliferation analyst's ability to monitor and track worldwide developments in the nuclear proliferation arena. The system, as envisioned, will intelligently manage information by systematically overlaying it into a framework representing the pathways necessary for creating a nuclear weapon. In a relatively automated mode, information contained in various external databases will be queried, sorted, and tagged to

appropriate pathway components within the framework, with the intent of greatly reducing the time analysts take to become cognizant of proliferation significant developments in a given country. The PF will be an integral part of the overall Proliferation Information Network System (PINS), currently under development with the oversight of the DOE national laboratories.

The development of the PF has been broken into three phases. In Phase I, a Conceptual Prototype was developed to demonstrate the key functions of the system and to obtain feedback from potential users of the system. In Phase II (in progress), an Operational Prototype of the PF will be developed. This version of the PF will build on the Conceptual Prototype and will incorporate comments received in Phase I. This Operational Prototype will include only a selected subset of pathway nodes (principally those associated with reactor and accelerator production of special nuclear materials and pit production). In the third phase, the PF will once again be refined according to the prospective users' comments and expanded to include additional proliferation pathways, before being released for analyst use.

The PF is being developed for use by analysts within the DOE. The concepts of human-machine collaboration proposed in the present study are nevertheless directly applicable to the PF/PINS problem domain. Specifically, the methods of assisting the analyst in accumulating and organizing evidence, annotating information for later reference, and developing arguments may be incorporated into the conceptual framework of the PF system.

5.2.2 INSIST

Pacific Northwest Laboratory is developing an information integration and analysis workstation for the IAEA that will assist in the maintenance and analysis of remote monitoring data and onsite inspection activities in Iraq. The International Nuclear Safeguards Inspection Support Tool (INSIST) is a geographically-based system for storing and retrieving all information relevant to long-term monitoring and inspecting of Iraqi areas/facilities. The data are geographically linked for quick and easy access by the user.

The workstation provides a single source of information on

- historical and periodically acquired remotely sensed (aerial and satellite) imagery
- geographically referenced maps, charts, and imagery
- point-source environmental collections (air, soil, water, and biota)
- onsite/facility acquired data/information (such as video tapes, photography, and building diagrams)
- treaty-related text (databases, trip reports, correspondence, treaty text)
- lessons-learned reports and documentation of inspection activities.

Because the INSIST system manages information in both analog (video) and digital formats, it can provide virtually unlimited storage and retrieval of all types of data. This system is implemented on a Sun workstation and is equipped with a variety of peripheral devices, such as videodisc player, large-screen TV monitor, and color printer. The users of the system will be technical safeguards personnel, inspectors, and policy/decision-makers at the IAEA.

Functions envisioned for the INSIST workstation include: pre-inspection planning, onsite inspection support, post-inspection analyses; remote monitoring support for establishing baseline imagery, identifying suspect site and special inspection candidates, and incorporating videotapes from onsite monitoring; and sampling activities, such as incorporation of results from sampling collections and integrating environmental sampling results.

The focus of the Phase I INSIST system, as described above, is initially: (1) somewhat more narrow than that of PASS; and (2) directed at a different set of users within the IAEA. However, the powerful processing capabilities for image processing, graphical visualization, and output/reporting features provide a foundation for future enhancements that would broaden the scope of the system as well as incorporate collaborative user interface features and automated support functions that have been proposed for PASS. In

the future IAEA information system environment, PC-based systems envisioned for IAEA COs (such as the PASS concept) can be networked to the INSIST workstations.

6.0 DIRECTIONS FOR FUTURE RESEARCH

Workshops and discussions conducted during the course of this research project have highlighted a number of possible directions for future research and development. Applications of collaborative human-machine concepts to ongoing programs--potential spin-offs of the work--were discussed in the previous subsection. Beyond this, further research is needed to continue the development and elaboration of the PASS concepts. Continued internally funded research should seek to refine the collaborative concepts for nuclear nonproliferation analysis. Brief descriptions of possible research tasks are as follows.

1. Knowledge Acquisition. Conduct more detailed task analysis and knowledge acquisition activity to increase the relevance and applicability of proposed functions. Focus on deriving a common thread that pulls all the data together to support the analyst's resolution of the decision problem.
2. Integration Over Time. Address the issue of time on task. Because the analysis activities occur over the space of many months (perhaps years), it is important for the computer system to assist in tracking progress, helping to focus tasks, and reminding the human to complete them. Further research should address how to do this effectively.
3. Team Integration. Proliferation analysis at the IAEA uses a team of analysts organized in a hierarchy. A given problem is divided into various component parts (such as design information analysis, proliferation path analysis, infrastructure analysis, safeguards inspection results analysis) that are handled by analysts at one level, then reaggregated at higher levels for other analysts. Effective computer support for this process requires a support system that starts with a holistic view of the task, and then assigns functions to teams on the basis of appropriate workloads. Additional research is required to design a support system that provides a proper integration of this network of people and machines.
4. Operational Prototype. Develop an operational prototype on a PC platform that extends the functionality of the Macintosh- based PASS concept prototype.
5. Collaborative Support. Explore enhancements to the collaborative support system concepts. Possible enhancements include
 - research on what constitutes a well-constructed case-examine modeling techniques that may provide a rigorous and impartial framework for evaluating the structure of a case
 - research on propagation of confidence or subjective probabilities--examine whether confidence measures can be propagated within the elements of cases and among the various associative links of the system, to help prioritize information treatment activity
 - research on human-machine interface factors for improving usability of multimedia features--examine techniques of information presentation and human-machine interaction to simplify and facilitate navigation through diverse information sources using hypermedia links
 - research on collaborative information filtering and retrieval--examine techniques for increasing the context-sensitivity of the text analysis component through better integration of human and machine functions.

7.0 CONCLUSIONS AND RECOMMENDATIONS

Collaborative human-machine interface concepts stress the need for problem-driven system design, as opposed to design that is technology-driven. Advanced technology should be exploited to provide tools that facilitate, guide, or constrain human information processing or decision-making rather than dominate or replace human activities. The critical contribution of the human lies in the ability to draw upon knowledge and experience, to view information in novel ways, to synthesize seemingly unrelated information, and to grasp implications that may not be evident through automated methods.

Automated support for the IAEA CO should focus on the integration of appropriate software tools and resources that

- facilitate access to and processing of large amounts of data
- establish electronic linkages reflecting the human's view of the problem and emerging solutions
- help track the status of many tasks conducted simultaneously over long periods of time
- provide information that fills gaps in a human's knowledge through automated assistance.

Key areas of need for collaborative support for IAEA information treatment include:

- portfolio management
- information filtering and retrieval analysis
- decision making.

Design concepts for collaborative support functions in these areas were explored and implemented in the p ASS interactive concept prototype to demonstrate collaborative human-machine problem solving. Future plans for upgrading the automated information system environment at the IAEA should include incorporation of these concepts.

Collaborative support functions proposed in the present research should be explored in more operational contexts. One way to conduct this exploration is to continue to develop operational prototypes on a PC platform that builds upon the PASS concept prototype that was implemented on a Macintosh. Another possible path to further exploration and specification of the proposed concepts is to integrate some of the features and functions with ongoing, related efforts such as INSIST or PINS. Expected benefits of further development and refinement of these ideas, and their eventual implementation, include:

- improved operability of safeguards information systems
- enhanced analysis through more consistent usage and outputs of the process
- decreased training requirements through more effective and user-friendly interfaces.

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