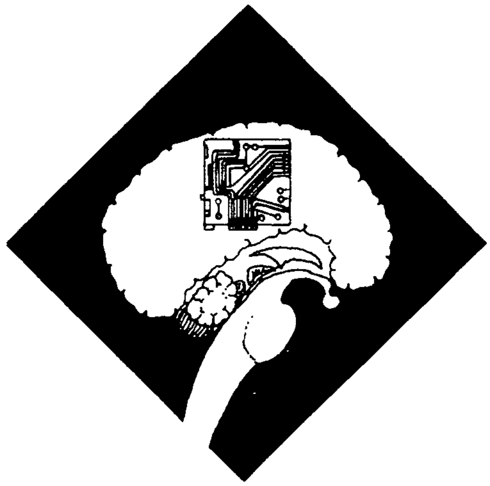
DOE/NE-0064
Dist. Category UC-79

DOE/NE--0064

DE86 011387



Artifical Intelligence and Nuclear Power

Report by the Technology Transfer Artificial Intelligence Task Team

June 1985

U.S. Department of Energy
Assistant Secretary for Nuclear Energy
Washington, D.C. 20545

DISCLAIMER

ARTIFICIAL INTELLIGENCE AND NUCLEAR POWER

TABLE OF CONTENTS

ARTIFICIAL INTELLIGENCE AND NUCLEAR POWER

LIST OF FIGURES

EXECUTIVE SUMMARY

The Artificial Intelligence Task Team was organized to review the status of Artificial Intelligence (AI) technology, identify guidelines for AI work, and to identify work required to allow the nuclear industry to realize maximum benefit from this technology. The state of the nuclear industry was analyzed to determine where the application of AI technology could be of greatest benefit. Guidelines and criteria were established to focus on those particular problem areas where AI could provide the highest possible payoff to the industry. Information was collected from government, academic, and private organizations. Very little AI work is now being done to specifically support the nuclear industry.

The AI Task Team determined that the establishment of a Strategic Automation Initiative (SAI) and the expansion of the DOE Technology Transfer program would ensure that AI technology could be used to develop software for the nuclear industry that would have substantial financial payoff to the industry. The SAI includes both long and short term phases. The short-term phase includes projects which would demonstrate that AI can be applied to the nuclear industry safely, and with substantial financial benefit. The long term phase includes projects which would develop AI technologies with specific applicability to the nuclear industry that would not be developed by people working in any other industry.

It has been estimated that AI related activities underway funded both by Government and by industry in 1985 total about $400 million. This is projected to increase rapidly over the next few years. NASA is conducting a substantial effort in support of space station. Both the Air Force and the Navy have established centers for Artificial Intelligence. The Department of Defense is conducting significant AI work. The National Science Foundation is funding AI related R&D at several universities. Industrial concerns have established significant AI efforts. This work is potentially of use for nuclear applications with appropriate nuclear domain specific work.

DOE assistance is needed to provide the nuclear industry access to this government funded work.

Currently DOE NE is conducting a modest amount of nuclear related AI work that provides the nucleus for a meaningful Nuclear Energy AI Program.

The short term phase of the SAI focuses on the application of currently available AI technologies to operating nuclear power plants. The particular projects identified for this area could be developed at test facilities such as the Fast Flux Test Facility, Experimental Breeder Reactor-II, and High Flux Research Reactor. They could then be implemented on operating commercial nuclear power plants. These projects include the following.

1. An Expert System for Fuel Loading

   EPRI has proposed teaming with DOE to develop an expert system for fuel loading. A central problem of fuel load management revolves around determination of the optimum fuel shuffling scheme to be used in re-configuring the reactor core during an outage. Spent fuel pools are in general too crowded to allow off-loading of an entire core before putting the next cycle core in place. An expert system for fuel handling could be developed cooperatively by DOE and EPRI, based on DOE supported technology originally developed at Westinghouse and Hanford Engineering Development Laboratory (HEDL). The expert system could be developed and demonstrated at FFTF and then field tested at a commercial nuclear power plant operated by a participating utility.

2. Management Decision Support System

   Managing the construction of a nuclear power plant or other large facility is a very complex task. Decisions regarding scheduling, resource assignment, cost, etc. must be made daily, and are based on large amounts of data and many complex constraints. The ability to make these decisions wisely is developed through years of experience, and is even then limited by the ability of the individual to assimilate all of the pertinent data. Currently available expert systems technology can provide the construction manager with an "intelligent" aid to enhance his ability to make these decisions.

An expert system can be developed with a knowledge base of construction management facts, rules of thumb, etc., obtained from experts in the field which would then be capable of duplicating the performance of these experts. For this task, experts would be sought from the utilities with the most successful recent construction projects in terms of construction costs. In this way the expert system would provide the construction manager with advice concerning scheduling, problem resolution, etc.

This task could use the NASA sponsored work to develop a similar type system for space stations as well as knowledge-based systems technology.

3. Control of Nuclear Power Plants

A major issue that has become increasingly important in recent years is to the man-machine interface to properly react to data regarding plant status during off-normal and accident conditions. The possibility of multiple system failures and incorrect interpretation of plant status are of major concerns. It is felt that new technologies for increased computer use in control of nuclear power plants can successfully address these concerns.

The long term phase of the SAI focuses on a R&D effort within those areas of AI technology that appear to have the greatest financial benefits to the nuclear industry. These are longterm, high payoff activities. These areas include the development of:

1. An Integrated Knowledge Base (IKB) of nuclear plant data that will represent all aspects of the plant. This will provide a single baselined plant database from which all needed plant information can be drawn for all applications for construction to decommissioning.

2. A Management Decision Support System (MDSS) that will use the IKB as a data source and will be capable of providing expert advise concerning managing the entire construction effort.

3. A Design Verification and Validation (DV&V) system that will support analysis and testing of the designs.

4. A Design Integration System (DIS) that will support integration of the design, fabrication, and construction efforts using a total systems approach.

5. An Integrated Plant Automation (IPA) system that will use AI technology to integrate the automation of all aspects of power plant operation, maintenance, repair, etc.

The SAI would provide for the development of AI and numeric techniques, methods, and systems supporting the nuclear industry. It will incorporate such technologies as robotics, modularization, advanced sensors and automated control systems as well as AI.

Expansion of the Technology Transfer efforts within DOE will ensure that the development resulting from the SAI will be communicated in a timely fashion to anyone who might benefit from their use. It will also ensure that developments in each area will be used to benefit the developments in other areas where applicable.

I. SUMMARY AND FINDINGS

A. Summary

The Task Team members were chosen from industry, universities, and national laboratories and have responsibility for AI programs within their respective organizations (see Section II of this report). This provided for a team of experts in the field of AI with a broad background of experience in many areas from research and development to industrial application. Each member provided information regarding AI projects ongoing in their organization, and contributed to the accumulation of similar information for other universities, national laboratories and industry. (See Section IV of this report).

The Task Team identified particular work projects that should be performed to apply AI technology to the nuclear industry with maximum benefit. These are enumerated in the potential projects (Section III A of this report). A major factor in the identification of the specific work areas was the finding that very little work in AI is presently occuring to meet the needs of the nuclear industry.

The Task Team identified specific guidelines for applying AI technology within the nuclear industry to produce the maximum possible benefits to the industry. (Section III B of this report). These guidelines included minimizing the duplication of effort so that the technology is developed efficiently, and so that only the most advanced techniques available will be used in the nuclear industry.

Lessons learned in AI were identified and will help to avoid pitfalls which others in the field have encountered. (Section III C of this report).

The specific projects identified and the underlying needs these projects satisfy are judged to be of very high importance. Recognizing the current state of the nuclear industry and the potential that AI represents to better the state of the industry, the application of AI and other advanced computer technologies within the nuclear industry offers a way to achieve major cost savings and productivity increases.

Future nuclear power plants are projected to be highly modularized, with the possibility of several plants being operated from one control room. AI-based diagnostics and control systems can make this possible by taking over the mundane day to day oversight tasks that the operators must perform to keep the plant running. While still maintaining control of the plant, the operators can use these systems to do the more simple tasks, allowing the operators to concentrate on the more complex ones. The diagnostics systems will enable the operators to spend less time on actual signal monitoring, and more time on continuing activities such as interpretation of data compiled over long intervals.

One of the more useful aspects of the AI-based systems is the ability to explain the reasons for the choices they have made and that they are recommending to the operators. The complete line of logic can be presented, with nothing left out, and allowing the operators to ensure that no oversights have been made. Deductions would be pre-checked, and would be representative of a consensus of many expert system operators.

AI systems can help to provide for the redundancy and diversity which make nuclear plants as safe as they are. Any system developed can be checked by another system which would use a different approach to arriving at the solution than the first one, and any system would always be checked by the operators before anything would be done. Systems can be developed to constantly monitor plant functions, altering operators to problem conditions, and reducing the need for design conservatisms.

B. Findings

The findings identify work that should be done in the AI field to apply this technology to the nuclear industry. The findings are divided basically into two sets: those that deal with AI developments for the nuclear industry in the short term, and those that deal with development of AI tools and technologies having very high potential financial benefit to the industry but will take longer to develop.

The needs, identified as important to the application of AI to the nuclear industry in the short term are:

1. to demonstrate that existing AI technologies can be applied to the nuclear industry, with resultant cost savings and productivity increases.
2. to show that when applied, these technologies can produce substantial financial benefit to the nuclear industry across the nuclear plant life cycle.
3. to provide testing and qualification of AI being applied to nuclear plants. This will be achieved by testing the technologies developed on existing facilities such as the Fast Flux Test Facility (FFTF), Experimental Breeder Reactor-II (EBR-II), and High Flux Isotope Reactor (HFIR).

The long term needs address the development of AI technologies which:

1. Have very high potential for substantial financial benefit to the nuclear industry;

2. Are specific enough to the nuclear industry that they will most likely not be developed by organizations representing any other industry; and

3. Are expected to have such long development times that they will not be developed by the nuclear industry without the help of the Department of Energy.

The short term needs could be met at the various national laboratories, universities, and private companies, tested at the FFTF, HFIR, and EBR-II facilities, and implemented at various existing nuclear power plants. In this way these projects can provide the greatest benefit to the nuclear industry.

The long term needs, however, will provide the greatest benefit to the nuclear industry by being applied to the nuclear plants presently in the design stage. These are geared toward the total plant concept, from initial conceptual design to final decommissioning. Here the benefits of the AI and other advanced computer technologies developed can be realized to their fullest extent, and can contribute significantly to reducing the cost of future nuclear power plants for the very first to the very last stages of design, construction, and operation.

Short Term Needs

The following short term needs could be appropriately met by application of AI technology to the nuclear industry. The work should be performed to enhance the transfer of the technology to interested parties. The work should be coordinated with the Electric Power Research Institute (EPRI) to facilitate transfer of the technology to the nuclear utilities. The FFTF, EBR-II, and HFIR reactor facilities could be used as test beds for development of the required software packages. Once completed, these software packages could then be tested at commercial nuclear power plants.

Task 1.0 - An Expert System for Fuel Loading

EPRI has proposed teaming with DOE to develop an expert system for fuel loading. A central problem of fuel load management revolves around determination of the optimum fuel shuffling scheme to be used in re-configuring the reactor core during an outage. Spent fuel pools are in general too crowded to allow off-loading of an entire core before putting the next cycle core in place. An existing expert system for fuel handling could be modified and developed cooperatively by DOE and EPRI, using the technology originally developed at Hanford Engineering Development Laboratory (HEDL). This expert system would be demonstrated at FFTF and then field tested at a commercial nuclear power plant operated by a participating utility.

Task 2.0 - Management Decision Support System

Managing the construction of a nuclear power plant or other large facility is a complex task. The ability to make decisions wisely is developed through years of experience, and is even then limited by the ability of the individual to assimilate all of the pertinent data.

An expert system can be developed with a knowledge base of construction management facts, rules of thumb, etc., obtained from experts in the field which would then be capable of duplicating the performance of these experts. The expert system would provide the construction manager with advice for how to handle scheduling, problem resolution, etc. This activity would use the Technology being developed by NASA for construction of Space Station.

Task 3.0 - Control of Nuclear Power Plants

A major need that has become increasingly important in recent years is to assure that nuclear plant operators can assimilate all of the necessary data and information regarding plant status to assist them in reacting appropriately during off-normal and accident conditions. Furthermore, the possibility of multiple system failures and incorrect interpretation of plant status are major concerns. New technologies for automatic computer control of nuclear power plants can successfully address these concerns.

Technology for automatic control of nuclear power plants developed by DOE could be implemented on the EBR-II test reactor's primary heat removal system. This could lay the groundwork for the acceptance of the plant automation concept.

Task 4.0 - Artificial Intelligence Support to the Robotics Tasks

The AI support to the robotics tasks is to provide the control software necessary to provide robots with the ability to make decisions about what to do next without having to consult with human operators for each minor task that must be performed. The AI effort here would be divided into two basic sections, the development of parallel processing and other hardware to support the advanced AI software that would be developed, and the actual software development. A major effort in the hardware development would be applied to increasing computer speed so that the robots would be able to respond in real time, while a major effort in the software development would be expanded in compiling the necessary knowledge bases for the control systems developed. This effort is discussed in the Robotics report.

Findings for Basic Research Areas

The Strategic Automation Initiative should be based on the five basic research and development areas identifies below along with an expansion of the Department of Energy Technology Transfer program. Figure I summarizes these priority efforts, identify the justification for this priority, and graphically shows the potential effect on integrated life cycle cost.

- Nuclear Power Plant Integrated Knowledge Base (IKB)
- Nuclear Power Plant Management Decision Support System (MDSS)
- Nuclear Power Plant Design Verification and Validation System (DV&V)
- Nuclear Power Plant Design Integration System (DIS)
- Nuclear Power Plant Integrated Plant Automation (IPA)

The IKB concept is a total plant database including all baseline information necessary for completely defining the plant configuration and design details. All application areas needing plant information will have access to this database, potentially eliminating problems originating from misinformation, use of outdated information, or improper dating of information by various diverse users of the same information. The IKB, when completed, will provide the database necessary to the other areas noted above. Until it is completed, each individual application will have its own database.

The IKB would be developed using AI technology such as entity-relationship modelling, and therefore be considerably more versatile than the current databases. The knowledge acquisition portion of this project will require significant effort.

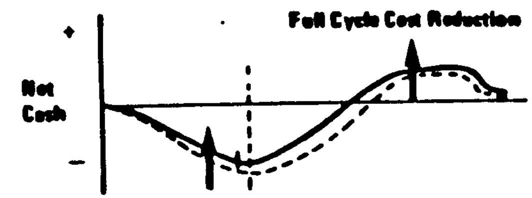
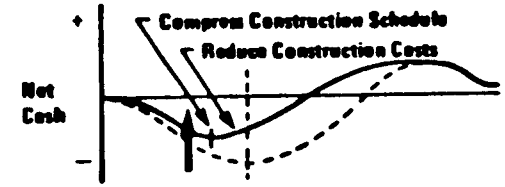
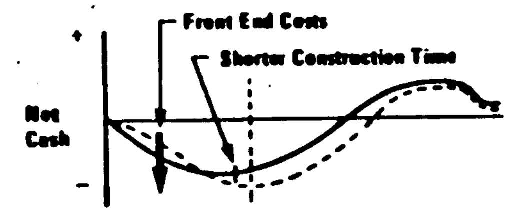
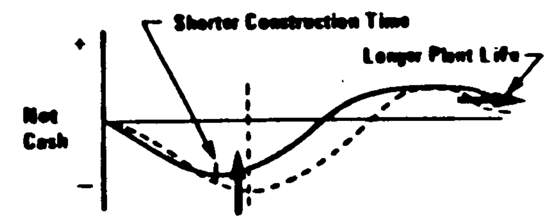
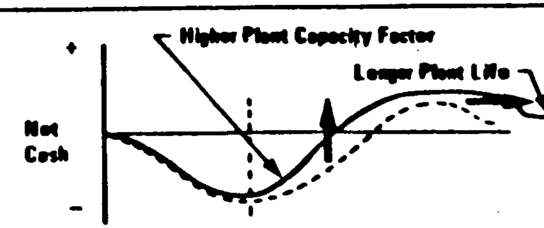
HIGH PRIORITY WORK AREA	DESCRIPTION	JUSTIFICATION	POTENTIAL EFFECT ON INTEGRATED LIFE CYCLE COST
(1) INTEGRATED KNOWLEDGE BASE	Life - Cycle Data Base Structured for Any Unforseen End Use	Generic -- Common to Nearly Every High Priority Work Area Considered	
(2) MANAGEMENT DECISION SUPPORT SYSTEMS	A System Which Incorporates AI Technology for Project Planning, Scheduling, and Construction	An Integrated Planning System is Needed to Appropriately Interface Vendors, A/E's Utilities, etc.	
(3) DESIGN VERIFICATION & VALIDATION	Analysis & Testing of Designs	Important to the Restoration of Public Confidence in Nuclear Systems	
(4) DESIGN INTEGRATION	Intergrating Design, Fabrication, and Construction (Synthesis of New Designs - Total Systems Approach)	Potential Positive Impact on Construction Schedule	
(5) INTEGRATED PLANT AUTOMATION	Application of AI Technology to Automation of Operational Procedures, Maintenance, Off-Normal Conditions, etc.	Improvement in Plant Capacity Factor and Operational Safety	

Figure I Identification of Payoff Potential

The MDSS would provide tools needed to assist in the management of the cost, resource allocation, schedule, and resolution of problems of a nuclear power plant project. Additionally, the MDSS would provide the means for both long range planning and short term management of a nuclear power plant project. Until the IKB technology is fully developed, the MDSS will have its own database. Once the IKB technology is fully developed it will use the IKB developed for a similar previously completed plant to assist in the development of the initial schedules and cost estimates for a new plant. It will then use the actual plant IKB for the management of the actual plant construction.

The DV&V, DIS, and IPA systems will all use the plant IKB to perform their respective functions. Other auxiliary systems could also be developed to form a coherent basis for Integrated Plant Automation for the full life cycle of the plant. Such systems might include systems for licensing, operating cost control, fuel management, etc.

Expansion of the Technology Transfer program (Figure II) can provide the framework for the transfer of AI technology between government agencies, universities, and the private sector through participation in cooperative development projects and maintain the liaison with the nuclear community.

Figure III summarizes high payoff Artificial Intelligence projects that can provide support to nuclear energy.

Figure II

ARTIFICIAL INTELLIGENCE TASK TEAM FINDINGS CONCERNING TECHNOLOGY TRANSFER TO THE NUCLEAR INDUSTRY

Findings	Discussion
1. Technology Transfer Program Leverage of existing Government programs in National Aeronautics and Space Administration, and various related DOD and industry activities with DOE Strategic Automation Initiative.	Various government agencies have active Artificial Intelligence programs in the research and development or applications areas. The establishment of an informal working arrangement with these agencies would provide a communication and technology exchange mechanism.
2. Expand the Technology Transfer effort to include Technology Transfer Activity involving universities and national laboratories that supports the Strategic Automation Initiative and ongoing Technology Transfer Program.	The university and national laboratory based Technology Transfer activity should be organized to be able to provide specific support to the projects defined in this report. The mechanism to conduct this work would be a 15-20 member team with representatives from industry, government agencies, and national laboratories.
3. Communicate the results of the Task Team Reports.	The Task Team report should be communicated to the nuclear industry and government agencies. This communication could be in the form of symposiums, presentations, and meetings. The Task Team members would be involved in the planning and presentations.

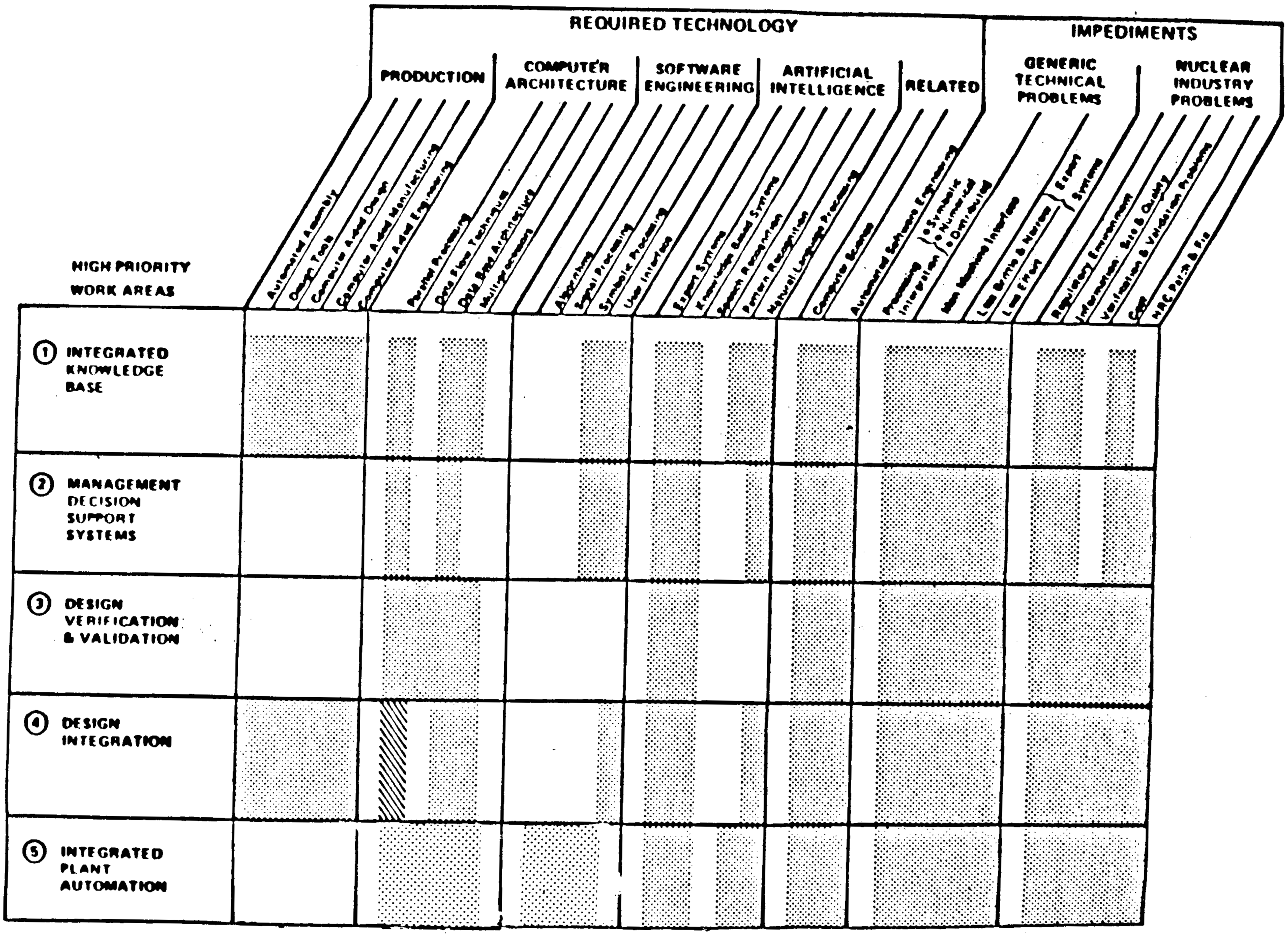


Figure III Artificial Intelligence High Payoff Projects that can Support Nuclear Energy

II. TASK TEAM CHARTER AND MEMBERSHIP

A. Charter

The Task Team on Artificial Intelligence (AI) will assess and evaluate all matters related to AI programs and strategies that are pertinent to its use in the Nuclear Industry.

The Task Team will:

1. Identify, review, and assess AI work among all organizations represented on the Task Team and key leaders in the field.

2. Review the status of AI Technology through an exchange of information between organizations represented on the Task Team, other organizations, and people working at the forefront of the field.

3. Identify guidelines for AI work and applications.

4. Identify and review lessons learned so that ideas and experiences can be used to avoid unnecessary duplication of effort.

5. Identify and plan specific work required to allow the nuclear industry to realize maximum benefit from the technology, and identify specific proposed mechanisms for its accomplishment, i.e., collaborative work, promotion of work by technology transfer coordination, identifying government sponsored work, grants, etc.

B. Membership of Artificial Intelligence Task Team

Name	Address
Edward E. Purvis, III Manager Artificial Intelligence Task Team	U. S. Department of Energy Office of Breeder Demonstrations Projects Washington, D.C. 20545
Saundra J. Walmsley Coordinator Artificial Intelligence Task Team	Westinghouse Advanced Energy Systems Division Post Office Box 158 Madison, Pennsylvania
Peter Papas	Westinghouse Productivity and Quality Center Post Office Box 160 Pittsburgh, Pennsylvania
Peter Fazekas	Burns and Roe 800 Kinderkamack Road Oradell, New Jersey 07649
A. D. Alley	General Electric Corporation P.O. Box 3508 Sunnyvale, CA. 94088
John Gabriel	Argonne National Laboratory Mathematics and Computer Science Division 9700 S. Cass Avenue Argonne, IL 60439

Membership (Continued)

Alan Waltar	Hanford Engineering Development Laboratory P.O. Box 1970 Richland, WA. 99352
Sarosh Talukdar	Prof. Electrical & Computer Eng. Director, Design Research Center Carnegie Mellon University Pittsburgh, PA. 15213

III. TECHNOLOGY EVALUATION

A. Potential Applications

A list of approximately fifty (50) potential applications of significance to the nuclear industry were identified by the AI Task Team and compiled in the next section of this report. This list was used as the basis for evaluating areas to determine where the application of Artificial Intelligence technology could be of greatest benefit to the nuclear industry.

The list serves to focus on areas where ongoing Artificial Intelligence research in university, industry, and government could be applied potentially by the United States nuclear industry. It is expected that much of the ongoing research should be part of the Department of Energy effort to achieve synergistic benefits from the large investment of resources worldwide that would utilize Artificial Intelligence to improve productivity and produce a more competitive industrial base.

The result was the identification of 22 key areas of needed work that would allow the long term mission objectives to be realized.

Potential Applications to Nuclear Power

	Applications of AI		
	Short Term	Long Term	Top 22
DESIGN			
o Lack of Plant Standardization	N/A	N/A	
o Volume and Complexity of Codes and Standards unique to the Nuclear Industry	X		X
o Technical and Social Conflicts	N/A	N/A	
o Need for Redundancy		X	
o Dictated Retrofits	X	X	X
o Information Retention and Retrieval	X	X	
o Detail Required to Support Technical Decisions		X	
o Public and Institutional Expectations	N/A	N/A	
o Design Integration (CAD/CAM)	X	X	X
o Common Data Base (Technical, Materials and Cost)	X	X	X
o Communications (Internal and External)	X	X	
o Conflict Resolution		X	

Potential Applications to
Nuclear Power (Cont'd)

	Applications of AI		
	Short Term	Long Term	Top 22
DESIGN			
o Economic Requirement for Certainty in Cost, Schedule, and Dependability		VLT*	
o Procurement Regulations	X		X
o Common Sense	N/A	N/A	
o Hierarchical Priorities	X	X	
o Verification of Design (or decision) Integrity		X	X
o Management	X		X
o Planning	X		X
o Data Base	X	X	
o Verification and Qualification of New Technology and Use	X	X	
o Knowledge Base of Licensing Procedures w/Expert Advisor	X	X	X
o Institutional Liabilities, Barriers to change. How do we overcome these?	N/A	N/A	

* Very Long Term

Potential Applications to
Nuclear Power (Con'd)

	Applications of AI		
	Short Term	Long Term	Top 22
FABRICATION			
o Experience feedback and update		X	X
o Illogical fabrication specifications			
o Data Transmittal	X		
o Quality Assurance	X		X
o Cycle Time and Inventory	X		
CONSTRUCTION			
o Logistics	X		X
o Productivity	X		
o Shop vs. Field Fabrication	N/A	N/A	
o Timing and Verification of Accomplishments	N/A	N/A	
STARTUP TESTING			
o Training	X		X
o Personnel Qualification	X		X
o Procedure Generation	X		X

Potential Applications to
Nuclear Power (Cont'd)

	Applications of AI		
	Short Term	Long Term	Top 22
OPERATION			
o Water Chemistry	N/A	N/A	
o Man Machine Integration	X	X	X
o Diagnostics of Component/System	X	X	X
o Crisis Management	X	X	X
o Simulation	X	X	X
o Maintenance and Repair	X		X
o Sensing of plant condition and feedback			X
o Verification of maintenance performance and inspection	X		X
GENERIC ISSUES			
o Data Base	X	X	
o Conflict Resolution		X	
o Procedure Generation	X	X	
o Diagnosis	X	X	
o Symbolic/Numeric Interaction and Manipulation	X	X	

B. Guidelines

1. Identification of Goals and Objectives

Potential DOE contributions in the area of Artificial Intelligence (AI) were identified as: development of Artificial Intelligence and numeric techniques, methods and systems through research and development programs which would be highly supportive of the goals of automation of the next generation of terrestrial and space-based nuclear power systems and plants. This mission was identified as the Strategic Automation Initiative (SAI).
The next generation of nuclear systems will necessarily incorporate the technology developed by current research in the area of VLSI, AI Robotics, Sensors, Supercomputers, Communications, Languages, Standardization, Modularization as well as many other key technologies.

While the area of AI is only a part of the overall Strategic Automation Initiative (SAI), which includes both numeric and symbolic computing technology research, it does have potential for spectacular breakthroughs into areas previously receiving little attention by the nuclear industry.

2. The Selection and Screening Process

Various criteria were identified for the selection of specific automation projects to include in the Strategic Automation Initative reflecting problems in the areas of nuclear systems development and operation including: requirements definition, plant design, fabrication, construction, start-up testing, operations, maintenance, decommissioning, and life extension, as well as generic problems which are applied over multiple areas of the life cycle process. This process is shown in the accompanying Figure IV Systematic Selection Process.
The initial criteria include:

- o Projects which remove known impediments to the achievement of the SAI and overall DOE strategic mission objective in terrestrial and space-based nuclear power systems.
- o Projects which contribute to the development of understanding within the areas of:

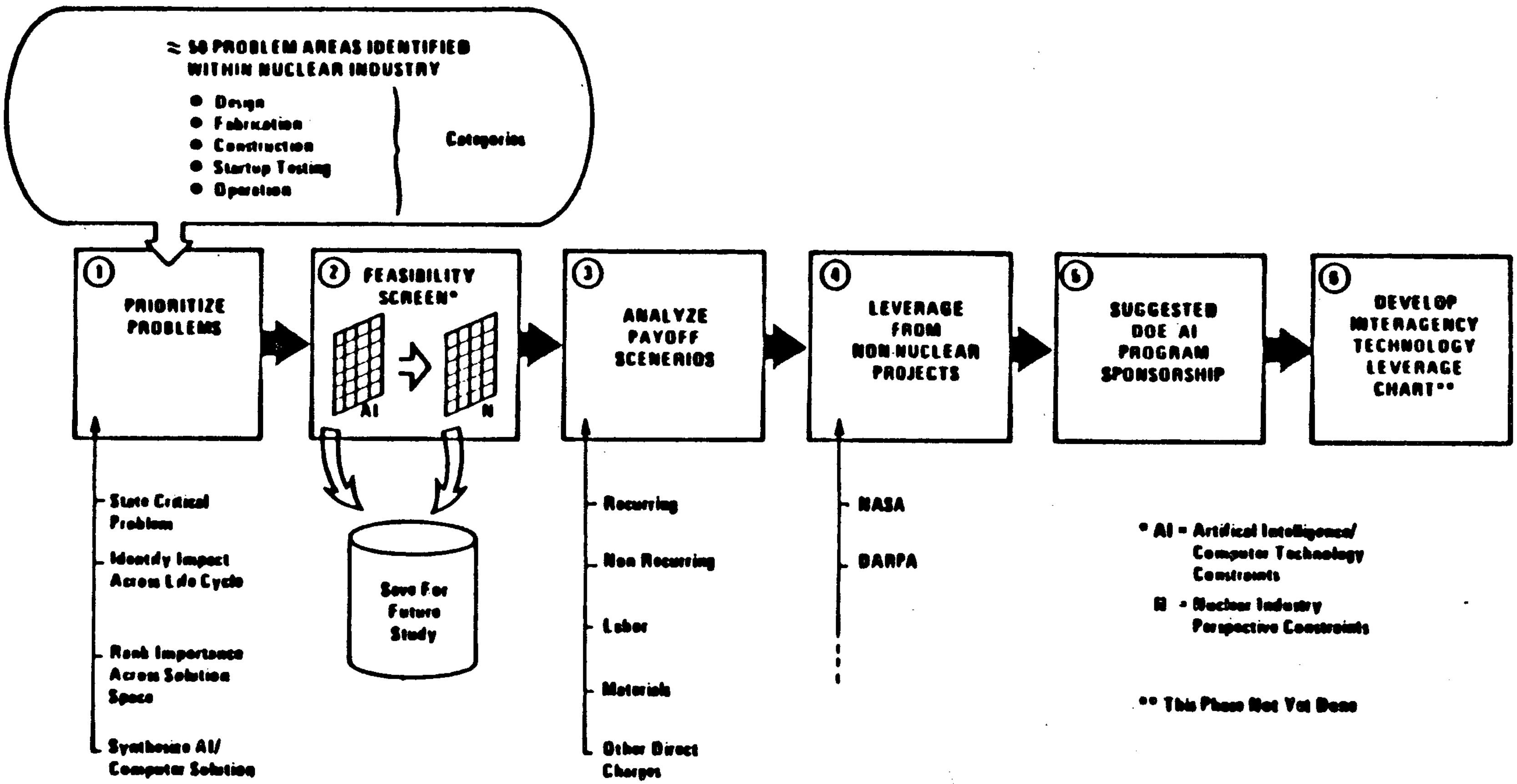


Figure IV Systematic Selection Process

- Intelligent knowledge base management and organization
- Conflict Resolution
- Procedure Generation
- System diagnosis
- Symbolic/Numeric interaction

o Identify projects which have nuclear applicability in both the short and long term.

  - Short term goals should provide meaningful and useful tools to the nuclear industry using currently available technology within a five-year time span.
  - Long term goals should provide a useful benefit to the nuclear industry by incorporation of specific technologies which mature in the AI field over the next ten years.

The systematic methodology utilized to develop the recommendations incorporated in this report included the following key steps:

o Prepare top level problem statements
o Assess long term/short term potential
o Prioritize each problem of significance within the major categories of:

  - Requirements Definition
  - Design
  - Fabrication
  - Construction
  - Start-up Testing
  - Operation
  - Decommissioning
  - Life Extension

o Select a problem from each category which represents the potential for greatest payoff to the nuclear industry and perform the following tasks:

- Identify potential impact of each selected problem across multiple phases (does the problem exist in both design and fabrication, for instance).
- Rank potential importance of selected problems across entire problem space as well as within the selected set of high payoff problems.
- Apply criteria of 1) technical, 2) potential payoff, 3) feasibility, and 4) opportunity to remove technological barriers through use of R&D which would result from breakthroughs in the field of AI and numeric computing, as follows:

  - o Synthesize a potential top-level solution.
  - o Evaluate the potential solution against decision screens constructed from both the AI computing and nuclear impediment perspective.
  - o Determine, analyze, and identify the payoff potential by developing life cycle cost curves and determining the overall impact each problem solution would have on the nuclear industry.
  - o Assess the commonality of R&D projects currently underway in government, industry, and the universities to determine the applicability to similar problems in the nuclear industry.

o Determine the DOE specific contributions required to augment the R&D efforts already underway on projects such as the Strategic Defense Initiative (SDI) and Strategic Computing Initiative (SCI). The combination of leverage and DOE sponsored R&D should be combined to meet the overall Strategic Automation Initiative.

o Develop a technology transfer cost/benefit ratio for each selected problem to assess the relative merits of each project.

3. Classification of Potential Payoff of Artificial Intelligence to the Nuclear Industry

In an attempt to provide a qualitative estimate of the potential payoff of each of the selected SAI projects, the Task Team required the use of a method which provided a quick visualization of the economic impact of AI to the typical life cycle cost unique to a nuclear system or plant as shown on the Figure V "Life Cycle Cost Model." If this figure is further examined in terms of the concept of recurring and non-recurring costs as well as cost breakdowns per phase in terms of labor, material, and other direct costs, several useful observations can be extracted. Similarly useful issues are raised by examination of products, tools, and activities per phase.

a. Background:

- o Current projections for productivity enhancements in software development due to AI are predicted at 2-4 (Boehm) and VLSI improvements by 100-1000.
- o Significant improvements in productivity can lead to a low cost information processing system (either numeric or symbolic) which can be applied to Nuclear Problems.
- o Initial payoffs are available by using expert systems where a considerable knowledge base exists.
- o Computerization in general (no AI) would probably lead to significant cost savings through less than that projected for AI.
- o Symbolic computing systems are still relatively slow for real-time applications.
- o Software costs for automatic systems are not big elements of recurring costs.
- o Software Validation and Verification (V&V) during development and testing will be a big issue on the next generation of automated plants.

As a result of putting the decision to utilize AI in the context of the life cycle curve, the following observations are intuitively obvious (but not rigorously developed):

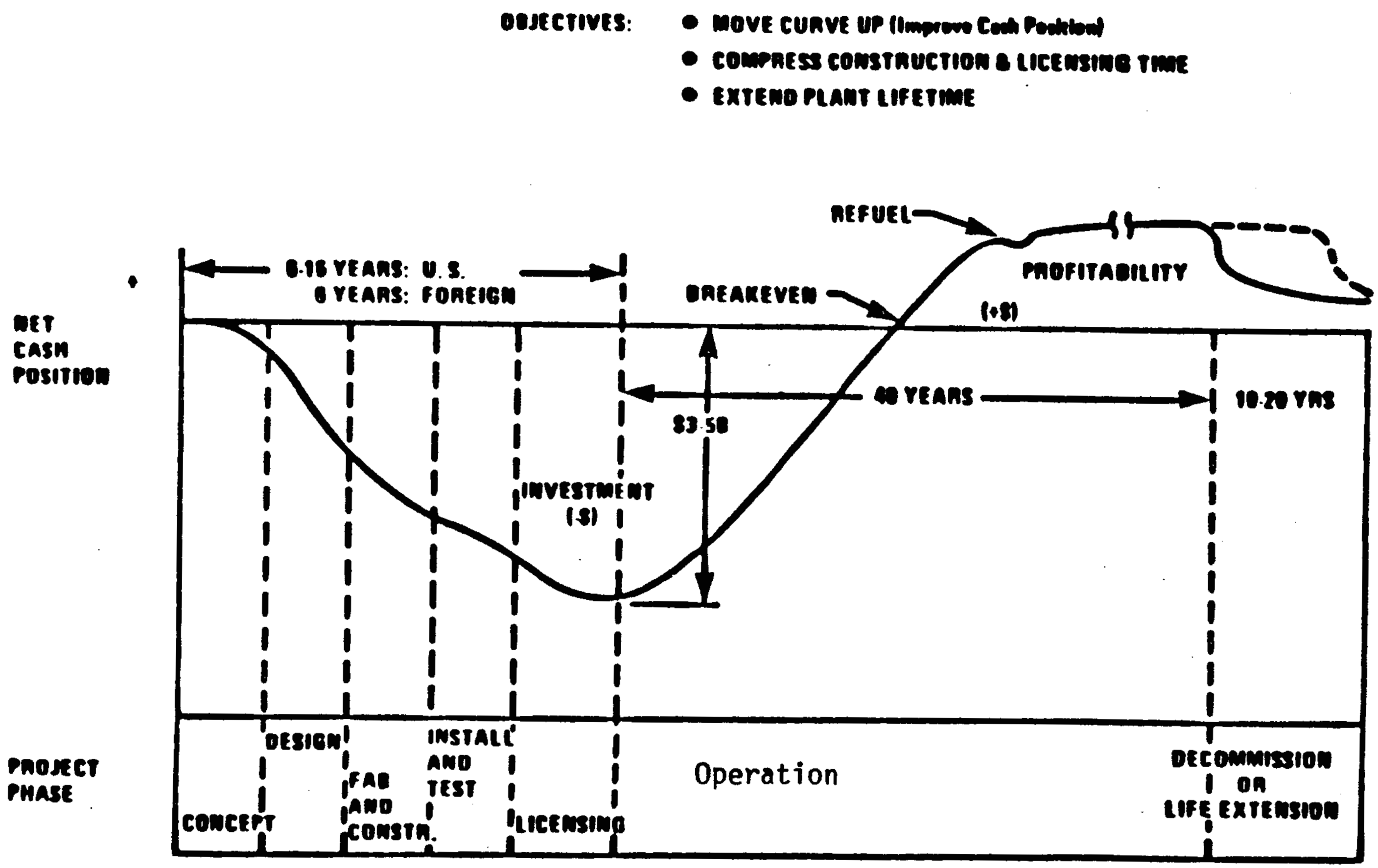


Figure V Life Cycle Cost Model

b. Observations:

- o Large opportunity exists to extend plant life by using low cost information systems.
- o The use of low cost informations systems tend to reduce development cost and reduce development time (time is money).
- o The use of low cost information systems to enhance plant operating performance shifts the breakeven point to the left and increases profitability.
- o The use of information systems in the operation phase through automation will reduce manpower requirements.
- o Major savings across the board are readily achievable by information systems (numeric/symbolic) by reduction of labor.
- o Through use of information systems from the outset as an element of design, potential reductions are possible in design margins re-specification (note: the key is to indicate to the designer that the information system is available as a low cost intelligent processor which is reliable and can, through proper implementation and testing, eliminate the need for over-specification, and conservatism in design).
- o Perhaps an indication of the degree of conservatism, which is built in, becomes apparent when the life extension concept is examined carefully. In other words, is there an advantage in reducing margins, which will certainly affect final wearout, in order to reduce the overnight cost of the nth unit? This becomes particularly important as DOE moves into the modular arena.
- o The new modular designs require the use of automation to reduce operational staff size and allow the goal of a single control room with a reasonably sized staff to be realized.
- o AI techniques would be particularly useful in existing LWR's in the development of operator/maintainer aids and would significantly change the shape of the profitability curve.
- o Use of AI or computer techniques and tools during development should have a significant impact on the overnight cost of the nth unit, since these development costs are typically recovered by the manufacturer and are incorporated into the production cost for each one.

4. Needed Activities

The first table identifies payoff potential and contains the five highest priority work areas, along with a brief description of the areas and the principal justification for their selection. Finally, the potential impact of each work area on improving the integrated life cycle cost is qualitatively sketched.

The integrated Knowledge Base is believed to have a positive effect throughout the life cycle. The Management Decision Support Systems approach would have maximum impact on reducing construction costs principally by reducing construction and licensing time. A major effort to develop a Design Verification and Validation approach would actually cost more early in the life cycle, but this is expected to result in a shorter construction time and considerably enhanced public confidence in the design. The Design Integration thrust would allow the synthesis of new designs, starting from basic project requirements, in a highly efficient fashion. As such, both shorter construction times and extended plant life should result. Finally, the Integrated Plant Automation approach would principally influence the plant capacity factor as well as extending plant life. Both result in substantially improved net cash positions.

In addition to the cost improvements outlined above, incorporating AI techniques will lead to enhanced plant reliability and safety. For instance, a successful Design Verification and Validation effort should markedly improve system reliability. Likewise, the Integrated Plant Automation initiative interacting with the Integrated Knowledge Base will allow early recovery from off-normal plant conditions avoiding accidents which could otherwise result in substantial consequences.

Figure II (Page 14A) identifies the required technologies to support the five high priority work areas as well as the potential impediments to achieving success. The technology areas are categorized according to a recent IEEE Spectrum article (IEEE Spectrum 20(11): 45, November 1983). The impediments are subdivided into technical problems generic to Artificial Intelligence and problems particular to the nuclear industry.

The SAI work areas could be focused on designs such as the innovative LMR designs, modular gas reactor, and key space based nuclear programs such as the SP-100 and possibly the multi-megawatt reactors (which are critical to the overall success of the major mission for NASA and the military community). The new projects envisioned in modular LWR by EPRI and the utilities potentially have the same needs as the SAI. It is appropriate to consider augmenting the current missions of the two DOE reactors, EBR-II and FFTF, to provide real-world testing of the SAI technology packages which are generated, as this will add credibility to the capabilities advertised for the packages developed.

C. Overview of Lessons Learned by the Artificial Intelligence Task Team

AI can contribute to significant cost reductions in the nuclear industry. Organizations represented on the team as well as many of the industries consulted were actively engaged in AI initiatives. However, relatively little work in Artificial Intelligence is currently in use in the nuclear industry. The Department of Energy can facilitate the communication of government agency developments in Artificial Intelligence to the nuclear community. The full promise of AI can only be realized when some of the generic research concerns in the following areas have been resolved:

1. Data base management and organization.
2. Conflict resolution.
3. Procedure generation.
4. System diagnosis.
5. Symbolic and numerical program integration.

Additional areas to be more fully understood have direct applicability to both short- and long-term applications:

- o AI adds cost and potential risk to development programs (relative).
- o Payoff and potential risk increase with the intelligence quotient (IQ)of the application.

- The lowest level IQ is represented by the current shallow expert system applications which represent relatively near term utility to the nuclear industry, including retrofits in the existing LWR industry.

- a mid-level IQ exists for applications such as expert advisors which are represented by relatively unbounded problem domains.

- the highest IQ is required of AI applications which must deal with a large amount of uncertainty. Many AI techniques are under development, but currently do not exist in this area. It is possible that the advent of intelligent knowledge bases will allow automated reasoners to explicitly solve many of the problems that currently appear to be intractable.

o Knowledge bottlenecks represent opportunities to use AI methods and techniques through the ability to leverage existing knowledge more widely and effectively.

o Current knowledge in expert systems and natural language processing is available now. However, the systems are particularly shallow at this time.

o The sheer size of many of the applications in the nuclear industry and the fledgling state of the current technology make it risky to promise near-term payoff on many expert system applications.

o Symbolic computing systems are still relatively fragile for real-time nuclear applications.

o There remains the problem of user acceptance of AI techniques for completely controlling any aspect of the overall nuclear plant life cycle. One way around this problem may be to emphasize near-term AI technology in the form of expert system advisors, i.e., ask the AI system whether a specific course of action is acceptable, rather than requiring the AI system to choose a course. Essentially the same technology is required in either case, but the advisor approach maintains a sense of human control. It has the further advantage of not requiring the AI system to be complete (as would be the case if course selections were mandated).

IV DEVELOPMENTS UNDERWAY AND CONTACTS

A. Team Member and National Laboratory Artificial Intelligence Programs

1. Argonne National Laboratory

Activities in the AI field within ANL are organized under specific people. These people, along with the efforts ongoing under them, are enumerated below. This information was provided by J. Gabriel.

a. Individuals Involved

J. R. Gabriel is currently working on Automated Diagnosticians for Nuclear Plant subsystems, including relay safety interlocks at the EBR-II reactor. Other activities include implementing PROLOG, and identifying work needs to improve productivity in design and manufacture of large, complex facilities.

E. L. Lusk is a principal designer and implementor of Logic Machine Architecture (LMA), a software system for Automated Inferencing. Other activities include implementing PROLOG, portable programming methods for parallel computers, especially inference software, using Automated Inferencing techniques in Nuclear Plant applications, implementing Expert Systems, database theory and design, and coupling of databases to reasoning systems.

R. A. Overbeek played a major role in the development of the architecture of LMA, as well as implementing it. He was a major contributor to the AURA design and implementation, and to the implementation of PROLOG for parallel machines. A co-author with E. L. Lusk on the methods for ensuring software portability in parallel processing environments, he also is an authority on databases.

B. T. Smith was a co-developer with R. A. Overbeek and E. L. Lusk of AURA, an automated reasoning system which has been under development since the 1960's. AURA uses reasoning strategies invented by Overbeek, Wos, and others. Currently, his work involves proof of properties for computer hardware and software with an eventual objective of making unequivocal statements concerning well defined aspects of system reliability.

L. T. Wos has distinguished himself in the field of Automated Reasoning with his invention of various reasoning strategies. Editor-in-Chief of the Journal of Automated Reasoning, his principal concern is with the development and use of new inference strategies for difficult problems. Wos and S. Winker jointly received the American Mathematical Society prize for current achievements in Automated Theorem Proving in January of 1983 for their solution of open problems in pure mathematics and logic using the AURA automated reasoning system.

b. Summary of Automated Reasoning Research & Applications

The Mathematics and Computer Science Division (MCSD) carries out basic research in Automated Inference, and conducts collaborative work with client organizations to help use the results of the research, and help decide how to make work most useful in meeting perceived needs in the Energy and Defense Industries.

Other MCSD responsibilities exist for Software Engineering, Numerical Methods, and Applied Analysis. Of particular concern is the development of methods for numeric and symbolic computation on the next generation of computers - both supercomputers and substantial personal workstations.

Because good software outlasts several generations of computing hardware we almost always have portability between machines of various sizes and architectures as part of any other objectives. It is becoming clear that the rapid development of widely different, very fast computer systems will make system portability almost a prerequisite for software development cost recovery and system reliability over the next half decade or decade.

The EBR-II division in Idaho and the FFTF reactor at Hanford are main clients from inside DOE.

Basic Research in MCSD is funded through the Applied Mathematical Science Program, managed by the Scientific Computing staff of the Office of Energy Research.

Collaborative work is usually begun with funding mainly from basic research. Funding from the client need be only enough to demonstrate serious interest until it becomes clear the work has potential to meet real needs. Once this has been established, the objective becomes to transfer the technology to the client so that work may be finished in a context of knowledge of the problem domain. The client is expected to cover most of the cost of the technology transfer, and the cost of any subsequent help and consultation from MCSD.

Collaborative projects are be selected carefully, for each one must be difficult enough to justify basic research, and yet easy enough to have a chance of success; there are many either too easy or too difficult. In addition, any collaborative venture must meet requirements from management that the project will improve ability to do work in the MCSD domain, and be of use in a significant foreign domain.

c. Present Work in Automated Inference

MCSD is mainly concerned with various means to obtain several orders of magnitude more speed in systems doing deep inference. This is because improvements this large could lead to unforeseen new uses of deep inference, as well as making existing uses more practicable on large problems.

Several methods are being used to gain execution speed. The DENELCOR HEP installed in the Advanced Computing Research Facility at Argonne is being used to determine the possible parallelism present in various kinds of inference problems. The eight processor LEMUR built by High Energy Physics Division with help from MCSD, are being used to investigate portability between two widely different experimental computer architectures. Experiments are also being done using other high performance computers such as the Cray X-MP.

(1) Parallel Processing and SuperComputers

The research on parallel processing and inference depends on use of the Argonne extensions to David Warren's abstract machine for PROLOG implementation. It seems likely that these extensions can be adopted to support resolution based theorem proving. If this turns out to be the case, quite loosely coupled multiprocessor architectures might be the systems of choice in supporting the large numbers of collaborating expert systems probably needed to completely automate most of Nuclear Steam Supply System (NSSS) design and construction. There are good grounds to believe that the Warren abstract machine could also support high performance LISP systems. Because of these things, the ANL Warren machine seems likely to be an important tool for ensuring software portability between different families of high performance computers and across time intervals of the order of a decade.

Another investigation hoped to improve performance of deep inference systems uses new high level strategies like linked inference to postpone decisions about paths in a solution space while the space is being locally explored. This is a "high-level" approach in the same class as weighting and set of support strategies, in that it tries to find the best way to approach a problem without doing too much backtracking. It contrasts with the "brute force" method of developing better hardware and more efficient compilers or interpreters.

(2) The Present State of the Computational Art

As an example of what can be done with the brute force approach, a year ago David Warren listed the Symbolics LISP machine, and C-PROLOG on the VAX 11/780 as typical of the slower commercial systems running about 1.5K Logical Inferences per second. A DEC 2060 running a Warren PROLOG compiler achieved 43K LIPS, an IBM 3033 achieved 27K LIPS.

Today, a year later, the 11/780 achieves 24K LIPS using a Warren system. The ANL experimental portable Warren engine, with some compromises for use on parallel machines, and without the use of methods proprietary to QUINTUS, achieves about 10K LIPS on an 11/780. This could be improved, but such improvements should be the concern of commercial vendors. The Warren/QUINTUS system on a SUN workstation achieves 18K LIPS.

A special purpose machine is expected to be announced soon by NEC having a speed of about 375K LIPS, other manufacturers from Japan are expected to follow in due course, and we are discussing ways to achieve between 200K and 1000K LIPS in a system almost able to fit on a desktop.

(3) Coordinating Multiple Processes

The problem of managing multiple processors in an MIMD (Multiple Instruction Stream, Multiple Data Stream) supercomputer is strongly reminiscent of the task of coordinating the work of several teams of engineers to perform a design. For this reason perhaps, progress on the computing problem may shed light on building expert systems to solve the management problem.

Although it is obviously unreasonable to expect conventional software operating system designs to contribute in this area, workers at Imperial College London have proposed use of languages already used in building Expert Systems as systems programming languages for large parallel computers. Since these languages bring with them built in capabilities for managing relational databases, and for logical inference, it does not seem unreasonable to hope that their use in computing in the next five years will shed helpful light on their use in automated management five years from now.

d. Collaborative Work

(1) Work with EBR-II and C.S. Draper Laboratories

The largest collaboration at present is with the EBRII division in Idaho, and C.S. Draper Laboratories in Boston. Failure of a number of the flowmeters in the primary loop of the EBR-II reactor, and the prospect of more failures, necessitates eventual development of indirect means for measuring sodium flow.

One method being investigated is computation of the flow from measurements of pump motor parameters such as RPM, current, and electrical or mechanical horsepower developed by the alternator driving the pump motor, or by the pump motor itself. Other plant parameters such as differential temperature across the reactor, and various pressures in the primary loop are also measurable.

The problem is to develop a reliable loss of flow trip from this data. To do this multiple sensors and multiple computers are used. However all three or four computers in the system run the same software. Therefore we must prove the software (both application and operating system) have no faults able to conceal a loss of flow, and that hardware failures able to conceal loss of flow have an acceptably small probability.

It turns out that similar questions are of interest to NASA and to EPRI. MCSD has technology able to perform these proofs from listings of the software, and the system build specification for the hardware, subject to certain assumptions about the compiler used to generate the operating system. It appears that adequate statistical data about compiler reliability will be obtainable; the rest of the proofs seem difficult but likely to be possible.

(2) Diagnosing the EBR-II Fuel Handling System

A relay failure in the interlocks for the EBR-II Fuel Unloading Machine (FUM) can take the order of a day and a half for a human expert to diagnose. The fundamental cause of the trouble is need for fairly extensive human inference from system schematics, and experimental data about the malfunction. Moreover, only a few people at EBRII are familiar in detail with the interlock system.

The object of this work is to first develop a machine-readable description of the system schematics simple enough to be entered by unskilled personnel. The system description, once entered, is transformed into a relational database of conditions for actuation of relays, motors, and other movable parts. This database is used to run a simulation of the interlock system. Another part of the diagnostician comprises sensors able to measure the voltage applied to each relay coil and motor.

The inference mechanism is a special purpose theorem prover asserting that for any non-faulted system, the measurements and the simulation must match. Discovery of a denial of this discloses a component where the correct voltage is not applied. This discovery will allow backward reasoning towards the last state where simulation and plant agreed, to provide a list of possible contact failures on relays and switches. This will be printed as a troubleshooting sheet for use by a technician in measuring voltages at various contacts. Once the sheet is filled out, it will be taken back to the computer and the measurements entered. The additional data thus obtained should allow the inference system to determine exactly which relay is at fault.

Of course, it would be easier if sensors could be placed on every coil and on every contact. But since there are about 1000 relays in the system, it seems a reasonable compromise to measure only coil voltages.

It is hoped to transfer a diagnostician for a subsystem of the full interlock system to EBR-II by the end of 1985. This will have been tested against a simulation of the plant. The diagnostician is designed so that it should be usable with other subsystems of the interlocks once descriptions of the other subsystems have been entered.

Errors in data entry, and cases where the plant does not match drawings have been considered, and plans have been made to deal with the resulting problems.

The present situation is that the drawing description language has been defined, and translators from it through intermediate representations to a description interpretable by a simulator have been written. If the simulation is stopped by being advised that a relay coil is not in its expected state,

- the conditions for operation of the coil can be determined.

- Parts of the software are generic in that they might be adapted to automated fault tree analysis on a P&ID, others have specific knowledge of behavior for electromechanical components.

e. Work with HEDL

The transfer of our Automated Reasoning systems to HEDL is largely complete, and at present work is being carried out mainly by personnel from FFTF. However they and we have a mutual interest in databases able to describe large plants. Two draft documents have been written on the subject, one about 18 months old by Colley, Gabriel, Lusk, Overbeek, and Smith; and a second more recently by Colley, Lusk, Overbeek and Smith. Both databases are entity-relationship models, and are related in some ways to the machine readable description of relay logic used in the EBR-II Fuel Unloading Machine Diagnostician.

There is still some disagreement about representations of plants, mainly because the only purpose of a representation is to allow it to be read by software such as an Expert System. A generic plant description such as an E-R model may require extensive domain dependent transformation to make it useful to an Expert System operating in a given domain, or at least that has been the experience with the EBR-II Diagnostician. Thus, although there is consensus about the ability of E-R models to describe arbitrarily complex plants, many questions need to be resolved about how the E-R models are to be used.

f. Collaboration with Industry

The possibility of a joint venture between Motorola, QUINTUS, and ANL MCSD to develop a very high performance PROLOG processor is being explored. A white paper containing a draft proposal has been presented to DARPA.

g. Argonne National Laboratory EBR-II Division

In addition to the AI activities of the Math and Computer Science Division of ANL, work is being performed at EBR-II to apply AI techniques to improve the reliability of operation and control of the EBR-II plant. The areas of both development and application reflect areas of greatest plant need including improving the reliability of fuel-handling, improving primary system flow and temperature monitoring and increasing the reliability of the reactor shutdown system on loss of flow. Because of the benefit to EBR-II and future plants, EBR-II is also serving as a test bed for the concepts developed by others.

(1) The component Configuration Control System (CCCS) project utilizes both classical and Artificial Intelligence (AI) program methodologies for its implementation. Its development has progressed to the point of limited off-line demonstration. The object of the CCS is to enhance operability of the fuel-handling system and reduce operator error. The CCCS is divided into four subtasks: functional impact analysis (FIA), parameter and component state validation (PCSV), alarm prediction and trend analysis (APTA), and administration.

FIA determines the administrative and functional impact caused by proposed changes to components and systems for either operation or maintenance.

Administrative impact is determined from constraints placed on the plant by technical specifications and plant administrative policy. Functional impact is determined from the ability (or lack of aability) of the system to perform a desired task. These impacts are determined automatically using AI methodology.

The PCSV function validates the plant sensor readings (parameters) and the state of the components.

The APTA function informs the operator that an alarm has occurred, predicts that other alarms will occur, and/or analyzes trends to determine anomalies.

Administration functions of the system provide data display, supply physical and functional models, maintain and isolation log, print isolation tags, and perform desired hard copy output.

(2) The Full Authority Fault Tolerant Reactor Control System (FAFTRCS) project has been established to determine the feasibility of using a fault-tolerant microprocessor computer system to provide a redundant flow trip for the Experimental Breeder Reactor-II (EBR-II).

The verification and validation of the fault-tolerant characteristics of the computer hardware and software utilize automated reasoning techniques. This includes the verification and validation of the software, hardware and their interactions. The use of automated reasoning techniques offers the advantage of analytically verifying properties of the hardware and software design. A second advantage is that the assumptions on which the claims are based become explicit in the verification process. It is also expected that the development of these automated techniques will eventually reduce the human intensive effort currently required to perform verification and validation of hardware and software. The computer is being built by C. S. Draper Laboratory, and the software is being developed in a cooperative program between ANL and Illinois Institute of Technology.

The EBR-II reactor is presently being prepared for installation of the computer for testing.

(3) Several enhancements of EBR-II fuel handling are also being incorporated using conventional computer technology in ways that have not normally been used in real-time applications. However, some artificial intelligence applications are to be utilized. Those mentioned in other sections of this document include the testing of DICON, in collaboration with W-AESD, to determine if the knowledge based systems are suitable for plant diagnostic tools and to what extent they can satisfy a safety committee or a licensing group that the knowledge base is sufficient. Another application is the

Diagnostician as reported by the MCSD Division of ANL. Refueling requires a complex array of circuits and relays which tends to complicate troubleshooting when failures occur. The "first principles" approach to the diagnostician should allow questions to be answered that have not been asked: i.e., the system as described to the reasoner should be amenable to correct diagnostics even though the particular failure has not been addressed.

2. Burns and Roe

Burns and Roe has developed and successfully implemented several programs which are based on Artificial Intelligence principles. These programs are based on Burns and Roe expertise in power plant design, construction and operation. This information was provided by P. Fazekas. The following examples provide a cross section of the AI applications at Burns and Roe.

Two of the Burns and Roe programs were developed to increase the accuracy of construction cost estimating, while dramatically reducing the time required for the preparation of the cost estimates. BRAES is an optimized, commodity-oriented, time frame structured cost estimating program which utilizes a sophisticated rule structure to account for the geographic location of the construction sites, and the effect of the climatic variations on the construction scheduling and productivity.

The COALS construction cost estimating program utilizes pattern recognition and statistical inference techniques to provide highly accurate fossil-fired power plant cost estimates from minimal amounts of input data. The COALS program's extensive database is capable of learning from the actual cost data and automatically updates the program's estimating rule library.

COGEN is a parametric modeling program which was developed for semi-automatic selection of an optimum cogeneration system configuration. The program examines key plant parameters, selects preferred cogeneration technology, determines plant performance specifications, and performs economic evaluation to determine cash flow and return on investment data.

The TOPS program is a real-time monitoring and performance evaluation progarm for fossil-fired power generating plants. This expert system program identifies out-of-tolerance conditions, optimizes load change conditions, and calculates the dollar value of the optional plant operator actions. The program also monitors the effect of maintenance actions and optimizes the maintenance schedules.

The BRAES, COALS, and COGEN programs are internal proprietary programs, and TOPS is being marketed for power plant operating utilities.

3. Carnegie Mellon University

CMU is active in all areas of Artificial Intelligence. However, here we will list only some projects from the sub area of expert systems. This information was provided by S. Talukdar.

MOVER is a prototype equipment diagnostician being used with an Automated Mass Transit System. MOVER takes information on system failures reported to the central control computer and combines these with requested status information to determine the fault and to suggest repair procedures. MOVER also is an example of a prototype operational planning system. Once a fault has been determined, it makes suggestions to the operational supervisor to facilitate the timely restoration of service.

CONE is an expert system used in the geotechnical engineering area for the interpretation of cone penometer data. As the cone is pushed into the soil, electrical signals provide raw data about tip resistance, friction, and pore pressure. These data are used by experts to infer the soil stratigraphy and other detailed engineering parameters about each soil level.

HI-RISE is an expert system which acts as an engineer's assistant for the preliminary structural design of high rise buildings. HI-RISE synthesizes feasible structural configurations for a building, performs the preliminary sizing and costing of key structural components, and then presents to the designer the "best" alternative.

SITECHAR is an expert system prototype performing an interpretation task in the geotechnical engineering domain to aid an engineer in inferring subsurface stratigraphy from available bore log data, field and lab test data, and overall site information and characteristics. Due to time limitations, an engineer can explore only a small number of potential inferences. The expert system aids in developing alternative inferences yielding three-dimensional models of site stratigraphy.

DESTINY is an extension of HI-RISE to encompass more building configurations, more design tasks, and to provide a more flexible design process. The system consists of a number of knowledge modules which communicate through a blackboard.

KADBASE (Knowledge Aided Database Management System) is a multiple database manager for knowledge-based structural engineering applications. It provides the capabilities for an integrated system to access a collection of databases, and it addresses the issue of interfacing databases with expert systems. Its overall architecture resembles a networked heterogeneous database management system. The individual databases may be based on different data models (relational, network, hierarchical) and may reside on different host computers. However, KADBASE is not concerned with the issues involved in the physical networking of the databases.

In current applications which combine databases and expert systems, the expert system is tightly coupled to the database in one of two ways: either the expert system has detailed knowledge of the syntax and semantics of the database, or the expert system and database form a combined system. KADBASE is an attempt to provide a flexible interface between expert systems and networks of databases by freeing the expert systems from the requirement that they contain detailed syntactic and semantic database knowledge.

DR. THEVENIN is an application of an expert system in the development of a tutor to aid beginning electrical engineering students to practice and learn the basics of solving electrical circuits.

THE POWER SYSTEM OPERATOR'S ASSISTANT is an expert system intended to diagnose power system failures and to suggest steps to remedy the failure.

WEAVER is a channel/switch-box knowledge-based routing program used in routing on VLSI chips.

ALLADIN is an expert system that uses Artificial Intelligence techniques to design and diagnose metal alloys.

RUBBK is a Rule Based system to be used to facilitate the construction and management of expert systems.

DPS-1 is a programming environment to facilitate the assembly of distributed problem solving systems.

CONPHYDE is a chemical engineering system to select the appropriate analytical program to use to evaluate a design, with respect to its physical properties.

DECADE is a prototype expert system for catalyst selection. From a specified reaction it attempts to propose a set of materials with high probability of being good catalysts for the input reaction.

ISIS is a system written in Schema Representation Language (SRL) for production planning and job-scheduling.

CALLISTO is a system written in SRL for project planning.

PRISM is a general tool for building production systems that are used to build expert systems.

CML is a Cell Management Language to facilitate communications between people and the different kinds of machines that make up manufacturing cells.

Other expert systems developed at CMU include a jet engine diagnostic system and a mobile robot strategy planning and control system.

Several programming languages are available at CMU, and have been used to write some of the expert systems enumerated above. These include:

SRL - A Schema Representation Language that is well-suited to knowledge representaion and to knowledge-based simulation and prescription.

PSRL - Production System using SRL.

OPS5 and OPS83 - Languages for writing rule-based systems. OPS5 is widely available and widely used in the USA. OPS83 is newer and more powerful, but not yet widely available.

4. General Electric

The following information will provide the AI Task Team with a brief overview of the current activities within the General Electric Company (GE) in the area of Artificial Intelligence and related applications in our various operating components. This information was provided by A. D. Alley of General Electric Corporation. GE's work in AI represents a measured response on a very broad front, largely the result of corporate planning which attempts to anticipate technology needs, across the board, which would enable the company to better compete on a world-wide scale. When the technology maturity indications are clearly understood, from a business point of view, simple directives from top GE management release a great deal of engineering innovation directed toward the commercialization of a variety of products and services. At the same time, each operating component has a clear incentive to maintain a technology edge in areas deemed critical to its continued success. As with any new technology, trade-offs must be made between risks due to the fledgling state of the technology and the potential benefits to be realized through its intended use. These types of trade offs have been made within the General Electric Company and prototype systems are under development as well as several systems currently reaching production unit status.

The specific GE infrastructure which supports the current AI activities resides at several locations including:

- Corporate Research and Development (CR&D), Schenectady, New York.
- Electronics Laboratory, Syracuse, New York.
- Industrial Controls Laboratory, Charlottesville, Virginia.
- Microelectronic Center, Research Triangle, North Carolina.
- Space Division, Valley Forge, Pennsylvania.

Most business operations, including Nuclear Energy Business Operation, interact strongly with CR&D in the screening and development of systems which would capture GE expertise and incorporate it in new producs. Some of the current applications include:

- o Diesel--Electric Locomotive Troubleshooting Aid--
  Transportation Systems Business Operation.
- o Troubleshooting Injection
  Molding Processes--Plastics Business Operation
- o F404 Engine Flight Line
  Troubleshooting--Aircraft Engine Business Group
- o Battle Damage Troubleshooting--Aerospace Control Systems Department
- o Special Purpose Symbolic Machine Architecture-
  Electronics Laboratory
- o GENEX System Building Tool --CR&D
- o Gas Turbine Troubleshooting--CR&D/Gas Turbine Department

Although this summary list of applications is by no means exhaustive, or necessarily complete, it does serve to illustrate the breadth of GE's effort to reduce to practice the new AI techniques as they mature into a proven technology.

5. Hanford Engineering Development Laboratory

The Hanford Engineering Development Laboratory (HEDL), operated by the Westinghouse Hanford Company, is the DOE lead laboratory for Man-Machine Integration (MMI) work. The emphasis of the MMI program at the laboratory has been in the development and application of advanced control and computer techniques (including Artificial Intelligence) for the control and operation of Liquid Metal Reactors. Once technologies and methodologies are developed they are applied and tested on the 400 MW Fast Flux Test Facility (FFTF). This is especially useful to the DOE program because this plant represents a prototypic degree of complexity in large liquid metal reactors. A number of highly successful products have been developed at HEDL since the program's inception in 1980. Several of these products are already being used on the FFTF.

Specific Products and Work at HEDL

The MIDAS Master Information and Data Acquisition System was designed and built in 1980/1981. This large computerized database system was developed specifically for the FFTF to aid with the scheduling of maintenance and repairs for the more than 60,000 operating plant components. The system is used by operators and operations engineers to aid them in making decisions relative to specific maintenance and repair work on the plant. MIDAS aids plant operators in tracking and understanding the status of plant components, their functions and their interrelationships. Although this computerized system does not embody artificial intelligence techniques it represents a bold step in the direction of centralization of the plant knowledge into one database. The MIDAS system has been the primary system for control of maintenance work at the FFTF since 1982.

The Procedure Generation System (PGS) developed at HEDL automatically synthesizes procedures for control of nuclear plants during off-normal operating conditions. Rather than being limited to using pre-developed procedures, the PGS is capable of actually snythesizing novel procedures based on the current situation in the plant. Developed in a computer laboratory environment, this system is now being tested on the FFTF Simulator for potential use at FFTF.

An Automated Reasoning Verifier has also been developed at HEDL. This represents an exciting application of the artificial intelligence methodology of automated reasoning that will significantly enhance the reliability of process control systems. The automated reasoning theorem prover software was modified to allow it to observe other software or human actions and form conclusions about the logic of these actions. The automated reasoning theorem prover, or "Verifier", uses as its knowledge base the rules that the other systems must obey in controlling their process. This system is nicknamed "MAL", and has been used to verify the logic and actions of the previously-developed Procedure Generation System.

The concept is relatively simple. Traditional software or human logic that is used to control a process system such as a nuclear reactor has the rules for its operation imbedded in the software coding or in the human's mind, or in written procedures. Although the quality of this information may be very good due to a high-level QA program, there still may be "lurking" errors. The automated reasoning theorem prover represents a completely diverse technology. The rules for the controlled process are not in the coding but are listed in axiomatic language as the code's knowledge base. As the traditional controller is performing its tasks, its conclusions are passed on to the theorem prover which then verifies that, according to its rules, the conclusion is an instance of what the rules allow. It verifies the logic of the traditional controller. If it disagrees with the actions of the traditional controller it can clearly state which rules it feels are being violated. Since the two technologies are so completely different this represents a diverse, redundant checker for the operator to use as an advisor.

An Automated Reasoning Refueling Advisor developed at HEDL has the ability to determine the type and sequence of moves that are necessary to refuel the core of the FFTF. Input consists of the locations of the existing fuel and experiments in the core, and the desired locations of the new fuel and experiment assemblies. Output consists of the moves, in sequence, necessary to get from the old configuration to the new one. This artificial intelligence tool is especially valuable when numerous changes are made in the desired configuration of the core as the time for refueling gets closer. This refueling assistant has been developed and is now being used in a test mode at the FFTF. During actual refueling the system is being used in parallel with the old manual system. The purpose is to evaluate the new system for accuracy and usefulness. The resulting reports will be provided to the designers of advanced plants for their efforts on the operational design of their plants.

An additional methodology involving the design and use of an Integrated Plant Knowledge Base is also under development at HEDL. This work will provide a central repository for all of the knowledge about the plant available from the plant designers and operators. It is essential that this type of system be developed so that the artificial intelligence systems all have access to the same bank of information. Initial efforts have shown that with the use of state-of-the-art software and hardware it is possible to build the knowledge base in such a way that it is directly useable by all of the different functions in the plant such as MIDAS, the Procedure Generation System, the Automated Reasoning Verifier, and the Refueling Advisor.

Facilities at HEDL

The HEDL facilities and equipment in direct support of the programs or artificial intelligence are extensive. They can be divided into the areas of development, testing, and application.

The development of the artificial intelligence methods and applications takes place mainly on a VAX-11/780 and micro computers. The major software for this work consists of ITP (the ANL-developed automated reasoner), PROLOG (the 20k lips Quintas version), expert system software packages for micro computers, and Pascal and other standard software systems. Other computer systems are available by modem dial-up.

The testing of artificial intelligence methods and applications is accomplished either in the development laboratory or on the FFTF Simulator. An MMI testing station has been developed in conjunction with the FFTF Simulator. The test station consists of two SEL computers and graphic display terminals. The SEL computers communicate with both the Simulator computers and with the VAX-11/780 in the development laboratory. The major value of testing the artificial intelligence aids on the simulator lies in the availability of the FFTF operators for testing and evaluation in a realistic environment under a wide range of normal and off-normal situations.

The application of Artificial Intelligence methods is also accomplished at HEDL facilities. The major facility, of course, is the Fast Flux Test Facility (FFTF) itself. This 400-MW liquid-metal cooled fast reactor is an ideal testbed for application of the artificial intelligence methods. It has the flexibility of a research reactor, yet the rigid demands of a production reactor in meeting experiment irradiation requirements. The environment at the plant is typified by the cooperation that is evident in the present application of the new Artificial Intelligence refueling advisor.

6. Oak Ridge National Laboratory

ORNL is presently conducting AI research in the areas of nuclear reactor controls and operation, signal processing, analytical chemistry, robotics, special-purpose computer hardware development, and software enhancement.

The nuclear reactor controls and operation effort is being conducted at the Instrumentation and Controls Division (I&C) and it is focused on ORNL's High Flux Isotope Reactor (HFIR).

The capabilities of rule-based expert systems to interface with and monitor real time processes was first investigated on an analog model to the HFIR using a Digital/Analog Hybrid computing facility. MacLisp primitives developed at the I&C interfaced an OPS5 based expert system to an analog model of the HFIR running in parallel to the digital expert system at 25 times faster than real time.

A phase-1 two-year internally funded effort is now under way for the development of an intelligent expert advisor to the operators of the HFIR itself. Intelligent information display will be integrated with heuristic and numeric simulations to produce a device capable of relieving the operator of routine tasks, monitoring the plant, and interacting with the reactor operator intelligently, i.e., with explanatory justification of the logic behind its actions.

Control of the HFIR without operator intervention will be implemented in successive phases since it requires hardware modifications for which there will not be funding immediately available. This is because there are a very limited number of process signals, and no control signals available to the plant computer. The computer which actually controlled the HFIR automatically through two complete fuel cycles some 17 years ago was removed, including all of the hardware.

In the area of signal and information processing several projects at ONRL funded by the Army and Navy involve the development of specific expert systems. The I&C and Information Divisions are collaborating in two Navy projects, I&C and Engineering Physics (EP) Divisions are working with Analytical Disciplines Inc. of Washington, D.C. on another Navy project.

In the analytical chemistry area two efforts are being funded. One of them involves a private AI consultant and the I&C and Analytical Chemistry (ACh) Divisions. It is internally funded, and it's goal is to develop an expert chemical synthesist by utilizing the knowledge of a prominent expert from the ACh Division. The other effort is being carried out at the ACh Division. It is funded by the Bureau of Printing and Engraving and involves the development of an ink-chemist expert system.

In the robotics area, the I&C and EP Divisions are working on a program funded by the Army and DOE's Basic Energy Sciences centered around the development of autonomous robots.

In the specialized hardware area there is an effort at the I&C Division to build a prototype multiprocessor device with innovative architecture for OPS5-like expert systems implementation. The experimental model is expected to perform 1000 times faster than a Lisp based OPS5 implementation in a VAX-780. An additional 100-fold increase in speed is expected for the final version of the machine. The machine is the invention of J. D. Allen, a consultant to I&C. I&C is engineering both hardware and software. Also, there is an effort at the EP Division that is now oriented towards number crunching but that may eventually be applied to AI. They are acquiring a DADO paralel computer in which they intend to implement and continue with the development of parallel algorithms for mathematical computations.

In the software area, I&C has developed AI interfaces to analog hardware, an enhanced version of OPS5 in FORTH to enable the implementation of expert systems in microprocessor based instrumentations, and has enhanced the Lisp based OPS5 implementations in NIL, MacLisp and ZetaLisp.

The following resources are being used at ORNL for AI research:

At I&C:

- o A two-AD4/KA-10 Hybrid computer, with Fortran, MacLisp, and OPS5.
- o A Lambda Lisp Machine, with ZetaLisp and OPS5.
- o A VAX-780 VMS, with Fortran, NIL, OPS5, Macsyma, and ITP.
- o A PDP-11/44, with Fortran and I&C's Advanced Signal Processing Environment.

At EP:

- o A Lambda Lisp Machine, with ZetaLisp.
- o A VAX-780 UNIX, as MILNET port for ORNL, with FranzLisp, OPS5, and UNSW Prolog.

At ACh:

- o A VAX-750 UNIX, with FranzLisp, OPS5, OPS83, KRL, and MRS.

7. Westinghouse Electric Corporation

Advanced Energy Systems Division

The Westinghouse Advanced Energy Systems Division (WAESD) has also been involved in the DOE Man-Machine Integration program. Information about the Westinghouse contributions to this program as well as other corporate programs were provided by S. J. Walmsley and P. Papas.

The DICON (DIagnostics and CONtrol guidance) system was developed to demonstrate the use of a rule-based expert systems approach in diagnosing the status of a nuclear plant system. This artificial intelligence system was successfully evaluated using a fast reactor Shutdown Heat Removal model which required over 400 rules for its definition. A joint program with the Experimental Breeder Reactor-II (EBR-II) has been set up with the objective of practical evaluation of DICON in a real plant environment. Work is currently underway to develop a model of an EBR-II subsystem. When this is finished, it will be tested and evaluated as a diagnostic tool under operational conditions at EBR-II. Use of the DICON system would allow a plant operator to have consistent, expert advice available during times of plant upset.

A Construction Management Artificial Intelligence Decision Support System (CMAIDSS) is currently under conceptual development at W-AESD. This system will embody the knowledge necessary to manage the construction of a large nuclear power (or other) plant. The main objective of the system will be to provide activities schedules for plant construction which will alleviate problems encountered such as shipping delays, adverse weather, design and construction errors, etc. Because of the numerous problems encountered in any large-scale construction project, this system is expected to be invaluable to the construction industry once it is fully developed.

Research and Development Center

AI research and development at the R&D Center has been in various areas. One of these is in the area of Knowledge Acquisition. In this area, Westinghouse has developed a goal-means representation methodology that has been applied to the development of decision support systems for nuclear power plant control rooms, and for data network control and management centers. The goal-means methodology is used as a means of identifying and organizing the clusters of related information that the decision maker needs to better see the implications of a piece of data. Since the particular configuration of information required depends on the user's intentions or point of view, the methodology is used to define the multiple viewpoints required, and to organize knowledge bases and display systems so that they can dynamically generate multiple views or data relationships to support a variety of user functions. Westinghouse has also developed an extensive knowledge base on power plant operator decision making that has involved a variety of knowledge acquisition techniques ranging from critical incidence analysis of operator performance during actual emergencies, to large scale studies of operator performance during simulated emergencies.

Another example of Westinghouse knowledge acquisition efforts is a study of the locus of problems in avionics diagnosis. Because avionics diagnosis involves multiple decision makers, a study was performed examining the multiple sources of diagnostic anomalies and communication breakdowns. The study included a scenario-based structured interview knowledge acquisition technique that used case descriptions of radar malfunction reports to assess the knowledge and diagnostic strategies of multiple radar technicians. In addition, performance-based protocol analysis techniques have been employed to extract tacit domain knowledge that is not easily verbalized. The knowledge thus obtained has served as the basis for an expert system that employs diagnostic strategies obtained from a domain expert to diagnose malfunctions in a cable converter.

Another area of research at the R&D Center is in the field of Expert Systems. An ongoing project exists to develop a layered expert systems concept. Called a "Multi-Domain Cooperating Expert System," this concept involves the combination of many specialist expert systems under the direction of a managing expert system. The advantage of this concept is that individual pieces of the total system can be developed independently, as long as communication methodologies are established initially.

Steam Turbine-Generator Division

The main thrust of efforts at the Steam Turbine-Generator Division has been to develop a generator diagnostics expert system. This rule-based system works in real time to diagnose the status of turbine generators using sensor data from Nuclear Plants. The system provides confidence levels for its diagnoses, and recommends appropriate remedial actions. It can be used to plan maintenance activities in order to increase plant availability.

B. Artificial Intelligence Work in Industry and Universities

This section of the report, as well as Appendix A, includes information on the work that has been done and is ongoing in various organizations within industry, universities, and national laboratories which are not represented by Task Team members. This is in no way an attempt to detail all work that is ongoing in the AI field, but is rather a summary of efforts within certain organizations that is felt to be representative of the type of work that is going on throughout the country in AI. This will provide a reasonable background from which the status of the AI field in general can be ascertained, and from which information helpful to the development of a plan of continuing work in AI can be obtained.*

This section provides information representative of the current Artificial Intelligence work in industry both within the United States and abroad. The following Table illustrates some of the work in the United States.

Appendix A provides an overview of work on PROLOG in Industry and abroad. University activity in Artificial Intelligence provided in Appendix B. The results of an inquiry into the application of AI by the nuclear utilities appear in Appendix C.

---

* In addition, reference is made to a recent summary by Mark S. Fox, Artificial Intelligence in Mnufacturing: Interium Results of a Survey, Robotics Institute Carnegie-Mellon University, November 6, 1984.

Artificial Intelligence Projects Within Industry

Organization Name	Affiliation Name	Org. Contact, Position	Project Name, Description
AT&T		G. T. Vesonder Supervisor	ACE - Telephone cable trouble expert system.
Control Data Corp.	ADMH		HELP - Medical Diagnostics Expert System
Columbia		D. E. Shaw	parallel processor computer
Comp. Th. Co.	Texas Instru- ments	S. K. Smith President	ADA tutor on Vax 11/780
Digital Equipment Corporation			XSEL - Computer sales aid expert system
Knowledge Research Association	UM & RU	W. R. Baker President	AI/RHEUM - Diagnostic for arthritis expert system.
	National Insti- tute of Health	W. R. Baker President	CLINFO - Data management for clinical
	Univ. of Pittsburgh	W. R. Baker President	CADUCEUS - Diagnostics for Internal Medi
Stanford Research Int'l.		N. J. Nilsson	PROSPECTOR - Mining exploration expert system.
Syntelligence		P. E. Hart President	Expert System for DCMNREL Ins. Cos.
Teknowledge	FSA		Oil exploration expert system.
TRW		E. C. Taylor	BETA - Military analysis expert system
TRW	Univ. of Pitt.	P. H. Winston Supervisor	XSEL - Telephone cable trouble expert system.

1. Tektronix

The Tektronix Corporation is making its first venture into the AI field with a new computer called the Tektronix 4404. This computer is basically a personal workstation with capabilities designed for AI development work. This entry into the market by Tektronix puts them into a very competitive position with respect to other hardware vendors, as this machine is priced at just less than $15K. Other AI machines produced by Symbolics Inc., and Texas Instruments, for example, are in a considerably higher price range.

Some of the capabilities of the machine are:

A. A SMALLTALK-80 programming environment.
B. A 32 BIT microprocessor.
C. 1 MegaByte of RAM memory.
D. An operating system based on Unix.
E. 640 X 480 BIT-mapped display.
F. A three button mouse.
G. A 40 MegaByte hard disk.
H. RS-232C communications interface.
I. ANSI X3.64 terminal emulation capability
J. Availability of Franz Lisp and Prolog programming languages.

Tektronix has committed itself to the development of more advanced AI machines as the field grows, and is expected to continue to provide the industry with competitive products. The Tektronix 4404 is the first of such products, with the large memory and programming environments which are needed in the AI field.

2. Symbolics

Symbolics Inc. was one of the first companies to sell computers designed specifically for efficient operation using the LISP programming language. This language has been the most prevalent language for use in the field of AI for many years because it was developed for the processing of symbols rather than numbers. For this reason, Symbolics has emerged as a leader in the AI hardware market.

The first LISP machines were developed at Massachusettes Institute of Technology. Because the University held the rights to the designs, several of the researchers decided to license them and produce the machines themselves. The first machine sold by the new Symbolics company was called the LM-2, and they sold 50 systems. Since then Symbolics has introduced several new machines including the Symbolics 3600, 3640, and 3670. These machines have been the basis for the success of the company, and are considered to be the most advanced LISP machines available.

The most advanced of the Symbolics machines is the 3670. This machine includes the following capabilities:

A. Networking facilities through Ethernet as well as serial links.
B. Support of VAX/VMS and BSD Unix hosts as alternative file servers.
C. Flavors, and object-oriented programming extension to LISP.
D. An interactive, display-oriented debugging system.
E. A real-time editor which interprets and compiles ZETALISP and other languages.
F. 1100 X 900, BIT-mapped, high resolution monitor with fast imaging and windowing capabilities.
G. A three-button mouse.
H. Up to 30 MegaByte real memory capacity.
I. 474 or 167.5 MegaByte fixed-media disk drive.

Optional capabilities include:

A. 1200/2400 bps modem for high-speed data transmission over telephone lines.
B. FORTRAN 77, InterLISP compatibility package, and MACSYMA software options.
C. Floating-point accelerator.
D. Laser graphics printer with BIT-mapping capabilities.
E. Color graphics.

Although the Symbolics computers are quite expensive, pushing $100K for the basic models and increasing substantially when options are included, they continue to be the machines of choice for LISP program development. This is because of their advanced design, extensive software tool kits for development work, and overall reputation for reliability. Their position in the market is being challenged, however, by the recent entrance of both Tektronix and Texas Instruments into the LISP computer market. These companies have introduced formidable computers into the market bearing price tags substantially below those sported by the Symbolics computers.

3. Texas Instruments

The Texas Instruments (TI) Explorer is the first TI computer designed specifically for the AI field. It is a single-user computer optimized for high-performance symbolic processing. The Explorer is based on the LISP programming language. Many program development tools are available for this machine. They include a Zmacs Editor, LISP Compiler, Debugging facilities, a window-oriented Inspector, and Performance monitoring facilities, as well as others.

The Explorer supports Local Area Networks (LAN) using Ethernet interfacing. This allows for transparent file I/O, remote log-in, and electronic mail within the LAN.

The computer includes the following advanced characteristics:

A. A 32 BIT LISP processor.
B. 2 MegaByte memory expandable to 16 MegaBytes.
C. Fiber optic interface to the monitor, keyboard, mouse, microphone, and headset.
D. 1 MegaByte of BIT-mapped graphics.
E. RS-232 communications interface.
F. 1024 X 808 resolution monitor.
G. Three button mouse.
H. 140 MegaByte Winchester disk available.

TI is not only active in the development of AI hardware, but is also developing various software tools for the AI field. One such tool is the Personal Consultant expert system development tool. This system uses production rules in the LISP language to build its expert systems. It uses the same rule structure as the EMYCIN system developed at Stanford University. Personal Consultant allows for both backward and forward chaining inferencing. Certainty factors can also be used in order to represent uncertain or imprecise data.

4. Electric Power Research Institute High Technology Initiatives

EPRI intends to provide practical near term technology solutions to current nuclear industry problems. All programs have utility involvement and most of the recent programs in AI and Robotics are well documented in the EPRI Journal and the AI workshop proceedings from the AI conference held in 1984. The EPRI high technology efforts are in two areas:

a. Robotics--TMI-2 High Radiation Environment
b. Expert Systems--the EPRI work focuses on three areas:
   - Nuclear Power
   - Electrical Load Management
   - Gas Turbine/Generators

Specifically, two AI applications and several more are described in the EPRI AI conference proceedings:

- Load Management Center--
  Troubleshooting Aids
  CMU/U. of Missouri development contracts
- Gas /Turbine Troubleshooting Aid--
  GE Genex-based product
  GE-CR&D, Schenectady, NY

In addition, EPRI is involved with AI work in MMI supported by Honeywell.

5. LTV Aerospace

LTV Aerospace feels that the development and implementation of computer-based knowledge systems is an essential central technology for the long range industrial modernization. Progress was made before in the process part, now they will attack the thought portion.

LTV is investigating applications in the areas of design, manufacturing, and support. Specifically, they are investigating the process planning area within manufacturing support.

They also have a requirement to apply a system on the shop floor that duplicates the heuristics of a person looking at a 2D drawing from a graphics data base and transforming it into a 3D model.

6. Lockheed

Lockheed has had a rule-based process planning system since 1979 called "GEN-PLAN." It is proprietary to Lockheed.

Lockheed is now looking at the preplanning (or Advanced Manufacturing Engineering) area. It will be an aid at the interface between engineering and manufacturing, that is, deciding on the method of manufacturing at the time of the design. This is an aid, not a replacement of the individual, and will serve a variety of functions including a checklist that is a set of "if-then" rules that lead to a method of manufacturing.

The second area of work is at the requirements planning level, where a reconciliation takes place of the product structure and quantities as a new model is released.

Similar work is taking place throughout Lockheed.

7. Utilities

A survey of applications of Artificial Intelligence by the nuclear utilities was performed by Burns & Roe and is provided in Appendix C.

8. NASA

NASA is very active in AI work and development of AI systems. Ames Research Center (ARC) at Moffit Field in California acts as an R&D center for the various space centers, and has a very large section devoted to AI R&D. The space centers then apply the concepts and products created at ARC. NASA may be interested in a technical interface with DOE to provide for technology transfer.

ARC is standardizing its AI work around Symbolics computers. NASA had a conceptual studies contract with Symbolics, and is providing financial support to them in order to keep them competitive in what is becoming highly competitive AI computer market. This is because at present the Symbolics hardware is felt to be the best available for AI work, although the processing architecture used is at present rather sensitive to environmental disturbances.

Robotics and AI technologies will both increase their productivity and make the proposed Space Station economically affordable. The computer hardware developed for the Space Station will probably be one of a kind, however the software will be designed to be more generic. It will be designed so that it can be used for other purposes and so that spin-offs into various areas will be possible. NASA will report to Congress on the success of this generic software effort. The push towards generic software comes as a result of a general software development productivity problem. Software development is often very time consuming and expensive, and it is felt to be very much in the national interest to solve this problem.

NASA AI technology will have a big impact on the design process at the component and system levels, and that it will be the major contributor to solving the satellite servicing problem. AI in conjunction with CAD/CAM technologies will be used for development of a satellite servicing system.

A library of AI Based subroutines for aircraft design has recently been developed at NASA. It is still under testing and validation, and is not expected to be ready for use in the light aircraft program for another two years. Before it can be used the issue of liability will have to be addressed.

To maintain and expand their expertise in the AI field, NASA has an apprenticeship program with universities and the space centers. Students of Computer Science or Electrical Engineering with experience in PASCAL programming are the preferred candidates for these positions.

Standardization is a very big issue at NASA because of its proved cost benefits. Research in the field of AI alone at NASA is funded at a level of about $20-25 million, with applicatons areas funded at even higher levels. Therefore considerable cost savings and productivity improvements can be realized using standardized programming languages, hardware, and generic software packages. Current software costs at NASA are about $1K per line broken down as shown below:

10% planning
40% engineering
20% productivity
30% coding

Knowledge and data acquisition are the most important contributors to these costs.

In pursuit of the goal of programming language standardization NASA is going to use the Department of Defense (DOD) ADA language for numerical processing, and they are looking at Common LISP and a possible standard symbolic processing language. NASA is willing to work with DOE to develop a standard symbolic language.

All future NASA conceptual designs will include an integral computer to take advantage of the benefits of the available advanced computer technologies.

APPENDIX A

Work on PROLOG in Industry and Abroad

The Japanese 5th Generation Project

There are two projects in Japan, sometimes confused with each other, the first is the "Fifth Generation", or ICOT, which is an R&D project with a staff of 50 people, supported by seven major manufacturers. Its' purpose is to improve productivity in areas largely untouched by the last thirty years of computer development. Examples commonly cited are teaching, engineering design, and the non-data processing aspects of government. It was decided early in the project to use PROLOG.

Work done by this group is shared by all the manufacturers. It seems to be entirely basic research, new ideas from the ICOT group are taken back to the factories and developed further into marketable products in a competitive way. Another interesting thing about ICOT is that each supporting manufacturer has a few people attached to ICOT but not on the staff whose only responsiility is to communicate basic research back to product R&D.

When the Fifth Generation project was begun, collaboration from both Europe and America was invited and declined.

The Japanese "Superspeed" project (this has sometimes been called the "Sixth Generation" by U.S. commentators) is to develop supercomputers in the CRAY class or better. This is essentially closed to non-participants. It also has strong links to the Fifth Generation project.

The UK and the Alvey Directorate

As a response to the work in Japan, the UK ministry of Technology formed an advisory body whose report is entitled "The Alvey Directorate." This may be purchased from HMSO and is the UK charter for R&D in information technology. English work on AI emphasizes PROLOG more than LISP, although there are very active LISP groups. There is at least one PROLOG/LISP hybrid.

The U.S. and MCC

MCC is a consortium funded by various computer manufacturers and contracts with DOD. Its' mission has components from both the Japanese Fifth and Sixth Generation charters, but larger efforts such as VHSIC also seem to have independent funding. There is a DARPA document setting out a charter for many of these efforts. MCC has only recently become at all interested in PROLOG.

QUINTUS

The major U.S. supplier of PROLOG software is QUINTUS, there are a few others with less satisfactory products. It is thought that a new product called PROLOG II from Oxford Expert Systems will have close to QUINTUS performance, but on VAX VMS, not VAX UNIX.

QUINTUS is a company in Palo Alto with about 20 employees. The technical leader of the group is David Warren, who developed the outstandingly successful Edinburgh DEC10 PROLOG of 1975-79. Most of the other technical staff are from Edinburgh, among them are: Fernando Pereira, possibly David Bowen, Lawrence Byrd, and Richard O'Keefe.

Syracuse University

Syracuse is one of a consortium of five institutions who joined together in providing expertise in AI. Ken Bowen, the leader of the consortium is also a collaborator with ANL.

University of New Hampshire

An interpreter supporting syntax said to be the same as DEC10 is available from Professor James Weiner. The cost is $300 for a single machine license. It is rather slow even compared to C-PROLOG on the VAX.

University of New South Wales

There is a UNSW PROLOG distributed in the U.S. for the IBM PC at a cost of $125. At one time the source was more nearly in the public domain, and a version was written for Data General (DG) computers.

Digital Equipment Corporation (DEC)

There is a PROLOG development effort on going at DEC. Little information is currently available on this effort.

IBM Corporation

The IBM R&D on PROLOG is led by Douglas de Groot. It has been suggested that the IBM effort is larger than that of the Japanese ICOT R&D center (The Fifth Generation).

It seems to be firm company policy to discourage any speculation about products being developed, so little information is available regarding their activities.

Edinburgh

Donald Michie is thought to still be at Edinburgh part of the time. Alec Rae is a representative on the Alvey governing body, and Tim Lindholm reports to Rae. There is a strong applications oriented group led by Alan Bundy, and as already noted the PROLOG development group is undergoing major change.

Imperial College London

ICL has a group of about 30 people working on PROLOG, parallel machines, and the relations between them. Three names known in the PROLOG community are Steve Gregory, K. L. Clark, and F. G. McCabe. Technical leadership descends from R. Kowalski, one of the original inventors with Alain Colmerauer of the original PROLOG concept in 1972. The current administrative leader is J. D. Ennals who was active in the successful effort to introduce use of PROLOG into the UK grade schools and high schools between 1978 and 1982. It seems likely that the ICL parallel dialect - PARALOG is a good language for systems programming on MIMD Machines.

Israel

Ehud Shapiro of the Weizmann Institute is the leader of the Israeli national effort, which centers on parallel computing and use of PROLOG. Shapiro also has a parallel dialect, but there are technical difficulties over certain issues in unification.

University of Waterloo, Ontario

M. H. van Emden is the leader of the Waterloo work. One of those early in the field, he is associted with Kowalski, Bruynhooghe, and Colmerauer. The Waterloo PROLOG is the only generally available version for IBM equipment. It is descended from an M. S. project of late 1978.

The Catholic University of Louvain

Work here is led by M. Bruynhooghe, the author of a second PROLOG interpreter. Copies of a later version in PASCAL have been circulated, but a licensing agreement is necessary for their use.

University of Marseilles

The first PROLOG interpreter was written at Marseilles by Alain Colmerauer after a sabbatical at Edinburgh where the idea of executing a subset of first order predicate calculus was discussed with Robert Kowalski. Colmerauer's interest was in translation of natural language. Their guess about a good language for doing this has been largely confirmed. PROLOG is a good language for writing knowledge transformations in general and natural language in particular.

APPENDIX B

SURVEY OF UNIVERSITY ACTIVITY IN ARTIFICIAL INTELLIGENCE

General Comments: This survey is not to be taken as the final word as to what is happening in the AI arena at any particular university. The reason is that it is difficult to find one person who can direct you to all the people who may be doing somthing in the AI field.

Clemson: There is an effort going on to combine functional and logic programming with the idea of combining the merits of both to help solve problems. In addition, a Command Control and Communications expert system is being worked on for the DOD headed by Jim Leathram. There is also some beginning work knowledge based systems for control under the direction of Bill Lewis.

Florida Atlantic: Most of the work being done here is proprietary in nature. There is work in the use of AI in the design of VLSI circuits, operating systems for computers, and some work in robotics and redundancy of control for robots.

University of Maryland: AI work here is mostly in the area of mission perception through visual input for robots. There is some beginning work in AI expert systems. Contact Dr. Chia-Hong Lee.

University of Tennessee: There are two projects in AI at this university: 1. An expert system being developed with/for Oak Ridge which is to assist in the design of control systems. It uses Prolog as the language of choice for the reasoner. The system is designed so that conventional math routines such as control algorithms can be invoked as part of the system. The university contact is Robert Cockett. 2. A system using image processing and integrating sensor data to study ocean currents etc. is being developed for the U.S. Navy.

University of Wisconsin (Madison): Several AI projects are being pursued including computervision, theorem proving, deduction, expert systems and databases, and natural language understanding and knowledge representation. Those involved are Charles Dyer, Len Uhr, and Roland Chin in the computervision area, Ken Kunen in theorem proving, Larry Travis in deduction, expert systems and databases. Greg Oden, Robin Cooper and Sheldon Klein in natural language and knowledge representation.

<u>Colorado State University</u>: Projects being pursued include: 1. Theorem proving using parallel algorithms with Rasiah Loganantharaj as the principal, 2. Formal derivation of logic programs from higher order logic specifications with Robert Mueller and Joseph Barghese, 3. Knowledge based methods in retargetable microcode methods with Robert Muller, Joseph Barghese, Michael Duda and Vicki Alan, and 4. Use of systolic arrays in signal process and pattern recognition with Jacek Walicki.

<u>University of California Berkeley</u>: Projects include natural language, knowledge representation, story understanding, and planning.

Rensselaer Polytechnic Institute

Currently, RPI funding in this area is well over $1M annually and spins several departments and centers.

Developments in base technology include fuzzy set theory and expert systems. Furthermore, the development of data sets for use in fault tree analysis, and development of tools for integration planning and evaluation, has been and is currently being undertaken. The integration of diagnostic systems based on fuzzy set theory with operational modules for instance from nuclear power plants is being undertaken for on-line diagnosis and control of such systems as nuclear steam generators. The development of intelligent control systems and robotics is being actively pursued for integration and manufacturing in both nuclear and non-nuclear environments.

APPENDIX C

THE APPLICATION OF ARTIFICIAL INTELLIGENCE BY THE NUCLEAR UTILITIES

In an effort to evaluate the extent to which Artificial Intelligence (AI) is being applied by the nuclear industry, inquiries were made with nuclear representative utilities in the United States.

In order to establish some consistency of response, persons at the vice presidential level were contacted since they would have the best overview of work in progress within the utility company. The names of the utilities and individuals contacted are listed in the attached table.

The inquiry included the following questions:

1. Are you aware of or up-to-date on the latest developments in artificial intelligence?

2. Is your utility pursuing any artificial intelligence developments on its own?

3. Would your utility be interested in participating in any joint efforts with othe utilities and/or the Department of Energy on artificial intelligence or developing artificial intelligence tools?

4. If so, which of the following areas would be of most interest to you?

   a. Operation of Power Plants
   b. Construction and Design - Management Control
   c. Database Management

Based on responses from 21 utilities we found that six of these individuals were quite knowledgeable on the subject of AI; eight were only familiar with the subject while another seven professed to have no knowledge of the matter at all. Five utilities reported that they were working on artificial intelligence (AI) applications in some limited manner. In all circumstances this work was in support of plant operations.

Interest in working with others on the subject of AI was expressed by only five utilities. Four others indicated they might have an interest, but were extremely cautious or noncommittal about it.

Those that indicated a preference of the three fields of study strongly favored plant operations (10). Four expressed an interest in database management while only one indicated any interest at all in construction and design control. This latter point was not surprising in that most contacts expressed skepticism concerning future nuclear construction and recognized that any AI development could not be accomplished in time to assist ongoing construction.

UNITED STATES NUCLEAR UTILITIES

UTILITY	CONTACT NAME
Northeast:	
Baltimore Gas & Electric Co.	C. H. Poindexter
Boston Edison Co.	A. L. Oxsen
Connecticut Yankee Atomic Power Co.	J. F. Opeka
Consolidated Edison Co.	Charles Jackson
Duquesne Light Co.	J. J. Carey
GPU Nuclear Corporation	R. D. Bright
Long Island Lighting Co.	J. D. Leonard, Jr.
Maine Yankee Atomic Power Co.	Mat Hunter
New Hampshire Yankee, Inc.	George S. Thomas
New York Power Authority	J. P. Bayne
Niagara Mohawk Power Corp.	T. E. Lempges
Northeast Utilities	J. F. Opeka
Pennsylvania Power & Light Co.	Bruce D. Kenyon
Philadelphia Electric Co.	V. S. Boyer
Public Service Electric & Gas Co.	Corbin A. McNeill, Jr.
Rochester Gas & Electric Co.	R. W. Kober
Vermont Nuclear Power Corp.	W. P. Murphy
Yankee Atomic Electric Co.	L. H. Heider
Midwest:	
Cleveland Electric Illinois	M. R. Edleman
Commonwealth Edison Company	Louis DelGeorge
Consumer Power Co.	Jim Taylor
Dairyland Power Corporation	J. Leifer
Detroit Edison Co.	W. H. Jens
Illinois Power Co.	William Gerstner

UTILITY	CONTACT NAME
Midwest: (Cont'd)	
Indiana & Michigan Electric Co.	Robert Hering
Iowa Electric Light & Power Co.	Dundesna Longer
Kansas Gas & Electric Co.	G. L. Koester
Nebraska Public Power District	Robert E. Wilbur
Northern States Power Co.	Larson
Omaha Public Power District	R. L. Andrews
Toledo Edison Co.	R. P. Crouse
Union Electric Co.	D. F. Schnell
Wisconsin Electric Power Co.	C. W. Fay
Wisconsin Public Service Corp.	C. W. Giesler
South:	
Alabama Power & Light Co.	R. P. McDonald
Arkansas Power & Light Co.	D. R. Sikes
Carolina Power & Light Co.	A. B. Cutter
Duke Power Co.	H. B. Tucker
Florida Power & Light Co.	C. O. Wood
Florida Power Corp.	W. J. Wilgus
Georgia Power Co.	J. T. Beckham
Gulf States Utilities Co.	J. G. Weigand
Louisiana Powe & Light Co.	R. S. Leddick
Mississippi Power & Light Co.	Oliver Kingsley
South Carolina Elec. & Gas Co.	O. W. Dixon
TVA	J. P. Darling
Virginia Electric & Power Co.	W. L. Stewark

UTILITY	CONTACT NAME
Southwest:	
Texas Utilities Generating Co.	B. R. Clements
Houston Lighting & Power Co.	J. G. DeWease
Arizona Public Service Co.	E. E. Van Brunt
West & Northwest	
Washington Public Power Supply Sys.	Alex Squire
Sacramento Municipal Utilities	R. J. Rodriquez
Portland General Electric Co.	B. D. Withers
Pacific Gas & Electric	James Shiffer
Public Service Co. of Colorado	Oscar Lee

*U.S. GOVERNMENT PRINTING OFFICE: 1986- 491-177:50012