CONF-9009110--2

CONF-9009110--2

DE90 012174

PROGRESS ON DEVELOPING EXPERT SYSTEMS IN WASTE MANAGEMENT AND DISPOSAL

Angel L. Rivera
Juan J. Ferrada
Chemical Technology Division, Oak Ridge National Laboratory*

Submitted for Presentation at the
1990 Combined ANS Power Division Topical Meeting and ASME Nuclear Engineering Conference
September 16-20, 1990, Newport, Rhode Island

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

"The submitted manuscript has been authored by a contractor of the U.S. Government under contract No. DE-AC05-84OR21400. Accordingly, the U.S. Government retains a nonexclusive, royalty-free license to publish or reproduce the published form of this contribution, or allow others to do so, for U.S. Government purposes."

*Research sponsored by the Office of Defense Waste and Transportation Management, Defense Programs, U.S. Department of Energy, under contract DE-AC05-84OR21400 with Martin Marietta Energy Systems, Inc.

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DISCLAIMER

Portions of this document may be illegible in electronic image products. Images are produced from the best available original document.

PROGRESS ON DEVELOPING EXPERT SYSTEMS
IN WASTE MANAGEMENT AND DISPOSAL

Angel L. Rivera
Juan J. Ferrada

Chemical Technology Division, Oak Ridge National Laboratory*

ABSTRACT

The concept of artificial intelligence (AI) represents a challenging opportunity in expanding the potential benefits from computer technology in waste management and disposal. The potential of this concept lies in facilitating the development of intelligent computer systems to help analysts, decision makers, and operators in waste and technology problem solving similar to the way that machines support the laborer. Because the knowledge of multiple human experts is an essential input in the many aspects of waste management and disposal, there are numerous opportunities for the development of expert systems using software products from AI. The spectrum of opportunities for expert systems development ranges from identification of waste and technology research needs to real-time control of waste management and disposal operations.

This paper presents systems analysis as an attractive framework for the development of intelligent computer systems of significance to waste management and disposal, and it provides an overview of limited prototype systems and the commercially available software used during prototype development activities.

INTRODUCTION

The development and operation of waste management and disposal systems for radioactive, chemical, and mixed waste are becoming increasingly complex problems in decision making. The complexity results from trends toward increasing emphasis on minimization of contaminant releases in gaseous and liquid effluents, increasing requirements for accountability to maintain and demonstrate operation within regulatory compliance, and the increasing reliability requirements for processes and waste forms. The reliability of waste forms is needed to (1) ensure the protection of groundwater quality in waste disposal in addition to the more conventional approach of source-to-receptor pathway limits, and (2) minimize the need for remedial actions from disposal system failures. Furthermore, these two objectives shall be accomplished cost effectively and in compliance with applicable safety, health, quality, technical, operational, and regulatory requirements.

There are several strategies to meet these requirements, but they are limited by waste elimination or minimization at the source and the development of integrated engineered systems. Waste minimization is viewed as a reduction in the amount of the contaminant (radionuclide, metals, organics, etc.) and the waste matrix (sludge, scrap metal, soil, etc.). Engineered systems are characterized by a high technology content, and they consider performance, cost, and reliability in the selection of waste technologies to manage waste from generation to disposal. The technology selection criteria include compliance with waste disposal requirements, production of secondary waste streams, costs, and the explicit treatment of uncertainties and risks. This technology management process provides the framework for establishing the set of defensible needs for real-life demonstrations of those technologies with a high potential for successful performance to provide additional data for decision making.

Information about management of hazardous and low-level radioactive wastes has been deposited in data bases, text files, and other types of computer programs. More often than not, managers are faced with the necessity to retrieve a subset of this information to make a decision. How to integrate the diverse nature of required data represents a very challenging problem for busy managers who expect fast answers to questions.

As shown in Fig. 1, successful disposition of any waste depends on teamwork, including decision makers, regulators, and technical experts. To support this concept of teamwork, there is a need for integration of existing and new information in many forms, such as data, knowledge, and expertise. This information will be integrated both horizontally (scope) and vertically (depth). This ability to integrate information is a salient feature of expert systems.

AI tools present one of the most appropriate computer methods to establish the integration of available knowledge in one environment. The development of expert systems will allow the user to interact with the knowledge in a direct and simple manner. AI offers an interesting spectrum of computational tools to serve the needs of software engineers and computer programmers in developing computer

*Operated by Martin Marietta Energy Systems, Inc., for the U.S. Department of Energy under contract DE-AC05-84OR21400.

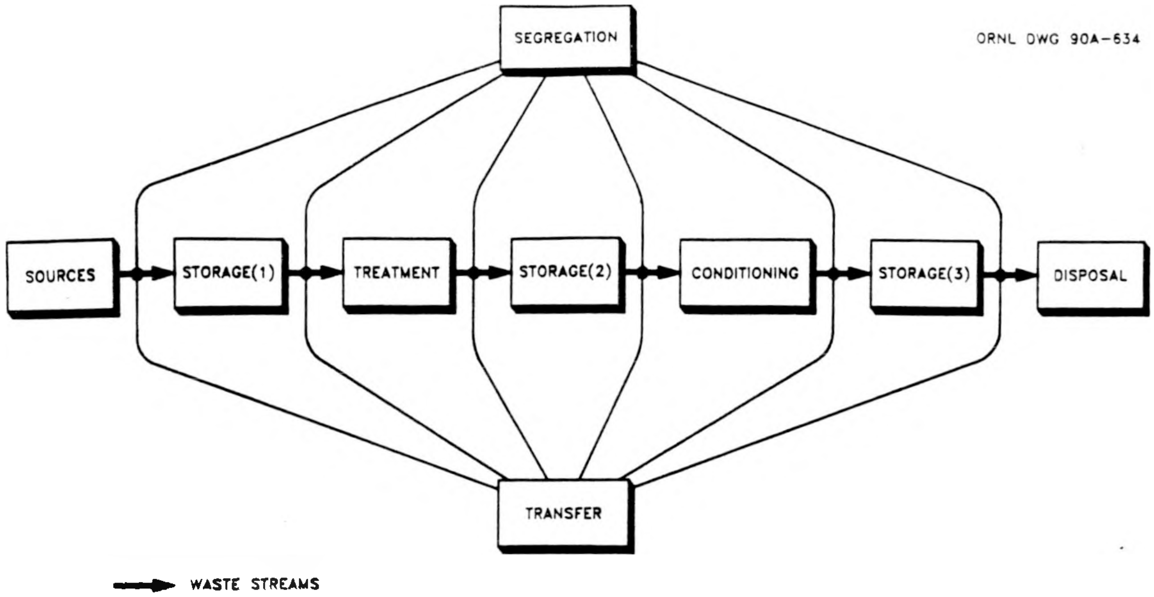

Fig. 1. Functional areas of waste systems.

systems in support of management and engineering. These tools include the use of commercially available products known as expert shells, AI computer languages, and neural networks.

One of the most popular applications of AI is the development of expert systems. AI techniques, correctly applied, make possible the development of an expert system to represent and manipulate knowledge at the same level as a human expert. Expert systems emulate human expertise by applying the techniques of logical inference to a knowledge base. Thus, an expert system consists of a knowledge base containing all the information about a specific problem, an inference mechanism that performs reasoning that will normally refer to a set of rules for using the knowledge to resolve a given situation, and a user interface that accesses the information to produce solutions.

As shown in Fig. 2, the development of intelligent computer systems or expert systems for waste management and disposal applications must consider the following general requirements for information integration during the system design phase:

1. Integrate existing relevant information in the form of data and knowledge. The data can be generated from experimental and operational activities at different scales of technology, from bench scale to full operational scale. These data can be interpreted, and the knowledge acquired can be applied in future uses. Conceptual models and specialized computer codes already available can be used as cost-effective generators of estimates during problem-solving activities.

2. Design and develop software to facilitate the access to this information resource by users with a wide spectrum of needs and backgrounds.

3. Augment this information resource by the identification of specialized areas of human expertise needed as value added to the computer system, and acquire this knowledge from the known human experts in each area of specialization. Develop conceptual models of the expertise and computerize the conceptual model software packages. This expertise could be accessed in specific waste management and disposal applications.

4. Maintain this information resource by adding new data, new interpretations, new conceptual models, new experiences and lessons, and newly refined technical expertise.

DEVELOPING EXPERT SYSTEMS - A DESIGN APPROACH

The mission of intelligent computer systems is to provide (and sometimes execute) relevant and reliable information structured in a timely and cost-effective manner. Systems analysis is a very useful framework for the development of specialized intelligent computer

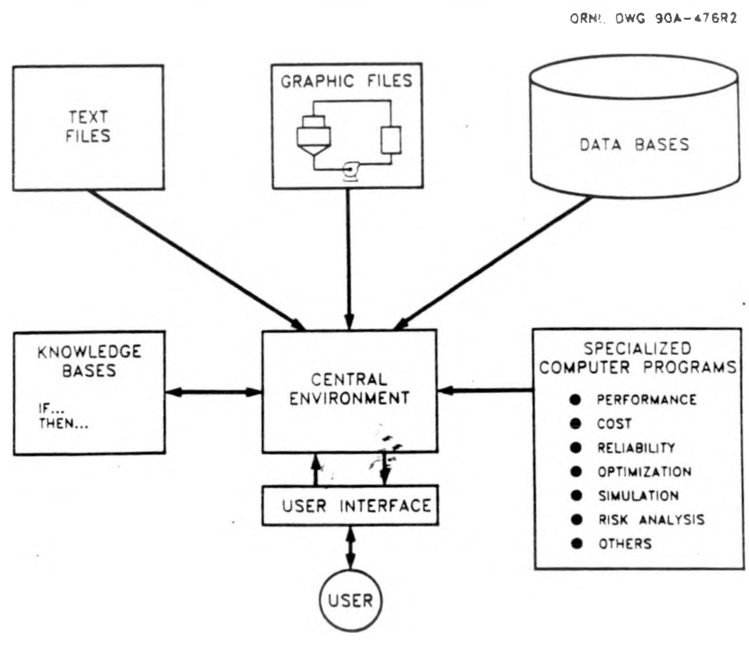

Fig. 2. A salient feature of expert systems is information integration.

systems. A brief overview of systems analysis considerations in artificial intelligence/expert systems technology applications has been presented previously.[1]

Systems analysis is a research strategy, a perspective in the proper use of the available tools, a practical philosophy on how best to support a decision maker with complex problems of choice under uncertainty. An operational definition of systems analysis, very useful in expert systems design, has been offered by Quade and Boucher:[2]

> **"A systematic approach to helping a decisionmaker choose a course of action by investigating his full problem, searching out objectives and alternatives, and comparing them in the light of their consequences, using an appropriate framework - in so far as possible analytic - to bring expert judgment and intuition to bear on the problem."**

Waste management and disposal decisions are predominantly decisions under uncertainty and risk. One of the salient features of systems analysis is the explicit treatment of uncertainties and risks. Information to be provided by intelligent systems falls into a spectrum of decision situations as shown in Fig. 3. This spectrum is characterized by three limiting decision-making situations.

Decision making under certainty - decision situation in which we can identify with certainty which controllable event will apply.

Decision making under risk - we do not know with certainty which of the uncontrollable events will result, but we can attach likelihoods or probabilities of occurrence to each event.

Decision making under uncertainty - when we cannot provide such probabilities, although we can identify the uncontrollable events; the future may be so uncertain that we are unable to estimate with any confidence the likelihood of the uncontrollable events.

ORNL DWG 89A-668R

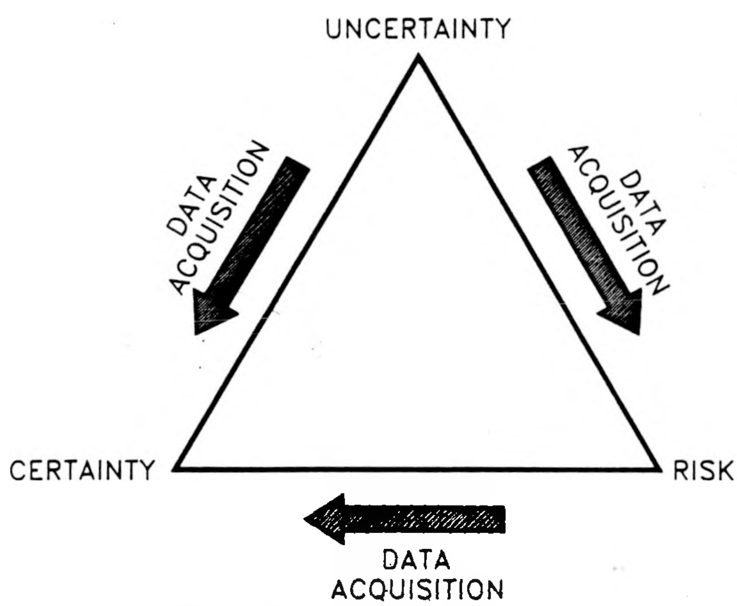

Fig. 3. Three decisionmaking situations.

Experimental, or data acquisition, activities such as research, development, and demonstrations are used to acquire data and knowledge for uncertainty reduction and risk estimation. Systems analysis can be used as a guide for experimental work by explicitly identifying the uncertainties to be addressed by this work. Data and knowledge acquisition will facilitate the evaluation of risks through risk analysis and the development of risk management programs for monitoring and control during decision implementation.

In the design of knowledge-based systems, systems analysis establishes the framework for knowledge acquisition and formulates the algorithm that allows for the manipulation and creation of knowledge. AI products provide programmers with a set of tools that allows the manipulation and retrieval of knowledge that has previously been created. It may include a knowledge set that establishes a decision-making procedure.

A SUMMARY OF PROTOTYPE SOFTWARE DEVELOPMENT OF RELEVANCE TO WASTE SYSTEMS

Applications of AI tools to chemical processes have increased slowly but steadily in recent years as more practical AI tools have become commercially available. Expert systems have been built for controlling plant operations in real time,[3] for process simulation using object-oriented programming,[4] for fault detection and process diagnosis,[5] for a waste treatment process advisory system,[6] etc. Other applications include the process design of an offshore oil- and gas-production system,[7] and the planning of a multistep synthesis of hazardous wastes to useful materials.[8]

Limited prototype software development and expert system design efforts have been conducted at the Chemical Technology Division of Oak Ridge National Laboratory. These prototypes have been motivated by the efforts of the Low-Level Waste Disposal Development and Demonstration (LLWDDD) Program. This program formulated a disposal strategy for the disposal of solid low-level waste (LLW) into LLWDDD disposal classes known as classes I, II, III, and IV. The framework for the management and disposal of solid LLW under the new strategy is shown in Fig. 4 as a subset of Fig. 1. Some examples of expert system prototypes are now presented.

The first prototype application is the use of a natural language interface for data base queries.[9] A multiplant data base on solid LLW

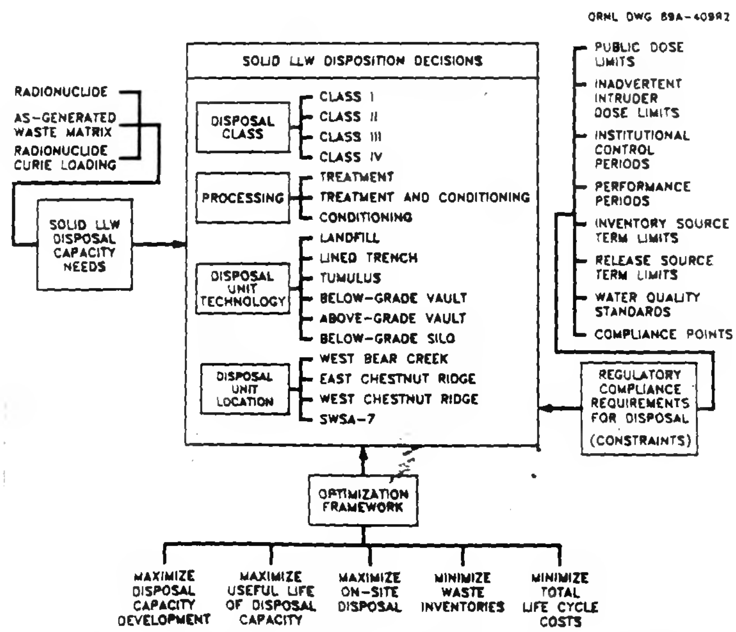

Fig. 4. A systems analysis framework for waste technology applications.

generation and disposition was developed as part of strategic planning activities for the LLWDDD Program. The data base provided for a very detailed and comprehensive characterization of solid LLW on a container-by-container basis. Each container of solid LLW was characterized in terms of the radionuclide and radionuclide concentration. These data were used to segregate the waste into the newly developed LLWDDD disposal classes. The segregation was accomplished on the computer using the concentration of each radionuclide in the waste container, a waste segregation code, and a preliminary set of concentration limits for solid LLW disposal by LLWDDD class. A second code was developed to segregate solid LLW using the classification scheme used by the Nuclear Regulatory Commission (NRC). Under the NRC scheme, solid LLW was segregated as classes A, B, C, and greater than class C. Each LLWDDD disposal class was based on a required level of confinement, disposal technology, and costs. For example, Class I disposal is characterized by low-activity solid LLW disposed in a landfill. Class II requires confinement through engineered barriers during the institutional control period, or until the radionuclide inventory at the disposal unit is depleted by radioactive decay. To facilitate the development of estimates for program planning, the LLWDDD data base was equipped with a natural language interface, which was developed as an alternative to the conventional menu-driven interface for preparing on-line flexible reports from the LLWDDD data base. Examples of the types of reports produced included disposal capacity needs projections by LLWDDD disposal classes under a different set of radionuclide concentration limits resulting from different dose limits, institutional control periods, disposal unit technology, and disposal site. The natural language interface allows for data base queries using English language to query the data base. For example:

"Give me a list of contact-handled solid LLW streams by container" and "give me a distribution of volume by container for streams that are candidates for Class II disposal"

A second prototype under development, also related to Fig. 4, is an expert system for waste processing technology selection. Selection of treatment processes for waste streams is an important problem in waste management. Treatment selection is based on several considerations. For the waste stream, relevant physical, chemical, and possibly radiological characteristics must be considered, as well as the potential environmental effects. Cost and performance must also be weighed for the treatment processes themselves. Some of these considerations are best represented and handled numerically. Others, however, include many points of judgment used by the expert, and these are difficult to quantify numerically. A limited prototype of such application is under development in the Chemical Technology Division at the Oak Ridge National Laboratory. The domain for this expert system spans treatment processes for low-level radioactive waste.

A commercially available expert shell that matched all the design requirements was chosen for the development. In this case, the choice of a shell over an AI programming language was logical because it resulted in shorter development time for the prototype, without loss of features. The chosen expert shell works in a graphic environment. This fact can be important in that it provides a visual aid in understanding the reasoning mechanism. Also, the expert system design was easily adapted to the shell's rule-based, if-then structure representation. For the case illustrated in Fig. 5, the following technology selection criteria are applied:

if waste type is trash
and process is extensively used,
then process applicable is compaction.

This states that if the waste type is classified as trash and the status of the desired process is extensively used, the recommended waste treatment process is compaction. The decision criteria for technology selection provides more emphasis to technology that has been demonstrated as illustrated by the process extensively used. Alternative criteria can be developed to identify innovative applications. Compared with other representational approaches, a rule-based approach generally permits a clearer understanding of the knowledge base. The knowledge base for the prototype was developed using information derived from several reports on low-level radioactive waste management. The final knowledge base will include information derived from several experts in the field. The data base includes the University of California-Davis scheme for classifying low-level radioactive waste.[10] The prototype includes modules related to equipment design, operational cost, and capital cost estimation. The result is that an expert program can combine data bases of information about waste stream characteristics and treatment processes with expert knowledge about treatment selection, design and cost estimation calculations, illuminating graphics, and helpful text in one application. Because it has factual information, calculational power, and interfacing resources, this expert system is a tool that is efficient, effective, and easy to use.

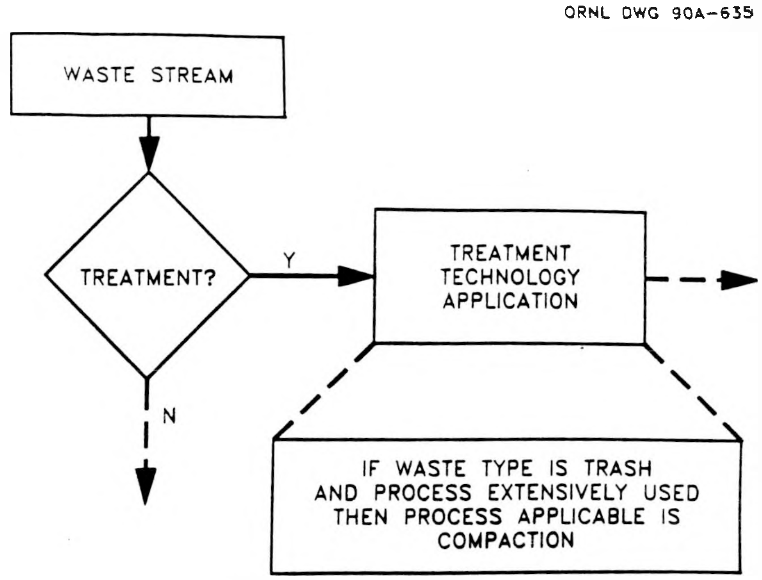

Fig. 5. A simplified element of a decision network for waste technology applications.

Expert systems can be built using either an expert shell or an AI computer language. The expert shell is a tool that provides a substantial amount of AI programming code, including an inference engine that has been tested, debugged, and maintained. The inference engine will match the information given by the user with the rules stored in the knowledge base, and it will develop an appropriate answer. The expert shell will load and consult different knowledge bases and apply the same rules of inference to solve a variety of problems. Building the expert system using an AI language provides greater flexibility than an expert shell would in addressing specific aspects of a problem. However, a considerable amount of code still has to be written.

Expert systems are best used to apply a fixed set of logical rules and related facts to a specific domain problem.[5] Expert systems have been less successful in applications that require the processing of raw sensory data in a way that is flexible and robust enough to deal with the real, unpredictable world.

There are many areas of waste management processes, such as fault detection and diagnosis, process control, process design, and process simulation, that could benefit from systems that adapt to and learn from raw process data. An emerging computer discipline, variously termed as neural networking, parallel distributed processing, connectionism, adaptive systems, or neurocomputing, seems to be promising for organizing and detecting patterns from unpredictable and/or imprecise inputs.

The neural network is composed of many simple processing elements that typically do little more than take a weighted sum of all its inputs. The neural network does not execute a series of instructions; it simply responds, in parallel, to the various inputs that are presented. The result is not stored in a specific memory location but consists of the overall state of the network after it has reached some equilibrium conditions. Knowledge is stored according to the way the processing elements are connected (i.e., the way in which the output signal of a processing element is connected to the input signals of many other processing elements) and according to the importance or weighting value of each input to the processing elements. Knowledge is more a function of the network's architecture or structure than it is a function of the contents of a particular location.

The mathematics involved above, although not highly complicated, may represent an initial programming hurdle for the novice in this field. Fortunately, commercial software packages are available. Most of the packages have no complicated systems generation or higher-level programming requirements. For those with more experience in neural networks, packages that allow one to build networks without the programming complications are available; however, they do require knowledge of the way in which the different learning rules interact with their respective parameters. In any event, commercial packages permit the knowledgeable engineer to concentrate on the problem and to determine how neural technology can be applied to solve it, rather than concentrating on the mechanics of the network.

An example of a prototype neural network application in support of Fig. 4 is the forecast of the monthly volume of low-level radioactive waste collected at the Oak Ridge National Laboratory. The actual monthly waste was known for the previous 28-month period. The system was used to forecast the waste volume for the following 12-month period. The system learned by entering the six known months and forecasting the seventh month, which was also known. The process was repeated until the 28th month. To forecast the 29th month, the system received months 23 through 28. The results of this application were compared with those given by a conventional statistical package. The results of a neural network prediction were always better than the moving average regression applied to the data.

A second example of prototype neural network application is the prediction of particle size of radioactive material from a spray drier, as shown in Fig. 6. Traditionally, the operation parameters of the spray drier are set according to previous experiences — the pressure, temperature, nozzle size, raw material, etc. Once the material has been dried, it is taken to the laboratory where the particle size is analyzed. If the material does not meet the requirements of particle size, it is returned to the plant for reprocessing. The analysis period may take several days and the outcome may not be satisfactory.

Information about previous experiences has been kept in files. This information was fed to a neural network, which can learn from it and is capable of predicting the resulting particle size for a given set of operating conditions. Initial studies with this prototype have shown that the neural network predicted the particle size within a ± 15% error. Research is under way to provide the neural network with additional operational data to predict the particle size more accurately. Once the neural network is certified for predicting particle size as a function of process characteristics, it will be enhanced with expert systems software to provide for process optimization and control. Considerable savings in time and resources can be obtained with this technology once the system is completed.

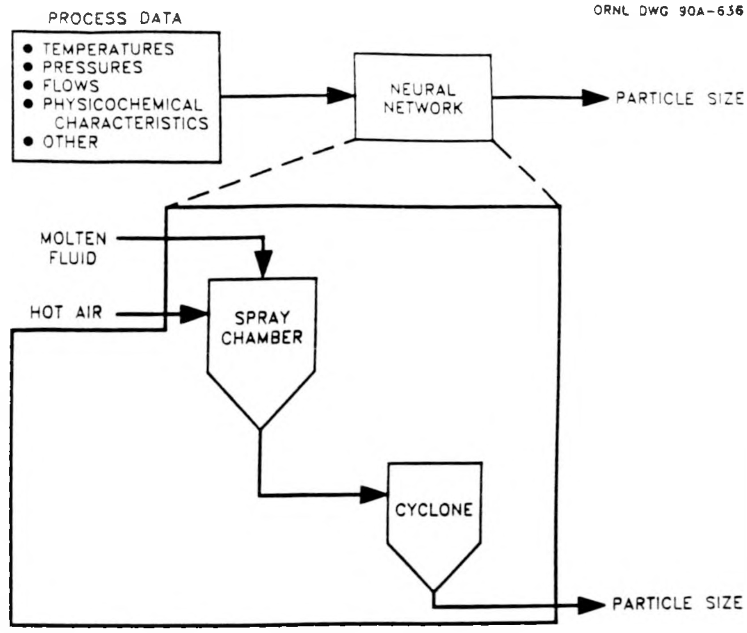

Fig. 6. Neural networks have the capability of developing systems analysis models.

Neural network software presents a few limitations compared with the conventional expert systems software. Applications of neural networks will give short answers as results to the problems and will not expand on other problem aspects. The network will not access other data bases and combine with other external procedures as easily as the conventional expert systems, and tracing of reasoning is not possible with neural networks.

The design of expert systems or intelligent systems using systems analysis provides for the creation of hybrid systems that realize the advantages of both neural networks and conventional expert systems software. Hybrid systems that will involve both types of AI tools are beginning to appear more frequently in engineering.

FUTURE PROSPECTS OF AI PRODUCTS IN WASTE SYSTEMS DEVELOPMENT AND MANAGEMENT APPLICATIONS

The expansion of AI into engineering is not surprising. With today's specialization, experts are rare and expensive, yet their knowledge is in great demand. Use of expert systems is frequently a good way to capture expertise and distribute it. Also, in solving many problems, computer speed would be beneficial, but computers cannot be used because they lack the reasoning capabilities that seem to elude conventional programming applications.

Work with neural networks has already begun, and some of the general uses are signal clean-up, pattern encoding and decoding, behavior predictions, mechanical controls, pattern and character recognition, speech synthesis, and optimization.

Neural networks are beginning to find engineering applications in industry. For example, AT&T has developed a neural network chip that processes each video frame by dividing the picture into easily encoded blocks of patterns. NASA is teaching robots to pick up randomly placed objects using neural networks. Normally, a robot requires that an object always be exactly oriented to fit its grippers before it can pick it up. The neural network estimates the angular difference in orientation between the object and itself. The robot uses this information to swivel its arms into the proper orientation with respect to the object. The basic idea is also being developed to help space shuttles dock with space stations. At the New York University Medical Center, researchers use tensor theory with neural networks to race through calculations that make robot limbs move with unprecedented grace, dextery, and speed. Conventional computers perform the complex calculations for arm/leg control too slowly to coordinate many simultaneous motions. And an improved military underwater listening system, developed by General Dynamics, identifies different types of ships, boats, and submarines by their engine sounds.[11]

Other examples include operation analysis from batch data in which performance and operational characteristics of the reactor can be analyzed by comparing its actual behavior with known data. These known data can represent a good basis for troubleshooting when the reactor is not performing adequately. Known data from different batch operations are used for the learning process of the system. After the system has learned, the user can classify new cases by entering input data. The system will respond with an analysis of the operations that may suggest which parameters the operator should change on the next batch. Some neural network packages allow the user to work as if it were a conventional expert system, for example, in the application of a neural network to an activated sludge troubleshooting guide for sanitary waste treatment system. A network was set up to identify a potential problem with the treatment system. A binary network was selected because the data used to classify each case do not take on certain numerical values but require a "yes" or "no" answer. The two inputs are the appearance of the clarifier and the settling test results, and the output lists possible problems within the system. In this case, the neural network acts as an adviser for the operator. The neural network provides a diagnosis of the situation, and the operator can determine the changes that need to be made to improve the performance of the operation.

A new initiative is under way for the development of an enterprise model for a mixed waste incineration system. This enterprise model will support management of the incinerator by providing planning, scheduling, and process control capabilities. The software package resulting from this effort will be an expert system.

CONCLUDING REMARKS

The AI concept presents a challenging opportunity in expanding the potential benefits from computer technology in waste management and disposal. The concept potential lies in facilitating the development of intelligent computer systems to help analysts, decisionmakers, and operators in waste and technology problem solving much the way that machines support the laborer. Because the knowledge of multiple human experts is an essential input in the many aspects of waste management and disposal, there are numerous opportunities for the applications of expert systems, a product from AI. The spectrum of opportunities for expert systems applications ranges from identification of waste and technology research needs to real-time control of waste management and disposal operations. In the field of waste management and disposal, both waste and technology management decisionmaking depend on teamwork and the effective integration of multiple areas of expertise. This need provides the opportunity for the application of cost-effective expert systems designed and developed within a systems analysis framework.

Intelligent computer systems could also be developed, with the support of human experts, to increase the contribution of computer technology to the advancement of the science and engineering of waste management and disposal, particularly the strategic management of the scientific and technological aspects. With the current trend of technology programs in waste management to be implemented as cooperative efforts among industry, national laboratories, and universities, expert systems can be used as an effective mechanism for integrating the information needed and developed by the projects under this umbrella of technology cooperation.

This paper presents systems analysis as an attractive framework for the development of intelligent computer systems of significance to waste management and disposal and provides an overview of limited prototype systems and the commercially available software used during prototype development activities.

REFERENCES

1. Rivera, A. L., "Systems Analysis Considerations in Artificial Intelligent/Experts Systems Technology Applications," presented at the Summer National Meeting of the American Institute of Chemical Engineers, Philadelphia, PA, August 23, 1989.

2. Quade, E. S. and Boucher, W. I., eds., "Systems Analysis and Policy Planning - Applications in Defense," North-Holland, Amsterdam, 1968, p. 14-17.

3. Bassler, E. J., "Expert Systems for Control of Plant Operations in Real Time," presented at the Spring Meeting of the American Institute of Chemical Engineers, New Orleans, LA, March 1988.

4. Robinson, J. T. and Otaduy, P. J., "An Application of Object Oriented Programming to Process Simulation" presented at the Summer National Meeting of American Institute of Chemical Engineers, Denver, CO, August 1988.

5. Hoskins, J. C. and Himmelblau, D. M., "Neural Network Models of Knowledge Representation in Process Engineering," Computers and Chemical Engineering, Vol. 12, No. 9/10, 1980, p. 881-890.

6. Ferrada, J. J. and Rodgers, B. R., "Applications of Expert Systems to Hazardous and Radioactive Waste Management," DOE Model Conference, Oak Ridge, TN, October 1988.

7. Montgomery, IV, J. and Amlani, A., "The Use of Expert Systems in Process Design of Offshore Oil and Gas Production Systems," presented at the Annual Meeting American Institute of Chemical Engineers, Denver, CO, August 1988.

8. Thiese, E. W. and Allen, J. D., "The Expert System for Chemistry: Planning Multistep Synthesis and Conversion of Polimeric or Hazardous Chemical Wastes to Useful Materials," New York, November 1987.

9. Osborne-Lee, I. W. and Rodgers, B. R., "A Natural Language Interface to Relational Database for Waste Management," presented at the Summer National Meeting of American Institute of Chemical Engineers, Denver, CO, August 1988 .

10. Jolley, R. L., et al., "Low-Level Radioactive Waste from Commercial Nuclear Reactors," ORNL/TM-9846/V2, Oak Ridge National Laboratory, Oak Ridge, TN, 1986.

11. Stanley, J., Introduction to Neural Network, California Scientific Software, CA, 1989.