Journal of the Korean Nuclear Society
Volume 25, Number 1, March 1993

Development of a Prototype Expert System for Intelligent Operation Aids in Rod Consolidation Process

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(Received February 8, 1991)

핵연료 밀집공정의 지능적 조업을 위한 전문가시스템 모형의 개발

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(1991. 2. 8 접수)

Abstract

This paper describes a prototype expert system to aid operation in rod consolidation process. The knowledgebase is composed of three database groups and 60 rules with production, and object oriented techniques that correlates database groups. The expert system is designed to track the transitions of nuclear materials through the operation areas of the rod consolidation process, to diagnose current status in any operating conditions, normal and off-normal, and to advise operators to properly recover off-normality. The expert system can give efficient management of nuclear material accountability and process operation in the rod consolidation.

요 약

핵연료 밀집공정의 조업을 보조하는 전문가시스템 모형을 개발하였다. 시스템의 지식기반은 3개의 데이타베이스와 60개의 규칙을 객체지향 방법에 의해 설계되었다. 본 전문가시스템은 핵연료 밀집시설의 물질계량관리 영역에서 핵물질의 이동 상황을 추적하여 체계적으로 데이타베이스화하고, 정상 및 비정상조업 조건하에서 현 운전상황을 진단하며, 비정상 조업상황을 적절히 회복할 수 있게 조업자에게 필요한 정보를 제공하여, 효과적으로 핵연료 밀집시설의 공정조업을 이룰 수 있도록 하였다.

1. Introduction

Spent fuels discharged from nuclear reactors are highly radioactive and require intensive care. An active mechanism in the accounting of spent fuels is important in the rod consolidation which is to extract spent fuel rods from a spent fuel assembly. Material accountability system should be carried out properly in any operating conditions. In the rod consolidation process, operation concerning spent fuels handling should be made in remote manner. Equipments are contained in hot cells, and operators are in clean area. They are interconnected through manipulators, robots, automation, etc. Remoteness adds complexity to operation, equipment design, and maintenance that may be trivial in usual contact operations. Remote operation involves potentially high risk of off-normal operation. Off-normal operation may eventually result in accident. Efficient diagnosis of failure in off-normal operation and recommendation of corrective action to operators is an optimal way to recover process. Combination of material accountability and diagnosis of off-normal operation can improve safeguardability and operability of rod consolidation process. [1,2] Off-normal operations usually cannot be described quantitatively. They involve qualitative modeling of fuel assembly conditions, operators mistakes, equipment failures, etc. This complex situation is considered to be good for the use of expert system.

2. Expert System

The expert system which is a branch of artificial intelligence, is a computer based problem solving technique. It has received wide attention in the last decade due to rapid growth in computer hardware and software technologies that have accelerated implementation of expert systems. It has been applied in such diverse fields as medicine, science, engineering, finance, et al. [3] In nuclear industries, the possibility that expert system techniques could be useful was realized only a few years ago [4]. However many exploratory research and development activities have been initiated and are under progress in many countries.

The power of an expert system derives from the knowledge it possesses, not from the particular formalism and inference schemes it has [5]. Most of expert systems are not built from scratch, which is very time consuming and may need a group of computer programmers with deep knowledge in LISP or Prolog. Recent advance in expert system development tools eases the applicants to configure own expert systems without extensive knowledge in programming. About 100 of knowledge engineering tools are commercially available. In this study, Nexpert Object is chosen due to its hybrid knowledge representation, speed, and open architecture [6].

3. Rod Consolidation

Rod consolidation is an advanced technique to minimize storage space of spent fuels that dissociates spent fuel and non fuel bearing component (NFBC) from spent fuel assemblies. Many researches are being carried out in several countries, however, none are in a practical stage. A reference rod consolidation system is designed to receive, extract, and store spent fuels, based on

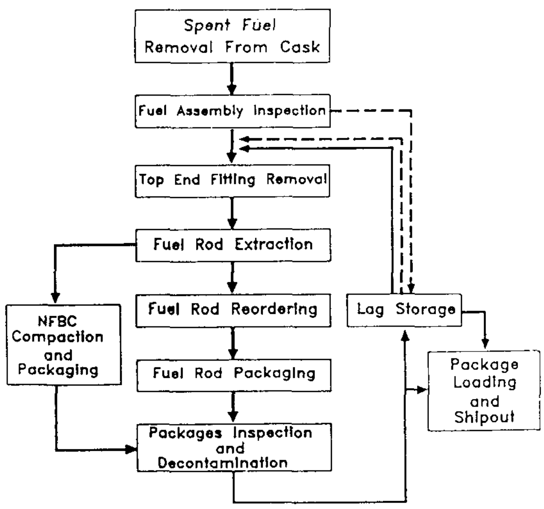

Fig. 1. Simplified Flow Diagram of Rod Consolidation

conceptual design of the KAERI(Korea Atomic Energy Research Institute) project [7].

Figure 1 Shows a Simplified Flow Diagram of the Rod Consolidation Process. A truck with a shipment of cask arrives at the receiving area of hot cell. The spent fuel assembly which is removed from a cask is inspected and identified against its history record through CCTV at the inspection stand. The inspected assembly is transferred to the lag storage. The lag storage provides necessary storage space for incoming spent fuel assemblies consolidated fuel canister, NFBC canister, and testing of the intact fuel assemblies. The fuel assembly out of the lag storage is horizontally placed by downender on the fuel clamping table to support and to position the fuel assembly for the nozzle removal and the rod extraction. The fuel clamping table accurately positions the fuel assembly to align with the nozzle removal system. Once top nozzle is removed, the clamping table positions the fuel assembly to align with the rod extraction system for automatic engagement. The rod extraction system is to remove an entire row of fuel rods for one fuel assembly at a time and to support the rods until collected by the rod reordering system. The spent fuel assembly is being clamped and positioned by the fuel clamping table during the rod extraction operations. The rod extraction system grips an entire row of fuel rods, completely withdraws them from the fuel assembly and deposits them on the fuel rod support rails. In case if a fuel rod is seized and cannot be extracted from the fuel assembly, the rod extraction system is switched from automatic operation mode to off–normal operation mode. Rod gripper in the pull head is released by using electromechanical manipulator. Special tools are used to free the rod and extraction operation is resumed. The rod reordering system removes the fuel rods from the rod extraction system, collects the rods in a tight row and separates the rods into a predetermined number, and delivers the rods to the slipsheet mechanism. The canister loading system receives the fuels rods from rod the reordering system and consolidates the fuel rods and loads them into a fuel canister with identification number.

The NFBC compactor reduces volume of NFBC that remains after extraction of the fuels from a spent fuel assembly and to load the compacted volume into a NFBC canister with identification number. The NFBC compactor provides volume reduction ratio of 5 : 1. The canister upender translates fuel and NFBC canisters from horizontal to vertical position. The canister welder assembly closes consolidated fuel canister and NFBC canister. The welder assembly provides structural and sealing welding of canister lid to canister body. It also provides capability of testing welds for leak tightness and structural soundness.

4. Expert System Description

4.1. Function

This expert system is designed as an operation's aid which gives the following functions :

- Facilitates the reliable accountability of nuclear material at any operating condition, normal and off–normal, and reports current status and history of material accountancy.
- Facilitates the immediate diagnosis of functional and equipment failure, and recommends corrective action to operators.

4.2. Development Environment

Figure 2 shows the development environment of the expert system. The development tool of this system is NEXPERT Object and NEXPERT Object RUNTIME Version is used to control database. The algorithm of inference engine is programmed by object–oriented concept which is consisted of calss, sub–class, object and properties. Each sub-

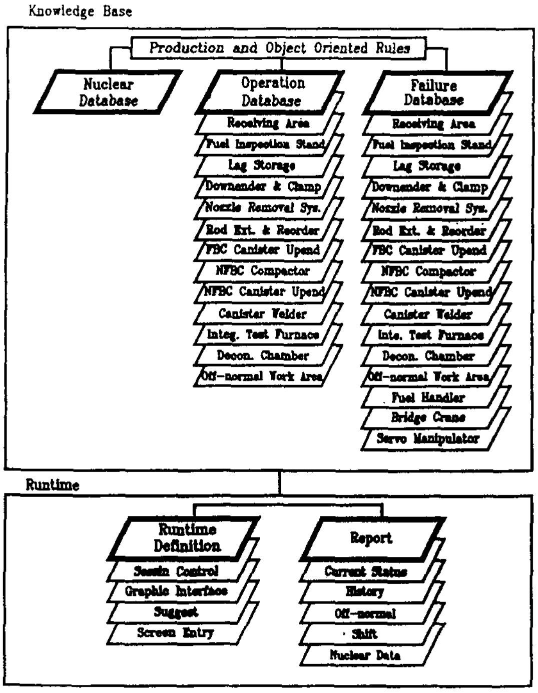

Fig. 2. Expert System Structure

Table 1. Fields of Nuclear Database

Fuel Assembly Number	Total Burnup
Plant Name	Decay Heat
Discharged Date	Radioactivity
Uranium Gross Weight	OFF–gas Sr
Uranium 235 Enrichment	Off–gas Kr
Plutonium Gross Weight	Off–gas I
Plutonium 239+241 Weight	Off–gas Cs

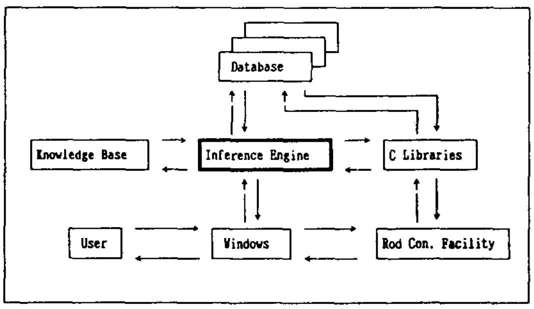

Fig. 3. Development Environment of Expert System

Table 2. Material Balance Areas (MBA)

MBA No.	Location
1	Receiving Area
2	Fuel Inspection Stand
3	Lag Storage
4	Downender & Clamping Table
5	Nozzle Removal System
6	Rod Extraction, Reordering and Canistering
7	Canister Upender
8	NFBC Compaction
9	NFBC Upender
10	Welding
11	Decontamination Chamber
12	Off–Normal Work Area
13	Fuel Rod Integrity test

–class which is equal to material balance area, is listed in Table 2, and each property is listed in Table 1 and Table 3.

4.3. Structure

Figure 3 shows the structure of the expert system. It consists of a knowledge base and a runtime file. The knowledgebase is composed of three database groups and 60 rules with production and object oriented techniques that correlates database groups. First database is nuclear database of spent fuel assemblies discharged from reactor pools. Table 1 shows a list of database fields. It covers necessary information for rod consolidation as well as other spent fuel management such as interim storage, disposal and reprocessing. Database includes fuel assembly number, plant name, and discharged date from reactor. Fuel assembly number denotes information on manufacturer, manufacturing year, and type of fuel assembly, and its location in reactor. Database also contains uranium gross weight, uranium 235

Table 3. Operation Database

Data Base Field	Number of Material Balance Areas												
	1	2	3	4	5	6	7	8	9	10	11	12	13
I/O Date	0	0	0	0	0	0	0	0	0	0	0	0	0
Operator	0	0	0	0	0	0	0	0	0	0	0	0	0
Off–normality	0	0	0	0	0	0	0	0	0	0	0	0	0
Comment	0	0	0	0	0	0	0	0	0	0	0	0	0
Cask Number	0												
Fuel Condition		0											
Fuel Canister No							0						
NFBC Canister No									0				
Recovery												0	

enrichment, plutonium gross and 239+241 weights, burnup, decay heat and off–gas concentrations. If necessary, database fields can be easily modified by addition or deletion. Date is identified and entered to database at the receiving area before cask is loaded onto hot cell.

Second is an operation database of rod consolidation. It consists of 13 sub–databases which correspond to operation areas of rod consolidation process. Table 2 shows a list of sub–databases. Each subdatabase has 5 to 6 database fields depending on its characteristics of operation as listed in table 2 and table 3. They are beginning date and finishing date, name of operator, off–normal condition, comments to describe each operation. Besides them, some operations need an additional field to cover activities of each area. Operators provide necessary information to answer database needs as operation proceeds.

Last is a failure database. It is composed of 16 sub–databases that cover potential functional and equipment failures of each area and associated material handling equipment tools. It provides diagnostic and advisory information to operators who monitor the rod consolidation process. It is mainly based on Failure Modes and Effects Analyses[5]. Table 4 shows a partial list of sample failure database. It includes classified number of failure event, cause, symptom, detection method, categorization of failure, effects on system, inherent compensating provision, correction method, etc. This database is directly related to the operation database through relevant rules. Whenever an off–normality is identified in operation, it works automatically.

Rules are implemented in production rule and object oriented methods. Function of rules correlates databases and operation. Relationships among different database are established by dynamically revising the systems' agenda of hypothesis. Fields of database correspond to properties of

Table 4. List of Failure Database

Field	Contents
No	Failure ID. Number for each Sub–system
Name	System Component and Associated Modules
Fail	Failure Description
Cause	Functional Failure Cause leads
Symptom	Symptoms and Local Effects Including Dependent Failures
Method	Corrective Action (i.e, Repairs)
Cat	Categorization of FMEA Functional Failure (1-5)

knowledge base. Objects, properties, classes, rules and hypothesis are assigned names with sufficient length in order that they can be easily recognized and modified.

4.4. Runtime

NORT (Nexpert Object Runtime) allows to control knowledge base to interface graphs, display forms, report results, and restart the session automatically. NORT in protected mode is used to speed up execution of the expert system and utilize large main memory, compared with that in real mode. Report includes current status of rod consolidation operation, history of fuel assemblies, consolidated fuel assemblies, fuel canister, NFBC canister, etc. Off-normal report and operation shift report are also generated, Report form can be easily modified if necessary.

4.5. Execution

Figure 4 shows the RUNTIME environment of this system. The expert system is carried out as three categories : New, Update and Report. New is the beginning of the expert system for incoming new spent fuels. Identification of spent fuel is mainly accomplished by the serial number of the fuel assembly from the receiving area to the nozzle removal system. In the rod extraction, the serial number of each fuel rod is the accounting basis. After canistering the serial number of a storage canister is used. Each shipment of a cask can carry maximum four spent fuel assemblies. So the nuclear database repeats as many as the number of fuel assemblies. There is a buffer for further continuation to the operation database. As the rod consolidation operation starts, the expert system runs the operation database. The expert system asks operators fields of each operation subdatabase which become properties of the knowledge base as the process continues. Between each subdatabase, there is a buffer to exit. Hierachically the failure database is under the operation database. When an off-normal event is detected, the field of off-normal in each operation subdatabase is entered with yes. It converts normal operation environment to off-normal. It needs date and time of off-normal event, and description of off-normality. It searches corresponding failure database through failure mode and symptom. Searched failure database suggests causes of off-normal event, effects upon plant, correction method, repair location. Off-normal events follow procedure as shown in Figure 5. Off-normal fuels such as broken rods are automatically identified in a corresponding material accounting category. The failure database is systematically classified as failure events with identification numbers. Detection of failure location in the rod consolidation like usual discrete event systems is not hard, in comparison with those of process industries, because it is unitly operated in a hot cell and continuously monitored through lead glass window by operators. Diagnosis should be based on accumulated operation experience and its systematic conversion to database. This failure database is not sufficient because it is mainly based on data at a conceptual design stage. Fixing off-normal event leads to normal operation environment, and goes next operation. Update allows correction of existing records of databases.

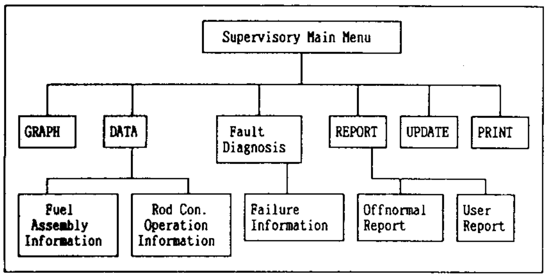

Fig. 4. Runtime Environment of Expert System

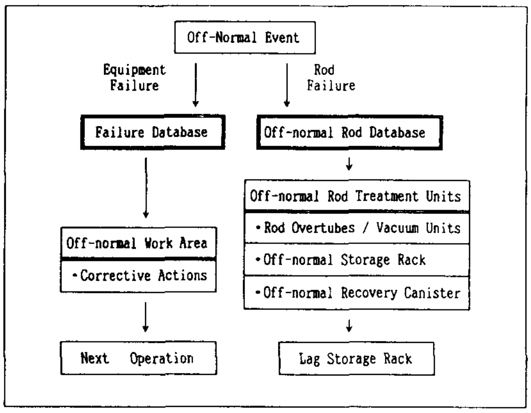

Fig. 5. Off-Normality Treatment Procedure

5. Conclusion

The paper describes a prototype expert system developed to advise operators concerning integration of material accountability and failure diagnosis. It can provide efficient operation of rod consolidation at any conditions and meet material accounting for safeguard. A successful system requires careful consideration of and design to accommodate the needs of the user and the environment in which the system will function. This system will be more useful when it is a part of supervisory control system after intensive test and evaluation.

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