Journal of the Korean Nuclear Society
Volume 21, Number 3, September, 1989

Simulation of Interim Spent Fuel Storage System with Discrete Event Model

Wan Ki Yoon, Ki Chan Song, Jae Sol Lee and Hyun-Soo Park
Korea Advanced Energy Research Institute
(Received April 21, 1989)

이산 모형을 이용한 사용후 핵연료 중간 저장 시설의 전산기 모사

윤완기 · 송기찬 · 이재설 · 박현수
한국에너지연구소
(1989. 4. 21 접수)

Abstract

This paper describes dynamic simulation of the spent fuel storage system which is described by statistical discrete event models. It visualizes flow and queue of system over time, assesses the operational performance of the system acitivies and establishes the system components and streams. It gives information on system organization and operation policy with reference to the design. System was tested and analyzed over a number of critical parameters to establish the optimal system. Workforce schedule and resources with long processing time dominate process. A combination of two workforce shifts a day and two cooling pits gives the optimal solution of storage system. Discrete system simulation is an useful tool to get information on optimal design and operation of the storage system.

요 약

본 연구는 이산 모형으로 표현되는 사용후 핵연료 중간 저장 공정을 전산기 모사하였다. 이는 계통 흐름을 보여주며, 기기 성능을 평가하고 계통 구성 요소와 흐름을 확립하여 설계에 관한 계통 구성 및 운전지침에 대한 정보를 제공한다. 공정 모사를 통하여 가장 좋은 시스템을 구성하기 위하여 주요 변수에 대하여 시험 분석하였다. 전산기 모사 결과에 의하면 하루 2교대 및 2대의 냉각 시설이 최적안으로 나타났다. 이산 공정 모사는 저장 시설의 최적 설계와 운전 자료를 얻는데 효과적으로 사용될 수 있다.

1. Introduction

Spent fuels discharged from nuclear power reactor are being stored at the reactor sites. The water pools at most nuclear power plants were designed to accomodate no more than several full fuel loading. From the beginning of 1990th, the storage water pools at some power plants are expected to be full of spent fuels due to their limited storage capacities. In 1988, the Korean Atomic Energy Commision adopted policies on the radioactive waste managements. One of the significant policies was the decision to build a wet type interim storage facility away from nuclear power plants for 3,000 MTU by 1997.

It appears timely, therefore, to examine the expertise which is involved in the design of the interim spent fuel storage facility, with particular reference to the conceptual design. The objective of this study is to evaluate and to analyze the interim spent fuel storage system through simulation, and to obtain information on system design. Simulation can be particularly useful to test design of a new system and to identify problems, thus suggesting design improvements before the system is built. And also by varying system parameters, it can be used to identify the critical elements and factors that are most important for efficient system operation. One theme which emerges from this is the desirability of getting things right at the conceptual stage so that the design which emerges is better. Another theme is to assess operability of storage system.

The spent fuel storage system is different from nuclear power plants, in that the spent fuel storage system is a discrete event system. The terms continuous and discrete applied to a system refers to the nature of behavior of changes with respect to time in the system state[1]. Systems whose changes in state occur continuously over time are continuous systems; systems whose changes occur in finite quanta, or jumps, are discrete. The models of continuous systems generally consist of sets of differential equations. Discrete system generally uses stochastic models which contains a certain amount of randomness in its transitions from one state to another. Some systems possess the properties of both continuous and discrete systems.

Discrete simulation system, SIMAN, is based on probability, statistical methods and queuing theory [2]. It can visualize system activity with complex interaction of the various timing discrete events. It is used in the domains of manufacturing, robotics, vehicular traffic, and logistics. As material flows from process to process, competing for resources, congestion becomes a problem. Congestion at one process can create a rippling effect throughout the entire system affecting overall operation. The treatment of congestion is not usually found in analytical models even though it has a major impact on operations. Queuing theory allows to make changes to the congested areas, testing different scenarios an effcient solution is found.

2. System Description

The proposed system is designed to receive, handle, and store spent fuels from nuclear power plants. The system described is a reference wet type spent fuel storage facility for the purpose of study.

Spent fuels discharged from nuclear power reactor and stored at the reactor site storage pool for minimum one year until the intense radioactivity and heat have decayed to a level suitable for shipment, are transported by the ship carrying shipping casks to receiving bay of the interim storage facility. A PWR shipping cask carries seven PWR assmeblies and a CANDU shipping cask does three CANDU baskets (60 bundlesbasket). Once a shipment reaches at receiving bay, shipping casks are prepared for unloading. A shipping cask is then placed onto the truck with the 150 ton crane mounted in ship to go to the spent fuel storage facility.

Figure 1 shows a simplified flow diagram of the spent fuel storage facility. Once a truck arrives at receiving area of the interim storage facility, the facility 150 ton crane places a shipping cask in the lag storage. A cask is placed in the cooling pit not to disturb storage facility thermally, even though spent fuels were cooled down at the reactor site pool. After adequate cooling of a cask, it is transferred on the top of the unloading section with the facility 150 ton crane, and placed on the rail-

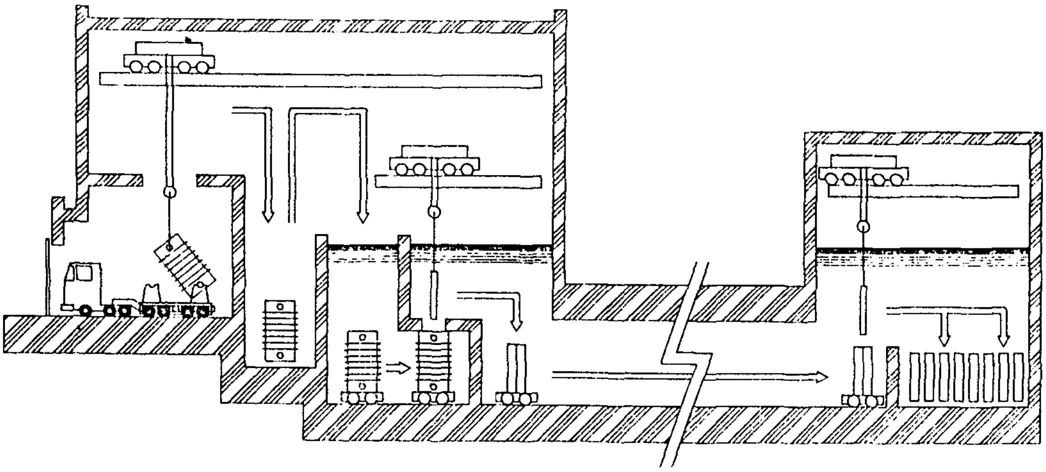

Fig. 1 Flow Diagram of Spent Fuel Storage Facility.

mounted self propelled cask cart which is submerged in water. A shipping cask on the cask cart is moved into the position to unload spent fuel assemblies. A shipping cask is prepared for unloading of spent fuel assemblies and is opened. The 20 ton unloading crane is used to lift spent fuel assemblies from a shipping cask to a storgae canister. Each PWR storage canister stores nine PWR spent fuel assemblies and each CANDU storage canister contains six CANDU spent fuel baskets. Each storage canister is loaded onto the canister cart with the 20 ton crane. The canister cart is self propelled. The canister cart with a storage canister is moved to the storage area. A storage canister is placed on storage water pool. An empty shipping cask is moved to the decontamination room with the cask cart and the 150 ton crane where the cask outer lid is replaced and the outer surface is decontaminated, if required. After an empty shipping cask is decontaminated, it is returned to the discharge section and loaded onto the truck using the 150 ton crane to go back to the ship.

System is operated with following conditions. The ship cruises at regular intervals based on annual amount of spent fuels discharged from the nuclear reactor water pools. Shipment may arrive at the receiving bay during shutdown period due to working shift schedules and holiday. This shipment is not handled until the first shift of the following working day. However the truck continues to transport a shipping cask to destination even during shutdown if the truck is on the way. The lag storage has enough space to hold casks waiting for operation. It does not take place that the truck queues due to the limited lag storage capacity. The cooling pit and the decontamination room are operated automatically for the prescribed period. Once a cask is placed on either facility, it is operated for the predetermined period during shutdown.

3. Modeling

Discrete event modeling consists of modeling a system by describing the changes that occur in the system at discrete points in time. Time does not advance within an event so changes in the system behavior can only occur at event time, while in continuous system changes take place continuously over time. The system behavior is simulated by state changes that occur as events happen. Block diagrams are the primary means for modeling dis-

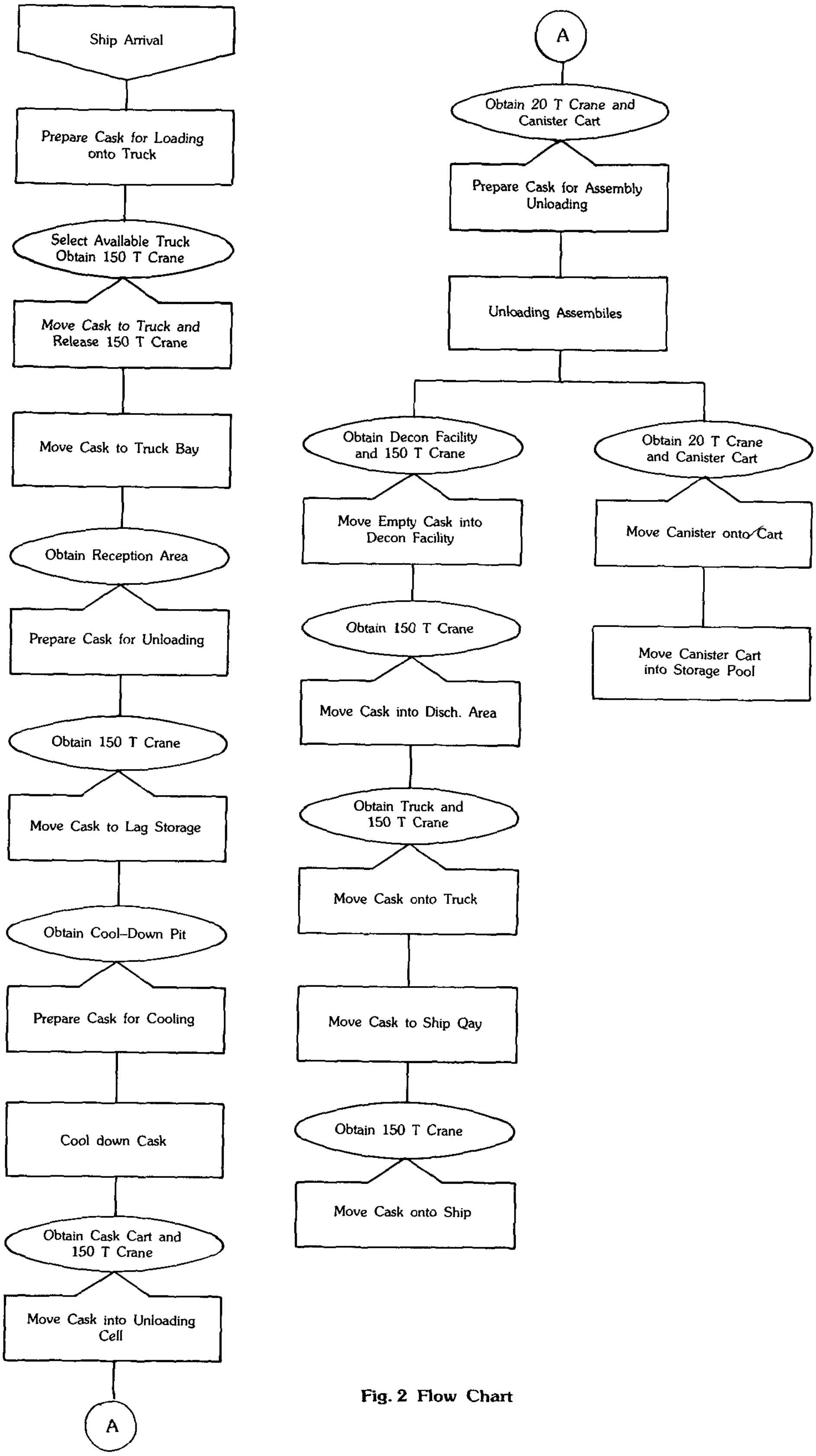

Fig. 2 Flow Chart

crete systems. These diagrams are linear top-down flowgraphs which show the movement of entities through the system.

Figure 2 shows a flow chart for the interim storage system to depict the activities of the spent fuels from ship arrival to storage. The structure of the model's logic in creating the model is nécessary. This system is modeled by appropriately grouping a series of operations into process stations. These groupings are illustrated in Table 1. The average process times were obtained from the Quarterly Progress Report of KAERI[3]. Because very few data on process times are available, the average process times were used with 10 percent allowance for minimum and maximum process times as parameters for a triangular distribution. 10 percent allowance is enough to compensate for scatterness of the average process times taken during operations. Values from a triangular distribution are used when all values within the range of the distribution can occur, but the probability for a specific value is greatest at the mode and decreases linearly from the mode to either end of the distribution. The triangular distribution closely approximates most single-mode probability distributions. Small variations in the minimum and maximum parameters of the triangular distribution do not affect simulation much because of its closeness to single-mode probability.

4. Simulation and Discussion

Simulations were carried out based on the five scenarios shown in Table 2 with spent fuel amount discharged from water storage pools of power reactors for ten years. Numbers of cooling pit, workforce shift a day and shipping cask are selected as dominant paramaters to affect system operation because processing time of the cooling pit is much longer than that of the other resources, and operation hour depends on numbers of workforce shift a day and shipping cask. The different scenarios and the varibale changes make case unique.

Simulation shows details in the movement of entities from block to block and the processing of entity such as resources seized, variable assignments at each event and details all operations executed within the event. Information on shipping cask processing and turnaround times is provided for each simulation year, for the system as a whole, and also specified as PWR or CANDU.

Table 1. Operation Grouping

1	Transport of shipping cask from ship to lag storage using truck placed by ship crane.
2	Transport of shipping cask from lag storage to cooling pit and placement onto cask cart using facility crane.
3	Unloading of fuel assemplies from shipping cask to storage canister using unloading crane.
4	Storage of canister in storage pool and transport of empty shipping cask to decontamination room.
5	Transport of empty shipping cask to quay using truck
6	Placement of empty shipping cask to ship using ship crane
7	Shutdown due to working shift schedule and holiday

Table 2. Simulation Scenarios

case	shift/day	work hour/week	cooling pit	shipping cask
1	2	96	1	3
2	2	96	1	4
3	2	96	1	5
4	2	96	2	5
5	2	168	2	5

Information concerning the length of time needed to process and turn around a shipping cask and the frequency with which a storage canister is stored. Information on time dependent quantities such as the time average for a number of shipping cask in lag storage, along with maximim and minimum numbers of shipping cask during each simulation year. Information on the time average, minimum and maximum value of utilization of all resources is provided.

Table 3 shows processing time of shipping cask for a year which has the maximum spent fuels. Terms PWR and CANDU indicate time to take for PWR and CANDU casks from entering storage facility to leaving facility. Term cask turnaround describes time to take for PWR and CANDU casks from ship arrival at the receiving bay to returning to ship. Depending to the scenarios, there are distinct differences. According to scenarios 1, 2 and 3, increase of shipping cask leads to increase of processing time due to long waiting line at each facility. Addition of a cooling pit which has longest processing hour decreases processing time of casks. Scenarios 4 and 5 shows that number of working shift is a crucial factor to diminish processing time drastically. Maximum cask turnaround processing time denotes total turnaround time for a set of casks of each shipment. Because turnaround times are smaller than the ship cruise interval calculated by the amount of annual spent fuel shipment, there are shoutdown periods. For the maximim operation efficiency, shutdown period should be minimized. Overally scenario 3 has the longest processing time for both PWR and CANDU, and the longest shipping cask turnaround time with scenario 4's slightly shorter times. Scenario 5 which has the shortest processing and turnaround times creates long idle time. The

Table 3. Processing Time

unit : hours

case	PWR		CANDU		cask t'around	
	avg.	max.	avg.	max.	avg.	max.
1	3.1106	3.9086	3.1076	3.9146	3.3047	4.1828
2	4.0743	5.8494	4.0572	5.8400	4.4388	6.1878
3	4.6878	6.8169	4.6540	6.8267	5.0572	8.1780
4	4.3416	6.8032	4.3711	6.3024	4.8257	8.1697
5	2.8205	4.0219	2.8693	3.8834	3.1097	4.4403

Table 4. Utilization of Resources

case	cooling pit	decon room	truck	cask cart	ship crane	facility crane	unload. crane
1	0.4358	0.2314	0.1830	0.2112	0.0211	0.2320	0.0554
	(1)	(1)	(2)	(1)	(1)	(1)	(1)
2	0.5181	0.3060	0.2259	0.2222	0.219	0.2420	0.0574
	(1)	(1)	(2)	(1)	(1)	(1)	(1)
3	0.5222	0.3185	0.2207	0.2263	0.0221	0.2448	0.0585
	(1)	(1)	(2)	(1)	(1)	(1)	(1)
4	0.7458	0.3308	0.2483	0.3724	0.0221	0.2448	0.0586
	(2)	(1)	(2)	(1)	(1)	(1)	(1)
5	0.4760	0.2259	0.1451	0 2426	0.0222	0.2447	0.0585
	(2)	(1)	(2)	(1)	(1)	(1)	(1)

bracket : no. of resource

amount of spent fuels is not enough for all day operation.

For the same year, the utilization rate are compared in Table 4. The utilization rates for cranes of ship, storage facility and unloading, show very slight diffencence regardless of scenarios. The utilization rates for trucks where two are used, are similar to one another for scenario 2, 3 and 4, and are higher than those of the other two scenarios. The utilization rate of decontamination room is very analogous to that of truck. For the cooling pit, scanario 4 has higher rate than the other four scenarios. Overally the utilization rate increases as increase of numbers of shipping cask and cooing pit with operation hour fixed. Increase of operation hour with three working shifts a day decreases system utilization.

Figures 3A and 3B show histograms of processing times of PWR casks. They consist of relative cell frequency and relative cumulative frequencies of processing time of PWR casks. The cell width which is the difference between the lower and upper limits, is 0.5 day. Figure 3A shows history of scenario 3. Each processing time cell has similar portion. Scenario 4 shown in Figure 3B has more evenly distributed relative cell frequency and smoother relative cumulative frequency that those of scenario 3. Each processing time cell of scenario 4 has less portion than that of scenario 3 because the former which has one more cooling pit

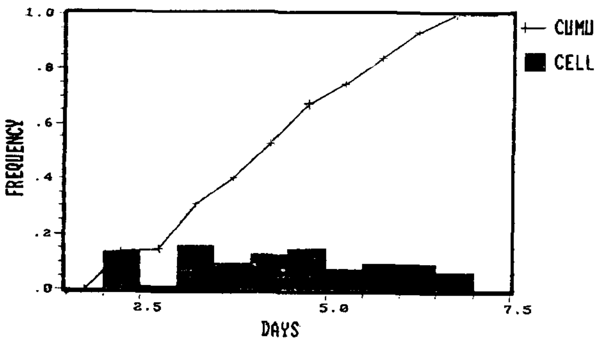

Fig. 3B Histogram of Processing Time of PWR Cask Scenario 4.

than the latter decreases waiting time to make flow smoother.

Queues are encountered, according to simulation results in almost every system that is modeled. There are delays in the movement of an entity through the system as the result of the system status. The reason of queueing is not enough serving facilities. The reason for an inadequate number of facilities is simple economics. Queues arise because of the competition for limited resources. Through the interim storage system, the most critical is the queueing at lag storage which buffers long operation hour of the cooling pit. Figures 4A and 4B compare numbers of PWR casks stored at lag storage depending on numbers of cooling pit. Figure 4A where a cooling pit is used, shows that more casks are held for longer period than those in Figure 4B. For comparison, sum of cask day

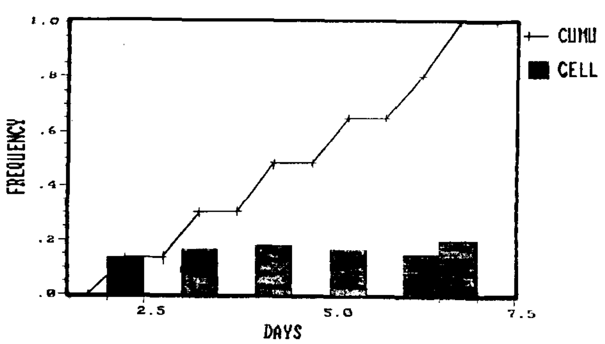

Fig. 3A Histogram of Processing Time of PWR Cask Scenario 3.

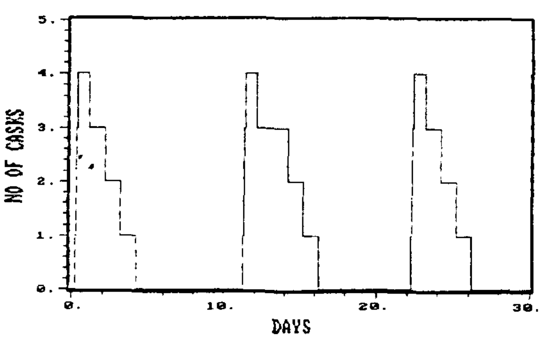

Fig. 4A Number of Cask Stored at Lag Storage Scenario 3.

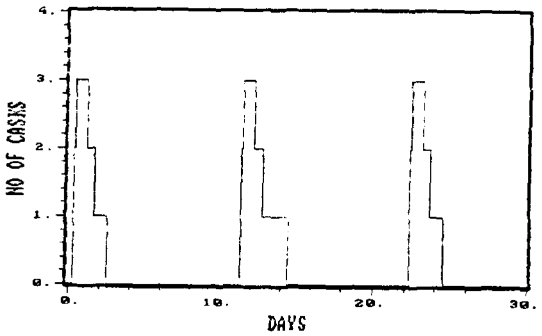

Fig. 4B Number of Cask Stored at Lag Storage Scenario 4.

(SCD) for each bach is used. For scenario 3, SCD is 10 for the first batch and 13 for the second batch. The second batch shows higher SCD due to holiday. For scenario 4, SCD is 4 for the first batch and 4 for the second batch. Two cooling pits make number of casks stored at lag storage decrease a lot.

5. Conclusion

Simulation of the wet type interim spent fuel storage system which is stochastically modeled, visualizes system, and shows that models predict storage system performance. It gives flow and queue of shipping casks, storage canister and spent fuels and availability of each process facilitiy. Simulation can give valuable information on design and operation of the storage system. Workforce shift schedule donimates system operation and design. The other variables such as number of shipping casks in a set and number of cooling pit are critical. Discrete system simulation is an useful tool to get information on optimal design and operation of the wet type interim spent fuel storage system.

References

1. W.J. Graybeal and U.W. Pooch, 'Simulation : Principles and Methods', Winthrop Publishers, Inc., MA 1980.
2. D.C. Pegden, 'Introduction to SIMAN', Systems Modeling corporation, PA 1985.
3 KAERI, Quarterly Progress Report, Spent Fuel Management Division, Vol. 1—2, 1988.