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SYSTEM MODELLING TO SUPPORT ACCELERATED FUEL TRANSFER RATE AT EBR-II

by

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The Experimental Breeder Reactor-II (EBR-II) ia a 62.5 MW(th) liquid metal reactor operated by Argonne National Laboratory for The United States Department of Energy. The reactor is located near Idaho Falls, Idaho at the Argonne-West site (ANL-W). Full power operation was achieved in 1964; the reactor operated continuously since that time until October 1994 in a variety of configurations depending on the programmatic mission. A three year program was initiated in October, 1993 to replace the 330 depleted uranium blanket subassemblies (S/As) with stainless steel reflectors. It was intended to operate the reactor during the three year blanket unloading program, followed by about a half year of driver fuel unloading. However, in the summer of 1994, Congress dictacted that EBR-II be shut down October 1, and complete defueling without operation. To assist in the planning for resources needed for this defueling campaign, a mathematical model of the fuel handling sequence was developed utilizing the appropriate reliability factors and inherent time constraints of each stage of the process. The model allows predictions of transfer rates under different scenarios. Additionally, it has facilitated planning of maintenance activities, as well as optimization of resources regarding manpower and modification effort. The model and its application is described in this paper.

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Introduction

To meet the objective of the original blanket unloading program (complete replacement in three years) it was required that the normal fuel handling rate be accelerated by at least a factor of two. It is interesting to note that the shutdown of EBR-II on October 1, 1994 does not affect the original plan. That is, the blanket S/As will be unloaded first over a period of about two years, followed by the core drivers in 1997. Removal of blankets first will minimize exposure to operations crews, as blankets have the lowest decay power. Additionally, most core drivers require active cooling for periods of up to a year; as there are a limited number of cooled storage locations, unloading drivers first would cause a restriction to the overall flow similiar to a capacitance effect.

The inventory in the primary tank of fueled S/As (including blankets) that must be transferred is

103	driver S/As (including control rods)
28	experimental S/As
321	depleted uranium blanket S/As

for a total of 452 S/As to be removed. The schedule requires that these S/As be removed in 2 1/2 years, which necessitates a rate of 14 transfers per month, or 167 per year. This rate is at least 50% greater than any historical experience, and is a factor of two above normal rates at ANL-W. The system modelling described in this paper will help determine the feasibility of achieving this rate, and what modifications to systems or procedures are needed.

The path of spent fuel out of EBR-II to storage is a multi-stage process, involving complex operations at a minimum of four different facilities at the ANL-W site. The process is shown schematically in Figure 1. Specifically, the path to temporary storage in the Radioactive Scrap and Waste Storage Facility (RSWF) (where S/As are stored awaiting future processing) consists of five stages: (1) transfer from the reactor grid to the in-tank storage basket, (2) transfer from the storage basket to the wash station (to wash residual sodium from the S/A) using the Fuel Unloading Machine (FUM) to load a S/A into the Inter-Building Cask (IBC), (3) transfer from the wash station via the IBC to the Hot Fuel Examination Facility (HFEF) where most S/As are placed in pits that are actively cooled, (4) transfer from the cooling pits to air storage racks (passively cooled), and (5) disassembly and packaging in HFEF for interim storage at RSWF in pits. Each stage has a set of criteria that must be satisfied before a subassembly can be received. The criteria are based on decay power and age of the S/A: decay power to ensure adequate cooling will be available, either active or passive, and age to ensure that certain isotopes have decayed to minimize the source term in facilities outside the reactor. Additionally, each stage typically has complicated handling and/or cooling equipment that must be periodically maintained, leading to both planned and unplanned downtime.

Using the information on the flow of material from the time that the fresh fuel enters the EBR-II building to the time that the depleted fuel and hardware are shipped to the interim storage location, the authors studied the feasibility of using different modelling approaches to model the situation. In the shutdown case, fresh fuel does not enter EBR-II, but rather stainless steel spacers are used. The spacers are needed to maintain the precise geometry needed for the under sodium fuel handling equipment. Upon careful evaluation of alternatives, it was decided that considering the complexity of fuel handling system at ANL-W, a deterministic model will not be able to depict the actual performance of the system over time. Therefore, it was decided to use a commercial simulation packages to simulate the fuel handling system in EBR-II.

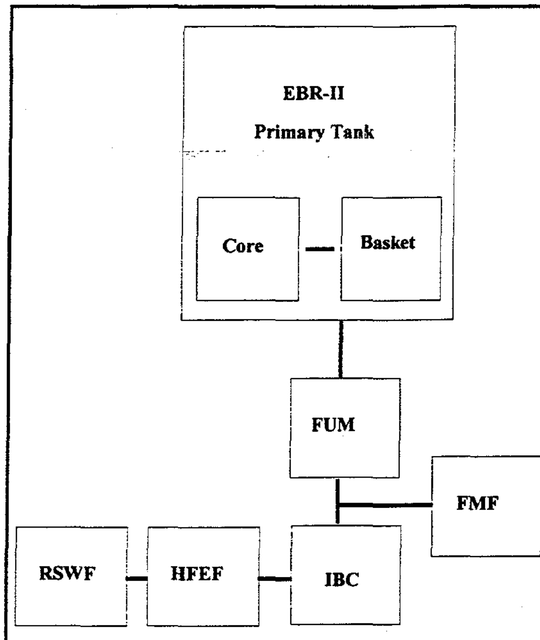

Figure 1.
Fuel Handling Process at ANL-W

Use of simulation modelling as a tool to address complex systems enables the modeller to measure the performance of the existing or proposed systems under different operating schemes. It can help management make basic evaluations of the different options. Therefore, simulation of the system's operation has rapidly become one of the most useful and common applications of computers. Simulation can be used 1) as an explanatory device to define a system; 2) as an analysis vehicle to determine critical issues; 3) as design evaluator to synthesize and evaluate proposed solutions, and 4) as predictor to forecast and aid in planning future.

In the simulation model, different scenarios were studied in which the number and the availability of different resources such as the IBC casks (normally there are two), the operating hours of different crews, the fuel handling operational procedures and the reactor cycle time were varied. Comparing the resulting number of transferred subassemblies in multiple years of simulation time, the authors were able to determine a few optimal policies that will help achieve the objective of defueling in 2 1/2 years.

Description of the Overall Fuel Handling Procedure

The overall fuel handling system can be divided into three segments : 1) depleted S/A transferral in the EBR-II reactor building (involving the reactor grid, basket, FUM, and IBC) , 2) transferral from EBR-II to HFEF using the IBC, and 3) storage, processing, and transferral of the S/A fuel elements and hardware to the RSWF using the HFEF-5 cask (a cask specially designed for transport of storage cans from HFEF).

Fuel handling operations in the reactor building are classified as unrestricted and restricted. Unrestricted fuel handling operations occur when the reactor is shutdown; S/A transfers occur between the reactor grid and the in-tank storage basket. Restricted fuel handling can be performed during reactor operation; S/A transfers occur between the storage basket and the outside world via the FUM.

To obtain a fair estimate of the operational times for performing different modes of fuel handling in the EBR-II reactor building, the fuel handling log-book for June 1993-April 1994, and the stored data on all fuel loading/unloading activities in the Data Acquisition System (DAS) for January 1994-April 1994 were analyzed and statistical tools were used to determine the best fit probability distribution. In some cases, modifications to the existing systems or practices are planned, but not yet incorporated. In those cases, best estimates of required times were made. The same information was used to estimate Mean Time Between Failures (MTBF) and Mean Time to Repair (MTTR) of different fuel handling equipment. All modelling assumptions were discussed with the staff and consensus was achieved. The statistical analysis for fuel handling operations in the EBR-II reactor are described in a previous paper (Reference 1) , and will not be repeated here.

The second phase of the operations to be modelled is the transfer of a S/A out of the reactor building (FUM to IBC), wash the S/A at the IBC wash station, transfer the S/A to the HFEF hot cell, return the IBC to the wash station, dry the IBC and return it to the EBR-II reactor building for the next transfer. The details of this process and the time estimates are summarized in Table 1. This sequence looks at the interaction between the reactor and the IBC; unlimited availability of HFEF is assumed. Note that in Tables 1-3, the column marked Duration of Operation contains information about the statistical model of durations (e.g., N(2,0.5) refers to a normal distribution with mean of 2 hours and standard deviation of 0.5 hours).

The next sequence of operations which was studied deals with the interaction beween HFEF and the IBC; cooling storage time in HFEF is also a factor. The sequence of steps begins with a loaded IBC cask; it is assumed that EBR-II is able to supply a loaded cask on demand. Limits on thermal loading of the stored S/A typically requires

Op. no.	Operation Description	Perquisite Operation	Duration of Operation	Required Resources
c1	Move the S/A to VAD station to be chopped off.	b6	U(.5,.15)	VAD crew
c2	Chop a blanket S/A and attach top and bottom caps.	c1	U(1,.25)	VAD crew
c3	Three S/A are accumulated before they are send through the small lock to the 3D.	c2		VAD crew
c4	Complete loading of 5-cask basket with the second set of three S/A.	c2-c3	U (1,.25)	VAD crew
c5	Load basket into inner can and bolt closed.	c4	U(1,.25)	VAD crew HFEF 5-Cask
c6	Section the blanket S/A hardware and load up to nine hardware into the waste can.	c2	U(7.5,.5)	VAD crew
c7	Load inner can into outer can, insert shield plug, and weld shut.	c5	U(2,.5)	VAD crew HFEF 5-Cask Welder Cask crew
c8	Transfer 5-cask back out of the truck-lock and chain to trailer.	c7	U(2,.5)	Cask crew HFEF 5-Cask Truck-lock
c9	Transfer 5-cask to RSWF and unload.	c8	U(3,1)	RSWF crew HFEF 5-Cask
c10	Transfer 5-cask to HFEF truck-lock.	c9	U(1,.25)	Cask crew HFEF 5-Cask
c11	Remove 5-cask from truck and into tunnel, install shield ring, load outer can into HFEF 5-cask, install support ring and bag can to the cell.	c10	U(3,1)	Cask crew Truck-lock HFEF 5-Cask

Table 3. Time Estimate for S/A Operations: Packaging in HFEF and Shipment to RSWF

The last sequence modelled deals with the dismantling of the cooled S/As in HFEF such that fuel elements are separated from the hex cans (in the case of driver fuel) or the top and bottom end fittings are cut off (in the case of blanket S/As), the fuel elements, hardware, or blanket S/As are packaged for shipment to RSWF, and the subsequently shipped. The details of this sequence are contained in Table 3.

Modelling of Different Segments of Fuel Handling System

At the outset of the study, the overall fuel handling system was divided into three independent segments: 1) EBR-II fuel loading/unloading activities; 2) the IBC's role in transferring depleted S/A from EBR-II to HFEF; and 3) storage and processing of those S/As at HFEF. In the final study the effect of interactions between the three segments was modelled, after understanding the behavior of each segment. The modelling procedure and the results of simulation runs for the first phase of the study is discussed below.

In the first model of the first phase of the study the complete process of fuel handling in and out of the reactor was modelled. The simulation starts with the reactor shut down. This phase lasts for 15 to 25 days, during which unrestricted fuel handling between the basket and the core can be performed. The reactor is then operated for 45 to 55 days, during which restricted fuel handling between the basket and the IBC (via the FUM) can be performed.

During the simulation, a fresh fuel S/A is transferred to the basket, where it waits to be transferred to the core. After being transferred to the core and remaining there for the length of its residence time in the core, the S/A is transferred back to the basket and remains there for a given period of time which depends on its decay power. The S/A is then qualified for removal from the reactor tank. The system's initial conditions are the number of fresh and depleted S/As in the basket and the core. One calendar year of simulation time resulted in 5 operating cycles for the reactor and transferral of 103 S/As to the core and removal of 102 S/As from the basket and out of the reactor building.

The second model is a continuation of the first model, in which the movement of the depleted S/A is followed through the IBC cask transfer to the point in time in which it is stored in one of the HFEF cooling pits (the sequence shown in Table 1). The S/A is moved from the basket to the FUM by using the transfer arm, and transferred to the IBC by using the FUM. The next step is to decontaminate the cask to remove any residual sodium or contamination. This operation is performed while the IBC is at the EBR-II building. The cask-handling crew then takes it to the wash station, where it is washed. This operation requires the wash station to be operational. After washing, the IBC is loaded on a truck and transferred to HFEF.

Upon arrival of the IBC at HFEF, the cask-handling crew unloads the cask, mates it with the port in the transfer tunnel, places the S/A inside the hot cell and loads the empty IBC back on the truck. This operation requires that the cask-handling crew and the HFEF truck lock system be operational and available. In the next step, the IBC is returned to the IBC wash station for the drying operation. At this time if there is a change in the type of S/A being transferred, the IBC insert has to bechanged (control rods and safety rods require a different type of insert). Finally, the IBC is transferred to the EBR-II building for its next transfer operation.

Table 4 is a summary of the one year simulation run for four different scenarios. It is observed that restricting the fuel handling operation to the use of one IBC cask reduces the system capability to transferring one S/A in every 2-3 working days (**109** S/A in 260 working days), whereas utilizing the second IBC cask increases the system performance by 44%.

The third model is a continuation of the first two models, in which the simulation starts with a loaded IBC arriving at the HFEF truck-lock (the sequence of Table 2). The S/A being delivered can be a full-worth driver, half-worth driver, control rod, or blanket. Their arrival rates are 10%, 10%, 2%, and 78%, respectively, which is representative of the current inventory in the reactor. Depending on the nature of the S/A, they are assigned a storage time in the cooled and uncooled pits. Unloading the IBC and loading it back into the truck requires the presence of the cask handling crew. The S/A's minimum storage time is a pre-determined value, and the simulation model is constrained to keep the S/A in the cooling pit until the pre-determined time has elapsed, **and** space becomes available in the air storage racks. The simulation uses the inventory of S/A in the cooled pits and air storageracks on April 1, 1994 as the initial stock. In addition, the simulation is designed to utilize S/As from a fully loaded core and basket; these S/As will enter the HFEF system upon availability of storage space.

After the cooling period, the S/A is dismantled and shipped to RSWF (the operations of Table 3). The Vertical Assembler Dismantler (VAD) is used to dismantle the drivers, half-worth drivers and control rods, and the cutoff saw is used to cut the blankets' end fittings so they can be placed in storage cans without further disassembly. Both operations require the VAD crew to be present. The VAD crew next loads the dismantled S/A into cans. Following this operation, the cask handling crew loads the cans into the HFEF-5 Cask, transfers the cask to the HFEF truck-lock, and prepares it for transferal to the RSWF site. To perform this task, the cask-handling crew and the truck-lock are needed. Completion of this task releases the truck-lock, but will keep the cask-handling crew engaged transporting the cask to the RSWF. The transfer operation also requires the RSWF transportation crew to be present. Table 5 outlines the results of this part of the simulation.

It is seen that the HFEF system is easily capable of transferring the required 167 S/As per year to meet the objectives of the defueling program.

Number of S/A processed (including storage)	**One 8-hour Shift**				**One 12-hour Shift**			**Two 8-hour Shifts**		
	1 yr.	2 yrs	3 yrs	4 yrs	1 yr.	2 yrs.	2.5yr	1 yr.	2 yrs.	2.25 yr.
Full-worth Drive/Cooled	43	68	95	95	53	81	81	58	83	83
Full-worth Drive/Uncool	60	86	108	119	64	105	105	70	107	107
Half-worth Drive/Cooled	20	50	77	77	39	79	79	50	80	80
Half-worth Drive/Uncool	20	50	74	81	39	83	83	51	84	84
Control Rods/Cooled	8	12	17	17	12	17	17	11	13	13
Control Rods/Uncooled	7	10	17	17	10	17	17	11	13	13
No. of Blankets/Uncool	168	346	526	550	291	562	562	356	563	563
No. of S/A cut by VAD	**65**	**126**	**181**	**217**	**85**	**190**	**202**	**106**	**197**	**204**
No. of S/A cut by SAW	**140**	**316**	**494**	**550**	**269**	**562**	**562**	**332**	**563**	**563**
No. of S/A Processed	**205**	**442**	**675**	**767**	**354**	**752**	**764**	**438**	**760**	**767**
No. of Cans of Fuel	32	63	90	108	42	94	101	52	98	102
No. of Cans of Blanket	23	52	82	91	44	93	93	52	93	93
No. of Waste Cans RSWF	**54**	**113**	**171**	**199**	**85**	**187**	**194**	106	191	195

Table 5. Number of Processed S/As at HFEF

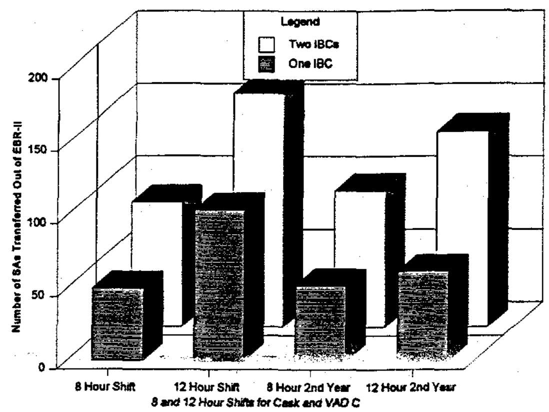

Figure 2 The Effect of One vs. Two IBC's on SAs Transferred Out of EBR-II for 2 Years

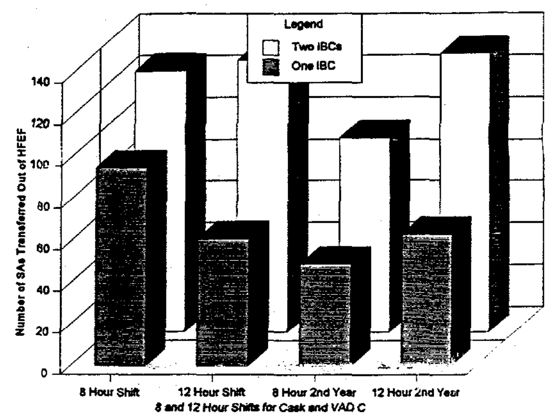

Figure 3 The Effect of One vs. Two IBC's on SAs Transferred Out of HFEF for 2 Years

Modelling of the Overall Fuel Handling System

The previously described analysis of each segment of the fuel handling system revealed that, depending on the availability of different resources, each of the three segments could be the constraining segment. To study the complex inter-relationship, a general model was developed that combines the modeling procedure of the previous three models, and is used to calculate the capability of the fuel handling system at ANL-W in transferring S/As from EBR-II to HFEF and on to RSWF.

To investigate the performance of the system, different operating scenarios were developed in which the number of available IBC casks, the number of IBC wash stations, and the number of operating hours for the cask-handling crew and the VAD crew were varied and the results on the number of transferred S/As were investigated. In addition, to understand the performance of the system under the reactor shut-down scenario (in which the reactor is shut down and all the fueled S/As are removed from the core) three shut down scenarios were developed and simulation results were evaluated. In the first part of this study, the reactor was assumed to be operating on a 70% plant factor.

The effects of transfers out of EBR-II and HFEF (to RSWF) for scenarios of one vs. two IBC's and different cask-handing and VAD crew shift lengths are shown in Figures 2 and 3.

The data presented in Figure 2 demonstrate the gains achieved in transfer rates out of EBR-II and into HFEF when two IBC's are available vs. one. In all cases, the addition of the second IBC allows transfer rates 50-100% greater than when only one IBC is available. This graphically demonstrates the critical need to perform preventative maintenance to ensure the availibility of both IBC's. The data in Figure 2 also demonstrates the benefit of using 12 hour shifts for the crews (cask-handling and VAD); data to follow will demonstrate that it is the cask-handling crew that is critical.

The data presented in Figure 3 represent the number of S/As processed at HFEF and shipped to RSWF. These data again demonstrate the need for two IBC's. It also shows that if two IBC's are available, the shift size does not make an effect in the first year; with only one IBC available, increasing the shift duration actually causes a decrease in S/As processed in HFEF in the first year. This is due to the fact that the cask-handling crew is utilizing the additional time to greatly increase the S/As transferred out of EBR-II, at the expense of transfers out of HFEF. The fact that the processing rate at HFEF is high in the first year with one IBC and 8 hour shifts reflects the fact that the HFEF crews are able to clear the existing inventory (in cooling pits and racks) because of the modest demand from EBR-II transfers.

The effect of crew shift hours for the cask-handling and VAD crews on total S/As transferred out of EBR-II and HFEF was studied, assuming that two IBC's would be available. The data are shown in Figures 4 and 5.

The data presented in Figures 4 and 5 demonstrate the insensitivity of transfer rates out of EBR-II and HFEF to the hours of the VAD crew; it is the cask-handling crew that dominates the transfer rate. Real gains are achieved by increasing the cask-handling crew's hours from 8 to 12 hours, and more modest gains when the hours are increased to 16 hours. Apparently, the VAD crew can handle the demand on a normal 8 hour shift; it should be noted however, that other duties of the VAD crew beyond fuel transfers are not incorporated into the model.

In the final phase of this study, the reactor was assumed to be shutdown. Three scenarios were modelled: 1) Both crews operate 8 hour shifts, and only one IBC is available, 2) the cask-handling crew operates 12 hours, the VAD crew 8 hours, and two IBC's are available, and 3) both crews work 12 hours, and there are two IBC's available. The results of this are summarized in Table 6.

The data presented in Table 6 demonstrate that the required transfer rate of 167 per year is achievable provided there are two IBC' available, and the cask-handling crew works at least a 12 hour shift. Based on these results, it was decided that the EBR-II crews would be trained in the cask-handling operations to supplement the existing cask-handling crew. Since EBR-II is staffed 24 hours per day, this allows the equivalent of extended shifts for the cask-handling crew, effectively removing that problem area with no extra committment of resources.

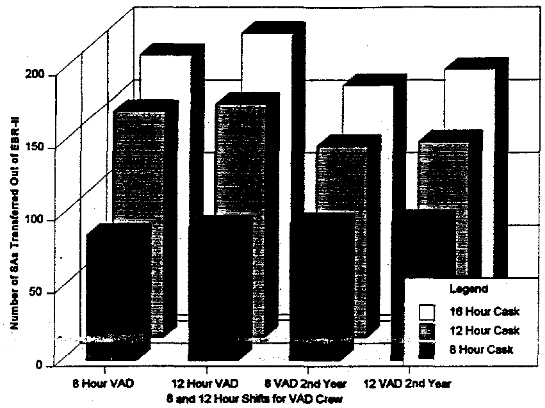

Figure 4 The Effect of Crew Hours on Transfers Out of EBR-II for 2 Years

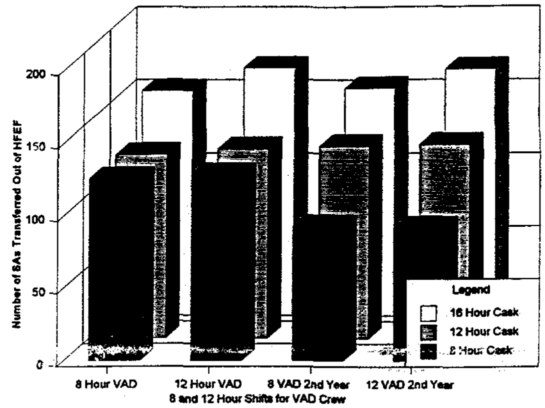

Figure 5 The Effect of Crew Hours on Transfers Out of HFEF for 2 Years

Features of the Simulation Model

A few features of the simulation model are:

1) The downtimes due to equipment unscheduled and/or scheduled maintenance, weekends and holidays are modelled. In addition, at the end of the shift, the modeler can decide to stop the ongoing activities or to continue to finish the unfinished tasks before ending the work day (some tasks can not be left unfinished at the end of a shift);
2) Adding to or deleting the capacity of any resource, changing the initial conditions (such as the number of existing S/As in the core, the basket, the HFEF cooled pits or uncooled racks), and changing the required time to perform an activity can be done easily;
3) The modeler has the option of starting the simulation from an initial stage in which the system's status matches with the current date, or the modeler can run the simulation for a given time, clear all the statistics, and start collecting statistics from then on;
4) Using animation features of the simulation model, a visual realization of S/A movement, IBC cask engagement, and operational status of crews or equipment is obtained. This is used to verify the model accuracy as well as study the speed of operation in different segments of the system. The bottleneck of resources at different time periods can be visually observed.

Year	IBC	Cask Crew	VAD Crew	EBR-II Transfers	HFEF Transfers
1	1	8	8	107	67
1	2	12	8	194	171
1	2	12	12	197	179
2	1	8	8	72	70
2	2	12	8	175	174
2	2	12	12	186	181

Table 6. Transfers Achievable With EBR-II Shutdown

Discussion

Simulation of the fuel handling system in any nuclear power plant is an important part of radioactive waste management. Lack of available models has forced the facilities to exploit deterministic models or personal judgement to estimate the required time to unload a nuclear reactor and to dispose of the radioactive waste materials. With the current emphasis on waste management and the cost associated with depleted fuel disposal, investigation into the behavior of the fuel handling system under different operating scenario is beneficial to the nuclear industry worldwide.

References

1. G. R. Imel and A. Houshyar, "System Modelling of Spent Fuel Transfers at EBR-II", Conference on DOE Spent Fuel, Salt Lake City, Utah, December, 1994.