A Computer Simulation of the Operations of a Spent Nuclear Fuel Receiving and Storage Station

Summer 1980

Jeanna Lorene Barnard
University of Central Florida

Find similar works at: https://stars.library.ucf.edu/rtd

University of Central Florida Libraries http://library.ucf.edu

Part of the Engineering Commons

STARS Citation

https://stars.library.ucf.edu/rtd/463

This Masters Thesis (Open Access) is brought to you for free and open access by STARS. It has been accepted for inclusion in Retrospective Theses and Dissertations by an authorized administrator of STARS. For more information, please contact lee.dotson@ucf.edu.
A COMPUTER SIMULATION OF THE OPERATIONS
OF A SPENT NUCLEAR FUEL
RECEIVING AND STORAGE STATION

BY

JEANNA LORENE BARNARD
B.S., Eastern Kentucky University, 1975

THESIS
Submitted in partial fulfillment of the requirements
for the degree of Master of Science In The Graduate
Studies Program of the College of Engineering
at the University of Central Florida at Orlando, Florida

Summer Quarter
1980
A COMPUTER SIMULATION OF THE OPERATIONS OF A SPENT NUCLEAR FUEL RECEIVING AND STORAGE STATION

BY

JEANNA L. BARNARD

ABSTRACT

Spent nuclear fuel is received at a storage facility in heavily shielded casks transported either by rail or by truck. Once at the storage facility, the casks are inspected, emptied, decontaminated, and reshipped.

Allied-General Nuclear Services' (AGNS) nuclear fuel reprocessing plant in Barnwell, South Carolina, is constructed but not yet licensed for spent nuclear fuel storage or reprocessing. Recently, however, AGNS was granted funds by the Department of Energy to prepare the necessary procedural and regulatory paperwork in order that the Fuel Receiving and Storage Station (FRSS) of the plant can be licensed by 1985. In this paper, the activities involved in the receiving and unloading of casks at the Barnwell FRSS is simulated by computer using IBM's program software package, General Purpose Simulation System (GPSS). The GPSS model is developed and verified, and steady-state output statistics are achieved. Also, several sensitivity analyses are performed such as, changes in expected arrival schedules and decision policies, and changes to the physical characteristics of the existing FRSS to monitor the effect of these changes in the existing system.
This thesis is dedicated to my parents.
ACKNOWLEDGMENTS

This thesis was prepared under the Chairmanship of Professor D. G. Linton. The other members of the Supervisory Committee were Professors Bauer and Hosni.

The author is exceedingly grateful to the members of the Supervisory Committee for their many suggestions. The contributions they made in terms of their time, wisdom, and guidance are greatly appreciated. The original idea for this paper stemmed from ideas suggested by Professor Linton.

The author is indebted to the personnel at Allied-General Nuclear Services (AGNS) in Barnwell, South Carolina, in particular, P. N. McCreery, P. F. Highberger, and R. T. Anderson who were most helpful in offering information and insight into the construction of the model. The Barnwell personnel supplied numerous reports, answered several data requests, and arranged a tour of the AGNS Barnwell Nuclear Fuel Plant.

The author is grateful to family, friends, and professional colleagues for their support during the preparation of this thesis.

Finally, the author claims responsibility for all mistakes.
TABLE OF CONTENTS

ACKNOWLEDGMENTS................................................................. iii
LIST OF TABLES........................................................................ v
LIST OF FIGURES....................................................................... vi
I. INTRODUCTION........................................................................ 1
II. BACKGROUND......................................................................... 4
   Description of the Fuel Receiving and Storage Station... 5
   Cask Arrival Times............................................................... 7
   Processing Times................................................................. 8
   Priority Constraints.............................................................. 15
III. MODEL DEVELOPMENT....................................................... 16
IV. MODEL VERIFICATION AND SENSITIVITY............................. 32
   Verification........................................................................... 32
   Validation............................................................................. 43
   Steady-State.......................................................................... 43
   Sensitivity Analyses............................................................ 46
V. CONCLUSIONS AND AREAS OF FUTURE RESEARCH.................... 56
APPENDIX A - Probabilistic GPSS Program Listing...................... 61
APPENDIX B - Deterministic GPSS Program Listing..................... 66
APPENDIX C - Glossary of Terms and Abbreviations.................... 70
References................................................................. 74
<table>
<thead>
<tr>
<th>Table</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I.</td>
<td>Unloading Spent Fuel - Definition of Activities and Estimated Mean Times</td>
<td>14</td>
</tr>
<tr>
<td>II.</td>
<td>Definition of GPSS Variables</td>
<td>17</td>
</tr>
<tr>
<td>III.</td>
<td>Deterministic Run (Three Arrivals) - Summary of GPSS Statistics</td>
<td>33</td>
</tr>
<tr>
<td>IV.</td>
<td>Verification of Model (Three Arrivals at Time = 0) - Manual Calculations of GPSS Simulation</td>
<td>38</td>
</tr>
<tr>
<td>V.</td>
<td>Verification of Model (Three Arrivals) - Manual Calculations of GPSS Output Statistics</td>
<td>39</td>
</tr>
<tr>
<td>VI.</td>
<td>Deterministic Run (Five Arrivals) - Summary of GPSS Statistics</td>
<td>40</td>
</tr>
<tr>
<td>VII.</td>
<td>Verification of Model (Five Arrivals at Time = 0) - Manual Calculations of GPSS Simulation</td>
<td>41</td>
</tr>
<tr>
<td>VIII.</td>
<td>Verification of Model (Five Arrivals) - Manual Calculations of GPSS Output Statistics</td>
<td>42</td>
</tr>
<tr>
<td>IX.</td>
<td>Base Case Run - Summary of GPSS Statistics</td>
<td>44</td>
</tr>
<tr>
<td>X.</td>
<td>Summary of GPSS Statistics - Steady-State Run Comparisons</td>
<td>45</td>
</tr>
<tr>
<td>XI.</td>
<td>Summary of GPSS Statistics - Sensitivity of Arrival Schedules</td>
<td>49</td>
</tr>
<tr>
<td>XII.</td>
<td>Summary of GPSS Statistics - Changes in Operational Policies</td>
<td>51</td>
</tr>
<tr>
<td>XIII.</td>
<td>Summary of GPSS Statistics - Physical Changes to the FRSS</td>
<td>55</td>
</tr>
</tbody>
</table>
# LIST OF FIGURES

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Fuel Unloading and Storage Building Configuration</td>
<td>6</td>
</tr>
<tr>
<td>2.</td>
<td>Block Diagram of Unloading Operations Sequence</td>
<td>9</td>
</tr>
<tr>
<td>3.</td>
<td>GPSS Program Block Diagram</td>
<td>23</td>
</tr>
</tbody>
</table>
I. INTRODUCTION

A growing awareness of the problems surrounding nuclear fuel and the nuclear fuel cycle has sparked intense research in the areas of spent nuclear fuel transportation and the storage and recycling of spent fuel. Presently there are seventy-two operating commercial nuclear power plants and ninety-two additional plants in various stages of construction [1]. With the commercial nuclear power industry under attack since the recent crisis at the Three Mile Island nuclear power plant near Harrisburg, Pennsylvania, citizens have been expressing deep concern about the burgeoning problems surrounding nuclear power and nuclear wastes. Highly radioactive wastes are generated from two primary sources—typical large commercial reactors and nuclear by-products of the government's weapons program. The vast majority of the existing highly radioactive wastes has been generated over the past thirty-four years by the defense program. The defense waste is enormous, consisting of some 500,000 tons of highly radioactive material and sixty-four million cubic feet of less radioactive wastes. By contrast, the spent fuel produced by a typical large reactor amounts to only about thirty to forty tons a year [1]. Projections indicate that the energy value represented by the uranium-235 (U-235) and plutonium-239 (P-239) in all the spent fuel rods accumulated in the United States by the year 2000 will be the equivalent of fifteen billion barrels of oil [1]. This fifteen
billion-barrel figure assumes that the U-235 and P-239 will be recycled in light water reactors (LWR).

The present policy of the federal government to defer nuclear fuel reprocessing indefinitely has prevented the recycling of spent nuclear fuel. Since the government has delayed the disposal or recycling of spent nuclear fuel, the existing nuclear power plants' storage pools are becoming overextended. When a solution is finally reached, transportation of spent fuel and the unloading of spent fuel assemblies must be the next areas of concern.

Spent nuclear fuel is shipped in massive, heavily shielded containers known as "casks" and is eventually transported to a nuclear storage facility or reprocessing plant. Once at the plant, the spent fuel assemblies must be unloaded from the casks and stored in water at the storage facility. This unloading process is very complicated and time-consuming. Generally, when a cask is received, it must be inspected, washed down, and moved into a test and decontamination pit (T/D pit) to undergo several preliminary unloading processes. From there it is moved into a cask unloading pool (CUP) where the fuel assemblies are removed and stored in water in the fuel storage pool (FSP). After the fuel assemblies are unloaded, the cask must be decontaminated, reinspected, and reloaded on the transport vehicle. The time it takes to complete this operation ranges from thirteen to twenty-eight hours depending on the size and type of casks being processed [2].

Allied-General Nuclear Services' (AGNS) nuclear fuel reprocessing plant in Barnwell, South Carolina, is constructed but not yet
licensed for spent fuel storage or reprocessing. Recently, however, AGNS was granted funds by the Department of Energy (DOE) to prepare the necessary procedural and regulatory paperwork in order that the Fuel Receiving and Storage Station (FRSS) of the reprocessing plant can be licensed for operation by 1985 [3]. Therefore, AGNS has begun making various operational assessments of its existing FRSS and analyzing different types of casks that will be processed at the FRSS. However, AGNS has not yet addressed any operational optimizing to minimize cask turnaround time. This thesis deals with the construction of a computer model to simulate the process of unloading spent nuclear fuel at AGNS' Barnwell plant. It is hoped that it will be used as a tool for analyzing various operating procedures and building configurations to begin optimizing cask turnaround time.
II. BACKGROUND

The queueing model of the Barnwell FRSS follows a cask as it arrives at the FRSS and undergoes the process of fuel unloading. The computer model was written in the General Purpose Simulation System (GPSS) software language available through International Business Machines Corporation (IBM) [4]. All data processing was done through the University of Central Florida's computing center on an IBM 370/165 mainframe at the Central Florida Regional Data Center in Tampa, Florida.

The procedure followed in defining the activities to be modeled is best described by discussing four generalized areas pertinent to the physical situation. These areas are:

a. description of the fuel receiving and storage station,
b. cask arrival times,
c. processing times, and
d. priority constraints.

Various reports and information were supplied by AGNS personnel describing the physical and operational configuration of the FRSS. However, to assure a true understanding of the complex receiving station, the author constructed a small scale mock-up of the FRSS which provided a visual means of going through the complicated steps the casks undergo during fuel unloading. The model also proved very helpful as a means of communication with AGNS personnel and other interested parties.
Description of the Fuel Receiving and Storage Station

The five major locations at the FRSS where casks undergo processing are: (1) the parking lot outside the building (or holding area), (2) the vehicle unloading bay inside the building, (3) the test and decontamination pit, (4) the cask unloading pool, and (5) a small decontamination pit. Figure 1 is a physical configuration of the FRSS at Barnwell. The physical limitations of each of the five locations are an important factor in the development of the model. The parking lot can essentially "store" (hold) an unlimited number of casks. However, the two bay areas, the small decontamination pit, and the two CUPs can hold only one cask each. The large T/D pit can hold up to four casks at one time. Thus, the combined capacity of the internal facilities of the plant is at most nine casks at one time. However, it should be pointed out that the small decontamination pit cannot "hold" any casks, therefore the maximum number of casks in the system can be only eight at any one time.

There are two cranes (a main crane and a fuel crane) that are used for all cask movement and fuel unloading. The 135-ton capacity hook on the main crane is used for all cask movements. A 25-ton auxiliary hook on the same crane is used to handle smaller items. It should be emphasized that these two hooks cannot be used simultaneously.

The dedicated fuel crane servicing the two CUPs (one at a time) and the fuel grapple are used for the removal of fuel assemblies from the cask and for placing the individual assemblies into the storage canisters in the fuel storage pool. A third crane moves canisters from the
Figure 1. Fuel Unloading and Storage Building Configuration
loading area in the CUP to the FSP. No two cranes can work in the same area at the same time (assuming the CUPs are in separate areas).

Cask Arrival Times

Probably the most important assumption made in a queueing model is the definition of the arrival times or the interarrival times of a "transaction" (or, in this case, a cask). Since actual arrival schedules were not available, several broad assumptions were made in order to simulate a pessimistic view of arrivals. The casks have been categorized into three types: legal weight (LW) truck casks, overweight (OW) truck casks, and rail casks. Based on discussions with AGNS personnel, it was assumed that out of a fleet of thirty rail casks the arrival rate will average one a day. To account for the possibility of arrivals in bunches with "dry spells" in between, a variance of plus or minus 24 hours was assumed. This resulted in interarrival times uniformly distributed over the integer values 0 to 48 hours with 24 hours as the mean value and an equal probability of $1/49$ of any event 0 to 48 occurring. The same basis of thought was applied to truck receipts. A fleet of fifteen LW trucks with an average round trip of five days will arrive at a rate of about three a day; but, to account for the uncertainty of arrival times, instead of scheduling an arrival every eight hours, AGNS assumed that any scheduled arrival time can vary as much as eight hours. The resulting interarrival times were uniformly distributed over the integer values 0 to 16 hours with eight hours as the mean value. The fact that overweight trucks cannot arrive on a Saturday or Sunday or
during hours of darkness makes the simulation more complex. Therefore, it was assumed that there will be approximately two arrivals of OW trucks each week (i.e., one every three days).

**Processing Times**

Several time-consuming activities are involved in receiving and unloading casks (processing times). A block diagram describing the general activities involved is shown in Figure 2. This diagram associates the activities of the cask with the location of the cask within the FRSS. Due to the capacity, design, and size of each cask, different processing times according to the cask type are expected. The rail cask can hold ten Pressurized-Water Reactor (PWR) spent fuel assemblies or 24 Boiling-Water Reactor (BWR) assemblies while the truck cask can hold one PWR assembly or two BWR assemblies.

A detailed outline of the steps involved in unloading truck casks based on the equipment and operational procedures developed for the Barnwell Nuclear Fuel Plant (BNFP) follows [5].

**Truck Casks:**

**Parking Lot**

1. Perform radiological inspections.
2. Perform vehicle safety inspection.
3. Remove the personnel barrier.
4. Survey cask body for radiation contamination.
5. Wash down road dirt from the cask and trailer.
6. Move the vehicle into the bay area in the FRSS.

**Bay Area**

7. Remove impact limiters.
8. Remove tie-down bolts.
9. Using the A lifting yoke (of the main crane), engage the lifting trunnions and rotate the cask to the vertical position.
Figure 2. Block Diagram of Unloading Operations Sequence
10. Raise the cask (with the crane) from the trailer and set it in the designated work station in the T/D pit.

**T/D Pit**

11. Remove outer head cavity valve cover plates.
12. Open outer head cavity valve.
13. Loosen bolts; remove outer head and store.
14. Remove the two inner fuel cavity valve covers.
15. Attach cooldown system hoses and cool down the system until the effluent water temperature is $150^\circ$ or less.
16. Loosen inner head bolts.
17. Attach guide brackets to lifting yoke.
18. Attach head slings to lifting yoke and inner head.
19. Attach lifting yoke to cask.
20. Transfer to CUP (with crane).

**CUP**

21. Lower cask to floor of pool unloading area.
22. Release yoke lift arms and raise lifting yoke bringing inner head with it.
23. Detach and store inner head.
24. Operate fuel grapple from fuel bridge and transfer fuel from cask to preassigned storage position in a cannister. Remove fuel canisters (with canister crane).
25. Re-engage cask with lifting yoke.
26. Transfer cask to decontamination area (with crane).

**Decontamination Pit**

27. Spray-rinse cask exterior (initial decontamination).
28. Move cask from Decontamination Pit to T/D pit.

**T/D Pit**

29. Replace inner head.
30. Flush cask with minimum of two volumes of clean demineralized water. Remove water from the fuel cavity of the cask.
31. Attach valve covers to the inner head.
32. Blot excess water from the surfaces of the outer cavity.
33. Allow water to drain from the two outer cavity access lines.
34. Attach outer head line.
35. Decontaminate accessible cask surfaces.
36. Return cask to trailer.

**Bay Area**

37. Replace tie-down bolts.
38. Attach impact limiters.
39. Move cask and truck from the FRSS to the parking lot.

Parking Lot

40. Install personnel barrier.
41. Complete all radiological inspections.
42. Complete shipping papers and sign-offs.

Following are the steps involved in unloading rail casks based on information provided by the BNFP personnel regarding the equipment and operational procedures developed for BNFP [6].

Rail Casks:

Parking Lot

1. Perform the required radiological inspection.
2. Perform a system safety inspection.
3. Open the top section of the "clam shell" type personnel barrier.
4. Complete the radiation and contamination survey of the cask system.
5. Move cask to washdown area.
6. Wash cask and vehicle down.
7. Move vehicle to unloading bay.

Bay Area

8. Shut down auxiliary cooling unit.
9. Remove rear tie-down pin and raise rear end of cask. Remove rear impactor and move turning fixture into place. Lower the cask into saddle supports by retracting the rear jack.
10. Remove front tie-down pin and raise front of cask. Remove front impactor.
11. Disconnect the secondary cooling unit. Flush and drain the cask internal cooling lines and cavities.
12. Disconnect the neutron shield water jacket expansion line.
13. Attach yoke to the lifting trunnions and raise cask to the vertical position (with crane).

T/D Pit

15. Remove lifting yoke.
16. Connect neutron water shield to a temporary expansion tank.
17. Perform steps for sampling the cavity and venting, if necessary.
18. Remove outer closure head and inspect gasket.
20. Connect the cask to the cool-down system and complete the cool down of the cask.
21. Install protective contamination barrier around the cask.
22. Remove specified number of closure head nuts.
23. Attach head lifting slings to yoke. Engage yoke to cask trunnion.
24. Lift cask from the T/D pit to the CUP (with crane).

CUP

25. Disengage the lifting yoke arms from the cask trunnions. Raise the yoke bringing inner head closure from the pool with the crane.
26. Using the proper fuel assembly grapple, unload the fuel from the cask to the pre-assigned position in the fuel canister. Remove canister from CUP to FSP using the canister crane.
27. Transfer cask to the decontamination area.

Decontamination Pit

28. Spray-rinse cask exterior (initial decontamination); then place cask in T/D pit.

T/D Pit

29. Replace the inner closure head. Drain and flush the cask using demineralized water.
30. Remove service hoses and replace valve covers.
31. Remove protective contamination barrier.
32. Decontaminate cask exterior surfaces.
33. Install valve box covers.
34. Replace outer closure head.
35. Return cask to rail car (with crane).

Bay Area

36. Lower cask to horizontal position on the rail car.
37. Reconnect neutron shield water line to the expansion tanks.
38. Install front impact structure using hydraulic jacking system. Lower jack and replace tie-down pins.
39. Raise bottom of cask and move the turning fixture to its travel configuration.
40. Install bottom impact structure; lower cask to support frame; and engage the bottom tie-down pins.
41. Conduct radiological inspection and contamination surveys.
42. Close the "clam shell" personnel barrier.
43. Move the rail car from the building into the parking lot.

Parking Lot

44. Complete required shipping papers and sign off.

The numerous steps involved in cask receiving and unloading were generalized into fourteen activities by cask type. The expected times to perform these tasks for the three types of casks are shown in Table I. Also, the detailed steps are mapped to the fourteen general activities for reference. This table is based on "normal" processing although approximately five percent of the casks may arrive with excessive exterior contamination (e.g., radioactive wastes). In case of such excessive contamination, the casks, still on their vehicles, must be washed down and "set aside" in the parking lot for 160 minutes. They then join the queue of casks at the point of arrival and proceed in the regular manner.

The information on cask handling operations is based on operations performed in the BNFP-FRSS under simulated conditions using both experienced and inexperienced personnel [2].

The Barnwell personnel suggested that in actual practice the frequency distribution of processing times should exhibit a marked skewing toward longer times. To achieve this type of behavior, a K-Erlang distribution function was constructed by summing K exponential distributions [7]. This distribution function was then normalized to exhibit a mean of one so that the different mean times for each activity could be easily mapped into the distribution function.
# Table 1

### Unloading Spent Fuel

**Definition of Activities and Estimated Mean Times**

<table>
<thead>
<tr>
<th>Description of Activities</th>
<th>Mean Times in Minutes by Cask Type</th>
<th>Detailed Steps For Each Cask Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LW Truck</td>
<td>OW Truck</td>
</tr>
<tr>
<td><strong>Parking Lot</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A</td>
<td>Receive, inspect, survey, and wash down cask and move vehicle into unloading bay.</td>
<td>125</td>
</tr>
<tr>
<td><strong>Bay Area</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Remove Impactor; ready cask for transport into T/O Pit.</td>
<td>75</td>
</tr>
<tr>
<td>C</td>
<td>Lift cask from vehicle to T/O Pit.</td>
<td>15</td>
</tr>
<tr>
<td><strong>T/O Pit</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Prepare cask for unloading (includes cask flush).</td>
<td>60</td>
</tr>
<tr>
<td>E</td>
<td>Additional time for cask cooldown.</td>
<td>65</td>
</tr>
<tr>
<td>F</td>
<td>Move cask into CDP.</td>
<td>30</td>
</tr>
<tr>
<td>G</td>
<td>Move fuel assemblies into cask.</td>
<td>45</td>
</tr>
<tr>
<td>H</td>
<td>Remove fuel canister(s) from CDP to FSP.</td>
<td>10</td>
</tr>
<tr>
<td><strong>Decommissioning Pit</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Move cask from CDP to decommissioning Pit and decontaminate cask.</td>
<td>35</td>
</tr>
<tr>
<td>J</td>
<td>Move cask from decommissioning Pit to T/O Pit.</td>
<td>30</td>
</tr>
<tr>
<td><strong>T/O Pit</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Prepare cask for return.</td>
<td>175</td>
</tr>
<tr>
<td>L</td>
<td>Move cask to carrier.</td>
<td>20</td>
</tr>
<tr>
<td><strong>Bay Area</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>Replace inspect limiters, complete tie-down.</td>
<td>30</td>
</tr>
<tr>
<td><strong>Parking Lot</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>Move vehicle to parking lot, finalize survey, replace barrier, prepare papers, sign off.</td>
<td>80</td>
</tr>
<tr>
<td><strong>Total processing time in minutes</strong></td>
<td>765</td>
<td>665</td>
</tr>
<tr>
<td><strong>Total processing time in hours</strong></td>
<td>12.75</td>
<td>15.75</td>
</tr>
<tr>
<td><strong>Time in FSS in hours</strong></td>
<td>9.25</td>
<td>12.45</td>
</tr>
<tr>
<td><strong>Time outside FSS in hours</strong></td>
<td>3.50</td>
<td>3.30</td>
</tr>
<tr>
<td><strong>Man hours/MTH (Metric tons of uranium)</strong></td>
<td>94.20</td>
<td>43.60</td>
</tr>
</tbody>
</table>
Priority Constraints

Exceptional actions enforced according to "priorities" often prove to be important factors in a queueing model. This area is sometimes the most difficult to define since in a real life situation certain actions are normal to an individual when, in fact, he is imposing a priority. However, in the case of a computer simulation, these actions may not be performed. For instance, in actual practice the AGNS personnel feel that no priorities will be imposed on its FRSS when it is in operation. However, if several casks are waiting to "seize" the crane in order to move into the T/D pit, the cask leaving the CUP should take priority over a cask leaving the bay. This is because operating personnel implicitly feel that it is more important to move a cask going out of the building instead of one coming in. Also, during a computer simulation where many casks are waiting to enter the FRSS, a situation might occur where the FRSS is full and no casks can get in or out, thus stopping the model of any further simulation. Consequently, one may assume that after a cask has been unloaded in the CUP, it has priority over a cask coming into the building. Since only one crane can move casks at any one time, this implicit priority proves important in trying to simulate actual operations.
III. MODEL DEVELOPMENT

The approach taken in selecting the type of model to simulate the activities in the Barnwell FRSS was to attempt to follow a cask through the different processes, step-by-step. This was done in order that operational policies and decisions could be made with the help of a dynamic model that could be easily updated for sensitivity analyses and operational changes.

A GPSS model was developed to simulate the process of cask receiving and unloading at the BNFP. The model accounts for the areas discussed in the prior section and analytically describes them in GPSS terms. Table II presents a list and interpretation of the GPSS entities used in the queueing model. These entities are developed and discussed below. Appendix A includes a listing of the GPSS program discussed. Refer to Appendix C for a brief description of the GPSS terms used herein.

The model is composed of a major segment and two supporting segments. Movement of the various casks through the FRSS is simulated in the major segment (Segment 2). The three cask types are brought into the model at various expected times in one of the supporting segments (Segment 1). They are then routed into the major segment. A timer is simulated to terminate the run at a designated time in the other supporting segment (Segment 3) which is self-contained.
<table>
<thead>
<tr>
<th>GPSS Entity</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Transactions:</strong></td>
<td></td>
</tr>
<tr>
<td>Model Segment 1</td>
<td>Generation of cask arrivals by type</td>
</tr>
<tr>
<td>Model Segment 2</td>
<td>Processing of casks at the FRSS</td>
</tr>
<tr>
<td>Model Segment 3</td>
<td>Timer</td>
</tr>
<tr>
<td><strong>Parameters:</strong></td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>Cask type:</td>
</tr>
<tr>
<td></td>
<td>1 = LW truck casks</td>
</tr>
<tr>
<td></td>
<td>2 = OW truck casks</td>
</tr>
<tr>
<td></td>
<td>3 = rail casks</td>
</tr>
<tr>
<td>P2</td>
<td>Parameter to denote a contaminated cask has arrived:</td>
</tr>
<tr>
<td></td>
<td>0 = uncontaminated cask</td>
</tr>
<tr>
<td></td>
<td>1 = contaminated cask</td>
</tr>
<tr>
<td>P3</td>
<td>Parameter to denote if cask enters one of the center spaces in the T/D pit</td>
</tr>
<tr>
<td></td>
<td>(PITC storage):</td>
</tr>
<tr>
<td></td>
<td>0 = entered PIT</td>
</tr>
<tr>
<td></td>
<td>1 = entered PITC</td>
</tr>
<tr>
<td><strong>Facilities:</strong></td>
<td></td>
</tr>
<tr>
<td>CRANE</td>
<td>The main 135-ton crane used for all cask movements (2 hooks, but only 1 in use at a time)</td>
</tr>
<tr>
<td>GRAP</td>
<td>A fuel grapple and crane used for moving the spent fuel from the cask into the FSP</td>
</tr>
</tbody>
</table>
TABLE II
Definition of GPSS Variables
(Page 2 of 3)

<table>
<thead>
<tr>
<th>GPSS Entity</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Functions:</strong></td>
<td></td>
</tr>
<tr>
<td>AAA - NNN</td>
<td>Functions describing the expected time it takes to process activities A through N (See Table I) based on the cask types 1, 2, or 3</td>
</tr>
<tr>
<td>XPDIS</td>
<td>Exponential distribution function</td>
</tr>
<tr>
<td>BAD</td>
<td>A function describing the distribution of contaminated casks. Five percent of the time it sets the parameter P2 equal to 1 to denote a contaminated cask</td>
</tr>
<tr>
<td><strong>Variables:</strong></td>
<td></td>
</tr>
<tr>
<td>ADIS - NDIS</td>
<td>Variables taking on a K-Erlang distribution function where $K = 3$ and the mean $K/\lambda$ = the respective values from functions AAA through NNN</td>
</tr>
<tr>
<td><strong>Storages:</strong></td>
<td></td>
</tr>
<tr>
<td>PARK</td>
<td>A storage simulating the parking lot (or holding area) outside the FRSS. Its capacity is essentially unlimited.</td>
</tr>
<tr>
<td>FRSS</td>
<td>A storage simulating the FRSS building with a normal capacity of six.</td>
</tr>
<tr>
<td>BAY</td>
<td>A storage simulating the two bay areas inside the FRSS</td>
</tr>
<tr>
<td>PIT</td>
<td>A storage simulating the two outside spaces of the four available in the T/D pit</td>
</tr>
<tr>
<td>PITC</td>
<td>A storage simulating the two center spaces of the four available in the T/D pit</td>
</tr>
<tr>
<td>POOL</td>
<td>A storage simulating the two CUPs available in the pool area to store casks when unloading</td>
</tr>
</tbody>
</table>
### TABLE II

**Definition of GPSS Variables**

(Page 3 of 3)

<table>
<thead>
<tr>
<th>GPSS Entity</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Storages: (continued)</strong></td>
<td></td>
</tr>
<tr>
<td>DPIT</td>
<td>A storage simulating the small decontamination pit beside the CUPs</td>
</tr>
<tr>
<td><strong>Queues:</strong></td>
<td></td>
</tr>
<tr>
<td>PARKQ</td>
<td>The queue in which casks wait in the parking lot until a bay area is available</td>
</tr>
<tr>
<td>BAYQ</td>
<td>The queue in which casks wait in the bay until a space in the T/D pit is available</td>
</tr>
<tr>
<td>PITQ</td>
<td>The queue in which casks wait in the T/D pit until a CUP is available</td>
</tr>
<tr>
<td>POOLQ</td>
<td>The queue in which casks wait in the CUP (POOL) until spaces in the T/D pit and the Decontamination pit are available</td>
</tr>
<tr>
<td>PITQ2</td>
<td>The queue in which casks wait in the T/D pit until one of the bay areas is available</td>
</tr>
<tr>
<td><strong>Tables:</strong></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>The table used to estimate the residence time of a type 1 cask (LW truck cask)</td>
</tr>
<tr>
<td>2</td>
<td>The table used to estimate the residence time of a type 2 cask (OW truck cask)</td>
</tr>
<tr>
<td>3</td>
<td>The table used to estimate the residence time of a type 3 cask (rail cask)</td>
</tr>
<tr>
<td>TOT</td>
<td>The table used to estimate the residence time of any type of cask that enters the model</td>
</tr>
</tbody>
</table>
Transactions are generated in Model Segment 1 to simulate the arrival of casks. Three separate generate blocks are used to model the different arrival schedules. As transactions are generated in each block, parameter one (Pl) is assigned a value of 1, 2, or 3 to denote an LW truck cask arrival, OW truck cask arrival, or rail cask arrival, respectively. This parameter is used as an index in the major segment to develop the respective processing times (see Table I) since cask types have different expected times for each specific activity. Also, in order to simulate the possibility of casks arriving with exterior contamination, parameter two is assigned a value from a function that has a value of one, five percent of the time, modeling the fact that approximately five percent of the casks arriving have exterior contamination. This parameter is tested in the major model segment to decide whether a cask needs exterior decontamination before processing.

Model Segment 2 of the program is constructed to represent the FRSS and the activities of the casks within the FRSS. Seven "storages" are defined to represent the locations in which casks move. The parking lot or holding area is represented by a storage named PARK with unlimited capacity. The FRSS building is represented by the storage FRSS with a capacity of six. Even though the building can "hold" eight casks at once, the Barnwell personnel feel that a maximum of six casks should be in the building at one time in order that casks can come in and out of the building with minimal congestion. The bay area is represented by a storage named BAY with a capacity of two. Theoretically, the T/D pit can hold four casks at one time. However, for certain activities such
as a cask cooldown, only the two center spots can be used. Therefore, two storages named PIT and PITC, each with a capacity of two, are used to define the T/D pit. A storage named POOL with a capacity of two represents the two CUPs.

Two "facilities" are defined to represent the limited equipment available at the FRSS for cask movement and fuel handling. A facility named CRANE is defined to represent the single 135-ton crane that is used for all cask movement. The fuel crane and grapple are represented by a facility named GRAP.

Five queues were developed to tabulate the time a transaction is waiting either for a location to become available or for a facility. The queue, PARKQ, keeps track of the time a cask waits in the parking lot for a bay area to become available. The queue BAYQ tabulates the time a cask waits in the bay area for a space in the T/D pit or for the crane if the crane is not available. The PITQ is a queue in which a cask waits for the crane or for one of the CUPs (POOL storage) to become available. The POOLQ queue tabulates the time a cask waits for a center space in the T/D pit (PITC storage) to become available or when it is waiting for the crane. The PITQ2 is a queue to tabulate the time a cask waits for the crane to become available or for one of the bay areas to become available.

To model the process of casks moving into a storage location and undergoing some activity, such as fuel unloading, several "advance" blocks are used, each with a mean time representing a specific activity. Mean times are defined by the use of several functions. Functions "AAA"
through "NNN" represent the expected times for cask types 1, 2, or 3 (depending on the parameter Pl) to undergo the activities "A" through "N" described in Table I, Section II. To simulate a variance in the mean times, a K-Erlang distribution function was developed [7]. It was constructed by summing three exponential distributions and normalizing it to exhibit a mean of one, thus simplifying mapping the mean times into the K-Erlang distribution. Taking the resultant distribution and multiplying it by the expected mean yields the formula for the K-Erlang distribution

\[ F_x(t) = \frac{k}{(K-1)!} \frac{e^{-\lambda t} \lambda^k}{t^{K-1}}, \quad t > 0, \]

where \( E(x) = K/\lambda \) and \( \text{VAR}(x) = K/\lambda^2 \).

To develop this distribution in the GPSS model, a function called XPDIS which approximates a cumulative exponential distribution with a mean value one is defined. Several real variables (ADIS – NDIS) select three independent and identically distributed random variables from the XPDIS distribution and calculate their average value. The random variables are then multiplied by the functions AAA through NNN prior to being considered as a value for the respective advance blocks. Thus, the desired skewed distributions are obtained.

A block diagram of the flow of a transaction through the model with an implicit time unit of 0.1 minutes is shown in Figure 3.

As a transaction (cask) moves from model Segment 1 to model Segment 2 and enters the storage location PARK, it is first tested for
Figure 3. GPSS Program Block Diagram
Figure 3. Continued
Figure 3. Continued
Figure 3. Continued
Figure 3. Continued

F. move casks from T/D pit to POOL

leave center spot in T/D pit

G. move fuel assemblies into pool

H. move fuel canisters from case

set higher priority for leaving

Figure 3. Continued
Figure 3. Continued
Figure 3. Continued
exterior contamination by verifying if $P_2 = 1$, where $P_2 = 1$ implies contamination. If the cask is contaminated, it is set aside in an "advance" block for 160 minutes. When the cask first arrives, it undergoes several preliminary unloading processes as simulated in the advance block A. The cask then waits in the parking lot until three conditions are met: (i) fewer than six casks must be in the FRSS; (ii) a bay area is available; and (iii) a center spot in the T/D pit is available. These conditions are necessary in order that the casks already in the FRSS are not "blocked" by a cask coming into a bay area. If this blocked condition occurs, the simulation will, in a sense, "halt" because no casks can get in or out of the FRSS. In actual practice, the Barnwell personnel will never move a cask into the FRSS if there is no space in the T/D pit for this processing. The three conditions are designed to simulate the operational policy that would be logical to the operating personnel. After the cask moves into a bay area, it is made ready for transport into the T/D pit as simulated by advance block B. The cask then waits for one of the two center spaces in the T/D pit. If neither space is available, the cask waits in the bay queue. When a space becomes available, the location is reserved for that cask which tries to seize the crane. If the crane is available, the cask moves into the T/D pit simulated by advance block C. If not, it waits in the bay area until the crane is available. After the cask is moved into the T/D pit, the outer head is removed, a cask sample is taken, and a cask cooldown is performed (advance blocks D and E). The cask then waits until one of the CUPs and the crane are available. Once the crane is
available, the cask moves into the CUP, simulated by advance block F. The fuel assemblies are then removed by the fuel crane and grapple (advance block G), and the fuel canisters are removed by the fuel crane (advance block H). When the cask is unloaded, a higher priority level is set for leaving POOL. The cask waits in the pool queue until the small decontamination pit and one of the center spaces in the T/D pit are available. The cask is then lifted over the small decontamination pit where it is initially decontaminated (advance block I). Next it is moved into one of the four spaces in the T/D pit (advance block J). In the T/D pit the cask is prepared for return as simulated by advance block K. At that time its priority level is again raised since the cask only has to be reloaded on the vehicle to exit the FRSS. The cask then waits in the T/D pit queue until the crane and one of the bay areas are available. At this point, it has priority over any other cask in the FRSS to seize the crane and enter a new location. When the crane and one bay area are available, the cask is moved from the T/D pit onto its carrier (advance block L). Once on the carrier, the cask is made ready for transport as simulated by advance block M. The carrier moves the cask from the FRSS into the parking lot where final survey and processing are performed (advance block N). When the transaction leaves the model, the total residence time (total time in the model) is recorded in Tables 1, 2, or 3 and a total table.
IV. MODEL VERIFICATION AND SENSITIVITY

Verification

A major factor in the validity of a simulation model and its output is the ability to determine the results of the computer analytically. The procedure employed to achieve this verification is threefold. The computer model is adjusted such that all arrival times and advance blocks are deterministic. The deterministic model is run under these conditions and the output statistics are recorded. Then, the output statistics are manually computed by going through the steps the program should have taken and the results are compared. This procedure should convince the programmer that the translated model executes as intended. Appendix B includes a listing of the GPSS model adjusted to simulate the deterministic situation discussed heretofore.

The probabilistic model developed in Section III is adjusted so that the steps the program undergoes can be followed analytically. All the advance blocks in the model are set with an A-operand only, making the processing times the mean durations shown in Table I of Section II. The generate blocks are adjusted so that all arrivals are deterministic. Several deterministic runs are analyzed in order that all queueing situations are addressed.

One such run of a deterministic model with three arrivals (one of each cask type) at time zero and the timer set to arrive at 1770 minutes generates the GPSS output shown in Table III.
### TABLE III

Deterministic Run (Three Arrivals)

Summary of GPSS Statistics

<table>
<thead>
<tr>
<th>Facility</th>
<th>Number Entries</th>
<th>Average Time/Trans.*</th>
<th>Average Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRANE</td>
<td>12</td>
<td>35.000</td>
<td>0.237</td>
</tr>
<tr>
<td>GRAP</td>
<td>3</td>
<td>133.333</td>
<td>0.225</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Storage</th>
<th>Capacity</th>
<th>Average Contents</th>
<th>Entries</th>
<th>Average Time/Unit*</th>
<th>Average Utilization*</th>
<th>Maximum Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARK</td>
<td>-</td>
<td>0.356</td>
<td>6</td>
<td>105.000</td>
<td>0.000</td>
<td>3</td>
</tr>
<tr>
<td>FRSS</td>
<td>6</td>
<td>1.653</td>
<td>3</td>
<td>975.000</td>
<td>0.275</td>
<td>3</td>
</tr>
<tr>
<td>BAY</td>
<td>2</td>
<td>0.328</td>
<td>6</td>
<td>96.667</td>
<td>0.163</td>
<td>2</td>
</tr>
<tr>
<td>PIT</td>
<td>2</td>
<td>0.661</td>
<td>3</td>
<td>390.000</td>
<td>0.330</td>
<td>2</td>
</tr>
<tr>
<td>POOL</td>
<td>2</td>
<td>0.418</td>
<td>3</td>
<td>246.667</td>
<td>0.209</td>
<td>2</td>
</tr>
<tr>
<td>DPIT</td>
<td>1</td>
<td>0.136</td>
<td>3</td>
<td>80.000</td>
<td>0.135</td>
<td>1</td>
</tr>
<tr>
<td>PITC</td>
<td>2</td>
<td>0.421</td>
<td>3</td>
<td>248.333</td>
<td>0.210</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Queue</th>
<th>Maximum Contents</th>
<th>Average Contents</th>
<th>Total Entries</th>
<th>Zero Entries</th>
<th>Percent Entries</th>
<th>Average Time/Trans.*</th>
<th>$Average Time/Trans.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARKQ</td>
<td>1</td>
<td>0.002</td>
<td>3</td>
<td>2</td>
<td>66.6</td>
<td>1.666</td>
<td>5.000</td>
</tr>
<tr>
<td>BAYQ</td>
<td>1</td>
<td>0.031</td>
<td>3</td>
<td>2</td>
<td>66.6</td>
<td>18.333</td>
<td>55.000</td>
</tr>
<tr>
<td>PITQ</td>
<td>1</td>
<td>0.033</td>
<td>3</td>
<td>2</td>
<td>66.6</td>
<td>20.000</td>
<td>60.000</td>
</tr>
<tr>
<td>POOLQ</td>
<td>1</td>
<td>0.019</td>
<td>3</td>
<td>1</td>
<td>33.0</td>
<td>11.666</td>
<td>17.500</td>
</tr>
<tr>
<td>PITQ2</td>
<td>1</td>
<td>0.000</td>
<td>3</td>
<td>3</td>
<td>100.0</td>
<td>0.000</td>
<td>0.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table</th>
<th>Entries</th>
<th>Mean*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>765</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>1025</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>1765</td>
</tr>
<tr>
<td>Total</td>
<td>3</td>
<td>1185</td>
</tr>
</tbody>
</table>

*Times shown in minutes. Stop Time = 1770.

$Average Time/Trans. = Average time/trans. excluding zero entries.
Following is a mathematical description of the calculations made by the GPSS processor to arrive at the statistics shown.

Define $\bar{T} =$ total time shown on the absolute clock when the run terminates.

Let $A_i(\cdot)$ be the function which determines the time for the $i$-th activity based on the "type" of transaction and let $y_i =$ "type" of the $i$-th transaction, that is $A_i: \{ \text{all possible transaction types} \} \rightarrow \mathbb{R}$. Thus, if $T_{i,j} =$ time that elapses during the $i$-th activity for the $j$-th transaction, then,

$$T_{i,j} = A_i(y_j).$$

Define $N(t) =$ total number of transactions entering the model at time $t = 0, 1, 2, \ldots \bar{T}$. Clearly then,

$$N(\bar{T}) = \sum_{T = 0}^{\bar{T}} N(T).$$

Define the set of integers, $X_k = \{ i : \text{the } i\text{-th activity is included in the GPSS entity } k \}$.

Define the function,

$$I_{j,k}(t) = \begin{cases} 1, & \text{if the } j\text{-th transaction has entered the GPSS entity } k \text{ at time } t, \\ 0, & \text{otherwise}. \end{cases}$$

Let $a_k(t) =$ average time per transaction for all activities included in the GPSS entity $k$ at time $t$. If $a_k(t) =$ the sum of all activities for all transactions entering the $k$-th GPSS entity at time $t$ divided by the number of transactions entering the $k$-th GPSS entity at time $t$, then,
\[ a_k(t) = \frac{\sum_{i \in X_k} \sum_{j=1}^{N(t)} T_{i,j} I_{i,j,k}(t)}{\sum_{j=1}^{N(t)} I_{i,j,k}(t)} \]

Let \( a_k(T) = \) average time per transaction for all activities included in the GPSS entity \( k \) by time \( T \) (the end of the simulation).

Clearly,
\[ a_k(T) = \sum_{T=0}^{T} a_k(T), \]

Let \( U_k(t) = \) average utilization per transaction for the GPSS entity \( k \) by time \( t \). Then,
\[ U_k(t) = \frac{\sum_{i \in X_k} \sum_{j=1}^{N(t)} T_{i,j} I_{i,j,k}(t)}{t} \]

Let \( U_k(T) = \) average utilization per transaction for the GPSS entity \( k \) by the end of the simulation (or time \( T \)). If \( U_k(T) = \) the sum of all activities for all transactions that have entered the \( k \)-th GPSS entity by \( T \) divided by \( T \), then,
\[ U_k(T) = \frac{\sum_{T=0}^{T} \sum_{i \in X_k} \sum_{j=1}^{N(T)} T_{i,j} I_{i,j,k}(T)}{T} \]

In particular, the GPSS statistics for each type of GPSS entity can be defined as follows:

Facility statistics of the \( k \)-th GPSS entity:
Number of entries $= \sum_{T=0}^{T} \sum_{j=1}^{I_{j,k}(T)} N(T)$.

Average time per transaction $= a_{k}(T)$.  
Average utilization $= U_{k}(T)$.

Storage Statistics of the $k$-th GPSS entity:

The capacity of each storage is defined by the user. Let $C_{k}$ denote the capacity of the $k$-th GPSS entity.

Average contents $= U_{k}(T)$.

Number of entries $= \sum_{T=0}^{T} \sum_{j=1}^{I_{j,k}(T)} N(T)$.

Average time per unit transaction $= a_{k}(T)$.

Average utilization $= \frac{U_{k}(T)}{C_{k}}$.

Maximum contents $= \max_{t} \sum_{j=1}^{I_{j,k}(t)} N(T)$.

Queue statistics of the $k$-th GPSS entity:

Maximum contents $= \max_{t} \sum_{j=1}^{I_{j,k}(t)} N(T)$.

Average contents $= U_{k}(T)$.

Total Entries $= \sum_{T=0}^{T} \sum_{j=1}^{I_{j,k}(T)} N(T) = n_{k}$.

Zero entries $= Z_{k} = \sum_{T=0}^{T} \sum_{j=1}^{I_{j,k}(T)} N(T)$.
\[ V \ j \text{ such that } \sum_{T=0}^{T} \sum_{i \in X_k} I_{i,j,k}(T) = 0. \]

Average time per transaction (including zero entries) = \( a_k(T) \).

Average time per transaction (excluding zero entries)

\[ \frac{a_k(T) n_k}{n_k - Z_k}. \]

Table IV is a summary of the manual calculations made of the GPSS simulation. Table V is a summary of the manual calculations of the GPSS output statistics (from information in Table IV) which compares with the deterministic output shown in Table III.

An additional deterministic run is presented to assure that every queueing situation was analyzed. Table VI is a summary of the GPSS output statistics from a deterministic run with five arrivals at time zero (two LW trucks, two OW trucks, and one rail cask) with the simulation ending at time 2150 minutes. Following the same logic as presented in the analytical definitions, Table VII is a summary of the manual calculations of the GPSS simulation. Table VIII is a summary of the manual calculations of the GPSS output statistics (from information in Table VII).

Comparing the results of Tables III and V and of Tables VI and VIII demonstrates that the GPSS model can be manually followed and the GPSS statistics reproduced, resulting in the conclusion that the model behaves as intended.
### TABLE IV

<table>
<thead>
<tr>
<th>Mean Time</th>
<th>T₁₂</th>
<th>LW Truck (J-1)</th>
<th>OW Truck (J-2)</th>
<th>Rail</th>
<th>Activity</th>
<th>Block Count</th>
<th>Zero Entries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Status T₁₁</td>
<td>Status T₁₂</td>
<td>Status T₁₃</td>
<td>Status T₂₁₂</td>
<td>Status T₂₁₃</td>
<td>T₁₁</td>
</tr>
<tr>
<td>A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PARFQ</td>
<td></td>
<td>125</td>
<td>125</td>
<td>120</td>
<td>120</td>
<td>160</td>
<td>160</td>
</tr>
<tr>
<td>B</td>
<td></td>
<td>25</td>
<td>150</td>
<td>55</td>
<td>175</td>
<td>100</td>
<td>265</td>
</tr>
<tr>
<td>RANQ</td>
<td></td>
<td>0</td>
<td>150</td>
<td>0</td>
<td>175</td>
<td>55</td>
<td>320</td>
</tr>
<tr>
<td>C</td>
<td></td>
<td>15</td>
<td>165</td>
<td>15</td>
<td>190</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>D</td>
<td></td>
<td>60</td>
<td>225</td>
<td>90</td>
<td>280</td>
<td>150</td>
<td>450</td>
</tr>
<tr>
<td>E</td>
<td></td>
<td>55</td>
<td>290</td>
<td>120</td>
<td>400</td>
<td>50</td>
<td>560</td>
</tr>
<tr>
<td>PITQ</td>
<td></td>
<td>0</td>
<td>290</td>
<td>WC 60</td>
<td>460</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>F</td>
<td></td>
<td>35</td>
<td>320</td>
<td>35</td>
<td>440</td>
<td>40</td>
<td>580</td>
</tr>
<tr>
<td>G</td>
<td></td>
<td>45</td>
<td>365</td>
<td>115</td>
<td>665</td>
<td>240</td>
<td>865</td>
</tr>
<tr>
<td>H</td>
<td></td>
<td>30</td>
<td>395</td>
<td>30</td>
<td>615</td>
<td>60</td>
<td>905</td>
</tr>
<tr>
<td>POOLQ</td>
<td></td>
<td>0</td>
<td>395</td>
<td>WC 20</td>
<td>655</td>
<td>WC 15</td>
<td>920</td>
</tr>
<tr>
<td>DFT / PIT</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td></td>
<td>35</td>
<td>430</td>
<td>35</td>
<td>690</td>
<td>C 35</td>
<td>955</td>
</tr>
<tr>
<td>J</td>
<td></td>
<td>30</td>
<td>460</td>
<td>30</td>
<td>720</td>
<td>C 40</td>
<td>995</td>
</tr>
<tr>
<td>K</td>
<td></td>
<td>175</td>
<td>635</td>
<td>180</td>
<td>900</td>
<td>510</td>
<td>1550</td>
</tr>
<tr>
<td>PITQ2</td>
<td></td>
<td>0</td>
<td>645</td>
<td>0</td>
<td>900</td>
<td>0</td>
<td>1550</td>
</tr>
<tr>
<td>L</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td></td>
<td>20</td>
<td>655</td>
<td>20</td>
<td>920</td>
<td>C 25</td>
<td>1530</td>
</tr>
<tr>
<td>N</td>
<td></td>
<td>30</td>
<td>695</td>
<td>30</td>
<td>970</td>
<td>150</td>
<td>1640</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>80</td>
<td>765</td>
<td>55</td>
<td>1025</td>
<td>85</td>
<td>1765</td>
</tr>
</tbody>
</table>

*Stop Time = 1770; C = crane in use; G = fuel grapple in use; WS = wait for storage available; WC = wait for crane available; WG = wait for fuel grapple available.*
TABLE V

Verification of Model (Three Arrivals)
Manual Calculations of GPSS Output Statistics*

<table>
<thead>
<tr>
<th>GPSS Entity</th>
<th>Activities Involved</th>
<th>Capacity</th>
<th>$\sum_{k=1}^{n} T_{l,k}(T)$</th>
<th>Block Count</th>
<th>Zero Entries</th>
<th>W/Zero Entries ( Minutes )</th>
<th>W/No Zero Entries ( Minutes )</th>
<th>Average Contents</th>
<th>Average Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Facilities:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRANE......</td>
<td>1 5,9,14,15,18</td>
<td>-</td>
<td>620</td>
<td>12</td>
<td>-</td>
<td>35.00</td>
<td>-</td>
<td>-</td>
<td>.237</td>
</tr>
<tr>
<td>GRAP......</td>
<td>2 11</td>
<td>-</td>
<td>600</td>
<td>1</td>
<td>-</td>
<td>133.33</td>
<td>-</td>
<td>-</td>
<td>.276</td>
</tr>
<tr>
<td>Storages:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PARK......</td>
<td>3 1,2,20</td>
<td>-</td>
<td>630</td>
<td>6</td>
<td>-</td>
<td>105.00</td>
<td>-</td>
<td>.356</td>
<td>-</td>
</tr>
<tr>
<td>FRSS......</td>
<td>4 3-19</td>
<td>6</td>
<td>2925</td>
<td>3</td>
<td>975.00</td>
<td>-</td>
<td>.163</td>
<td>.421</td>
<td>.275</td>
</tr>
<tr>
<td>BAY......</td>
<td>5 3,5,18,19</td>
<td>2</td>
<td>580</td>
<td>6</td>
<td>96.67</td>
<td>-</td>
<td>.136</td>
<td>.418</td>
<td>.209</td>
</tr>
<tr>
<td>PITCH......</td>
<td>6 5-9</td>
<td>2</td>
<td>745</td>
<td>3</td>
<td>248.33</td>
<td>-</td>
<td>.261</td>
<td>.210</td>
<td>.163</td>
</tr>
<tr>
<td>POOL......</td>
<td>7 8-13</td>
<td>2</td>
<td>740</td>
<td>3</td>
<td>246.67</td>
<td>-</td>
<td>.261</td>
<td>.210</td>
<td>.163</td>
</tr>
<tr>
<td>DEPT......</td>
<td>8 13-15</td>
<td>1</td>
<td>240</td>
<td>3</td>
<td>80.00</td>
<td>-</td>
<td>.261</td>
<td>.210</td>
<td>.163</td>
</tr>
<tr>
<td>PIT......</td>
<td>9 13-18</td>
<td>2</td>
<td>1170</td>
<td>3</td>
<td>390.00</td>
<td>-</td>
<td>.261</td>
<td>.210</td>
<td>.163</td>
</tr>
<tr>
<td>Queues:</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PARKQ......</td>
<td>10 2</td>
<td>-</td>
<td>5</td>
<td>3</td>
<td>2</td>
<td>1.67</td>
<td>5.00</td>
<td>.002</td>
<td>-</td>
</tr>
<tr>
<td>BAYO......</td>
<td>11 4</td>
<td>-</td>
<td>55</td>
<td>3</td>
<td>2</td>
<td>18.33</td>
<td>55.00</td>
<td>.031</td>
<td>-</td>
</tr>
<tr>
<td>PITO......</td>
<td>12 8</td>
<td>-</td>
<td>60</td>
<td>3</td>
<td>2</td>
<td>20.00</td>
<td>60.00</td>
<td>.033</td>
<td>-</td>
</tr>
<tr>
<td>POOLQ......</td>
<td>13 13</td>
<td>-</td>
<td>35</td>
<td>3</td>
<td>1</td>
<td>11.67</td>
<td>17.50</td>
<td>.019</td>
<td>-</td>
</tr>
<tr>
<td>PITO2......</td>
<td>14 17</td>
<td>-</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>-</td>
</tr>
</tbody>
</table>

*Stop time = 1770
### TABLE VI

**Deterministic Run (Five Arrivals)**  
**Summary of GPSS Statistics**

<table>
<thead>
<tr>
<th>Facility</th>
<th>Number Entries</th>
<th>Average Time/Trans.*</th>
<th>Average Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRANE</td>
<td>20</td>
<td>34.000</td>
<td>.316</td>
</tr>
<tr>
<td>GRAP</td>
<td>5</td>
<td>112.000</td>
<td>.260</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Storage</th>
<th>Capacity</th>
<th>Average Contents</th>
<th>Entries</th>
<th>Average Time/Unit*</th>
<th>Average Utilization*</th>
<th>Maximum Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARK</td>
<td>-</td>
<td>.667</td>
<td>10</td>
<td>143.500</td>
<td>.000</td>
<td>5</td>
</tr>
<tr>
<td>BRSS</td>
<td>6</td>
<td>2.388</td>
<td>5</td>
<td>1027.000</td>
<td>.398</td>
<td>5</td>
</tr>
<tr>
<td>BAY</td>
<td>2</td>
<td>.644</td>
<td>10</td>
<td>138.500</td>
<td>.322</td>
<td>2</td>
</tr>
<tr>
<td>PIT</td>
<td>2</td>
<td>.665</td>
<td>4</td>
<td>357.500</td>
<td>.332</td>
<td>2</td>
</tr>
<tr>
<td>POOL</td>
<td>2</td>
<td>.579</td>
<td>5</td>
<td>249.000</td>
<td>.289</td>
<td>2</td>
</tr>
<tr>
<td>DPIT</td>
<td>1</td>
<td>.174</td>
<td>5</td>
<td>75.000</td>
<td>.174</td>
<td>1</td>
</tr>
<tr>
<td>PITT</td>
<td>2</td>
<td>.786</td>
<td>6</td>
<td>281.666</td>
<td>.393</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Queue</th>
<th>Maximum Contents</th>
<th>Average Contents</th>
<th>Total Entries</th>
<th>Zero Entries</th>
<th>Percent Entries</th>
<th>Average Time/Trans.*</th>
<th>$Average Time/Trans.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARKQ</td>
<td>3</td>
<td>.199</td>
<td>5</td>
<td>2</td>
<td>39.9</td>
<td>86.000</td>
<td>143.333</td>
</tr>
<tr>
<td>BAYQ</td>
<td>2</td>
<td>.279</td>
<td>5</td>
<td>1</td>
<td>19.9</td>
<td>120.000</td>
<td>150.000</td>
</tr>
<tr>
<td>PITO</td>
<td>2</td>
<td>.141</td>
<td>5</td>
<td>1</td>
<td>19.9</td>
<td>61.000</td>
<td>76.250</td>
</tr>
<tr>
<td>POOLQ</td>
<td>1</td>
<td>.023</td>
<td>5</td>
<td>3</td>
<td>59.9</td>
<td>10.000</td>
<td>25.000</td>
</tr>
<tr>
<td>PITQ2</td>
<td>1</td>
<td>.013</td>
<td>5</td>
<td>4</td>
<td>79.9</td>
<td>6.000</td>
<td>30.000</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table Entries</th>
<th>Mean*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Total</td>
<td>5</td>
</tr>
</tbody>
</table>

*Times shown in tenths of minutes. Stop Time = 2150 minutes.  
$Average Time/Trans. = Average Time/Trans. excluding zero entries.
| Table VII |

**Verification of Model (Five Arrivals at Time = 0)**

Manual Calculations of UPSS Simulation

<table>
<thead>
<tr>
<th>Mean Time $- T_{i,j}$</th>
<th>LW Truck $(j)$</th>
<th>LW Truck $(j-2)$</th>
<th>OW Truck $(j)$</th>
<th>OW Truck $(j-2)$</th>
<th>Fall $(j)$</th>
<th>Activity</th>
<th>Count</th>
<th>Entries</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LW Ground</td>
<td>Rail</td>
<td>Status $T_{1,1}$</td>
<td>$\sum T_{1,1}$</td>
<td>Status $T_{1,1}$</td>
<td>$\sum T_{1,1}$</td>
<td>Status $T_{1,2}$</td>
<td>$\sum T_{1,2}$</td>
</tr>
<tr>
<td>A PARKQ</td>
<td>125</td>
<td>120</td>
<td>160</td>
<td>125</td>
<td>125</td>
<td>125</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>B BAY</td>
<td>25</td>
<td>35</td>
<td>100</td>
<td>25</td>
<td>25</td>
<td>215</td>
<td>25</td>
<td>230</td>
</tr>
<tr>
<td>C FITQ</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>D FIT</td>
<td>30</td>
<td>30</td>
<td>40</td>
<td>30</td>
<td>30</td>
<td>670</td>
<td>30</td>
<td>360</td>
</tr>
<tr>
<td>E FITQ</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>F FIT/FIT</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>35</td>
<td>820</td>
<td>35</td>
<td>785</td>
</tr>
<tr>
<td>G FITQ</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>H FITQ</td>
<td>20</td>
<td>20</td>
<td>25</td>
<td>20</td>
<td>20</td>
<td>1065</td>
<td>20</td>
<td>810</td>
</tr>
<tr>
<td>I FITQ</td>
<td>30</td>
<td>30</td>
<td>120</td>
<td>30</td>
<td>30</td>
<td>1240</td>
<td>30</td>
<td>1160</td>
</tr>
</tbody>
</table>

**PARK**

- $T_{1,1}$: Cranes in use
- $T_{1,2}$: Fuel grapples in use
- $T_{1,3}$: Wait for storage available
- $T_{j}$: Wait for crane available
- $T_{j-2}$: Wait for fuel grapples available

*Note: Time = 21360; C = cranes in use; G = fuel grapples in use; WA = wait for storage available; WC = wait for crane available; WFC = wait for fuel grapples available.*

*Additional note: If entered FITQ instead of FIT on its way out.*
### TABLE VIII

Verification of Model (Five Activities)

Manual Calculations of GPSS Output Statistics*

<table>
<thead>
<tr>
<th>GPSS Entity</th>
<th>Activities Involved</th>
<th>Capacity</th>
<th>$N(T)$</th>
<th>$\sum T_{j,k} I_{j,k}$/$T_k$</th>
<th>Block Count</th>
<th>Zero Entries</th>
<th>Average Time Per Transaction (Minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>W/Zero Entries</td>
</tr>
<tr>
<td>FRAIL</td>
<td>1</td>
<td>5, 10, 16, 17, 20</td>
<td>10</td>
<td>680</td>
<td>20</td>
<td>112</td>
<td>36.00</td>
</tr>
<tr>
<td>FRAIL</td>
<td>2</td>
<td>12</td>
<td>660</td>
<td>5</td>
<td>112</td>
<td>112</td>
<td>36.00</td>
</tr>
<tr>
<td>STORAGES</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRAIL</td>
<td>3</td>
<td>1, 2, 22</td>
<td>-</td>
<td>1435</td>
<td>10</td>
<td>143</td>
<td>36.00</td>
</tr>
<tr>
<td>FRAIL</td>
<td>4</td>
<td>3-21</td>
<td>6</td>
<td>1435</td>
<td>10</td>
<td>143</td>
<td>36.00</td>
</tr>
<tr>
<td>EXPERT</td>
<td>6</td>
<td>14, 15, 16, 17</td>
<td>5</td>
<td>1435</td>
<td>10</td>
<td>143</td>
<td>36.00</td>
</tr>
<tr>
<td>FRAIL</td>
<td>7</td>
<td>5-10 ***</td>
<td>2</td>
<td>1435</td>
<td>10</td>
<td>143</td>
<td>36.00</td>
</tr>
<tr>
<td>FRAIL</td>
<td>8</td>
<td>14, 16, 17</td>
<td>4</td>
<td>1435</td>
<td>10</td>
<td>143</td>
<td>36.00</td>
</tr>
<tr>
<td>FRAIL</td>
<td>9</td>
<td>14, 16, 20</td>
<td>2</td>
<td>1435</td>
<td>10</td>
<td>143</td>
<td>36.00</td>
</tr>
<tr>
<td>QUEUE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FRAIL</td>
<td>10</td>
<td>2</td>
<td>630</td>
<td>4</td>
<td>2</td>
<td>10</td>
<td>32.00</td>
</tr>
<tr>
<td>FRAIL</td>
<td>11</td>
<td>4</td>
<td>630</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td>32.00</td>
</tr>
<tr>
<td>FRAIL</td>
<td>12</td>
<td>8, 9</td>
<td>630</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td>32.00</td>
</tr>
<tr>
<td>FRAIL</td>
<td>13</td>
<td>14, 15</td>
<td>630</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td>32.00</td>
</tr>
<tr>
<td>FRAIL</td>
<td>14</td>
<td>16</td>
<td>630</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td>32.00</td>
</tr>
</tbody>
</table>

*Stop time = 21:56

*Transaction #1 entered PITC instead of PIT when leaving, i.e., for transaction #1 activities 14-20 are included for k=6 and excluded from k=9.
Validation

The validation of a simulation model is a relatively difficult task and involves the determination of whether the computer model is a reasonable representation of the existing system being modeled. The comparisons made should be of both past system outputs and experimental knowledge of the system performance behavior [8]. Since the Barnwell FRSS is not yet operating, no such past experience is available; and one must assume that validation will follow since the verification of the model proved that the program will execute as intended.

Steady-State

Now that the model has been developed and verified, the probabilistic model should be run over a number of total run times so that a steady-state occurs. The time span is determined by running the model over various time periods, such as one month, six months, and one year in order that a steady-state output is achieved (i.e., output statistics would not change drastically if the time were extended). This steady-state condition is desired so the true behavior of the system can be studied.

Comparing the outputs of a run where the total run time is equal to six months with a run where the total run time is equal to one year suggests that the model achieves its steady-state values in six months.

Table IX is a summary of the GPSS output from a run of the probabilistic model developed in Section II with a "stop time" of 2,526,000 (tenths of minutes) which represents a total run time of six months.
### TABLE IX

**Base Case Run**

**Summary of CPSS Statistics**

<table>
<thead>
<tr>
<th>Facility</th>
<th>Entries</th>
<th>Average Time/Trans.*</th>
<th>Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRANE</td>
<td>3129</td>
<td>340.168</td>
<td>.405</td>
</tr>
<tr>
<td>GRAP</td>
<td>783</td>
<td>957.133</td>
<td>.285</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Storage</th>
<th>Capacity</th>
<th>Average Contents</th>
<th>Entries</th>
<th>Average Time/Unit*</th>
<th>Average Utilization*</th>
<th>Maximum Contents</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARK</td>
<td>-</td>
<td>.744</td>
<td>1564</td>
<td>1250.926</td>
<td>.000</td>
<td>6</td>
</tr>
<tr>
<td>FRSS</td>
<td>6</td>
<td>2.639</td>
<td>783</td>
<td>8856.601</td>
<td>.439</td>
<td>6</td>
</tr>
<tr>
<td>BAY</td>
<td>2</td>
<td>5.526</td>
<td>1564</td>
<td>884.585</td>
<td>.263</td>
<td>2</td>
</tr>
<tr>
<td>PIT</td>
<td>2</td>
<td>.943</td>
<td>675</td>
<td>3670.918</td>
<td>.471</td>
<td>2</td>
</tr>
<tr>
<td>POOL</td>
<td>2</td>
<td>.659</td>
<td>783</td>
<td>2212.668</td>
<td>.329</td>
<td>2</td>
</tr>
<tr>
<td>DPIT</td>
<td>1</td>
<td>.212</td>
<td>782</td>
<td>713.343</td>
<td>.212</td>
<td>1</td>
</tr>
<tr>
<td>PITQ</td>
<td>2</td>
<td>.853</td>
<td>890</td>
<td>2517.964</td>
<td>.426</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Queue</th>
<th>Maximum Contents</th>
<th>Average Contents</th>
<th>Total Entries</th>
<th>Zero Entries</th>
<th>Percent Entries</th>
<th>Average Time/Trans.*</th>
<th>$Average Time/Trans.*</th>
</tr>
</thead>
<tbody>
<tr>
<td>PARKQ</td>
<td>3</td>
<td>.090</td>
<td>783</td>
<td>605</td>
<td>77.2</td>
<td>303.904</td>
<td>1336.836</td>
</tr>
<tr>
<td>BAYQ</td>
<td>2</td>
<td>.066</td>
<td>783</td>
<td>519</td>
<td>66.2</td>
<td>222.461</td>
<td>659.799</td>
</tr>
<tr>
<td>PITQ</td>
<td>2</td>
<td>.093</td>
<td>783</td>
<td>501</td>
<td>63.9</td>
<td>315.492</td>
<td>875.996</td>
</tr>
<tr>
<td>POOLQ</td>
<td>2</td>
<td>.041</td>
<td>783</td>
<td>529</td>
<td>67.5</td>
<td>139.492</td>
<td>428.704</td>
</tr>
<tr>
<td>PITQ2</td>
<td>2</td>
<td>.038</td>
<td>781</td>
<td>493</td>
<td>63.1</td>
<td>128.000</td>
<td>347.111</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table</th>
<th>Entries</th>
<th>Mean*</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>530</td>
<td>9063.113</td>
</tr>
<tr>
<td>2</td>
<td>60</td>
<td>10783.414</td>
</tr>
<tr>
<td>3</td>
<td>191</td>
<td>17889.488</td>
</tr>
<tr>
<td>Total</td>
<td>781</td>
<td>11353.839</td>
</tr>
</tbody>
</table>

*Times shown in tenths of minutes. Stop Time = Six months = 2526000.

$Average Time/Trans. = Average Time/Trans. including zero entries.
**TABLE X**

Summary of GPSS Statistics
Steady State Run Comparisons

<table>
<thead>
<tr>
<th></th>
<th>1 Month</th>
<th>6 Months</th>
<th>9 Months</th>
<th>12 Months</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Utilization</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRANE (Main Crane)</td>
<td>.417</td>
<td>.405</td>
<td>.399</td>
<td>.406</td>
</tr>
<tr>
<td>GRAP (Fuel Crane &amp; Grapple)</td>
<td>.259</td>
<td>.285</td>
<td>.278</td>
<td>.280</td>
</tr>
</tbody>
</table>

| **Average Contents (Number of Casks)** |          |          |          |           |
| BAY (Bay Areas)               | .558     | .526     | .512     | .518      |
| PITC (Center spots T/D pit)   | .936     | .853     | .838     | .868      |
| PIT (Outer spots T/D pit)     | .930     | .943     | .919     | .923      |
| POOL (CUPS in POOL)          | .635     | .659     | .646     | .657      |
| DPIT (Small Decontamination Pit) | .220     | .212     | .211     | .215      |

| **Average Queue (Minutes)** |          |          |          |           |
| PARKQ (Waiting to Enter FRSS) | 18       | 30       | 30       | 31        |
| BAYQ (Waiting to Enter T/D PIT) | 41       | 22       | 20       | 21        |
| PITQ (Waiting to Enter CUP)   | 33       | 32       | 33       | 35        |
| POOLQ (Waiting to Enter T/D PIT) | 12      | 14       | 14       | 14        |
| PITQ2 (Waiting to Enter BAY)  | 15       | 13       | 12       | 13        |

| **Average Time in FRSS (Minutes)** | 874 | 886 | 876 | 874 |
| **Average Contents in FRSS (Number of Casks)** | .709 | 2.639 | 2.581 | 2.621 |

| **Total Processing Time (Hours)** |          |          |          |           |
| LW Casks                        | 15.30    | 15.11    | 15.02    | 15.11     |
| OW Casks                        | 19.65    | 17.97    | 17.85    | 17.92     |
| Rail Casks                      | 29.31    | 29.82    | 29.52    | 29.32     |
| All Cask Types                  | 18.48    | 18.92    | 18.75    | 18.72     |
Table X is a summary of selected GPSS statistics from runs ranging from one month to one year in order to demonstrate that steady-state has, in fact, occurred in six months. For convenience, this steady-state six-month run of the probabilistic model will be referred to as the "base case" run.

Sensitivity Analyses

The model has been developed and tested for validity, and steady-state outputs have been achieved. It can now be used as a tool to test the sensitivity of the system it is modeling, i.e., operations of unloading casks in the FRSS. In addition to the base case run, three additional categories of runs are presented so that the effects of these changes to the system may be observed. Logically, one of the areas addresses sensitivity of arrival schedules which is probabilistic in nature. Two other areas address changes to certain operational policies and physical characteristics of the FRSS.

The base case run was presented in Table IX. The assumptions are summarized here again to provide a basis for comparison.

a. Arrival schedules are uniformly distributed with a mean of 8 hours, 72 hours and 24 hours for LW trucks, OW trucks, and rail cars, respectively.

b. Processing times (advance blocks) are defined by mapping the mean durations from Table I into a K-Erlang distribution with K=3.

c. Facilities at the FRSS include two bay areas (which casks can enter and leave), two center spots in the T/D pit, and two outer spots in the T/D pit, two CUPs, one main crane, and one canister crane and fuel grapple.
d. The model assumes the FRSS will operate 24 hours a day, 7 days a week, with personnel always available to process the activities the model dictates.

Sensitivity of Arrival Schedules:

Three additional runs of different distributions applied to the mean arrival schedules are presented to demonstrate that arrival patterns play an important role in the turnaround time of processing casks. Also, since this is probably the most unpredictable assumption made in the model, it should be studied carefully in order that all possible arrival scenarios can be examined. The three additional runs present arrival patterns that range from predictable (deterministic) to very unpredictable (completely random).

Run 1 - Deterministic Arrivals:

The base case program is changed so the arrivals will occur at exactly the mean values stated in the base case. This is achieved by removing the B-operand of the generate blocks.

Table XI on page 49 presents a summary of the output statistics from Run 1 and the base case run. Comparing the output statistics from the two runs shows that the model is sensitive to arrival patterns. A deterministic arrival pattern displays a more conservative (fewer arrivals) schedule; therefore, the total turnaround time is reduced; the waiting time in the various queues is reduced; and the average processing time by cask type is reduced.

Run 2 - K-Erlang Interarrivals:

The base case program is changed so that the mean values of the generate blocks are mapped into a K-Erlang distribution (with $K = 3$)
resulting in interarrival times skewed to higher values. This is accomplished by defining a real variable that adds three independent and identically distributed random values from the function XPDIS (exponential distribution function), multiplies the resultant by the mean arrival rate, and then divides by three. This real variable is then used as the A-operand of the corresponding generate block for LW truck casks, OW truck casks, and rail cask arrivals.

The output statistics from Run 2 and the base case run are shown in Table XI on page 49. From the summary of the statistics, one can see that the 3-Erlang interarrival schedules produce a more congested situation; i.e., more casks arrive in shorter interarrival times, or more casks arrive over the total six months. This situation creates a more utilized FRSS (the average contents increase 7%) with longer overall turnaround times.

Run 3 - Poisson Arrivals:

The base case program is changed to generate a Poisson arrival process [9]. This arrival process is the most random of all the cases presented. When a Poisson arrival process is to be simulated, it is not the arrival rates which are of interest, but the corresponding interarrival times which must be calculated. It can be shown that, when arrivals are Poisson-distributed, the corresponding interarrival times are exponentially distributed [9]. Thus, to achieve this behavior in the model, the B-operand in the generate blocks is replaced by the function XPDIS, which selects values randomly from an exponential distribution.
| TABLE XI |

Summary of GPSS Statistics
Sensitivity of Arrival Schedules

<table>
<thead>
<tr>
<th></th>
<th>Base Case</th>
<th>Run 1 Deterministic Arrivals</th>
<th>Run 2 3-Erlang Interarrivals</th>
<th>Run 3 Poisson Arrivals</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Utilization</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRANE (Main Crane).....</td>
<td>.405</td>
<td>.408</td>
<td>.424</td>
<td>.399</td>
</tr>
<tr>
<td>GRAP (Full Crane &amp; Grapple)</td>
<td>.285</td>
<td>.286</td>
<td>.316</td>
<td>.303</td>
</tr>
<tr>
<td><strong>Average Contents</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Number of Casks)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAY (Bay Areas).........</td>
<td>.526</td>
<td>.499</td>
<td>.539</td>
<td>.569</td>
</tr>
<tr>
<td>PITC (Center spots T/D pit)</td>
<td>.853</td>
<td>.778</td>
<td>.948</td>
<td>.956</td>
</tr>
<tr>
<td>PIT (Outer spits T/D pit)</td>
<td>.943</td>
<td>.964</td>
<td>.975</td>
<td>.907</td>
</tr>
<tr>
<td>POOL (CUPS in POOL)....</td>
<td>.659</td>
<td>.628</td>
<td>.737</td>
<td>.725</td>
</tr>
<tr>
<td>DPIT (Small Decontamination Pit)</td>
<td>.212</td>
<td>.210</td>
<td>.229</td>
<td>.221</td>
</tr>
<tr>
<td><strong>Average Queue (Minutes)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PARKQ (Waiting to Enter FRSS)</td>
<td>30</td>
<td>11</td>
<td>28</td>
<td>106</td>
</tr>
<tr>
<td>BAYQ (Waiting to Enter T/D pit)</td>
<td>22</td>
<td>14</td>
<td>21</td>
<td>36</td>
</tr>
<tr>
<td>PITQ (Waiting to Enter CUP)</td>
<td>32</td>
<td>21</td>
<td>41</td>
<td>55</td>
</tr>
<tr>
<td>POOLQ (Waiting to Enter T/D pit)</td>
<td>14</td>
<td>9</td>
<td>15</td>
<td>18</td>
</tr>
<tr>
<td>PITQ2 (Waiting to Enter BAY)</td>
<td>13</td>
<td>12</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td><strong>Average Time in FRSS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Minutes)</td>
<td>886</td>
<td>850</td>
<td>910</td>
<td>961</td>
</tr>
<tr>
<td><strong>Average Contents in FRSS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(Number of Casks)</td>
<td>2,639</td>
<td>2,552</td>
<td>2,833</td>
<td>2,804</td>
</tr>
<tr>
<td><strong>Average Processing Time (Hours)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LW Casks</td>
<td>15.11</td>
<td>14.56</td>
<td>15.47</td>
<td>16.95</td>
</tr>
<tr>
<td>OW Casks</td>
<td>17.97</td>
<td>17.80</td>
<td>18.73</td>
<td>20.31</td>
</tr>
<tr>
<td>Rail Casks</td>
<td>29.82</td>
<td>28.42</td>
<td>30.44</td>
<td>32.53</td>
</tr>
<tr>
<td>All Cask Types</td>
<td>18.92</td>
<td>17.99</td>
<td>19.32</td>
<td>21.37</td>
</tr>
</tbody>
</table>
The output statistics of this run and the base case run are shown on Table XI. The Poisson arrival schedule generates the most random arrival pattern studied, resulting in the longest overall turnaround times. The average waiting times at the various queues are drastically increased, especially the "park queue" (time casks waiting to get into the FRSS increased from an average of 30 minutes to 106 minutes).

Changes in Operational Policies:

Probably one of the most useful roles a simulation model has is one of testing decision policies. There are many runs that could be made to change, implement, and test decision policies. However, only two are presented in order to demonstrate the dynamics of the model.

Run 4 - In One Bay/Out The Other:

It was suggested that if a fleet servicing building were attached to the Barnwell FRSS, the casks would go in one bay and out the other [3]. The base case program is modified to achieve this behavior by changing the storage BAY (with a capacity of two) to two separate storage entities, each with a capacity of one. Casks enter one storage entity (BAYI) and go out the other (BAYO).

The output statistics for Run 4 and the base case are presented in Table XII. Interestingly, the two runs are very similar. However, because casks can enter and exit only one specific bay, the waiting time in the park, the waiting time in the T/D pit, and the total overall turnaround time are increased slightly (approximately 3%).
### TABLE XII

**Summary of GPSS Statistics**  
***Changes in Operational Policies***

<table>
<thead>
<tr>
<th></th>
<th>Base Case</th>
<th>Run 4 Bay Change</th>
<th>Run 5 Take Out Cooldown</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Utilization</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRANE (Main Crane)</td>
<td>.405</td>
<td>.427</td>
<td>.416</td>
</tr>
<tr>
<td>GRAP (Fuel Crane &amp; Grapple)</td>
<td>.285</td>
<td>.286</td>
<td>.291</td>
</tr>
<tr>
<td><strong>Average Contents (Number of Casks)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAY (Bay Areas)</td>
<td>.526</td>
<td>.528</td>
<td>.515</td>
</tr>
<tr>
<td>PITC (Center spots T/D pit)</td>
<td>.853</td>
<td>.944</td>
<td>.750</td>
</tr>
<tr>
<td>PIT (Outer spots T/D pit)</td>
<td>.943</td>
<td>.962</td>
<td>.949</td>
</tr>
<tr>
<td>POOL (CUPS in POOL)</td>
<td>.659</td>
<td>.687</td>
<td>.683</td>
</tr>
<tr>
<td>DPIT (Small Decontamination Pit)</td>
<td>.212</td>
<td>.229</td>
<td>.221</td>
</tr>
<tr>
<td><strong>Average Queue (Minutes)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PARKQ (Waiting to Enter FRSS)</td>
<td>30</td>
<td>54</td>
<td>43</td>
</tr>
<tr>
<td>BAYQ (Waiting to Enter T/D pit)</td>
<td>22</td>
<td>19</td>
<td>18</td>
</tr>
<tr>
<td>PITQ (Waiting to Enter CUP)</td>
<td>32</td>
<td>39</td>
<td>36</td>
</tr>
<tr>
<td>POOLQ (Waiting to Enter T/D pit)</td>
<td>14</td>
<td>14</td>
<td>13</td>
</tr>
<tr>
<td>PITQ2 (Waiting to Enter BAY)</td>
<td>13</td>
<td>32</td>
<td>35</td>
</tr>
<tr>
<td><strong>Average Time in FRSS (Minutes)</strong></td>
<td>886</td>
<td>894</td>
<td>842</td>
</tr>
<tr>
<td><strong>Average Contents in FRSS (Number of Casks)</strong></td>
<td>2.639</td>
<td>2.767</td>
<td>2.557</td>
</tr>
<tr>
<td><strong>Average Processing Time (Hours)</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LW Casks</td>
<td>15.11</td>
<td>15.95</td>
<td>14.92</td>
</tr>
<tr>
<td>OW Casks</td>
<td>17.97</td>
<td>19.18</td>
<td>16.25</td>
</tr>
<tr>
<td>Rail Casks</td>
<td>29.82</td>
<td>29.74</td>
<td>28.95</td>
</tr>
<tr>
<td>All Cask Types</td>
<td>18.92</td>
<td>19.49</td>
<td>18.39</td>
</tr>
</tbody>
</table>
Run 5 - Take Out Additional Time forCooldown Operation:

The base case program assumes that all entering casks must first be placed in one of the center spots in the T/D pit (near the water pumps) for a cask cooldown. This is a federal restriction at this time. However, with spent nuclear fuel being aged at the power plants' pools, the fuel may be sufficiently decontaminated so that the cooldown operation could be replaced by a "cask flush." In this case, the additional time for the cooldown operation could be eliminated. This change is made to the base case program by deleting the advance block labeled E.

The output statistics for Run 5 and the base case run are shown in Table XII. The results indicate that the overall time spent in the FRSS is reduced by approximately 5% (from 886 minutes to 842 minutes). The only change is due to taking out the additional time for the cooldown operation which averages from 50 minutes to 120 minutes depending on the cask type (see Table I).

Physical Changes to the FRSS:

The model can also be used to look at physical changes to the FRSS and determine if the average throughput is affected and the physical change is warranted. The three changes to the FRSS were chosen based on the average contents of certain areas in the FRSS. It seems logical to add additional facilities to areas that appear to be overcrowded.

Run 6 - Add a Bay:

The base case program is changed to reflect an additional bay
area. This is accomplished by changing the capacity of the storage bay from two to three.

The GPSS output statistics for Run 6 and the base case run are summarized in Table XIII on page 54. Interestingly, the total turnaround time is increased over the base case when one would expect just the opposite. This is because more casks can enter the FRSS since the bay area capacity has been increased. This run demonstrates that without increasing the other areas such as the T/D pit in the FRSS, the addition of a new bay area would not help the efficiency of operations at the BNFP-FRSS, but instead would increase the time for the total processing of casks.

Run 7 - Add a CUP:

Since the average contents of the storage POOL is .659 in the base case, it seems a logical step to add an additional CUP. This is accomplished by changing the capacity of the storage POOL from two to three.

The output statistics for this run and the base case are shown in Table XIII. Comparing the statistics from the two runs shows that the addition of another CUP in the pool would help the efficiency of the operations in the FRSS. The average time in the FRSS decreased from 886 minutes to 859 minutes, and the waiting times in the various queues all decreased. The addition of a third CUP in the FRSS proves to be the most dramatic physical change presented.

Run 8 - Add a Location in the T/D Pit:

The average contents of the two storage entities that simulate
the T/D pit range from .85 to .98. Since the outer spots in the T/D pit seem to be utilized the most, an additional outer space is needed. This is accomplished by changing the value of the storage entity PIT from two to three.

The output statistics of Run-8 and the base case run are summarized in Table XIII. The average time in the FRSS decreased slightly from 886 minutes to 874 minutes, and the average waiting time in the queues decreased except for the waiting time in the T/D pit which increased by only 5.6 minutes.
<table>
<thead>
<tr>
<th></th>
<th>Base Case</th>
<th>Run-6 Add a Bay</th>
<th>Run-7 Add a Cup</th>
<th>Run-8 Add Spot In T/D Pit</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average Utilization</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CRANE (Main Crane)</td>
<td>.405</td>
<td>.412</td>
<td>.400</td>
<td>.403</td>
</tr>
<tr>
<td>GRAP (Fuel Crane &amp; Grapple)</td>
<td>.285</td>
<td>.295</td>
<td>.269</td>
<td>.277</td>
</tr>
<tr>
<td><strong>Average Contents (Number of Casks)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BAY (Bay Areas)</td>
<td>.526</td>
<td>.551</td>
<td>.490</td>
<td>.506</td>
</tr>
<tr>
<td>PITC (Center spots T/D pit)</td>
<td>.853</td>
<td>.932</td>
<td>.824</td>
<td>.780</td>
</tr>
<tr>
<td>PIT (Outer spots T/D pit)</td>
<td>.943</td>
<td>.924</td>
<td>.899</td>
<td>1.034</td>
</tr>
<tr>
<td>POOL (CUPS in POOL)</td>
<td>.659</td>
<td>.690</td>
<td>.657</td>
<td>.649</td>
</tr>
<tr>
<td>DPIT (Small Decontamination Pit)</td>
<td>.212</td>
<td>.219</td>
<td>.211</td>
<td>.207</td>
</tr>
<tr>
<td><strong>Average Queue (Minutes)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PARKQ (Waiting to Enter FRSS)</td>
<td>30</td>
<td>45</td>
<td>21</td>
<td>20</td>
</tr>
<tr>
<td>BAYQ (Waiting to Enter T/D pit)</td>
<td>22</td>
<td>31</td>
<td>17</td>
<td>18</td>
</tr>
<tr>
<td>PITQ (Waiting to Enter CUP)</td>
<td>32</td>
<td>42</td>
<td>17</td>
<td>38</td>
</tr>
<tr>
<td>POOLQ (Waiting to Enter T/D pit)</td>
<td>14</td>
<td>14</td>
<td>17</td>
<td>10</td>
</tr>
<tr>
<td>PITQ2 (Waiting to Enter BAY)</td>
<td>13</td>
<td>11</td>
<td>15</td>
<td>11</td>
</tr>
<tr>
<td><strong>Average Time in FRSS (Minutes)</strong></td>
<td>886</td>
<td>901</td>
<td>858</td>
<td>874</td>
</tr>
<tr>
<td><strong>Average Contents in FRSS (Number of Casks)</strong></td>
<td>2.639</td>
<td>2.740</td>
<td>2.551</td>
<td>2.618</td>
</tr>
<tr>
<td><strong>Average Processing Time (Hours)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>LW Casks</td>
<td>15.11</td>
<td>15.80</td>
<td>15.00</td>
<td>14.90</td>
</tr>
<tr>
<td>OW Casks</td>
<td>17.97</td>
<td>18.83</td>
<td>17.68</td>
<td>17.46</td>
</tr>
<tr>
<td>Rail Casks</td>
<td>29.82</td>
<td>30.01</td>
<td>29.23</td>
<td>29.96</td>
</tr>
<tr>
<td>All Cask Types</td>
<td>18.92</td>
<td>19.47</td>
<td>18.33</td>
<td>18.52</td>
</tr>
</tbody>
</table>
SECTION V. CONCLUSIONS AND AREAS OF FUTURE RESEARCH

Conclusions

The goal of this study was to develop a computer model that accurately and simply simulates the activities involved in spent nuclear fuel receiving and unloading at AGNS' Barnwell FRSS. The model was designed to be general enough to be expanded and modified to address operational studies of real concern to the Barnwell personnel. The development and verification of the program produced several interesting results.

The simulation of the seemingly straightforward and uninterrupted operations quickly became very complicated with situations arising that caused "blocks" in the computer simulation. The fact that all casks can both enter and exit the bay areas and the T/D pit caused them to become blocked in the CUPs (in the storage POOL) and the T/D pit. For instance, if four casks are waiting in the T/D pit to move into one of the CUPs and both CUPs are already occupied, movement of all casks would come to a halt. Another more common example of the blockage occurs when two casks enter the FRSS in each of the bay areas, undergo preliminary unloading, and are ready to move into the T/D pit while the T/D pit is already full with four casks waiting to leave the FRSS through one of the occupied bay areas. Movement of all casks would halt because no casks could enter the FRSS through a bay and no casks could be moved into a bay for departure. During normal operations of the
Barnwell FRSS, neither of these two blockage problems would occur because operating personnel would anticipate such situations and would not move casks into an area when the area is needed for a cask to exit the FRSS.

To prevent the possibility of blocking casks during simulation, several conditions were imposed on casks preparing to enter and leave the FRSS as discussed in Section III. Casks waiting in the parking lot to enter a bay area must meet the following conditions: (i) fewer than six casks must be in the FRSS; (ii) a bay area must be available; and (iii) a center spot in the T/D pit must be available. Also, because of the cooldown operation performed on casks entering the FRSS, casks must move from the bay area to one of the center spots in the T/D pit near the water pumps. Therefore, entering casks will move into one of the center spots in the T/D pit from a bay area, and casks leaving the CUPs will try to enter one of the outer spots in the T/D pit. It will enter a center spot if neither of the outer spots is available. This situation produces an "in one door, out another" effect in the movement through the T/D pit and reduces the blocking problem.

Verification of the simulation model through manual calculations uncovered queueing situations in certain storages that are not addressed in a specific queue. For example, in the storage POOL (storage block that simulates the CUPs) casks had to wait at certain times for the facility GRAP (the facility that simulates the fuel crane and grapple). Also, all of the time spent in the regular queues set up in the model are included in a storage and, in some cases, in two storages.
This occurs because movement of the casks from one facility to the next actually occurs in the air (with the help of the crane), and until the cask is placed in the second storage, it occupies both storages.

Steady-state output of the model was achieved in a six-month run. Many runs were addressed with longer simulation times, but the output statistics changed only slightly. Therefore, the six-month simulation run as developed in Sections III and IV was used as a basis for comparison in several sensitivity analyses.

The three general areas presented were: (i) sensitivity of arrival schedules; (ii) changes in operational policies; and (iii) physical changes to the FRSS. The model proved to be very sensitive to arrival patterns. For instance, Poisson arrivals, which are the most random (unpredictable) compared to uniform arrivals, as in the base case, increased the turnaround time by approximately thirteen percent. The average processing time of all types went from 18.92 hours to 21.37 hours. Changing the operational policy governing entering casks, from casks entering either bay to casks entering only one bay and exiting the other, resulted in only a slight increase in the total turnaround time.

Run 5 presented the elimination of the operational policy of a mandatory cask cooldown for all entering casks (which takes from 50 to 120 minutes depending on the cask type). The deletion of this processing time decreased the total turnaround time by approximately 5%. Several physical changes to the FRSS such as adding a bay, a CUP, or another spot in the T/D pit were analyzed. Interestingly enough, the addition of a bay or spot in the T/D pit increased the processing time
of the casks. This result demonstrates that without increasing other areas in the FRSS, these additions would decrease the efficiency of the facility. However, the addition of a third CUP proved to increase the efficiency and decrease the total time spent in the FRSS by approximately three percent.

Areas for Future Research

The generalized model developed in this study has many future applications. It was designed to be a tool to use in simulating the general operation of unloading casks at the Barnwell FRSS. The AGNS personnel at Barnwell have expressed an interest in several areas in which the model can be used as the initial step in solving some of their problems. Since the FRSS is not in operation at the present time, the unloading sequence presented in this study is only preliminary. Therefore, the model could be used to help in the development of optimal unloading sequences. This can be accomplished by changing, expanding, or rearranging the fourteen activities currently incorporated in the model.

Another area of concern to AGNS is operator radiation exposure during unloading. By expanding the activities and adding another segment to simulate the personnel, the model could be adjusted to compile the time each operator spends during each unloading process. This information can be used as a tool to minimize operator radiation exposure.

The AGNS personnel have been looking at the possibility of augmenting their existing unloading facilities to add the capability of "dry unloading." Dry unloading is the process of unloading spent
nuclear fuel from casks in a hot cell facility (a dry room with mechanical machines to facilitate the unloading). The model could be adjusted to determine the potential capacity increases in the ability to unload spent fuel at the FRSS. This adjustment is simply adding another segment to the model to simulate the dry unloading facility.

To address each of these areas properly and in depth is not within the scope of this paper. However, the model developed in this study can be used as the initial step in each of the areas of interest.

Other applications are to impose different decision policies during the unloading process and to analyze potential arrival schedules. With the simulation tool developed and verified, the possible uses are truly up to the modeler. Many valuable applications await the thoughtful user.
APPENDIX A

Probabilistic GPSS Program Listing

00150  REALLOCATE XAC,1500,BLO,200,FAC,10,QUE,10,STO,10
00160  REALLOCATE TAB,5,FUN,25,VAR,25,COM,18460
00180  *
00200  * GPSS MODEL OF BARNWELL REPROCESSING PLANT
00220  * UNLOADING NUCLEAR SPENT FUEL FROM CASKS
00240  *
00260  * JEANNA L. BARNARD
00280  * UNIVERSITY OF CENTRAL FLORIDA
00300  *
00320  *
00340  *
00360  *
00380  SIMULATE
00390  *
00400  AAA FUNCTION P1,L3 TIMES IN TENTHS OF MINUTES
00420  1,1250/2,1200/3,1600 SERVICE TIMES BY CASK TYPE
00440  BBB FUNCTION P1,L3 SERVICE TIMES A THROUGH N
00460  1,250/2,2550/3,1000
00480  CCC FUNCTION P1,L3
00500  1,150/2,150/3,200
00520  DDD FUNCTION P1,L3
00540  1,600/2,900/3,1500
00560  EEE FUNCTION P1,L3
00580  1,650/2,1200/3,500
00600  FFF FUNCTION P1,L3
00620  1,300/2,300/3,400
00640  GGG FUNCTION P1,L3
00660  1,450/2,1150/3,2400
00680  HHH FUNCTION P1,L3
00700  1,300/2,300/3,600
00720  III FUNCTION P1,L3
00740  1,350/2,350/3,350
00760  JJJ FUNCTION P1,L3
00780  1,300/2,300/3,400
00800  KKK FUNCTION P1,L3
00820  1,1750/2,1800/3,5100
00840  LLL FUNCTION P1,L3
00860  1,200/2,200/3,250
00880  MMM FUNCTION P1,L3
00900  1,300/2,500/3,1500
00920  NNN FUNCTION P1,L3
00940  1,800/2,550/3,850
00960  BADT FUNCTION P1,L3
00980  1,1600/2,1600/3,1600
EXPONENTIAL DISTRIBUTION FUNCTION

EXPONENTIAL DISTRIBUTION FUNCTION RN1,C24

0.07,1.104/.2.222/.3.355/.4.509/.5.69/.6.915/.7.1.2.75.1.38

EXPONENTIAL DISTRIBUTION FUNCTION RN2,D2

0.05,1/1.0

MAPPING MEAN TIMES INTO A K-ERLANG DISTRIBUTION WITH K=3 AND THE MEAN VALUES FROM FN AAA-NNN

ADIS FVARIABLE (FN$XPDIS+FN$XPDIS+FN$XPDIS)/3*FN$AAA
BDIS FVARIABLE (FN$XPDIS+FN$XPDIS+FN$XPDIS)/3*FN$BBB
CDIS FVARIABLE (FN$XPDIS+FN$XPDIS+FN$XPDIS)/3*FN$CCC
DDIS FVARIABLE (FN$XPDIS+FN$XPDIS+FN$XPDIS)/3*FN$DDD
EDIS FVARIABLE (FN$XPDIS+FN$XPDIS+FN$XPDIS)/3*FN$EEE
FDIS FVARIABLE (FN$XPDIS+FN$XPDIS+FN$XPDIS)/3*FN$FFF
GDIS FVARIABLE (FN$XPDIS+FN$XPDIS+FN$XPDIS)/3*FN$GGG
HDIS FVARIABLE (FN$XPDIS+FN$XPDIS+FN$XPDIS)/3*FN$HHH
IDIS FVARIABLE (FN$XPDIS+FN$XPDIS+FN$XPDIS)/3*FN$III
JDIS FVARIABLE (FN$XPDIS+FN$XPDIS+FN$XPDIS)/3*FN$JJJ
KDIS FVARIABLE (FN$XPDIS+FN$XPDIS+FN$XPDIS)/3*FN$KKK
LDIS FVARIABLE (FN$XPDIS+FN$XPDIS+FN$XPDIS)/3*FN$LLL
MDIS FVARIABLE (FN$XPDIS+FN$XPDIS+FN$XPDIS)/3*FN$MMM
NDIS FVARIABLE (FN$XPDIS+FN$XPDIS+FN$XPDIS)/3*FN$NNN
EADDD FVARIABLE (FN$XPDIS+FN$XPDIS+FN$XPDIS)/3*FN$BADDT

TABLE DEFINITIONS

M1,7200,600,50 TABLE CASK TYPE 1
M1,10200,600,50 TABLE CASK TYPE 2
M1,16200,600,50 TABLE CASK TYPE 3
M1,7200,600,50 TABLE OF ALL CASKS

MODEL SEGMENT 1 (GENERATE ARRIVALS)
01900 *
01920 GENERATE 4800,4800 LW TRUCK CASKS ARRIVE
01940 ASSIGN 1,1 SET P1 = CASK TYPE 1
01960 ASSIGN 2,FSN$BAD GENERATE BAD CASKS
01980 TRANSFER ,GOIN
02000 *
02020 GENERATE 43200 OW TRUCK CASKS ARRIVE
02040 ASSIGN 1,2 SET P1 = CASK TYPE 2
02060 ASSIGN 2,FSN$BAD GENERATE BAD CASKS
02080 TRANSFER ,GOIN
02100 *
02120 GENERATE 14400,14400 FAIL CASKS ARRIVE
02140 ASSIGN 1,3 SET P1 = CASK TYPE 3
02160 ASSIGN 2,FSN$BAD GENERATE BAD CASKS
02180 TRANSFER ,GOIN
02200 *
02210 MODEL SEGMENT 2 (ACTIVITIES IN FRSS)
02220 *
02240 GOIN ENTER PARK PARKING LOT
02260 TEST E P2,1,NORM TEST IF BAD CASK
02280 ADVANCE VS$ADD DECONTAMINATE CASK IF BAD
02300 *
02320 NORM ADVANCE VS$ADIS A. CASK RECEIPT, WASH DOWN ETC...
02340 QUEUE PARKQ
02350 GATE SNF FRSS WAIT TO MOVE INTO BUILDING
02360 GATE SNF BAY WAIT TILL OK TO MOVE INTO BAY
02365 GATE SNF PITG WAIT FOR A SPOT IN T/D PIT
02370 ENTER FRSS BUILDING
02375 ENTER BAY BAY AREA
02380 DEPART PARKQ
02400 LEAVE PARK
02420 *
02460 ADVANCE VS$DIS
02500 QUEUE BAYQ
02640 ENTER PITG ENTER CENTER SPACE IN T/D PIT
02660 SEIZE CRANE GET CRANE IF AVAILABLE
02680 DEPART BAYQ
02700 *
02720 ADVANCE VS$DIS
02740 LEAVE BAY
02760 *
02780 RELEASE CRANE
02800 *
02820 ADVANCE VS$DIS
02840 *
02860 ADVANCE VS$DIS

B. READY FOR TRANSPORT INTO PIT
C. MOVE CASK INTO T/D PIT
D. REMOVE OUTER HEAD, CASK SAMPLE
E. ADDITIONAL TIME FOR COOLDOWN
02880  QUEUE    PITQ
02910  ENTER    POOL
02920  SEIZE    CRANE
02960  DEPART   PITQ
02980 *   ADVANCE VSFDIS
03000   LEAVE    PITQ
03100 *   RELEASE CRANE
03140   SEIZE    CRANE
03160 *   ADVANCE VSFDIS
03180   RELEASE CRANE
03200   LEAVE    CRANE
03220 *   ADVANCE VSFDIS
03240   PRIORITY 1
03260   QUEUE    POOLQ
03310   ENTER    DPIT
03320   TRANSFER BOTH,PATH1,PATH2
03330   PATH1 ENTER PIT
03340   ASSIGN  3,0
03345   TRANSFER 5,PATH3
03350   PATH2 ENTER PITC
03360   ASSIGN  3,1
03380   PATH3 SEIZE CRANE
03400   DEPART   POOLQ
03420   LEAVE    POOL
03440 *   ADVANCE VSIDIS
03460   LEAVE    CRANE
03500 *   ADVANCE VSJDIS
03520   LEAVE    DPIT
03540   RELEASE CRANE
03580 *   ADVANCE VSJDUBIS
03600   PRIORITY 2
03620   QUEUE    PITQ2
03640   ENTER    BAY
03680   SEIZE    CRANE
03700   DEPART   PITQ2
03740 *   ADVANCE VSLDIS
03760   TEST E  P3,1,PATH4
03765

POOL AREA
GET CRANE IF AVAILABLE
F. MOVE CASK FROM T/D PIT TO POOL
LEAVE CENTER PIT
GET FUEL GRAPPLE IF AVAILABLE
G. MOVE FUEL ASSEMBLIES INTO POOL
H. MOVE FUEL CASI'ETERS FROM CASK
SET HIGH PRIORITY FOR LEAVING
DECON. PIT
SET P3 TO DENOTE PIT
ENTER CENTER SPACE IN T/D PIT
SET P3 TO DENOTE PITC
I. DECONTAMINATION
J. MOVE CASK FROM DECON. TO T/D PIT
K. CASK PREPARATION FOR RETURN
UP PRIORITY TO LEAVE PIT
BAY AREA (GOING OUT)
L. MOVE CASK ONTO CARRIER
CHECK TO SEE WHICH PIT TO EXIT
03767   LEAVE   PITC   LEAVE CENTER PIT
03770   TRANSFER PATH5
03780   PATH4   LEAVE   PIT   LEAVE OUTER PIT
03800   *
03820   PATH5   RELEASE CRANE
03840   *
03860   ADVANCE V$MDIS
03880   LEAVE   BAY
03890   LEAVE   FRSS   LEAVE BUILDING
03900   *
03920   ENTER  PARK   PARKING LOT (LEAVING)
03940   *
03960   ADVANCE V$NDIS
03980   LEAVE  PARK
04000   *
04020   TABULATE P1  PLACE RESIDENCE TIME IN TABLES 1 - 3
04060   TABULATE TOT  PLACE RESIDENCE TIME IN TABLE TOT
04080   TERMINATE
04100   *
04160   MODEL SEGMENT 3 (TIMER)
04180   *
04200   GENERATE 5256000  TIMER ARRIVES AFTER ONE YEAR
04240   TERMINATE 1
04260   *
04280   CONTROL CARDS
04300   *
04320   *
04340   START 1
04360   END
04380   *
04400   *
04420   *
04440   *
04460  //
APPENDIX B

Deterministic GPSS Program Listing

01060 *
01080 *
01100 *
01120 *
01140 *
01160 *
01180 *
01200 *
01220 *
01240 *
01260 *
01290 *
01300 AAA FUNCTION P1,L3 TIMES IN MINUTES
01320 1,125/2,120/3,160 SERVICE TIMES BY CASK TYPE
01340 BBB FUNCTION P1,L3
01360 1,25/2,55/3,100
01380 CCC FUNCTION P1,L3
01400 1,15/2,15/3,20
01420 DDD FUNCTION P1,L3
01440 1,60/2,90/3,150
01460 EEE FUNCTION P1,L3
01480 1,65/2,120/3,50
01500 FFF FUNCTION P1,L3
01520 1,30/2,30/3,40
01540 GGG FUNCTION P1,L3
01560 1,45/2,115/3,240
01580 HHH FUNCTION P1,L3
01600 1,30/2,30/3,60
01620 III FUNCTION P1,L3
01640 1,35/2,35/3,35
01660 JJJ FUNCTION P1,L3
01680 1,30/2,30/3,40
01700 KKK FUNCTION P1,L3
01720 1,175/2,180/3,510
01740 LLL FUNCTION P1,L3
01760 1,20/2,20/3,25
01780 MMM FUNCTION P1,L3
01800 1,30/2,50/3,150
01820 NNN FUNCTION P1,L3
01840 1,80/2,55/3,85
02000
02020
02040
02060
02080
02100 PARK STORAGE
02120 FRSS STORAG 6
02140 STORAGE $BAY, 2/$SPIT, 2/$SPool, 2/$SPIT, 1/$SPITC, 2
02150 *
02150 * TABLE DEFINITIONS
02200 *
02220 1 TABLE M1, 720, 60, 50 TABLE CASK TYPE 1
02240 2 TABLE M1, 1020, 60, 50 TABLE CASK TYPE 2
02260 3 TABLE M1, 1620, 60, 50 TABLE CASK TYPE 3
02280 TOTAL TABLE M1, 720, 60, 50 TABLE OF ALL CASKS
02300 *
02320 *
02340 *
02360 *
02380 MODEL SEGMENT 1 (ACTIVITIES PROCESSING CASKS)
02400 *
02420 *
02440 *
02460 *
02480 *
02500 *
02520 *
02540 *
02560 *
02580 *
02600 *
02620 *
02640 *
02660 *
02680 *
02700 *
02720 *
02740 *
02760 *
02780 *
02800 *
02820 *
02840 *
02860 *
02880 *
02900 *
02920 *
02940 *
02960 *
02980 *

STORAGE DEFINITIONS REPRESENT AREAS CAVKs ENTER AND AMOUNT OF AREA AVAILABLE TO THE CASKS.

02020 *

02040 *

02060 *

02080 *

02100 PARK STORAGE

02120 FRSS STORAGE 6

02140 STORAGE $BAY, 2/$SPIT, 2/$SPool, 2/$SPIT, 1/$SPITC, 2

02150 *

02150 * TABLE DEFINITIONS

02200 *

02220 1 TABLE M1, 720, 60, 50 TABLE CASK TYPE 1

02240 2 TABLE M1, 1020, 60, 50 TABLE CASK TYPE 2

02260 3 TABLE M1, 1620, 60, 50 TABLE CASK TYPE 3

02280 TOTAL TABLE M1, 720, 60, 50 TABLE OF ALL CASKS

02300 *

02320 *

02340 *

02360 *

02380 MODEL SEGMENT 1 (ACTIVITIES PROCESSING CASKS)

02400 *

02420 *

02440 *

02460 *

02480 *

02500 *

02520 *

02540 *

02560 *

02580 *

02600 *

02620 *

02640 *

02660 *

02680 *

02700 *

02720 *

02740 *

02760 *

02780 *

02800 *

02820 *

02840 *

02860 *

02880 *

02900 *

02920 *

02940 *

02960 *

02980 *

PARKING LOT

A. CASK RECEIPT, WASH DOWN ETC...

WAIT TO MOVE INTO BUILDING

WAIT TILL OK TO MOVE INTO BAY

BUILDING

PAY AREA

3. READY FOR TRANSPORT INTO PITC

T/D PIT

4. MOVE CASK INTO T/D PIT

BAY
03000  *  RELEASE  CRANE
03020  ADVANCE  FNSDDDD  D. REMOVE OUTER HEAD, CASK SAMPLE & FLUSH
03040  ADVANCE  FNSSEEIE  E. ADDITIONAL COOLDOWN TIME
03060  QUEUE  PITQ
03100  *
03120  ENTER  POOL  C.
03140  SEIZE  CRANE  GET CRANE IF AVAILABLE
03160  DEPART  PITQ
03180  ADVANCE  FNSFFF  F. MOVE CASK FROM T/D PIT TO POOL
03200  LEAVE  PITQ
03220  *
03240  RELEASE  CRANE
03260  SEIZE  GRAPPLE  GET FUEL GRAPPLE IF AVAILABLE
03280  ADVANCE  FNSGGO  G. MOVE FUEL ASSEMBLIES INTO POOL
03300  RELEASE  GRAPPLE
03320  ADVANCE  FNSHHH  H. MOVE FUEL CANISTERS FROM CASK
03340  QUEUE  POOLQ
03360  *
03380  ENTER  DECON. PIT
03400  TRANSFER  BOTH PATH1, PATH2 WAIT TO MOVE INTO T/D PIT
03420  *
03440  *  T/D PIT (GOING OUT)
03460  PATH1 ENTER  PIT  ENTER OUTER PIT SPOT
03480  ASSIGN  5,0
03500  TRANSFER ,PATH3
03520  PATH2 ENTER  PITQ  ENTER CENTER PIT SPOT
03540  ASSIGN  5,1
03560  PATH3 SEIZE  CRANE
03580  DEPART  POOLQ
03600  LEAVE  POOL
03620  ADVANCE  FNSIII  I. DECONTAMINATION
03640  *
03660  PRIORITY  1  SET HIGH PRIORITY FOR LEAVING
03680  ADVANCE  FNSJJJJ  J. MOVE CASK FROM DECON. TO T/D PIT
03700  LEAVE  PITQ
03720  RELEASE  CRANE
03740  ADVANCE  FNSKKK  X. CASK PREPARATION FOR RETURN
03760  PRIORITY  2  UP PRIORITY TO LEAVE PIT
03780  QUEUE  PITQ2
03800  *
03820  ENTER  BAY  BAY AREA (GOING OUT)
03840  SEIZE  CRANE
03860  DEPART  PITQ2
03880  ADVANCE  FNSLLLL  L. MOVE CASK ONTO CARRIER
03900  TEST &  P5,1,PATH4
03920  LEAVE  PIT
03940  TRANSFER ,PATH5
03960  PATH4 LEAVE  PIT
03980 *
04000 PATHS RELEASE CRANE
04020 ADVANCE FNNM N. REPLACE IMPACT LIMITOR, TIE DownS
04040 LEAVE BAY
04060 LEAVE FRSS LEAVE BUILDING
04080 *
04100 ENTER PARK PARKING LOT (LEAVING)
04120 ADVANCE FNNN N. SURVEY, COMPLETE PROCESSING
04140 LEAVE PARK
04160 *
04180 TABULATE P1 PLACE RESIDENCE TIME IN TABLE 1,2 OR 3
04200 TABULATE TOT PLACE RESIDENCE TIME IN TABLE TOTAL
04220 TERMINATE
04240 *
04260 *
04280 *
04300 *
04320 *
04340 GENERATE 1770 TIMER ARRIVES AFTER LAST CASK LEAVES
04360 PRINT "FUT"
04380 TERMINATE 1
04400 *
04420 *
04440 *
04460 *
04480 START 1
04500 END
04520 *
04540 *
04560 *
04580 *
04600 //
APPENDIX C

Glossary of Terms and Abbreviations[9], [10], [11]

AFR — Abbreviation for an away-from-reactor-storage facility for nuclear spent fuel.

advance blocks (GPSS term) — The advance block is provided in GPSS to accomplish the task of freezing a transactions motion for a prescribed length of time. This is consistent with the experience that service time usually varies from one service to the next.

Boiling Water Reactor (BWR) — A nuclear reactor in which boiling light water is used as the coolant.

canister — A metal container for solid radioactive water.

cask — A container that provides shielding and containment for the shipment or storage of radioactive material.

contamination — The disposition of radioactive material on a surface or the presence of fission products in a process stream.

CUP — Cask Unloading Pool.

decay (radioactive) — The spontaneous transformation of one nuclide into a different nuclide or into a different energy state of the same nuclide.

decommissioning — The selective removal of radioactive material from a surface or from within another material.

disposal — The planned release of radioactive and other waste in a manner that precludes recovery, or its replacement in a manner which is considered permanent so that recovery is not provided for.


facility (GPSS term) — In GPSS, the term "facility" is a synonym for "server." The utilities which place demands on facilities for service are transactions. The "meaning" of a facility is determined by the model builder.
fleet servicing facility - A facility for inspecting, maintaining, and requalifying spent nuclear fuel transportation systems (rail, truck, etc.).

fuel (nuclear reactor) - Fissionable material used as the source of energy when placed in a nuclear reactor.

fuel assembly - A grouping of fuel elements which is not taken apart during charging and discharging of a reactor core.

fuel cycle - The complete series of steps involved in supplying fuel for nuclear reactors. The cycle includes uranium mining and refining, uranium enrichment, fuel element fabrication, irradiation, chemical reprocessing (to recover the fissionable material remaining in the spent fuel), and disposal of radioactive waste. Later steps in the fuel cycle are re-enrichment of the enriched fuel material and refabrication into new fuel elements. In a "stowaway" fuel cycle, spent fuel is not reprocessed to recover usable fuel; spent fuel is treated as waste.

function (GPSS term) - The two types of functions that can exist in GPSS are continuous and discrete. A continuous GPSS function is initially evaluated in the same way as a discrete function. When the function is called, a number is first drawn from the random-number stream used as the functions argument. Then, a table-lookup is performed to determine the cumulative probability interval in which the random number falls. At this point, if the function was defined to be discrete, the second member of the corresponding pair of points would be returned as the functions value. In contrast, when the function is defined as continuous, a linear interpolation is performed next between the pairs of points at the ends of the cumulative probability interval.

FSP - Fuel storage pool.

generate block (GPSS term) - The generate block can be thought of as a door through which transactions enter a model.

health physics - The science and profession devoted to the protection of man and his environment from unnecessary exposure to ionizing radiation.

heavy water - Deuterium oxide, D2O. Water in which hydrogen atoms have been replaced with deuterium atoms.

kWh - Kilowatt-hour, a unit of energy generation or consumption in a given hour.

light water - Normal water (H2O), as distinguished from heavy water (D2O).
light water reactor (LWR) - uses light water (H$_2$O) as coolant and as the moderator for slowing fast neutrons. Most common types are pressurized water reactors (PWR) and boiling water reactors (BWR).

LWT - Abbreviation for legal weight truck.

MW - Megawatt (1 MW = 1 million watts), a unit of the rate of energy production or consumption.

MREM = Millirems.

MTU = Metric tons of uranium (2,200 pounds, or 1,000 kilograms).

nonproliferation - Limits the number of nations capable of producing nuclear weapons without limiting world-wide use of nuclear power.

NRC - U.S. Nuclear Regulatory Commission.

parameters (GPSS term) - Each transaction in a GPSS model possesses a set of from 0 to 100 parameters. As a transaction moves through a model, its parameter values can be assigned and modified according to logic provided by the analyst.

personnel barrier - A lightweight thermal and radiation safety shield placed around but not in contact with the surface of a shipping cask to prevent human contact.

plutonium - a radioactive element with an atomic number of 94. Its most important isotope is fissionable plutonium-239, produced by neutron irradiation of uranium-238.

pool or pool cell - A concrete chamber filled with water to provide shielding for irradiated fuel elements.

processing times - (In this case) activities involved in the receiving and unloading of casks.

queue - A waiting line.

queue (GPSS term) - When a model builder uses the GPSS Queue entity at points in a model where constrained resources are simulated, the GPSS processor responds by automatically collecting statistics describing the waiting (if any) which occurs at those points.

queueing model - A computer model which simulates a sequence of events including probable waiting lines.

radioactive - Unstable in a manner shown by spontaneous nuclear disintegration with accompanying emission of radiation and particles.
radioactive decay - The spontaneous decrease of a radioactive substance due to disintegration by the emission of particles and radiation.

radioactivity - The spontaneous decay or disintegration of unstable nuclei accompanied by the emission of radiation and particles.

reactor - A device in which a fission chain reaction can be initiated, maintained, and controlled.

reprocessing - Dissolving spent reactor fuel to recover useful materials such as thorium, uranium, and plutonium. Other radioactive materials are usually separated and treated as waste.

shielding - The material interposed between a source of radiation and the environment for protection against the danger of radiation. Common shielding materials are concrete, water, and lead.

shipping cask - A specifically designed container used for shipping radioactive materials (see cask).

spent fuel - Irradiated nuclear reactor fuel at the end of its useful life.

storage - Retention of waste in some type of man-made device.

storage (GPSS term) - A facility can be used in GPSS to simulate a single server. Two or more servers can be simulated by a storage definition.

storage basin - A water-filled, stainless steel lined pool for the interim storage of spent fuel.

transaction (GPSS term) - Dynamic (i.e., moving) entities in a GPSS model. Their movement from block to block takes place as an execution of a GPSS model proceeds. The "meaning" of transactions is determined by the model builder. This is done by establishing an analogy, or correspondence, between transactions and elements of the system being modeled.

uranium - A naturally radioactive element with the atomic number 92 and an atomic weight of approximately 235. The two principal naturally occurring isotopes are the fissionable uranium-235 (0.7% of natural uranium) and the fertile uranium-238 (99.3% of natural uranium).

variables (GPSS term) - The value of an arithmetic variable is the value of the user supplied arithmetic expression which defines the variable.

waste, radioactive - Equipment and materials (from nuclear operations) that are radioactive or have radioactive contamination and for which there is no recognized use or for which recovery is impractical.
REFERENCES


