INTERN EXPERIENCE AT ARKANSAS NUCLEAR ONE STEAM ELECTRIC STATION

AN INTERNSHIP REPORT

by

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in partial fulfillment of the requirement for the degree of

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Approved as to style and content by:

(Chairman of Committee)

(Head of Department)

(Member) (Member)

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ABSTRACT

Intern Experience at Arkansas Nuclear

One Steam Electric Station (May 1979)

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Chairman of Advisory Committee: Dr. John D. Randall

This report is a survey of the author's experience as an intern at Arkansas Nuclear One Steam Electric Station with Arkansas Power & Light Co. The author worked as a Assistant Engineer in the Station Nuclear Engineering Group for the duration of the internship period. His assignments were primarily, but not exclusively, related to the operation of Arkansas Nuclear One, Unit One. The intent of the report is to demonstrate that this experience fulfills the requirements for the Doctor of Engineering internship.

The author's assignments may be categorized into three broad areas of activity. First, he developed several interactive computer programs that are used by the reactor operators as computational aids. Second, he was extensively involved in the Unit One Cycle 3 reactor refueling. This refueling activity included creating a computer program to optimally sequence the fuel assembly and control component movements and participation in the actual fuel handling activities. Third, he assisted in the post-refueling Unit One Cycle 3 physics testing by preparing test procedures and aiding in the performance of the actual tests.

DEDICATION

Dedicated to my Father,

Thomas Abrum Miller,

November 10, 1897-September 12, 1973.

ACKNOWLEDGEMENTS

This internship could not have been completed without the help and encouragement of many individuals. My sincere gratitude is hereby expressed to all who were instrumental in helping me to attain the objectives of the Doctor of Engineering Program.

A special word of thanks is extended to these members of my committee for guiding me through the program;

Dr. John D. Randall, Nuclear Engineering, Committee Chairman

Dr. Robert S. Wick, Nuclear Engineering

Dr. Ron R. Hart, Nuclear Engineering

Dr. William L. Perry, Mathematics

Dr. Kenneth D. Riener, Finance

Dr. Robert E. Stewart, Agricultural Engineering, College of Engineering Representative

Dr. Garland E. Bayliss, History, Graduate Council Representative

A great deal of special appreciation is expressed to my internship supervisor, Mr. Thomas H. Cogburn, for providing an outstanding internship experience, despite the trials of an already full schedule. Also, thanks are extended to the Arkansas Nuclear One Plant Staff for their friendship, support and knowledge.

Mr. William Cavanaugh III and Mr. Leo J. Jennings of Arkansas Power & Light Co. are acknowledged for arranging this internship.

The Engineering Design Graphics Department and Dr. James H. Earle are recognized for providing financial support during most of my graduate studies.

A word of thanks is extended to Lajuan Wood for typing this manuscript.

A note of gratitude must be extended to my former mathematics teacher, Mr. Raymond Bowen, who indirectly helped me to choose Engineering as my profession.

Finally, my most sincere thanks are expressed to my wife, Patricia, for her support and patience throughout my studies, and to my mother, Mrs. Thomas A. Miller, for her continuing encouragement.

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INTRODUCTION

This report documents the experience accrued by the author during a fourteen month Doctor of Engineering internship served with Arkansas Power & Light Company between May 31, 1977 and July 21, 1978. The internship was served at Arkansas Nuclear One Steam Electric Station located near Russellville, Arkansas. For the duration of the internship the author was an Assistant Engineer assigned to the Station Nuclear Engineer. Included in the report are some details of projects completed by the author and general observations made during the internship.

Internship Objectives

The general objectives of the internship portion of the Doctor of Engineering program are:

a. to enable the student to demonstrate his ability to apply his knowledge and technical training by making an identifiable engineering contribution in an area of practical concern to the organization or industry in which the internship is served, and
b. to enable the student to function in a non-academic environment in a position where he will become aware of the organizational approach to problems in addition to traditional engineering design or analysis.[1]

Using these general guidelines, the author consulted with his internship supervisor and developed tentative internship objectives prior to commencing the internship. The pattern followed throughout the internship was established by these objectives, which related specifically to the duties of an Assistant Engineer. These objectives were:

A. Engineering Objectives
   1. To work under the direction of the ANO Station Nuclear Engineer in performing the activities of the Nuclear

Engineering Group. These activities may include monitoring reactor performance, performing reactor testing, maintaining fuel accountability and fuel management records, performing core physics calculations, and providing technical assistance to other parts of the plant staff.

2. To assist in the fuel loading and testing for Unit 2 and refueling for Unit 1 as directed by the Nuclear Engineer.
3. To execute any special projects assigned by the ANO Nuclear Engineer.

B. Organizational Objectives
   1. Interface with other organizational elements of the Arkansas Nuclear One plant staff and Arkansas Power & Light Co. These other organizations may include: Operations, Instrument Group, Quality Control Group and Arkansas Power & Light Co. General Office.
   2. Through this interface learn how the plant is organized and operated, and how the decision making process works within the plant.[2]

Internship Organization

Arkansas Power & Light Company

Arkansas Power & Light Company (AP&L) is a subsidiary of Middle South Utilities, Inc. an investor-owned electric utility system. The company supplies electric power to nearly half a million customers and owns electric facilities in 62 of Arkansas' 75 counties. Additionally, AP&L has an aggressive generation facility construction program with two coal-fired generating stations under construction and is committed to meeting almost ninety percent of the company's requirements with nuclear fuel and coal by 1985.[3]

Generation and Construction Department

Within the Arkansas Power & Light corporate organization, the Generation and Construction Department is responsible for all activities related to electric power generation facilities, including; planning, design, research, administration, construction and operation. Figure 1 shows a simplified organization chart for this department.

The Generation and Construction Department was formed, during the author's internship, by a reorganization of the "old" Production Department. The responsibilities and capabilities of this organization were expanded by this reorganization.

Arkansas Nuclear One Station

Arkansas Nuclear One Steam Electric Station (ANO) is a two unit nuclear power station, located near Russellville, Arkansas on the Dardanelle Reservoir. Unit One contains a Babcock & Wilcox Nuclear Steam Supply System and is nominally rated at a full power output of 836 MWe. This unit commenced commercial operation in 1974, making the facility the first nuclear fueled electric generating station in the Southwest. Unit Two which will commence commercial operation in 1979, contains a Combustion Engineering Nuclear Steam Supply System and is nominally rated at a full power output of 912 MWe.[4] Both units were designed and constructed by Bechtel Corporation.

The ANO Plant Manager reports to the Director of Generation Operations, as shown in Figure 1. The Plant Manager directs the activities of the plant staff. Figure 2 is an organization chart of the Plant Staff. This chart depicts the station organization as it existed during the author's internship and may not reflect the present organization. The author's internship position in the Nuclear Engineering Group is also identified on Figure 2.

ANO Station Nuclear Engineering Group

The ANO Nuclear Engineering Group is supervised by the Station

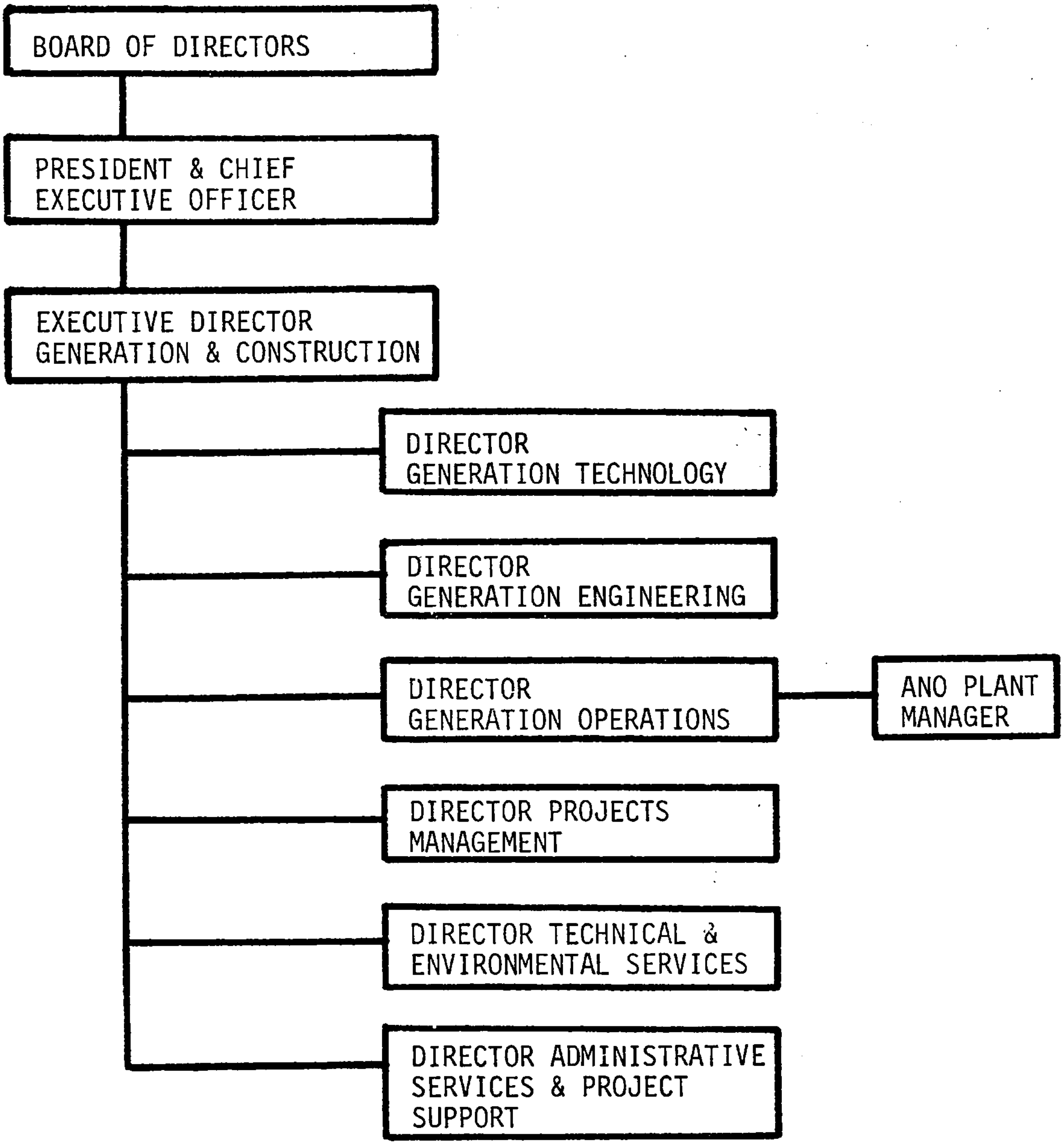

Figure 1 - A. P. & L. Generation and Construction
Department Organization

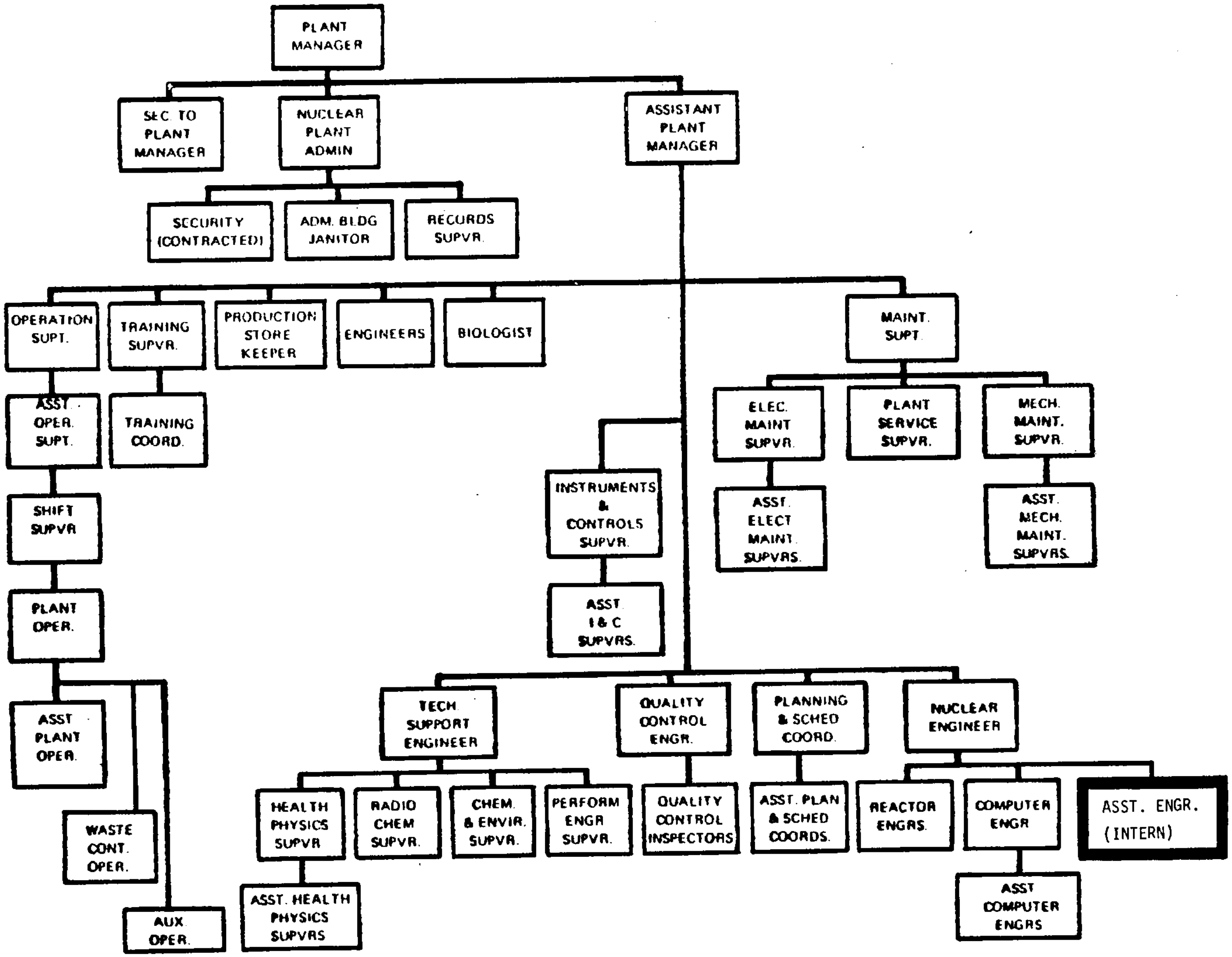

Figure 2 - ANO Station Organization

Nuclear Engineer, Thomas H. Cogburn, who was also the internship supervisor. Personnel in the group include one Reactor Engineer for each unit, a Computer Engineer and Assistants, and one or more Assistant Engineers. The group is responsible for reactor core performance monitoring and for providing support of nuclear fuel handling and core operation activities.

The technical responsibilities of the group involve: collection and analysis of data from core performance monitoring and physics testing; preparation of procedures, computer software and computational aides to support reactor operation; and preparation of procedures for, and providing support during, reactor refueling operations.

The administrative duties of the Nuclear Engineering Group include: maintenance of nuclear fuel accountability records; reporting core performance data to the appropriate fuel management personnel; assisting in the preparation and/or review of appropriate procedures to ensure that regulatory requirements are not violated; and interfacing with other organizations internal and external to Arkansas Power & Light Co. on matters relating to reactor operation.

Other organizations that the group frequently interfaces with would include:

(1) Other elements of the ANO Plant Staff

(2) AP&L Nuclear Fuel Management Group

(3) AP&L Licensing Group

(4) AP&L Startup Engineering

(5) Middle South Services, Inc., Nuclear Fuels Group

(6) U.S. Nuclear Regulatory Commission (NRC)

(7) Babcock & Wilcox (B & W)

(8) Combustion Engineering (CE)

(9) Other Nuclear Steam Supply System Owners.

Because of the broad range of activities and the number of interfaces, working with the Nuclear Engineering Group is a very interesting and dynamic experience. From this viewpoint the author was able to observe the impact of management decisions, made at several different levels, upon the day-to-day operation of the station and to observe the interactions of the various organizations involved. Additionally, the author was able to contribute to the solution of problems that were of immediate interest to the entire organization, as well as to longer range development projects.

OPERATIONS COMPUTER PROGRAM DEVELOPMENT

The Station Nuclear Engineer felt that as an initial assignment the author should develop several interactive computer programs to be used as computational aids to support the station operations personnel. This assignment was ideal for three reasons. First, it provided an introduction to the plant computer, which is frequently used by the Nuclear Engineering Group. Second, it introduced the author to the methods of writing procedures and the approval process associated with station operating procedures. Third, the author was provided with an opportunity to become personally acquainted with the plant operators and to begin learning how to work effectively with these personnel.

SAXON Modification

The SAXON computer program is a computational aid used to predict the Unit One Xe-135 reactivity worth as a function of time and reactor power history. The program was written during Unit One initial startup and has been modified several times. A test to measure the Xe-135 reactivity worth, performed on May 12, 1977 prior to the author's arrival, indicated the program was predicting values that were less than the actual Xenon worth. The author modified the program by multiplying the predicted flux by a constant factor of 1.345, which brought the predicted Xenon worth into agreement with the test. Figure 3 is a plot of the measured Xenon worth and the SAXON predictions before and after the correction factor was applied.[5]

On June 27, 1977 the author attended a Babcock & Wilcox owners meeting held in Little Rock, Arkansas. During this meeting Tom Cogburn gave a presentation on the Unit One Xenon test and the author followed

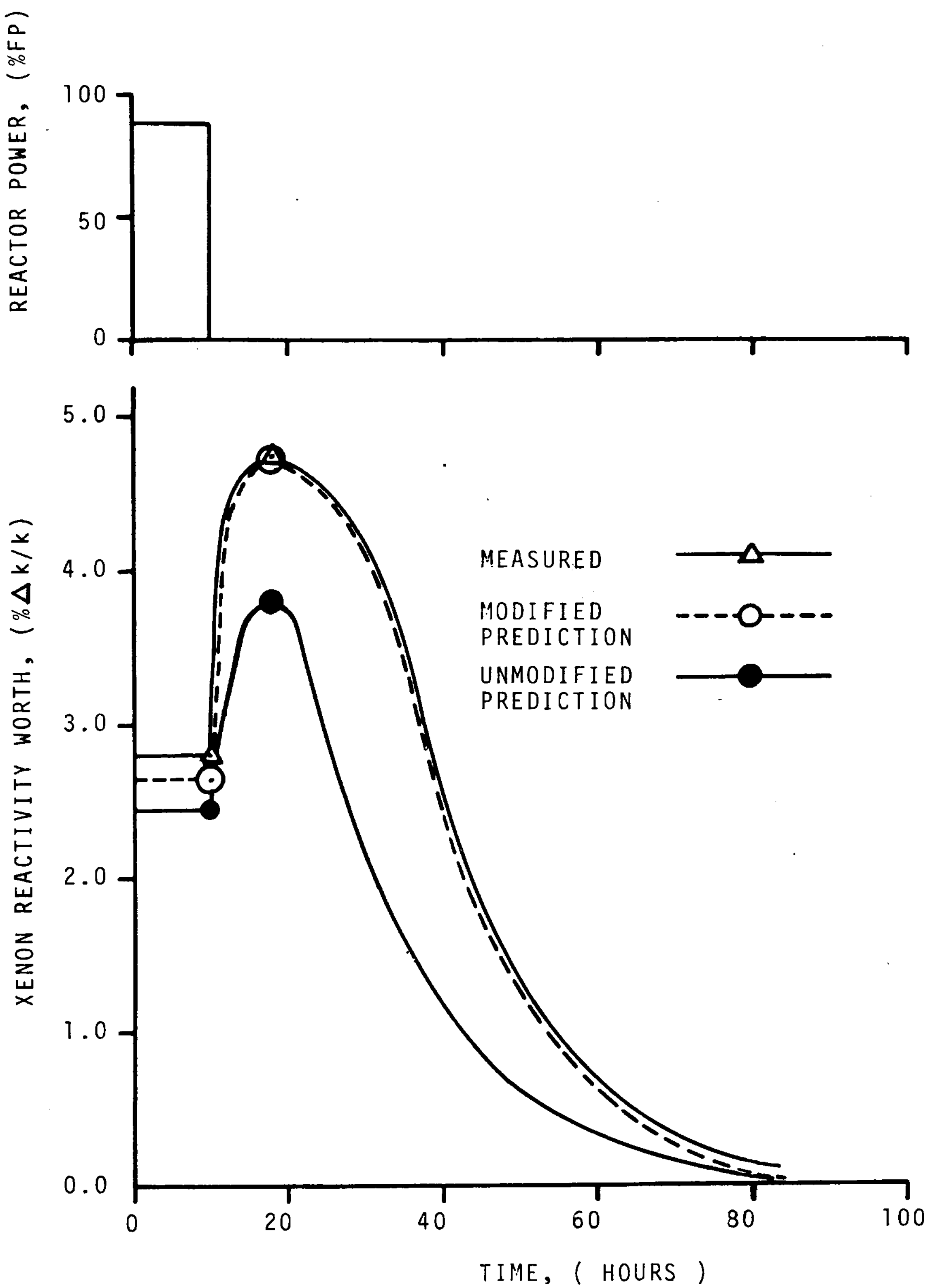

Figure 3 - SAXON Xenon Reactivity Worth Data

with a brief discussion of the SAXON modification.

Later the author wrote an up-to-date documentation manual for the SAXON program, incorporating all the program modifications up to that time.[6]

SAXON2

The need for a Unit Two Xenon reactivity worth program was identified during the internship and the author was assigned the task of developing this program. However, unlike Unit One, the data to write this program and update it for each depletion cycle was not available from the vendor's software updates. Because the costs to obtain this data from Combustion Engineering were prohibitive and because AP&L desired to develop independent capability in this area, the author specified the necessary data requirements and requested, through the AP&L Fuel Management Group, that Middle South Services (MSS) generate this data. Middle South Services performs certain fuel management and analysis functions for all the operating companies of Middle South Utilities. After MSS completed the data, the author wrote the SAXON2 program. The input/output characteristics of the program are virtually identical to the SAXON program, hence, operating personnel already familiar with that program would have no difficulty using the SAXON2 program.

SAM2

In addition to the Xenon data, the author requested that MSS provide the data necessary to compute the Unit Two Sm-149 reactivity worth. Using this data the author wrote the SAM2 program to predict the Samarium reactivity worth as a function of time and reactor power history. Figure 4 shows a Samarium transient predicted by this program.[7] SAM2 contains no burnup dependence since this is not significant because of the small magnitude of the Samarium worth. The buildup and burnout of Samarium is only important during Cycle 1 startup and after shutdowns with long duration; even after refueling nearly equilibrium conditions exist because of the Samarium contained in the two-thirds irradiated fuel remaining in the core.

BORON

Boron in the form of boric acid is used as a soluble poison in pressurized water reactors because of its high neutron cross section. Throughout a depletion cycle the Boron concentration in the reactor coolant is decreased to compensate for the decrease in fuel reactivity worth. Typically, the beginning of cycle (BOC) reactor coolant system Boron concentration is 900 ppmB and at end of cycle (EOC) is 30 ppmB. For refueling the Boron concentration is increased to approximately 2000 ppmB to ensure adequate shutdown conditions during the fuel handling operations. The plant operators must therefore frequently change the reactor coolant system Boron concentration during operation.

To enable the Unit One reactor operators to predict the amount of demineralized water and/or boric acid that must be added to the reactor coolant system to obtain a specified change in Boron concentration the author prepared the BORON interactive computer program. The program utilizes equations derived from a reactor coolant system mass balance and addresses two basic cases; batch and feed/bleed boration. Other special cases are also solved,such as boration during cooldown, boration from the borated water storage tank and spent fuel pool Boron

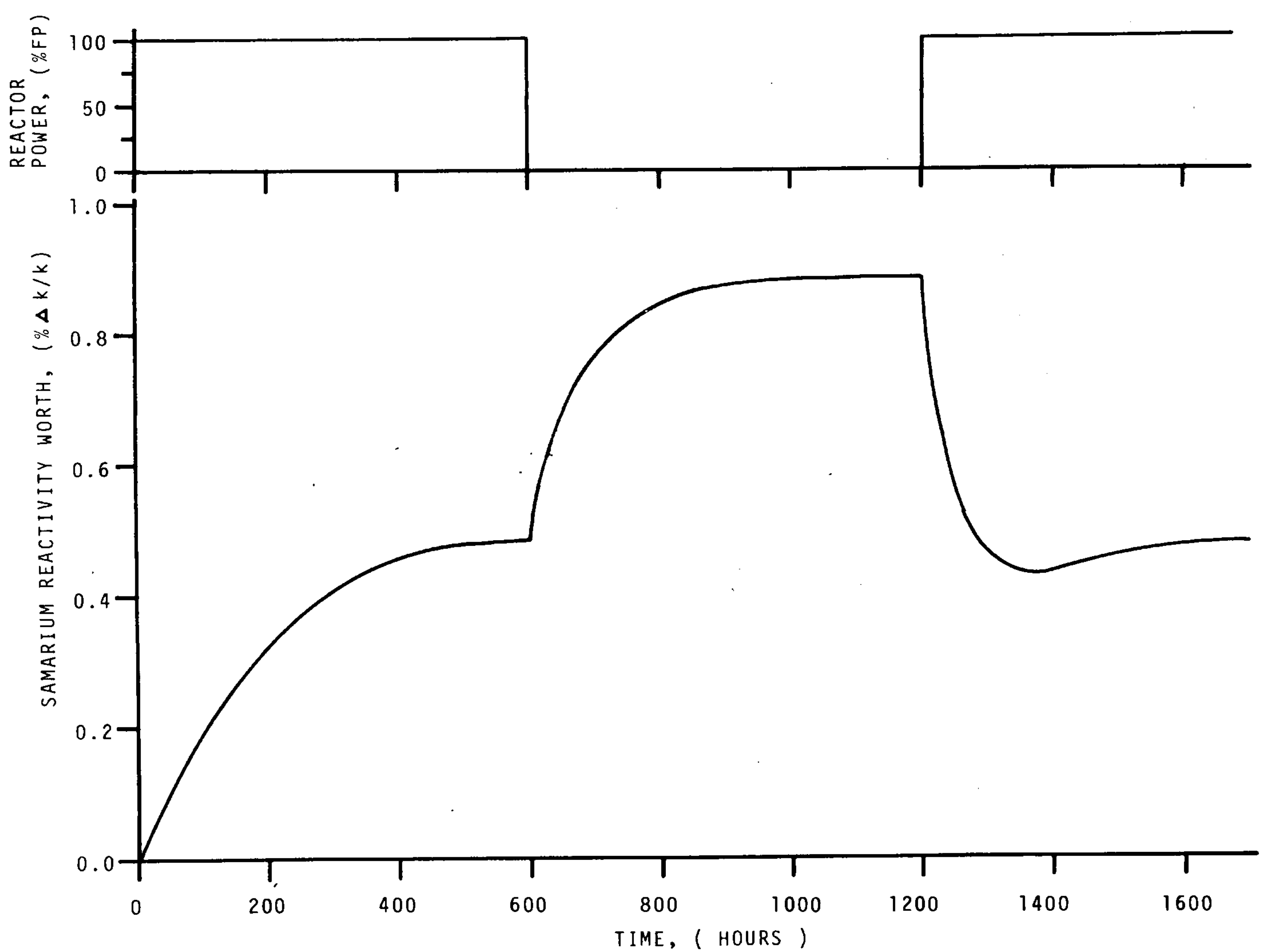

Figure 4 - SAM2 Samarium Reactivity Worth Data

concentration control. BORON has been benchmarked to actual operating data and, hence, accurately predicts Boron concentration changes. Less liquid radwaste is produced if the borations and dilutions are performed precisely, making BORON a useful program.

The author revised OP 1103.04, Unit One Soluble Poison Concentration Control, to implement the use of the BORON program. This procedure also contains tables and computational worksheets to substitute for the program in the event of a computer failure.

BORON2

BORON2 is a interactive program the author prepared to predict the required liquid additions to change the Unit Two reactor coolant system Boron concentration. Computationally the program is similar to BORON, but with different volume data and input/output characteristics.

After writing the BORON2 program, the author wrote OP 2103.04, Unit Two Soluble Poison Concentration Control, and gave a training session on the use of the program and procedure to the reactor operators.

Later during hot functional testing, the author observed a boration/dilution test designed to checkout the chemical and volume control system functions and to provide data to adjust the boration/ dilution computations. Although prior to the end of the internship the author did not have time to satisfactorily resolve the test results and BORON2 predictions, subsequently BORON2 was shown to provide accurate boration/dilution predictions.

UNIT ONE - CYCLE 3 REFUELING

The author's participation in the Unit One Cycle 3 refueling may be divided into three areas of activity. These are: (1) nuclear fuel receipt and inspection, (2) development of the Refueling Shuffle Fuel Movement Sequencing Program (RSFMSP) and (3) refueling shift support. This experience was valueable because the author was involved to a considerable depth and was able to participate from the planning stages all the way until the completion of fuel handling operations.

Fuel Receipt and Inspection

Nuclear fuel is delivered and stored usually several months prior to the actual refueling. The fuel arrives from the B & W fabrication facility in Lynchburg, Virginia by truck shipment. Asingle shipment consists of up to six shipping containers with two fuel assemblies in each container. This fuel is unloaded, inspected for shipping damage and stored in a predesignated location, usually the spent fuel pool. This process is described in OP 1502.05, Control and Accountability of Special Nuclear Material, and OP 1503.02, Fresh Fuel Inspection and Storage. The extent of the author's involvement in this activity was to assist in expediting the required paperwork and inspecting the fuel assemblies prior to storage.

Refueling Shuffle Fuel Movement Sequencing Program

Every nine to eighteen months, at the end of a depletion cycle, nuclear power stations must be refueled. During this refueling approximately one third of the fuel assemblies are discharged from the reactor core and a batch of new fuel assemblies are introduced to replace the discharge batch. Also, the fuel assemblies and control components remaining in the reactor are rearranged to optimize the physics and economic parameters during the next cycle. The entire process is called a refueling shuffle. Prior to refueling the operating staff of the station must determine the most efficient fuel assembly and control component movement sequence to shuffle from the initial, to the final, reactor configuration.

After working at Arkansas Nuclear One a month the author was asked to study the possibility of developing a computer program to generate the fuel assembly and control component movement sequence each refueling, for Unit One. The author's first step was to investigate how other companies generate this type of fuel shuffle sequence. It was determined that most utilities accept the vendor's sequence, which is not optimal, or generate the sequence manually, and at least one computer program is commercially available at a relatively high cost. But, the author did obtain a shuffle program from Philadelphia Electric Co., which was for a boiling water reactor and could not be readily adapted for Unit One. Hence, the author decided to develop a program in-house and the task became a major internship activity.

Program Objectives

The Refueling Shuffle Fuel Movement Sequencing Program (RSFMSP) had to satisfy four general objectives. First, the input data would be before shuffle and after shuffle maps of the reactor and spent fuel pool loading configurations, showing the serial numbers and locations of all fuel assemblies and control components. Figure 5 shows a

ANO-1, CYCLE 3

CORE LOADING PLAN

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
A						X6	X2	WL OXX	XC	XN					
B				X3 OXX	Y6	WW C30	1C03	1C45 C14	1C42	XK C31	XG	Y7 R00004			
C			XS	HK OXX	1C28 C43	1C09 OXX	J1 C11	1C23 OXX	HG C15	1C25 OXX P	1C53 C57	HT OXX	WZ		
D		XQ	H6 OXX	H9 C10	GY OXX	J6 A04	1C17 OXX	XU C45	1C16 OXX	GW A05	J7 OXX	HF C16	HE OXX	XP	
E		Y5	1C55 C55	HZ OXX	HL C29	JF OXX	JE C44	1C47 OXX	JH C46	J5 OXX	HN C32	H2 OXX	1C51 C47	XZ	
F	WN	Y4 C28	1C08 OXX	JG A03	J9 OXX	1A39 C12	1C60 OXX	1C32 C13	1C40 OXX	1A29 C18	GX OXX	J2 A06	1C01 OXX	XX C33	WR
G	XE	1C44	HV C09	1C11 OXX	H4 C42	1C36 OXX	Y1 C56	1C30 OXX	XJ C58	1C57 OXX	J3 C48	1C10 OXX	JD C17	1C41	XH
H	WT OXX	1C29 C08	1C20 OXX	Y2 C41	1C49 OXX	1C18 C07	1C15 OXX	1A28 C61	1C14 OXX	1C33 C19	1C48 OXX	XV C49	1C19 OXX	1C46 C20	WM OXX
K	X9	1C02	HH C05	1C06 OXX	HP C40	1C59 OXX	X4 C54	1C21 OXX	WY C60	1C37 OXX	H1 C50	1C13 OXX	H3 C21	1C43	XA
L	X8	XD C27	1C07 OXX	GZ A02	JA OXX	1A31 C06	1C56 OXX	1C22 C01	1C58 OXX	1A35 C24	J8 OXX	H5 A07	1C05 OXX	WX C34	WF
M		Y0	1C50 C39	HC OXX	HJ C26	HR OXX	HD C38	1C27 OXX	H8 C52	HW OXX	HX C35	J4 OXX	1C52 C59	Y3	
N		X1	HQ OXX	HY C04	HO OXX	JC A01	1C31 OXX	XT C37	1C12 OXX	J8 A08	HM OXX	J0 C22	HU OXX	XF	
O			XM	HB OXX	1C39 C53	1C04 OXX P	HA C03	1C38 OXX	H7 C23	1C24 OXX	1C54 C51	HS OXX	XL		
P				XR R00003	XB	XW C25	1C35	1C26 C02	1C34	XY C36	WV	X7 OXX			
R						WQ	X5	WE OXX	X0	WU					

Figure 5 - Reactor Loading Map

typical reactor loading map,[8] each block representing a reactor grid location which contains a single fuel assembly and may contain a control component, inserted into the fuel assembly. Second, the program must be consistent with existing fuel handling and fuel accountability procedures. Third, to the extent possible the program should optimize the shuffle sequence so that the refueling can be accomplished in a reasonable time with a minimum potential for fuel damage. Fourth, the engineering manhours and clerical effort required for manual preparation of the shuffle sequence should be reduced or eliminated.

Fuel Handling Equipment Design and Operation

Before formulating and writing RSFMSP the author studied the fuel handling equipment confiquration and capability. Figure 6 is a pictorial drawing of a fuel handling equipment configuration similar to Arkansas Nuclear One, Unit One and the exact arrangement is shown in Figure 7 which is a schematic diagram of the handling equipment layout at Arkansas Nuclear One, Unit One. The next several paragraphs are a description and explanation of the operation of this equipment during a refueling shuffle or a complete defueling and reloading of the reactor.

The New Fuel Pool (NFP), shown in Figure 7, has racks which can accept 72 fuel assemblies. This pool is not filled with demineralized water but is designed for dry storage of the fuel assemblies. New fuel may, therefore, be stored in the NFP under dry storage conditions prior to irradiation. But before introducing a new fuel assembly to the reactor, the assembly must first be lifted by the New Fuel

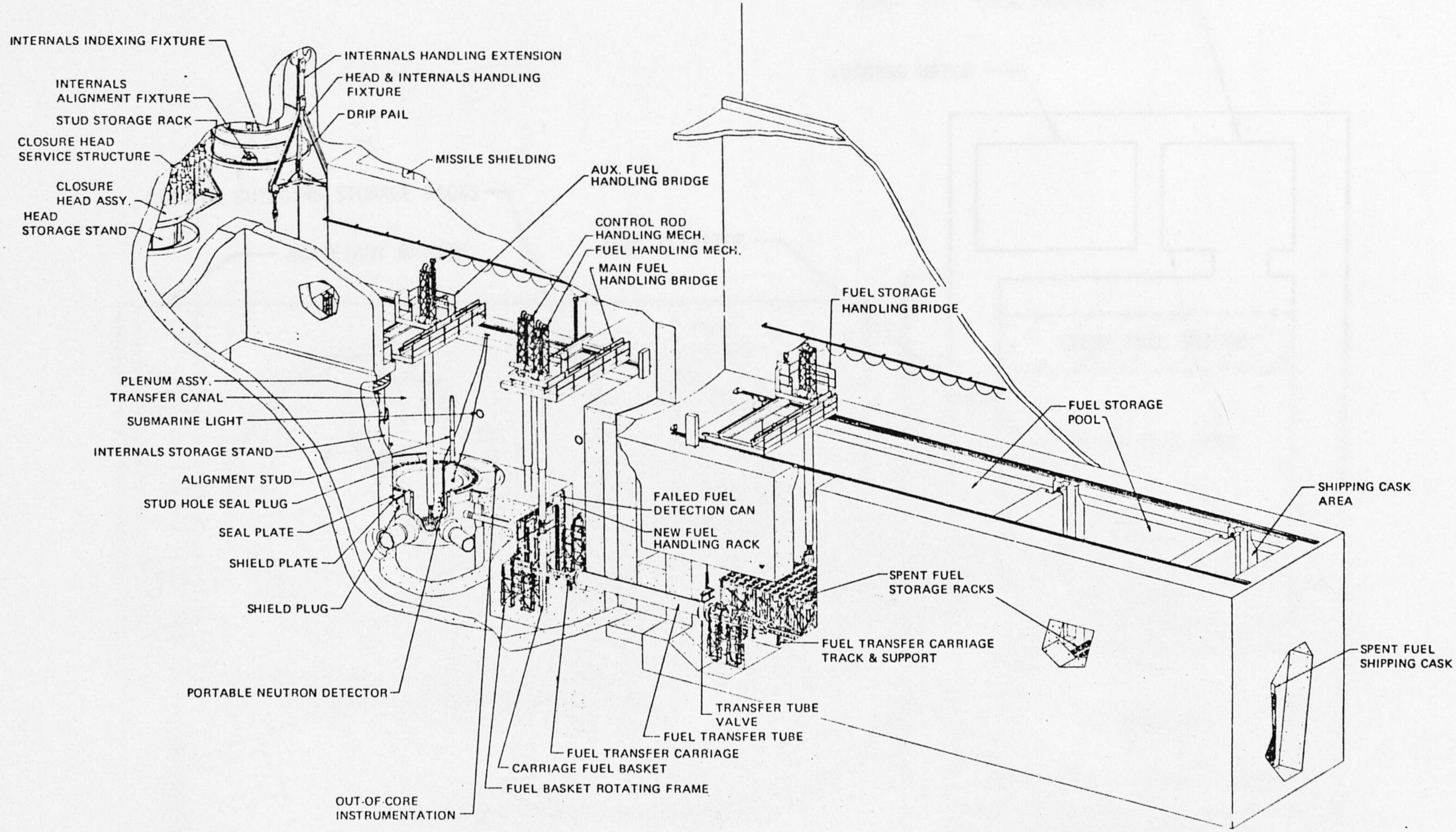

Figure 6 - Fuel Handling Equipment Configuration

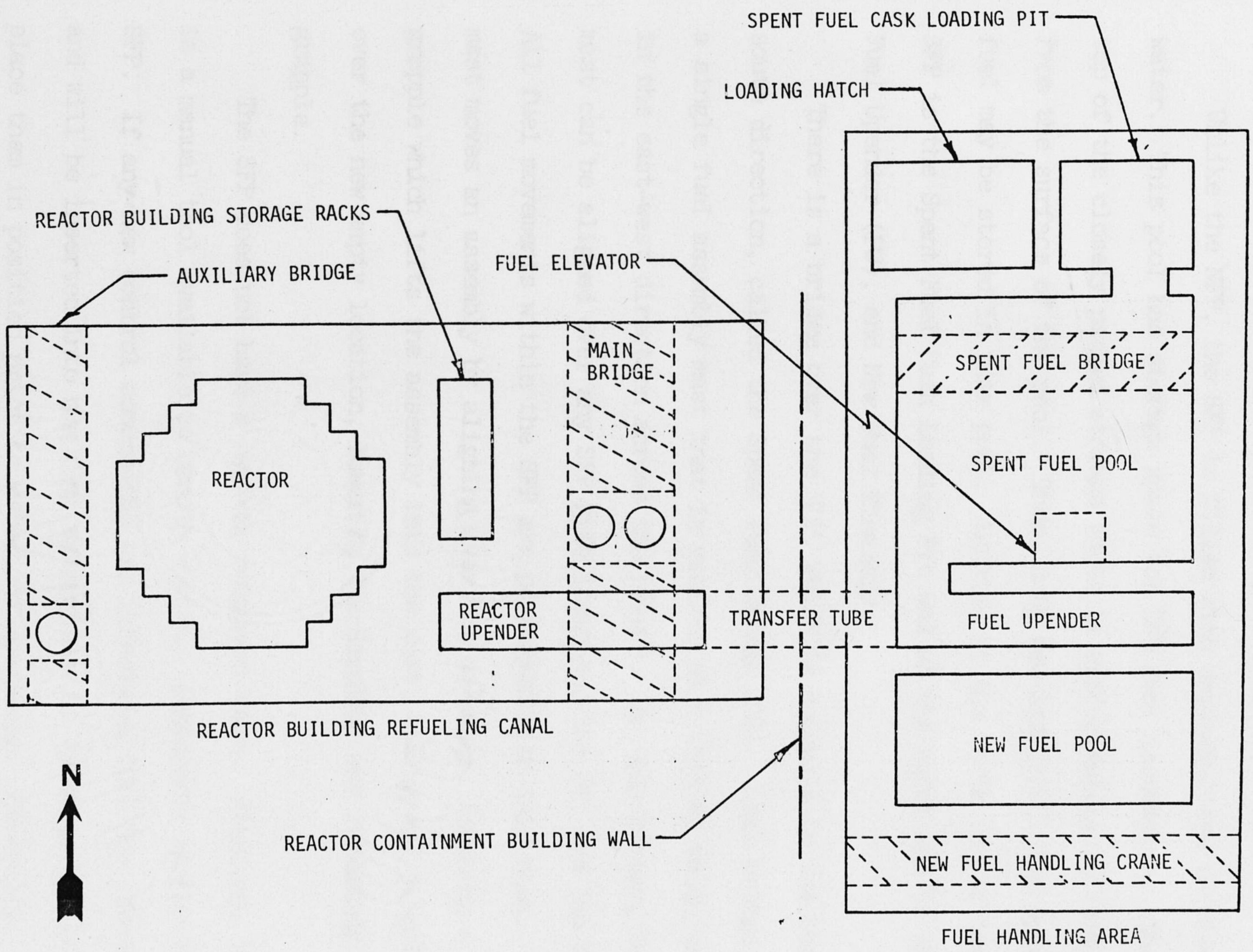

Figure 7 - ANO Unit One Fuel Handling Equipment Arrangement

Handling Crane (NFHC), inserted by the NFHC into the New Fuel Elevator (FE), and lowered by the FE into the Spent Fuel Pool (SFP).

Unlike the NFP, the SFP is filled with demineralized borated water. This pool has storage space for 589 fuel assemblies. The top of the closely packed storage racks is approximately 25 feet from the surface of the pool. Thus, both new and irradiated spent fuel may be stored in this pool. Located at the north end of the SFP is the Spent Fuel Cask Loading Pit and at the south end is the Fuel Upender (FU), and New Fuel Elevator.

There is a bridge over the SFP, which is moveable in the north-south direction, called the Spent Fuel Bridge (SB). This bridge has a single fuel assembly mast that is mounted on a trolley which travels in the east-west direction across the bridge. In this manner, the mast can be aligned over any SFP grid location, the FE, and the FU. All fuel movements within the SFP are performed with this mast. The mast moves an assembly by aligning over the assembly, lowering a grapple which lifts the assembly into the mast, moving and aligning over the new empty location, lowering the assembly and releasing the grapple.

The SFP does not have a control component mast. Although, there is a manual tool available to handle control components within the SFP. If any new control components are introduced into the reactor and will be inserted into new fuel assemblies, it is desirable to place them in position prior to refueling operation. Generally, however, control components are not replaced as often as fuel assemblies.

Movement steps may also be saved during refueling by storing the new fuel in the SFP after inspection. This eliminates the NFHC movements during the refueling outage. But, the NFP has some small advantage because of the dry storage capability.

Fuel assemblies may be transferred between the SFP and the Reactor Building Refueling Canal (RBRC) through the Fuel Transfer Tube. First, an assembly is inserted into the transfer basket by the SB Mast. Next, the FU is used to lay the transfer basket onto the transfer carriage, in a horizontal position. The carriage, which is pneumatically operated travels through the Fuel Transfer Tube. Finally, on the reactor side, the Reactor Upender (RU) is used to raise the basket upright and the fuel assembly may be removed. The Fuel Transfer Tube is thirty inches in diameter and may be isolated by a gate valve to maintain the reactor building integrity during reactor operation. Control components may be moved through the Fuel Transfer Tube only within a fuel assembly or in a special Control Component Handling Container.

Access to the reactor during refueling is gained through the RBRC. This canal is situated over the Reactor Vessel in such a manner that the Reactor Vessel Head Flange is nearly flush with the bottom of the RBRC. The arrangement is depicted by Figure 8. Therefore , when the Reactor Vessel Head is removed, the Reactor is open to the RBRC. This canal is dry during reactor operation and must be flooded with demineralized borated water before the Reactor Vessel Head may be removed. Besides the Reactor Vessel opening this canal

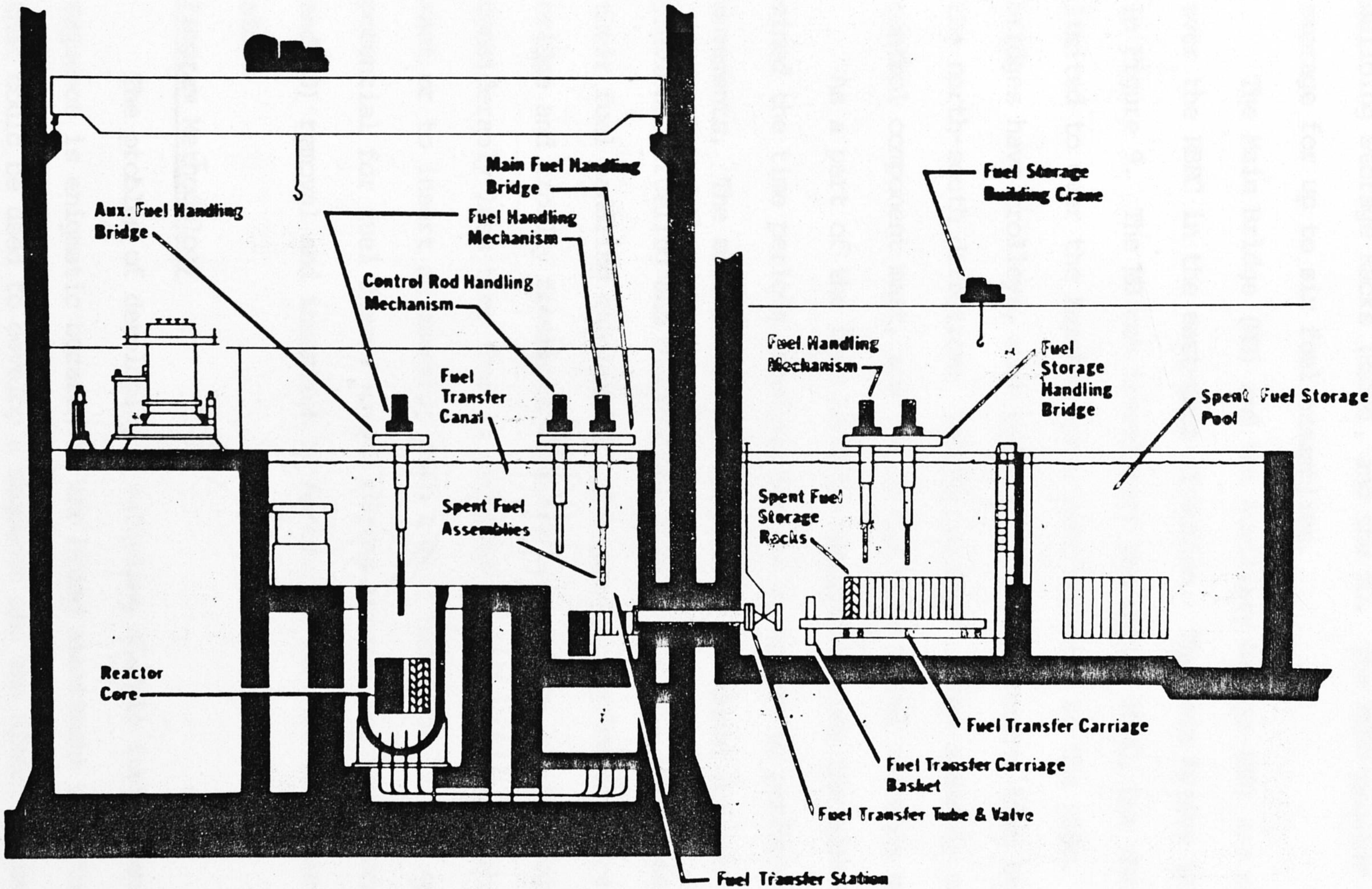

Figure 8 - Reactor Building Refueling Canal and Transfer Tube

has storage area for various reactor internal components, the Reactor Building Storage Racks (RBSR), and the RU. The RBSR provide temporary storage for up to six fuel assemblies.

The Main Bridge (MB) and the Auxiliary Bridge (AB) are moveable over the RBRC in the east-west direction. The Main Bridge is sketched in Figure 9. The MB can travel over the entire RBRC, but the AB is limited to over the Reactor and a hold position to the side. Both bridges have trolleys, with component handling masts, that travel in the north-south direction. The MB has both a fuel assembly mast and a control component mast, and the AB has only a fuel assembly mast.

As a part of the fuel handling equipment study the author determined the time periods required for the equipment to perform specific movements. The sources of this data were procedural records from the previous refueling and discussions with the reactor operators about their fuel handling experience. The general conclusions were: (1) bridge and trolley movements from one location to another require considerably less time than is required to lift a fuel assembly into a mast or to insert an assembly into a grid location, (2) the greatest potential for fuel damage exists during removal and insertion operations, and (3) removal and insertion of control components is particularly slow.

Program Methodology

The problem of developing a refueling shuffle fuel movement sequence is enigmatic because of the broad assortment of methods that could be used to develop a sequence and the almost unlimited

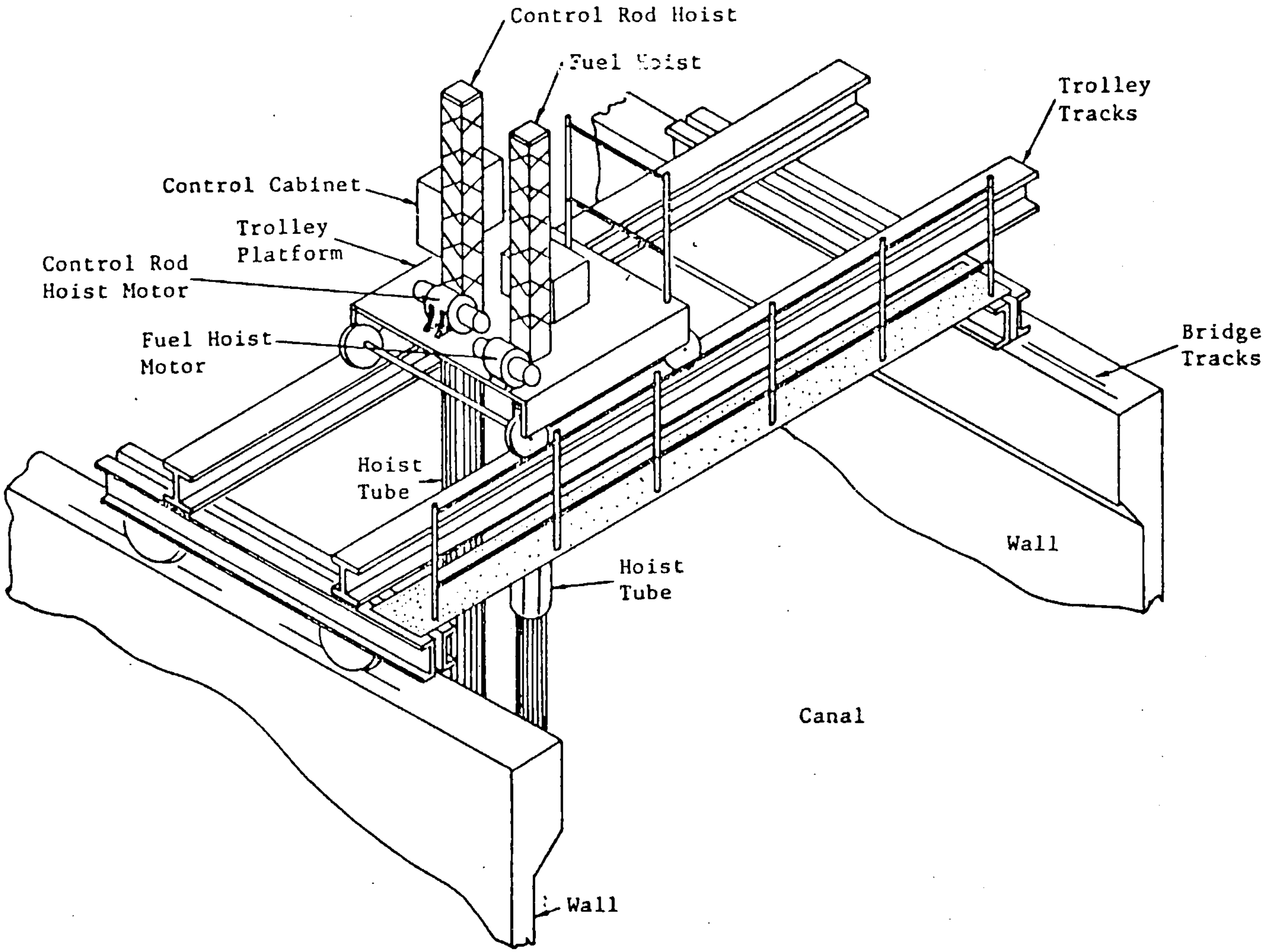

Figure 9 - Reactor Building Main Bridge

possible combinations of fuel movements. The approach used for the Refueling Shuffle Fuel Movement Sequencing Program (RSFMSP)[9] has as its basis the fundamental criterion that no fuel assembly or control component should be inserted unnecessarily into a temporary location and then be removed and placed into a final location. In this manner, no unnecessary or extra movements are performed, especially insertion and removal movements.

At any time during refueling within the reactor there are a fixed number of grid locations that may be occupied by fuel assemblies and initially all the locations are filled. At the time a fuel assembly is removed from the reactor, and discharged to the spent fuel pool, a single opening is created. A review of the final location information will determine if the new open position is the final location for a new fuel assembly or an irradiated assembly currently in another reactor grid location. Perhaps the open location will be the final position for a new fuel assembly, which may be transferred form the fuel handling area and inserted, however, if it is the final location for an irradiated assembly, then the assembly may be moved from its initial location to the open location. After moving the irradiated assembly, the situation is the same as before, that is with a single open location. Again the final location maps may be checked to determine if the open position is a final location for a new or irradiated assembly. If it is an irradiated assembly the process continues, but, if it is a new assembly the open location is filled and another assembly must be discharged to create another open location. Always after moving some variable number of irradiated assemblies the final location for a new assembly will be opened.

Extending this logic leads to the concept of a replacement queue, which is illustrated by Figure 10. Fuel Assembly A is the irradiated assembly being discharged from the Reactor to the Spent Fuel Pool. The replacement for Fuel Assembly A is another irradiated assembly, Fuel Assembly B, and similarly Fuel Assembly C is the replacement for Fuel Assembly B. Finally, the initial grid location of Fuel Assembly C is opened, and the replacement is Fuel Assembly D, a new assembly. The entire series of fuel assemblies from the discharge assembly to the new assembly is called a replacement queue. It should be noted, that the number of fuel assemblies in each replacement queue is variable and depends on the number or irradiated assemblies that must be moved within the Reactor between the discharge assembly and the new assembly.

The importance of the replacement queue concept is twofold; first, that all assemblies in replacement queues are always moved from their initial location to their final location without any unnecessary intermediate movement steps, thus satisfying the basic criterion and, second, that there is a replacement queue corresponding to each discharge assembly and after the movements within all replacement queues are completed all discharge batch assemblies are removed, all new assemblies are introduced and all shuffling movements within the Reactor will be complete, except for direct interchange movements.

Direct interchange movements are those where the initial location of Fuel Assembly A is the final location for Fuel Assembly B and the initial location for Fuel Assembly B is the final location for Fuel

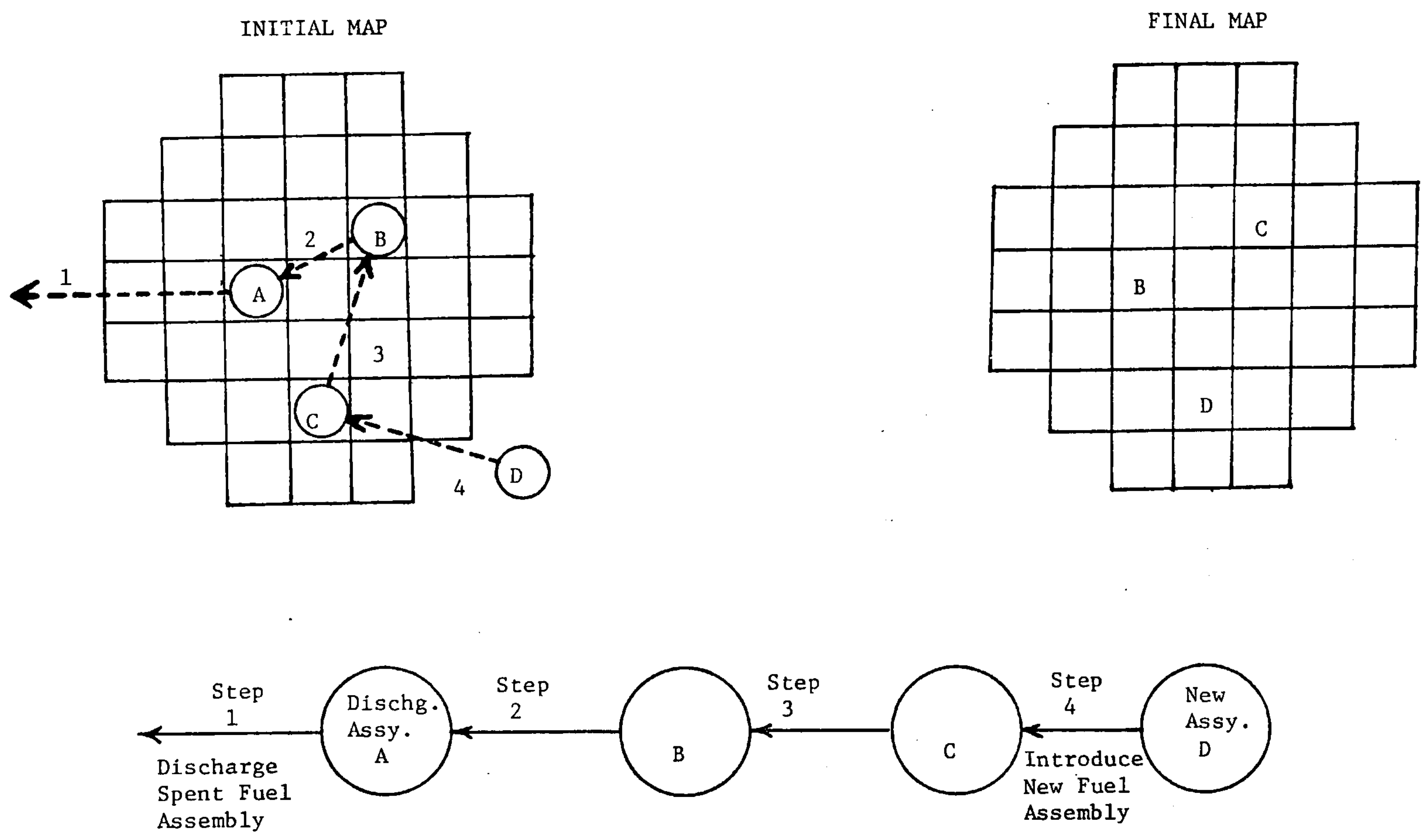

Figure 10 - Fuel Assembly Replacement Queue

Assembly A. To complete this interchange without placing one assembly in a temporary location and hence making unnecessary movements, both the main bridge and auxiliary bridge must be utilized. This type of movement does not occur within replacement queues, so these movements must be performed separately after the replacement queue movements are complete.

Replacement queues also provide an approach to the refueling shuffle movement sequence problem that may be easily adapted to a computer algorithm. The Gantt Chart, shown in Figure 11, shows the basic movement cycle for a replacement queue. Initially, Fuel Assembly 1 is removed by the main bridge from its initial location and inserted into the reactor upender (see Figure 7). When the main bridge is over the reactor upender, the Auxiliary Bridge can commence moving Fuel Assembly 2 from its initial position to the position opened by Fuel Assembly 1. Meanwhile, Fuel Assembly 1 may be transferred from the reactor upender to the fuel upender. Next, Fuel Assembly 3 is moved from its initial location to the position opened by Fuel Assembly 2, and concurrently the spent fuel bridge removes Fuel Assembly 1 form the fuel upender and stores the assembly in a spent fuel pool location. After storing Fuel Assembly 1, the spent fuel pool bridge removes Fuel Assembly 4 from its initial spent fuel pool location and inserts the assembly into the fuel upender. Next, Fuel Assembly 4 is transferred from the Fuel Upender to the Reactor Upender. Finally, the main bridge removes Fuel Assembly 4 from the Reactor Upender and inserts the assembly into the location opened by Fuel Assembly 3, and the replacement queue movements are complete.

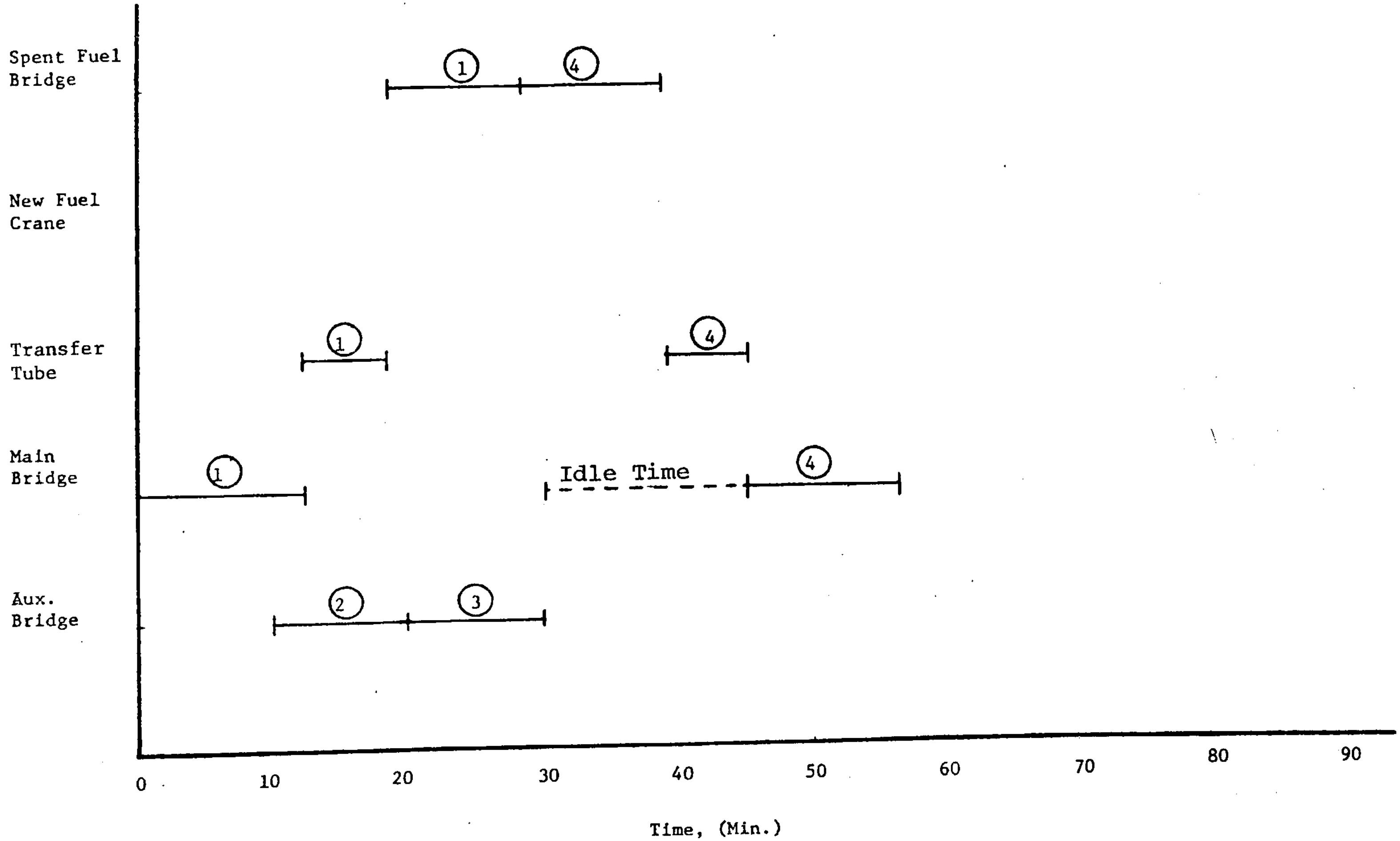

Figure 11 - Gantt Chart of Replacement Queue Movement Cycle

One observation that may be ascertained from Figure 11 is that the time period required to discharge an assembly to the Spent Fuel Pool and the return with a new assembly (transfer time) will be constant, regardless of the number of assemblies in a particular replacement queue. However, the time period needed to move the irradiated fuel assemblies (shuffle time) in the replacement queue, within the reactor, is not constant, but depends on the number of assemblies in the queue. If the transfer time is greater that the shuffle time, the refueling canal will be idle, waiting for a new assembly to arrive at the reactor upender, as shown in Figure 11. On the other hand, if the shuffle time is greater that the transfer time, the Fuel Handling Area will be idle more than necessary and a new fuel assembly will wait at the reactor upender, this situation is shown by Figure 12.

Idle time in the refueling canal may be utilized to perform several types of useful movements. Included are the following types of of component movements: (1) A control component movement, (2) a 'half' control component movement, which consists of removing a control component and holding it in the Main Bridge Control Component Mast, to be inserted during the next replacement queue movement cycle, (3) Rotation of a fuel assembly, and (4) A 'half' fuel assembly movement, which consists of removing the second assembly in the next replacement queue movement cycle, with the Auxiliary Bridge Mast, and holding it until the next cycle commences. Figure 13 illustrates a "half" fuel assembly movement Gantt Chart.

The key to optimizing (minimizing) the total shuffle time is to

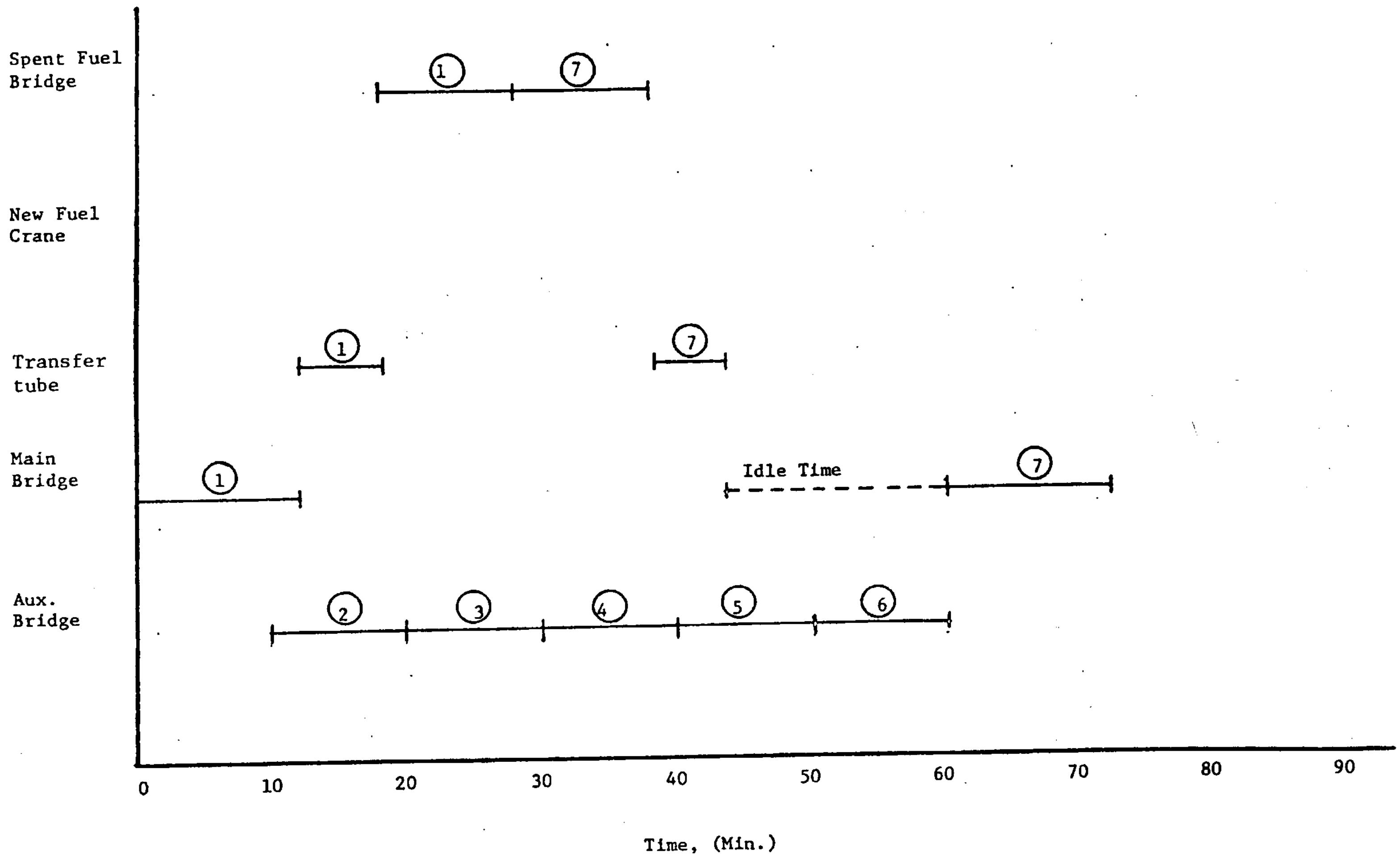

Figure 12 - Long Replacement Queue Gantt Chart

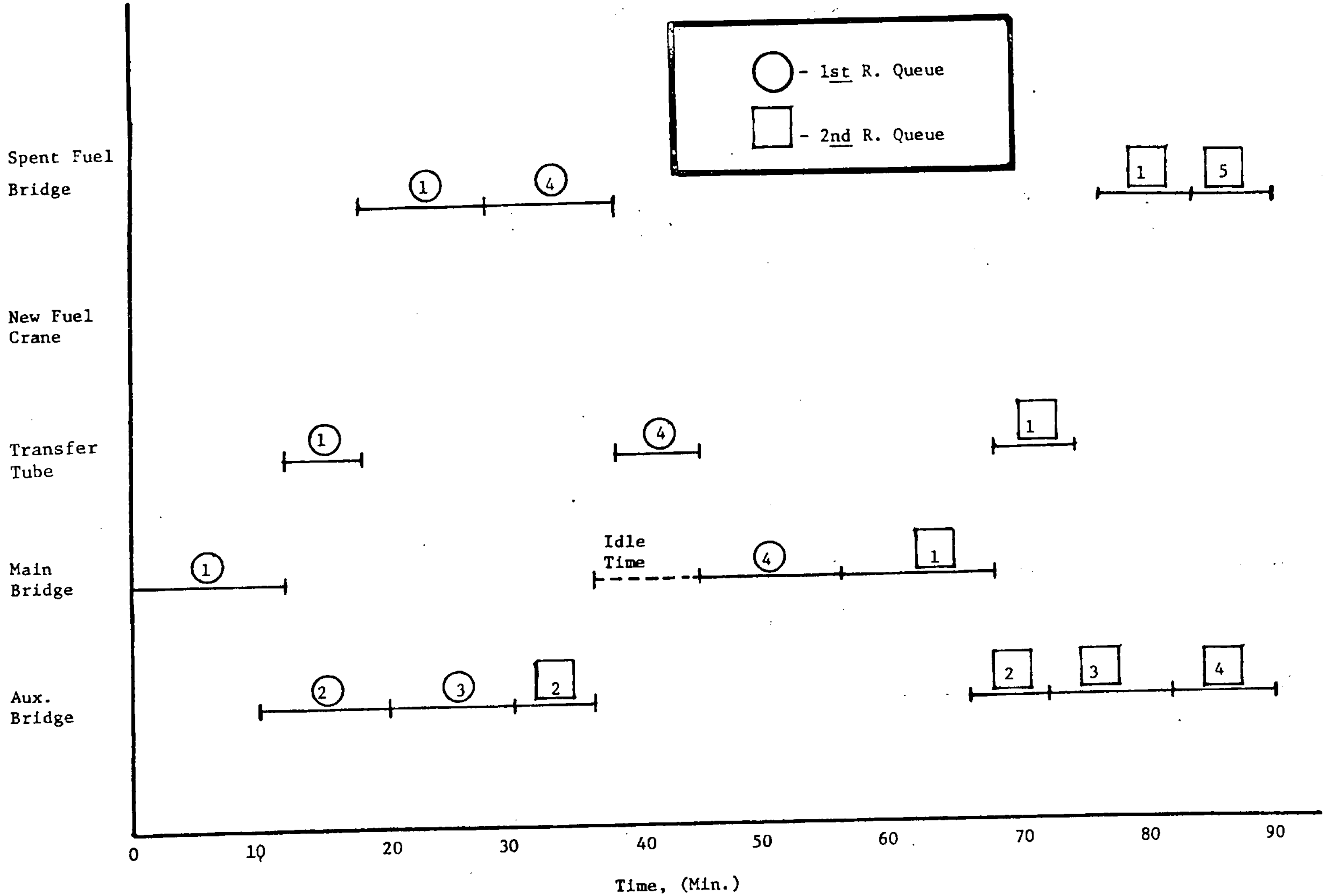

Figure 13 - Replacement Queue Gantt Chart With 'Half' a Fuel Assembly

select the best combination of replacement queue movement time and additional refueling canal movement time to make the shuffle time and transfer time as nearly equal as possible each time a spent fuel assembly is discharged. For a particular replacement queue movement cycle, if the two times are equal, then the idle time is reduced to zero. Thus, it is convenient to optimize the idle time, which may be formally defined as the absolute value of the transfer time minus the shuffle time. Dynamic programming[10] is the technique that was used to implement this optimization.

Figure 14 shows the structure of the refueling shuffle sequence problem, formulated as a dynamic programming problem. Each stage, n, of this problem will represent a replacement queue movement cycle. Therefore, the number of stages, N, will be equal the number of replacement queues or equal the number of spent fuel assemblies in the discharge batch. The input state, S_n, for the nth stage is the type of movement left to be completed from the previous stage and the replacement queues left to be sequenced. The return function, r_n, is the idle time, which is to be minimized. The decision, d_n, to be made at each stage is which replacement queue to sequence (hence, how many fuel assemblies to be moved within the reactor) this stage and what type of additional movement, if any, may be sequenced with the replacement queue.

The decision at each stage is made by solving the following integer programming problem.

$$r_n(S_n,d_n) = \min\Big[\pm T_{SFP} - T_{PREV}(S_n) - a_{SHUF}(X_{RQ}-2) - a_{cc}X_{cc} - a_{HM}X - a_{ROT}X_{ROT} - a_{HCC}X_{HCC}\Big]$$

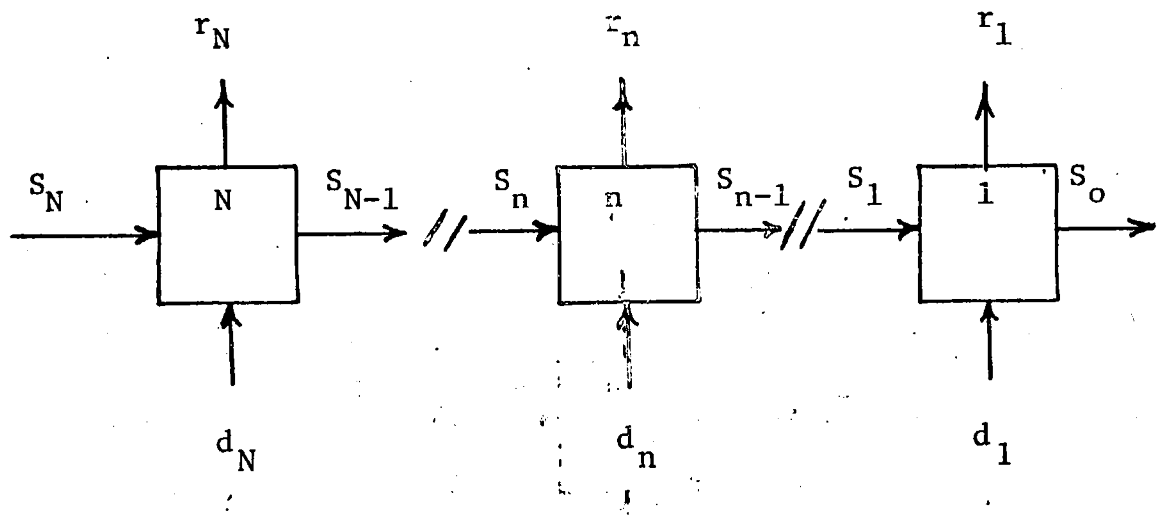

Figure 14 - Dynamic Programming Formulation

subject to:

$$X_{RQ} = K_1, K_2, K_3, K_4, \ldots$$

$$X_{cc} \geq 0$$

$$X_{ROT} \geq 0$$

$$0 \leq X_{HM} \leq 1$$

$$0 \leq X_{HCC} \leq 1$$

Where;

T_{SFP} = time required to discharge assembly and return with new assembly

T_{PREV} = time required to complete movement left from previous stage

a_{SHUF} = time required to move an assembly within the Reactor

a_{cc} = time required to move a control component within the Reactor

a_{HM} = time required to remove or insert an assembly with the auxiliary bridge as part of a 'half' move

a_{ROT} = time required to rotate an assembly, including removal and insertion time

a_{HCC} = time required to remove or insert a control component as part of a 'half' move

X_{RQ} = number of fuel assemblies belonging to the nth replacement queue

X_{HCC} = number of 'half' control component movements each replacement queue cycle, must be less than or equal one

X_{HM} = number of 'half' fuel assembly movements each replacement queue cycle, must be less than or equal one

X_{ROT} = number of fuel assemblies to be rotated each replacement queue cycle

X_{CC} = number of complete control component movements each replacement queue cycle

With only slightly more limiting restraints, this problem may be reformulated as a one-zero integer program. But, RSFMSP solves the problem by evaluating all possible solutions, because for this problem that technique is simpler that the standard integer programming alogrithms.

Once the sequence of replacement queues and additional movements is determined by dynamic programming additional logic algorithms are needed to accept this information and generate the actual fuel assembly and control component movement sequence. The basic scheme of these logical operations is to schedule all control component movements that can be accomplished prior to commencing the replacement queue movements, then schedule the replacement queue movement cycles in the order dictated by the dynamic program and finally schedule any control component or direct interchange movements that remain to be completed. All movement steps determined by these logical routines are listed in an array to generate the procedural output and to provide the input data for the critical path subroutine.

The RSFMSP uses the standard critical path techniques treating each movement step as an activity. The result is an estimate of the total refueling time which is equal the total critical path time, and the slack time for each activity. This information is an important input to planning for the overall refueling outage.

Results

Appendix A contains sample pages from OP 1502.04, Refueling Shuffle Sequence,[11] which is the procedure followed throughout the fuel handling operations. These pages were generated by the Refueling Shuffle Fuel Movement Sequencing Program and are for the Cycle 3 refueling. Appendix B contains loading maps and critical path report sample pages, also generated by RSFMSP.

To complete the Cycle 3 refueling only required five days (approximately four and a half days actual working time). This is a Babcock & Wilcox unit record, since similar operations have typically taken eight days at other facilities.

The author believes that three other factors, besides RSFMSP, contributed to this accomplishment: (1) an outstanding effort by the station operating personnel involved, (2) no significant handling equipment failures during the shuffle, because of on-site preventative maintenance supervised by the equipment vendor (Stearns-Roger) prior to the shuffle, and (3) always moving the fuel into or out of a boxed configuration (surrounded by other assemblies on four sides), which minimized assembly twist and spacer grid interference problems.

Post-refueling Development

After refueling the author further developed the Refueling Shuffle Fuel Movement Sequencing Program and wrote detailed documentation for the program. The post-refueling development included the statistical analysis of Cycle 3 refueling movement time data, addition of two new program options and simulation of the next refueling. During this period the author was assisted by other engineers and tried to use these activities as a vehicle to help the others become familiar with the program before the end of the internship period.

With assistance from AP&L General Office personnel the author collected fuel handling equipment time and motion data during the Cycle 3 refueling. This data was analyzed and more accurate movement times were determined for particular types of steps. The new times were then entered into RSFMSP in place of the previously estimated movement times and the Cycle 3 shuffle was reran. The optimization based on the new movement times changed the shuffle sequence slightly from the sequence previously generated and used during the refueling. The new total estimated shuffle time was very close to the actual working time, computed from the refueling chronological log. The close correspondence, the author feels, validates the methodology and indicates the Cycle 3 refueling was very nearly optimal.

The program was originally developed for a refueling shuffle within the reactor. However, for inspection and other purposes it is likely that all fuel assemblies and control components would have to be off-loaded to the spent fuel pool and reloaded in the same or another configuration. Hence, the author developed an algorithm for this situation. This algorithm has no optimization and simply logically sequences themovements to unload and reload the reactor. A checkerboard pattern is used because this is consistent with the "boxed in" handling technique that appears sucessful.

For fuel accountability all fuel assembly movements within the station must be recorded. To satisfy this need, the author added an option to RSFMSP to output transfer reports for all fuel assembly and control component movements, per OP 1502.05, Control and Accountability of Special Nuclear Material. In fact, RSFMSP could become a important part of a computerized fuel accountability system, if AP&L desired that type of system.

The Cycle 4 refueling may be a limiting case for RSFMSP because it is the first eighteen month cycle and burnable poison rods will be introduced in the core to replace many of the orfice rods. Thus, on the basis of a preliminary design report the author developed the location data and confirmed that the program would adequately generate the refueling sequence when the actual serial numbers are provided by Babcock & Wilcox.

Refueling Shift Support

The licensed Senior Reactor Operators, from the station operations group, are responsible for the safe conduct ofthe refueling fuel handling operations. However, the Nuclear Engineering Group provides shift support to monitor the fuel handling operations and provide advice and assistance as necessary. The author served in this capacity for several shifts during the Cycle 3 refueling and found the experience beneficial. The refueling fuel handling operations were conducted from February 13, 1978 to February 18, 1978.

UNIT ONE - CYCLE 3 PHYSICS TESTING

Prior to operation after refueling the reactor physics tests must be conducted to verify acceptable agreement with design predictions, thereby demonstrating that the reactor may be safely operated, and to collect data to be used during operation. The author's involvement in the Unit One Cycle 3 physics testing was related to three areas: (1) procedure revision and development, (2) physics testing shift support, and (3) data analysis and test review. This is an important activity of the Nuclear Engineering Group because of the significance of the test data and because physics testing is on the critical path for the entire outage. This experience was useful to the author by reason of the exposure received to the practical considerations involved in the operation of the reactor and the methods of collecting and interpreting physics data.

Physics Testing Sequence Description

The governing procedure for physics testing that references the other testing procedures is OP 1302.13, Sequence For Physics Testing Following Refueling.[12] Below in chronological order is an outline of the major steps occuring during the startup physics testing sequence, as specified in greater detail by OP 1302.13:

(1) Establish initial conditions, reactor coolant system at hot conditions and the reactor subcritical by at least 200 ppmB. Attain 'all rods out' configuration and commence deboration to measure the 'all rods out' critical Boron concentration, hence, determining the fuel react-

ivity worth.

(2) Measure the hot zero power moderator temperature coefficient with 'all rods out'.

(3) Commence deboration/rod insertion and concurrently measure differential and integral control rod assembly worth.

(4) Measure 'all rods in' critical boron concentration and hot zero power moderator temperature coefficient with 'all rods in'.

(5) Measure the ejected rod worth by boration of the rod to fully withdrawn position and reinsertion by control rod group swap technique.

(6) Perform test for radial flux distribution, a series of single rod swap tests conducted for Cycle 3 only.

(7) Proceed to 40% full power and verify the heat balance calculation and incore detector operation.

(8) Verify that the extrapolated maximum linear heat rate and the extrapolated minimum departure from nucleate boiling ratio are acceptable, and verify the core power distribution is acceptable.

(9) Proceed to 75% full power, verify heat balance calculation, hold at 75% until equilibrium Xenon conditions are established and verify incore detector operation.

(10) Verify that the extrapolated maximum linear heat rate and the extrapolated minimum departure from nucleate boiling ratio are acceptable, and verify the core power distribution

is acceptable.

(11) Proceed to 100% full power, establish equilibrium Xenon conditions, verify the extrapolated maximum linear heat rate and the extrapolated minimum departure from nucleate boiling ratio are acceptable, and verify the core power distribution is acceptable.

(12) Measure the power doppler coefficient and moderator temperature coefficient at power.

(13) After at least one week, but no more than two weeks, at a power level in excess of 95% full power return to 75% full power and establish equilibrium Xenon conditions and perform the power imbalance detector correlation test to determine the relationship between out-of-core detector and incore detector measured imbalance.

(14) Return to 100% full power and commence normal station operation.

The detailed instructions for each specific test are found in the appropriate physics test procedure.

Physics Test Procedure Development

In preparation for the refueling the author was assigned the task of rewriting the Unit One physics testing prodecures. The existing procedures were written by several different individuals for the previous refueling outage and some improvement was desirable, particularly with respect to the organization of the procedures and the data analysis worksheets. Babcock & Wilcox recommended some changes when the Cycle 3 Physics Test Documents were issued and some changes were made as a result of the previous testing experience of the Station Nuclear Engineering Group.

The initial portion of this assignment involved reading and studying all the procedures and related documents, and identifying the changes to be made and all unresolved issues. The author then satisfied all the unresolved issues through discussions with Tom Cogburn. The final portion of this task was to write and/or revise the procedures and expedite them through the approval process.

The author revised or wrote the following procedures as a part of this effort:

(1) OP 1302.05, Revision 2, Core Power Distribution

(2) OP 1302.06, Revision 1, Determination of Reactivity Coefficients

(3) OP 1302.07, Revision 3, Determination of Critical Boron Concentration

(4) OP 1302.08, Revision 2, Control Rod Reactivity Worth Measurements

(5) OP 1302.10, Revision 1, Ejected Rod Worth Measurement

(6) OP 1302.11, Revision 0, Determination of Radial Flux Distribution at Hot Zero Power

(7) OP 1302.13, Revision 1, Sequence for Physics Testing Following Refueling.

Also, the author reviewed OP 1302.04, Revision 1, Power Imbalance Detector Correlation Test.

Physics Testing Shift Support

The zero power physics testing sequence commenced on March 25, 1978, despite difficulty maintaining the reactor coolant system average temperature due to leakage through the turbine valves. The power escalation testing sequence was delayed by the turbine repairs, but began on April 23, 1978 and was completed on May 7,1978.

The author participated in the zero power physics testing by providing shift coverage on the midnight shift with two other engineers. The shift responsibility was to conduct the tests and verify by signoff the acceptance criteria as the tests proceeded. A chronological log of the test activities was also maintained. To provide twenty-four hour coverage the Station Nuclear Engineering Group was assisted by personnel from the AP&L Fuel Management Group, Middle South Services, and Babcock & Wilcox. The power escalation tests were conducted at irregular times, instead of on a shift basis, and the author also participated in several of these tests.

From this experience the author concluded that the keys to being a proficient test engineer are: (1) thorough knowledge of the practical details of the system being tested, (2) ability to make sound judgements in relatively short time periods, (3) ability to follow the procedures, plan ahead of the ongoing activities and anticipate problems, and (4) ability to accurately record test results and maintain documentation of the tests.

Data Analysis and Test Review

The physics test data is analyzed during the testing activities to verify all acceptance criteria. However, during idle periods while the tests are underway and after the tests are completed, the raw data (strip charts, computer printouts, data sheets, chronological log, etc.) must be analyzed further to carefully check the results and to obtain operating data. The results and supporting data must then be organized and stored in the station records vault.

The author assisted other engineers in completing the data analysis and he prepared detailed comments on the test procedures for use in preparing Cycle 4 test procedures.

Additionally, the author reviewed and commented on the Cycle 3 Startup Report[13] to be submitted to the U. S. Nuclear Regulatory Commission. This report is intended to describe the startup testing and to demonstrate acceptable agreement with the design predictions, and thereby, show that the reactor may be safely operated.

CONCLUSIONS

The internship experience at Arkansas Nuclear One with Arkansas Power & Light Company was enlightening to the author and more than satisfies the objectives mentioned in the introduction. The author was afforded close observation of the operation of a nuclear power station through almost an entire depletion cycle, including a refueling outage. The author also witnessed some phases of the startup of a second and different unit at the same station. Additionally, the author had the opportunity to develop a single project, the Refueling Shuffle Fuel Movement Sequencing Program, from the conceptualization of an idea to a useful end result.

The general attitude at Arkansas Power & Light was receptive to the full participation and professional development of an intern. However, the interest and involvement of the internship supervisor is the vital ingredient of a sucessful internship and the author was extremely fortunate to have a supervisor who made every effort to assign tasks that were non-trivial in nature and educational as well as useful to the internship organization.

Often on internship the author was reminded of the importance of being able to communicate effectively with people at all levels within an organization to accomplish specific objectives. The author concluded that an individuals integrity and technical competence are very important in an engineering organization, but often without the ability to communicate effectively and empathize with other individuals these attributes are less meaningful.

One important lesson learned by the author during the internship has to be the realization of how management decisions made in one segment of a large organization can affect the activities, attitudes and performance of other segments of the organization. Therefore, the wise engineering practitioner with managerial responsibility should look at problems from several viewpoints, considering both the tactical and strategic implications; then, and only then, is he prepared to make judicial decisions. Understanding this simple concept likely made the entire internship worthwhile for the author.

Overall the author's internship was a most challenging and invaluable experience. The internship assignments generally complimented the academic coursework and, hence, contributed to the author's total professional development. There is no doubt in the mind of the author that the internship is the high point of participation in the Doctor of Engineering program and that this internship will provide a solid foundation for future engineering practice.

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APPENDIX A

The next seven pages are samples of the Refueling Shuffle Fuel Movement Sequencing Program output for the Cycle 3 Refueling. This output was incorporated into OP1502.04, Refueling Shuffle Sequence, as Appendix D.

FUEL SHUFFLE SEQUENCE LEGEND

MB - REACTOR BUILDING MAIN BRIDGE
C - CONTROL ROD ASSEMBLY MAST ON THE MAIN BRIDGE
F - FUEL ASSEMBLY MAST ON THE MAIN BRIDGE
AB - REACTOR BUILDING AUXILIARY BRIDGE
SB - SPENT FUEL POOL BRIDGE
RU - REACTOR BUILDING UPENDER
FU - SPENT FUEL POOL UPENDER
NFHC - NEW FUEL HANDLING CRANE
FE - NEW FUEL ELEVATOR
DFA - DUMMY FUEL ASSEMBLY

STEP 1 : MOVE MB TO O- 6 USE C MAST TO REMOVE 022 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 2 : MOVE MB TO F- 1 USE C MAST TO INSERT 022 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 3 : MOVE MB TO L- 3 USE C MAST TO REMOVE 070 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 4 : MOVE MB TO L-15 USE C MAST TO INSERT 070 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 5 : MOVE MB TO H- 9 USE C MAST TO REMOVE 037 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 6 : MOVE MB TO N- 2 USE C MAST TO INSERT 037 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 7 : MOVE MB TO H- 7 USE C MAST TO REMOVE 008 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 8 : MOVE MB TO P- 5 USE C MAST TO INSERT 008 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 9 : MOVE MB TO G- 8 USE C MAST TO REMOVE 055 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 10 : MOVE MB TO F-15 USE C MAST TO INSERT 055 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 11 : MOVE MB TO F- 3 USE C MAST TO REMOVE 075 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 12 : MOVE MB TO M-14 USE C MAST TO INSERT 075 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 13 : MOVE MB TO C-10 USE C MAST TO REMOVE 018 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 14 : MOVE MB TO N-14 USE C MAST TO INSERT 018 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 15 : MOVE MB TO N-12 USE C MAST TO REMOVE C10 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 16 : MOVE MB TO O-13 USE C MAST TO INSERT C10 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 17 : MOVE MB TO N- 4 USE C MAST TO REMOVE C16 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 18 : MOVE MB TO O- 3 USE C MAST TO INSERT C16 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 19 : MOVE MB TO M- 9 USE C MAST TO REMOVE C44 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 20 : MOVE MB TO R- 9 USE C MAST TO INSERT C44 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 21 : MOVE MB TO M- 8 USE C MAST TO REMOVE 048 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 22 : MOVE MB TO M- 2 USE C MAST TO INSERT 048 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 23 : MOVE MB TO M- 7 USE C MAST TO REMOVE C46 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 24 : MOVE MB TO R- 7 USE C MAST TO INSERT C46 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 25 : MOVE MB TO L- 5 USE C MAST TO REMOVE 049 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 26 : MOVE MB TO L- 1 USE C MAST TO INSERT 049 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 27 : MOVE MB TO K-11 USE C MAST TO REMOVE C42 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 28 : MOVE MB TO K-15 USE C MAST TO INSERT C42 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 29 : MOVE MB TO K- 5 USE C MAST TO REMOVE C48 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 30 : MOVE MB TO K- 1 USE C MAST TO INSERT C48 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 31 : MOVE MB TO H-11 USE C MAST TO REMOVE 046 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 32 : MOVE MB TO P-11 USE C MAST TO INSERT 046 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 33 : MOVE MB TO G-11 USE C MAST TO REMOVE C40 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 34 : MOVE MB TO G-15 USE C MAST TO INSERT C40 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 35 : MOVE MB TO G- 5 USE C MAST TO REMOVE C50 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 36 : MOVE MB TO G- 1 USE C MAST TO INSERT C50 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 253 : MOVE MB TO O-11 USE C MAST TO REMOVE C11 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 254 : MOVE MB TO N- 9 USE C MAST TO INSERT C11 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 255 : MOVE MB TO C-12 USE C MAST TO REMOVE R00004 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 256 : MOVE MB TO B-12 USE C MAST TO INSERT R00004 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 257 : MOVE MB TO C- 6 USE C MAST TO REMOVE 004 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 258 : MOVE MB TO C-12 USE C MAST TO INSERT 004 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 259 : MOVE MB TO C- 6 USE F MAST TO REMOVE NJ1B48 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 260 : MOVE MB TO RU USE F MAST TO INSERT NJ1B48 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 261 : TRANSFER NJ1B48 FROM THE RU TO THE FU INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 262 : MOVE AB TO O-12 REMOVE NJ1C09 & 020 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 263 : MOVE AB TO C- 6 INSERT NJ1C09 & 020 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 264 : MOVE AB TO B- 4 REMOVE NJ00HS & 011 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 265 : MOVE AB TO O-12 INSERT NJ00HS & 011 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 266 : MOVE SB TO FU REMOVE NJ1B48 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 267 : MOVE SB TO G- 6 INSERT NJ1B48 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 268 : MOVE SB TO B- 9 REMOVE NJ00X3 & 013 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 269 : MOVE SB TO FU INSERT NJ00X3 & 013 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 270 : TRANSFER NJ00X3 & 013 FROM THE FU TO THE RU INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 649 : MOVE AB TO K- 2 INSERT NJ1C02 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 650 : MOVE AB TO L- 4 REMOVE NJ1C51 & A06 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 651 : MOVE AB TO E-13 INSERT NJ1C51 & A06 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 652 : MOVE AB TO F-14 REMOVE NJ00GZ & C27 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 653 : MOVE AB TO L- 4 INSERT NJ00GZ & C27 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 654 : MOVE SB TO FU REMOVE NJ1B01 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 655 : MOVE SB TO M-10 INSERT NJ1B01 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 656 : MOVE SB TO E- 7 REMOVE NJ00XX INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 657 : MOVE SB TO FU INSERT NJ00XX INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 658 : TRANSFER NJ00XX FROM THE FU TO THE RU INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 659 : MOVE MB TO RU USE F MAST TO REMOVE NJ00XX INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 660 : MOVE MB TO F-14 USE F MAST TO INSERT NJ00XX INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 661 : MOVE MB TO K-14 USE F MAST TO REMOVE NJ1B42 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 662 : MOVE MB TO RU USE F MAST TO INSERT NJ1B42 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 663 : TRANSFER NJ1B42 FROM THE RU TO THE FU INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 664 : MOVE AB TO E- 3 REMOVE NJ1C43 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 665 : MOVE AB TO K-14 INSERT NJ1C43 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 666 : MOVE AB TO L-12 REMOVE NJ1C55 & A03 INIT:______DATE:_______TIME:______ZZ TAPE:______
COMMENTS:

STEP 919 : TRANSFER NJ00WM & 012 FROM THE FU TO THE RU INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 920 : MOVE MB TO RU USE F MAST TO REMOVE NJ00WM & 012 INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 921 : MOVE MB TO H-15 USE F MAST TO INSERT NJ00WM & 012 INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 922 : MOVE MB TO L- 8 USE F MAST TO REMOVE NJ1B23 INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 923 : MOVE MB TO RU USE F MAST TO INSERT NJ1B23 INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 924 : MOVE AB TO L- 8 INSERT NJ1C22 & C01 INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 925 : TRANSFER NJ1B23 FROM THE RU TO THE FU INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 926 : MOVE AB TO R- 8 REMOVE NJ00HN & C32 INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 927 : MOVE AB TO E-11 INSERT NJ00HN & C32 INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 928 : MOVE SB TO FU REMOVE NJ1B23 INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 929 : MOVE SB TO M-11 INSERT NJ1B23 INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 930 : MOVE SB TO A- 8 REMOVE NJ00WS & 039 INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 931 : MOVE SB TO FU INSERT NJ00WS & 039 INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 932 : TRANSFER NJ00WS & 039 FROM THE FU TO THE RU INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 933 : MOVE MB TO RU USE F MAST TO REMOVE NJ00WS & 039 INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 934 : MOVE MB TO R- 8 USE F MAST TO INSERT NJ00WS & 039 INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 935 : MOVE MB TO C- 7 USE F MAST TO REMOVE NJ1B16 INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 936 : MOVE MB TO RU USE F MAST TO INSERT NJ1B16 INIT:______DATE:______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 1045 : MOVE MB TO H- 3 USE F MAST TO REMOVE NJ1C19 & 001 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 1046 : MOVE AB TO H-13 REMOVE NJ1C20 & 045 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

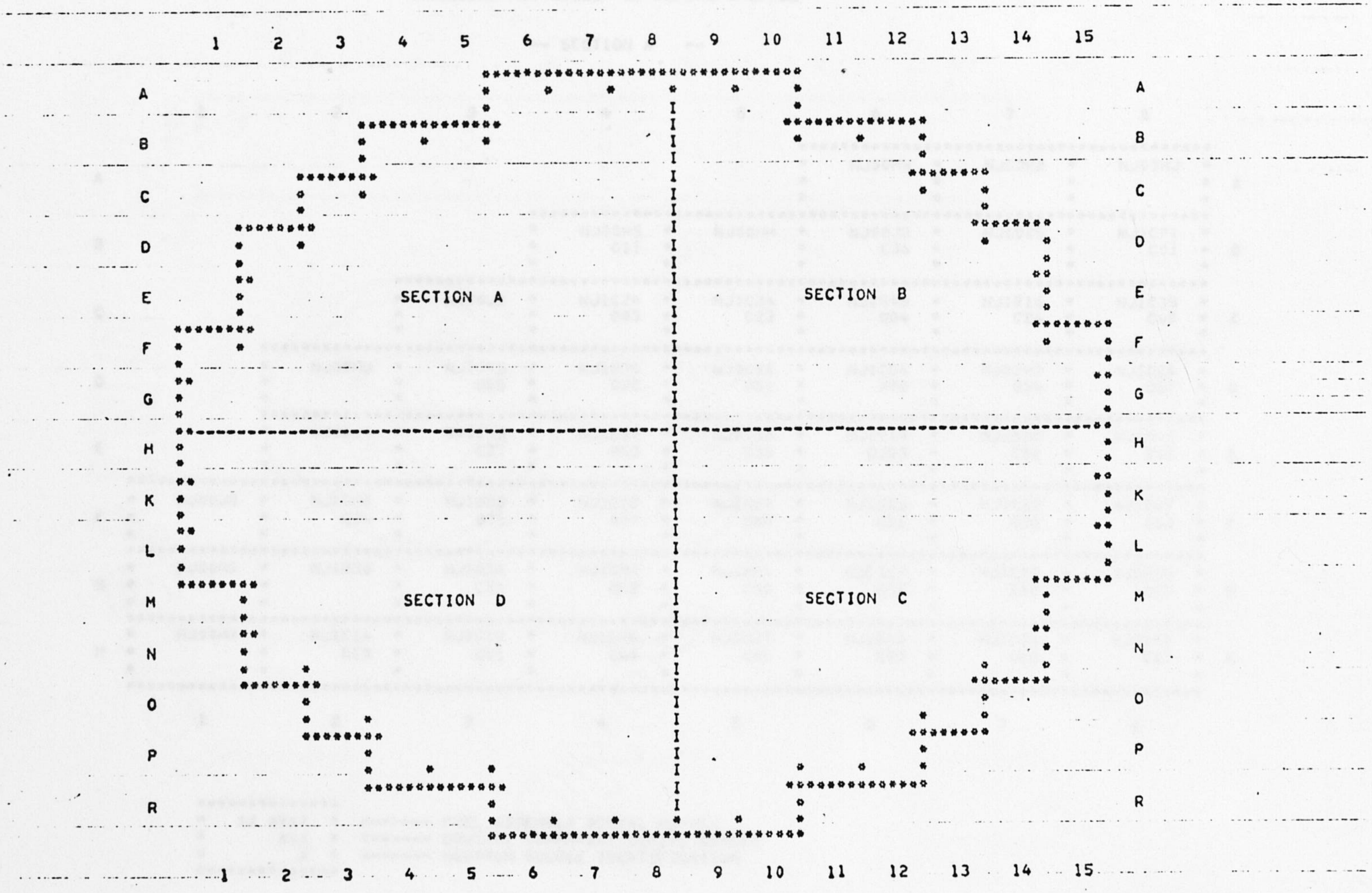
STEP 1047 : MOVE AB TO H- 3 INSERT NJ1C20 & 045 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

STEP 1048 : MOVE MB TO H-13 USE F MAST TO INSERT NJ1C19 & 001 INIT:______DATE:_______TIME:_____ZZ TAPE:______
COMMENTS:

APPENDIX B

The next eleven pages are samples of the other outputs generated by the Refueling Shuffle Fuel Movement Sequencing Program. These are not included in the refueling procedure, but are useful for planning the fuel shuffle and the overall outage.

ANO-1 CORE LOADING MAP
REFUELING FOR CYCLE 3, BEFORE SHUFFLE



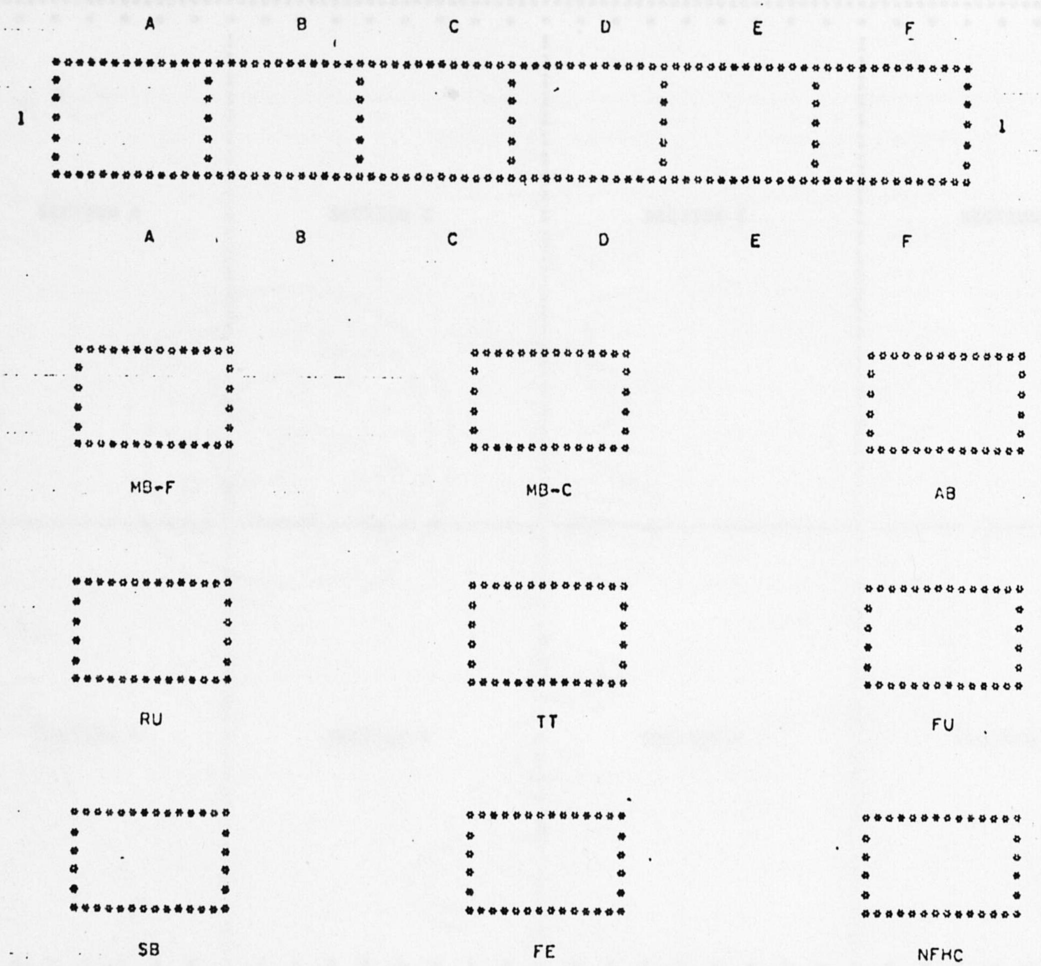
ANO-1 CORE LOADING MAP
REFUELING FOR CYCLE 3, BEFORE SHUFFLE

-- SECTION A --

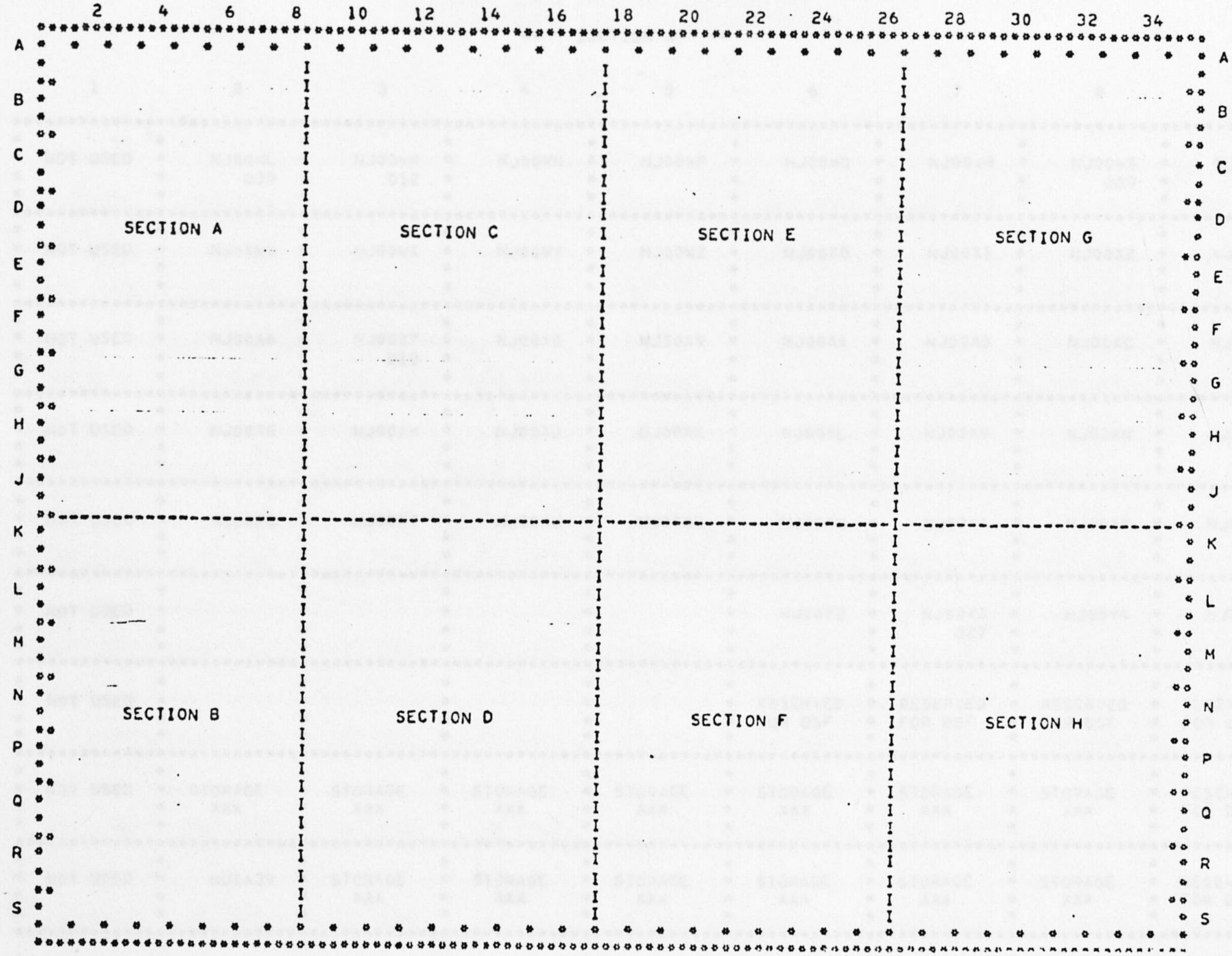
	1	2	3	4	5	6	7	8	
A						NJ00HW	NJ00H8	NJ00HJ	A
B				NJ00HS 011	NJ00HM	NJ00JB C36	NJ1B25	NJ1C21 C01	B
C			NJ00J0	NJ1C24 003	NJ1C34 C23	NJ1B48 004	NJ1B16 C24	NJ1C38 C40	C
D		NJ00HU	NJ1C05 050	NJ1B36 C22	NJ1C58 061	NJ1C54 A08	NJ00H7 054	NJ1C26 C37	D
E		NJ00J4	NJ1C43 C21	NJ1C37 063	NJ1C33 C35	NJ1B19 0353	NJ1B20 C52	NJ1B43 041	E
F	NJ00J8	NJ00H5 C34	NJ1B50 075	NJ1C52 A07	NJ1B54 064	NJ1B06 C51	NJ1C12 021	NJ1B07 C53	F
G	NJ00H1	NJ1B38	NJ1B58 C20	NJ00H3 052	NJ1B24 C50	NJ1C13 035	NJ1C48 C60	NJ1B33 C55	G
H	NJ00HX	NJ1C14 C19	NJ1C19 001	NJ1C46 C49	NJ1B37 065	NJ1B08 C59	NJ1B34 008	NJ1E26 C61	H
	1	2	3	4	5	6	7	8	

XX XXXX <------ FUEL ASSEMBLY SERIAL NUMBER
XXX <------ CONTROL COMPONENT SERIAL NUMBER
X <------ NEUTRON SOURCE IDENTIFICATION

ANO-1 REACTOR BLDG. STORAGE RACK AND HANDLING EQUIPMENT LOADING MAP
REFUELING FOR CYCLE 3, BEFORE SHUFFLE



ANO-1 SPENT FUEL POOL LOADING MAP
REFUELING FOR CYCLE 3, BEFORE SHUFFLE



ANO-1 SPENT FUEL POOL LOADING MAP
REFUELING FOR CYCLE 3, BEFORE SHUFFLE

-- SECTION A --

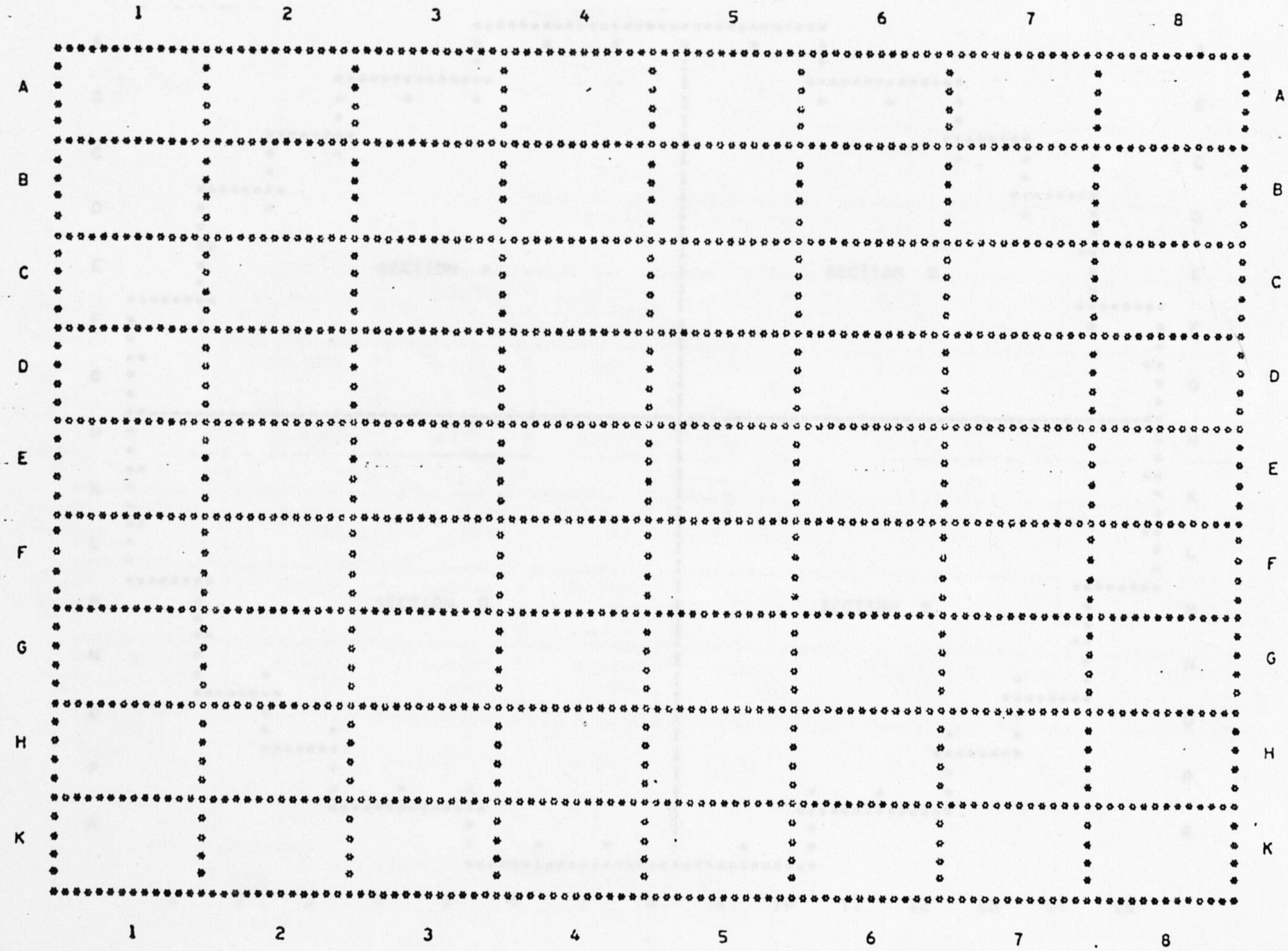
	1	2	3	4	5	6	7	8	9	
A	NOT USED	NJ00WL 030	NJ00WM 012	NJ00WN	NJ00WP	NJ00WQ	NJ00WR	NJ00WS 039	NJ00WT 071	A
B	NOT USED	NJ00WW	NJ00WX	NJ00WY	NJ00WZ	NJ00X0	NJ00X1	NJ00X2	NJ00X3 013	B
C	NOT USED	NJ00X6	NJ00X7 019	NJ00X8	NJ00X9	NJ00XA	NJ00XB	NJ00XC	NJ00XD	C
D	NOT USED	NJ00XG	NJ00XH	NJ00XJ	NJ00XK	NJ00XL	NJ00XM	NJ00XN	NJ00XP	D
E	NOT USED	NJ00XS	NJ00XT	NJ00XU	NJ00XV	NJ00XW	NJ00XX	NJ00XY	NJ00XZ	E
F	NOT USED					NJ00Y2	NJ00Y3 027	NJ00Y4	NJ00Y5	F
G	NOT USED					RESERVED FOR DSF	RESERVED FOR DSF	RESERVED FOR DSF	RESERVED FOR DSF	G
H	NOT USED	STORAGE XXX	STORAGE XXX	STORAGE XXX	STORAGE XXX	STORAGE XXX	STORAGE XXX	STORAGE XXX	RESERVED FOR DSF	H
J	NOT USED	NJ1A39	STORAGE XXX	STORAGE XXX	STORAGE XXX	STORAGE XXX	STORAGE XXX	STORAGE XXX	RESERVED FOR DSF	J

ANO-1 SPENT FUEL POOL LOADING MAP
REFUELING FOR CYCLE 3, BEFORE SHUFFLE

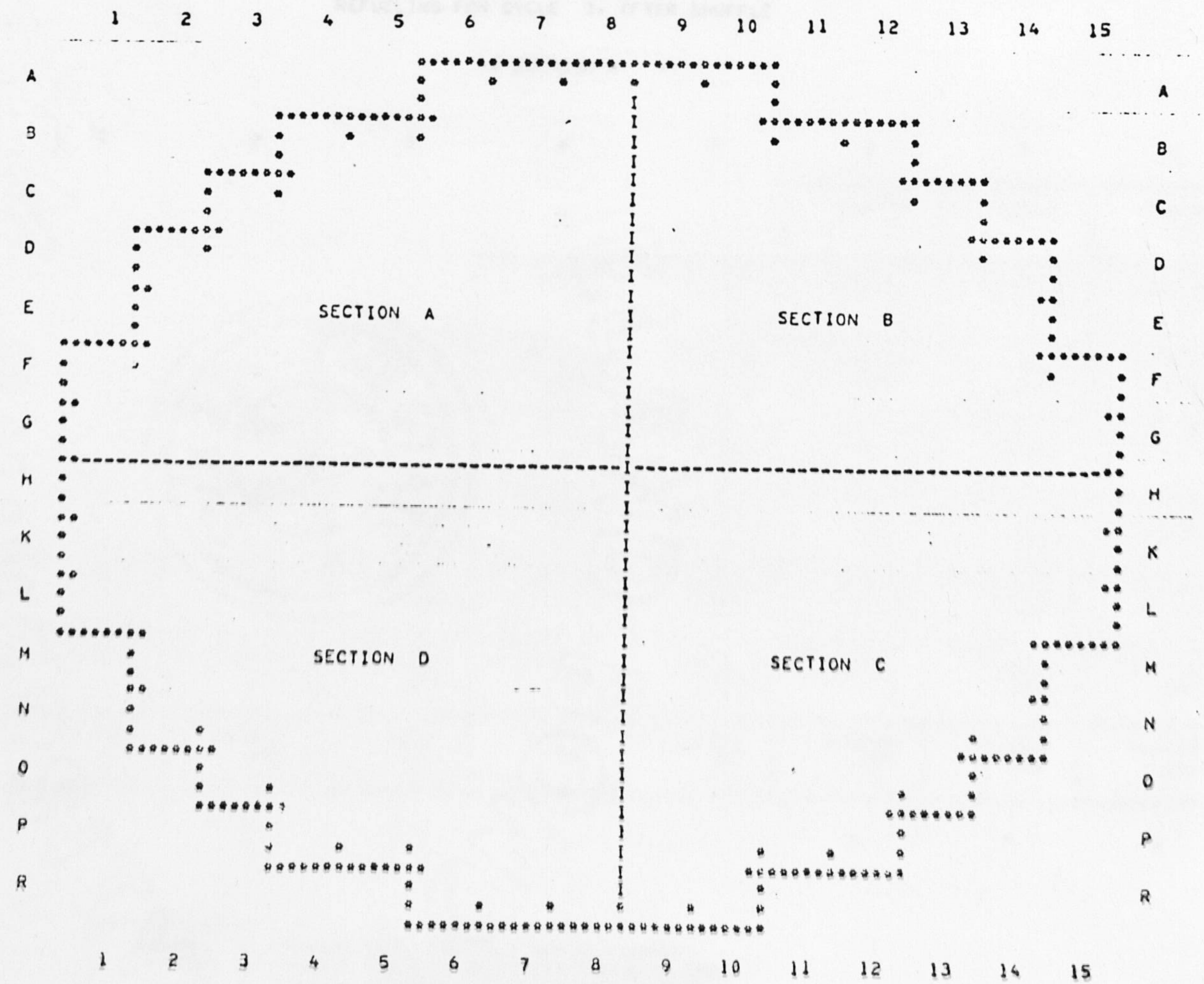
-- SECTION E --

	18	19	20	21	22	23	24	25	26	
A	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	A
B	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	B
C	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	C
D	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	D
E	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	E
F	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	F
G	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	G
H	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	H
J	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	NOT USED	J

ANO-1 NEW FUEL POOL LOADING MAP
REFUELING FOR CYCLE 3, BEFORE SHUFFLE



ANO-1 CORE LOADING MAP
REFUELING FOR CYCLE 3, AFTER SHUFFLE



ANO-1 CORE LOADING MAP
REFUELING FOR CYCLE 3. AFTER SHUFFLE

-- SECTION A --

	1	2	3	4	5	6	7	8	
A						NJ00X6	NJ00X2	NJ00WL 030	A
B				NJ00X3 013	NJ00Y6	NJ00WW C30	NJ1C03	NJ1C45 C14	B
C			NJ00XS	NJ00HK 010	NJ1C28 C43	NJ1C09 020	NJ00J1 C11	NJ1C23 C02	C
D		NJ00XQ	NJ00H6 018	NJ00H9 C10	NJ00GY 046	NJ00J5 A04	NJ1C17 C17	NJ00XU C45	D
E		NJ00Y5	NJ1C55 C55	NJ00HZ 075	NJ00HL C29	NJ00JF 064	NJ00JE C44	NJ1C47 C69	E
F	NJ00WN	NJ00Y4 C28	NJ1C08 058	NJ00JG A03	NJ00J9 070	NJ1A39 C12	NJ1C60 059	NJ1C32 C13	F
G	NJ00XE	NJ1C44	NJ00HV C09	NJ1C11 068	NJ00H4 C42	NJ1C36 006	NJ00Y1 C56	NJ1C30 066	G
H	NJ00WT 071	NJ1C29 C08	NJ1C20 C45	NJ00Y2 C41	NJ1C49 007	NJ1C18 C07	NJ1C15 C62	NJ1A28 C61	H
	1	2	3	4	5	6	7	8	

XX XXXX	<-------	FUEL ASSEMBLY SERIAL NUMBER
XXX	<-------	CONTROL COMPONENT SERIAL NUMBER
X	<-------	NEUTRON SOURCE IDENTIFICATION

FUEL SHUFFLE REPORT FOR THE STATION NUCLEAR ENGINEER

CRITICAL PATH STATISTICS

-- TOTAL ESTIMATED SHUFFLE TIME = 130.97 HOURS
= 5.46 DAYS

PERCENT OF SHUFFLE TIME REFUELING CANAL ACTIVE = 92.08 %
PERCENT OF REFUELING CANAL ACTIVE TIME ON CRITICAL PATH = 95.80 %

PERCENT OF SHUFFLE TIME TRANSFER TUBE ACTIVE = 8.81 %
PERCENT OF TRANSFER TUBE ACTIVE TIME ON CRITICAL PATH = 29.34 %

PERCENT OF SHUFFLE TIME FUEL HANDLING AREA ACTIVE = 15.53 %
PERCENT OF FUEL HANDLING AREA ACTIVE TIME ON CRITICAL PATH = 11.89 %

FUEL SHUFFLE SEQUENCE DEFINITIONS

OBSERVED TIME = DURATION OF STEP OBSERVED AND RECORDED DURING REFUELING SHUFFLE

STEP TIME = PLANNED DURATION OF STEP USED TO DEVELOP THE SHUFFLE SEQUENCE

SLACK TIME = TIME BEYOND STEP TIME BEFORE STEP BECOMES A CRITICAL PATH ITEM

FUEL SHUFFLE REPORT FOR THE STATION NUCLEAR ENGINEER

FUEL SHUFFLE SEQUENCE

STEP 1 :	MOVE MB TO O- 6 USE C MAST TO REMOVE COMMENTS:	022	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN
STEP 2 :	MOVE MB TO F- 1 USE C MAST TO INSERT COMMENTS:	022	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN
STEP 3 :	MOVE MB TO L- 3 USE C MAST TO REMOVE COMMENTS:	070	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN
STEP 4 :	MOVE MB TO L-15 USE C MAST TO INSERT COMMENTS:	070	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN
STEP 5 :	MOVE MB TO H- 9 USE C MAST TO REMOVE COMMENTS:	037	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN
STEP 6 :	MOVE MB TO N- 2 USE C MAST TO INSERT COMMENTS:	037	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN
STEP 7 :	MOVE MB TO H- 7 USE C MAST TO REMOVE COMMENTS:	008	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN
STEP 8 :	MOVE MB TO P- 5 USE C MAST TO INSERT COMMENTS:	008	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN
STEP 9 :	MOVE MB TO G- 8 USE C MAST TO REMOVE COMMENTS:	055	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN
STEP 10 :	MOVE MB TO F-15 USE C MAST TO INSERT COMMENTS:	055	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN
STEP 11 :	MOVE MB TO F- 3 USE C MAST TO REMOVE COMMENTS:	075	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN
STEP 12 :	MOVE MB TO M-14 USE C MAST TO INSERT COMMENTS:	075	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN
STEP 13 :	MOVE MB TO C-10 USE C MAST TO REMOVE COMMENTS:	018	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN
STEP 14 :	MOVE MB TO N-14 USE C MAST TO INSERT COMMENTS:	018	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN
STEP 15 :	MOVE MB TO N-12 USE C MAST TO REMOVE COMMENTS:	C10	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN
STEP 16 :	MOVE MB TO O-13 USE C MAST TO INSERT COMMENTS:	C10	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN
STEP 17 :	MOVE MB TO N- 4 USE C MAST TO REMOVE COMMENTS:	C16	OBSERVED TIME______MIN STEP TIME = 16 MIN	SLACK TIME =	0 MIN

VITA

William Bruce Miller

1004 Timm

College Station, Texas 77840

Birthplace:	Little Rock, Arkansas
Birthdate:	July 18, 1953
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Family:	Married wife, Patricia Ann, and have one daughter, Suzanne Marie, age two.
Education:	B. S. Nuclear Engineering, University of Missouri-Rolla, 1975 M. Eng. Nuclear Engineering, Texas A&M University, 1977 D. Eng., Texas A&M University, 1979
Experience:	Instructor, Engineering Design Graphics Department, Texas A&M University September 1978 - Present Assistant Engineer, Arkansas Nuclear One, Arkansas Power & Light Co. May 1977 - July 1978 Instructor (Halftime), Engineering Design Graphics Dept., Texas A&M University September 1976 - December 1976 Graduate Assistant, Engineering Design Graphics Dept., Texas A&M University September 1975 - May 1976 Engineering Cadet, Nuclear Services, Production Department, Arkansas Power & Light Co. May 1974 - August 1974

The typist for this report was Lajuan Wood.