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An application of artificial intelligence and neural networks to in-core fuel management

Faisal Husni Al-Gutifan
University of Tennessee

To the Graduate Council:

I am submitting herewith a thesis written by Faisal Husni Al-Gutifan entitled "An application of artificial intelligence and neural networks to in-core fuel management." I have examined the final electronic copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Science, with a major in Nuclear Engineering.

Lawrence F. Miller, Major Professor

We have read this thesis and recommend its acceptance:

Accepted for the Council:
Carolyn R. Hodges

Vice Provost and Dean of the Graduate School

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To the Graduate Council:

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L F Miller

Dr. Lawrence F. Miller, Major Professor

We have read this thesis and recommend its acceptance:

Robert E Uhrig

Tsoung-Hwa Hsu (?)

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Date NOV-27-1991

AN APPLICATION OF ARTIFICIAL INTELLIGENCE AND NEURAL NETWORKS TO IN-CORE FUEL MANAGEMENT

A Thesis

Presented for the

Master of Science

Degree

The University of Tennessee, Knoxville

Faisal Husni Al-Gutifan

December 1991

DEDICATION

This thesis is dedicated with love to my parents, Ashe Abazid and Husni Algutifan, to my wife Elizabeth, and to my children, Adam Husni and Noor Al-Deen.

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I would like to thank my major professor, Dr. L. F. Miller, for his support and understanding throughout my research. I would also like to thank the other members of my committee, Dr. Lefteri Tsoukalas and Dr. Robert E. Uhrig, for their assistance and insight along the way.

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ABSTRACT

This research demonstrates the feasibility of using neural backpropagation networks to perform neutronic calculations in a pressurized water reactor. The LEOPARD (Lifetime Evaluating Operations Pertinent to the Analysis of Reactor Design) code is used to generate data for training four (4) different models to relate the infinite multiplication factor, K-INF, of a fuel assembly at the end of a burnup step to the assembly local parameters. The RPM (Reload Power Mapping) code is used to generate training and testing data for three (3) different models to relate relative power distribution of fuel assemblies to the infinite multiplication factor of each assembly. Testing LEOPARD models has shown that it is not possible to utilize a general fuel assembly network to relate K-INF to the assembly domain parameters, rather a different network should be designed for each assembly type. Of the RPM models tested, the patterned network has resulted in the most accurate predictions of relative power distribution. An expert system is also designed using OPS5 to assist in the determination of core reload patterns. A computer code is written using Microsoft Excel to provide an interface between the operator and the neural network code, to construct an interaction between RPM and the user, and to develop a manual fuel shuffling capability using a graphical interface.

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LIST OF ABBREVIATIONS

Artificial Neural Systems Simulation Program	ANSim
Backpropagation Network	BPN
Beginning of Cycle	BOC
Disk Operating System	DOS
Electric Power Research Institute	EPRI
End of Cycle	EOC
Infinite Medium Multiplication Factor	K-INF
Kilograms per Megawatt-Day	KG/MWD
Left-Hand Side	LHS
Lexicographic-Sort Strategy	LEX
Lifetime Evaluating Operations Pertinent to the Analysis of Reactor Design	LEOPARD
Maximum Error	MAX
Means-Ends-Analysis Strategy	MEA
National Aeronautics and Space Administration	NASA
Neural Network Software	NETS
Official Production System 5	OPS5
Parallel Distributed Processing	PDP
Pressurized Water Reactor	PWR
Reload Power Mapping	RPM

Right-Hand Side .... RHS

Root Mean Square .... RMS

Working Memory Element .... WME

CHAPTER I

INTRODUCTION

The determination of initial core and reload core parameters is the primary concern of In-Core Fuel Management. These parameters include refueling schedules, refueling patterns and control plans that will satisfy energy requirements, safety criteria, and design limitations.

Most pressurized water reactors (PWRs) operate for a cycle of 16-18 months. At the end-of-cycle (EOC), the reactor is shut down to be refueled. During shutdown, about one third of the fuel assemblies are discharged and replaced with fresh fuel assemblies. This partial refueling scheme is selected based upon the results of optimization studies on reload cores. These studies are performed with the objective of minimizing fuel cost. Six to eight months prior to shutdown, the reload batch parameters are predicted in order to determine the amount of fuel that should be ordered for the new cycle.

Determination of the core loading pattern is based on the previous history of the reactor core and the characteristics of the fresh batch. Normally, the configuration of fuel assemblies inside the core is determined based on a set of rules and the experience of the in-core fuel management group. Once this configuration is chosen, computer codes are implemented to verify the selection. The computer codes evaluate core power distribution, fuel depletion, and control adjustment requirements which will ultimately satisfy the thermal limitations, safety and economic constraints of the reactor cycle. Multigroup diffusion theory is one of the methods used to calculate the core power distribution. One-, two-, or three-dimensional analysis may be used, depending upon the constraints of the problem of concern. For example, a preliminary feasibility study would require only a one-dimensional analysis, while determination of power peaks in a fuel assembly would require a much more involved three-dimensional analysis. [1, 2, 3, 4, 5, 6]

A fuel depletion analysis is performed to determine isotopic changes over time and space in the reactor core. A rate equation is written for each of the principal isotopes (i.e., ^{238}U, ^{235}U, and ^{239}Pu). Other less significant isotopes are lumped together by groups into fictitious elements, and a rate equation is written for each of these fictitious elements. In order to solve the rate equation, the neutron flux must be known. The core cycle is divided into time intervals known as burnup steps, and neutron flux is calculated for each burnup step using multigroup diffusion theory. Assuming the flux is constant over a burnup step, the neutron fluence can be determined over the entire core cycle. Neutron fluence is then used to determine the isotopic inventory of the reactor core for each burnup step. [1, 2, 3, 4, 5, 6]

Additionally, a control plan must be implemented to ensure criticality in the reactor. [1, 2, 3, 4, 5, 6] The three control mechanisms at the disposal of the in-core fuel management group include control rods, chemical shim, and burnable poisons. The in-core fuel manager must make decisions concerning the locations of control rod assemblies throughout the core, the isotopic composition of the control material inside each burnable poison pin and their locations, and soluble poison scheduling.

An expert system may assist in and coordinate the planning tasks of the in-core fuel management group by speeding up the process of decision making and preserving the experience of the experts in a set of rules, thereby minimizing shutdown time of the reactor.

The amount of time and money which neutronic calculations require is costly. [5] Thus, a new model designed to mimic reactor power distribution, as well as determine other core parameters, would be highly beneficial. A neural network lends itself well to performing neutronic calculations because it has the ability to capture the non-linear behavior of many reactor phenomena. In this research a neural network using back propagation is introduced to model certain neutronic parameters extracted from computer codes, including Reload Power Mapping (RPM) and Lifetime Evaluating Operations Pertinent to the Analysis of Reactor Design (LEOPARD).

CHAPTER II

NEURAL BACKPROPAGATION NETWORK

Background

A neural backpropagation network (BPN) is so named because of the training algorithm used in modifying the connection weights of the neural network. The BPN was discovered in 1969 by Bryson and Ho, and rediscovered in independent research by Werbos in 1974, Parker in the 1980s, and by Rumelhart, Williams, and other members of the PDP group in 1985. [7] In this chapter, a fully-connected, feed-forward, three-layered BPN network is utilized. The operation of training and testing the network and the premanipulation of data are also discussed.

Network Structure

A BPN is a hierarchical network consisting of, at a minimum, three layers: an input layer, a hidden layer, and an output layer. The input layer is connected to the hidden layer and the hidden layer to the output layer via connection weights. Each layer can be fully or partially connected to the succeeding layer. The input layer is a fan-out layer which means that no modification of the input vector is performed, since no transfer function (sometimes called activation function) exists for nodes at this layer. The input layer accepts an input vector from the outside world and the output layer sends the processed input back to the outside world. The function of the hidden layer is to create an internal representation between input and output patterns. Every layer consists of a set of nodes (sometimes called neurodes, units, processing elements, or artificial neurons). These nodes are abstractions of the neurons found in the brain. The biological neuron consists of the following components, as shown in Figure 2-1: 1) a nucleus; 2) dendrites; 3) the axon; and 4) synapses. The nucleus receives the inputs through the dendrites from neurons connected to it via the synapses. The nucleus then processes the inputs and sends the resultant signal to the output path (axon). The axon splits into other paths and sends the output to other neurons via junctions called synapses. The adjustment of the synapse represents the basic process of memory, and it occurs during the training process of the brain. The synapse modifies the signal and transmits it to the dendrite. The artificial neuron, or neurode, behaves in a similar manner. The processing element (see Figure 2-2) consists of the following components: 1) input paths; 2) the transfer function; 3) output paths; and 4) junction weights. The neurode operates in the following manner: A neurode sends a signal through its output paths (axon) to the input paths (dendrites) of other neurodes, and the processing elements sum all the inputs as a net weighted sum. The transfer function (nucleus) then modifies the weighted inputs and sends the outputs to other neurodes in the succeeding layer or layers. The similarities between the artificial neuron and the biological neuron are clear. One operational difference, however, is the nature of processing information. A biological neuron is primarily electro-chemical in nature, whereas the artificial neuron is electrical in nature. [8]

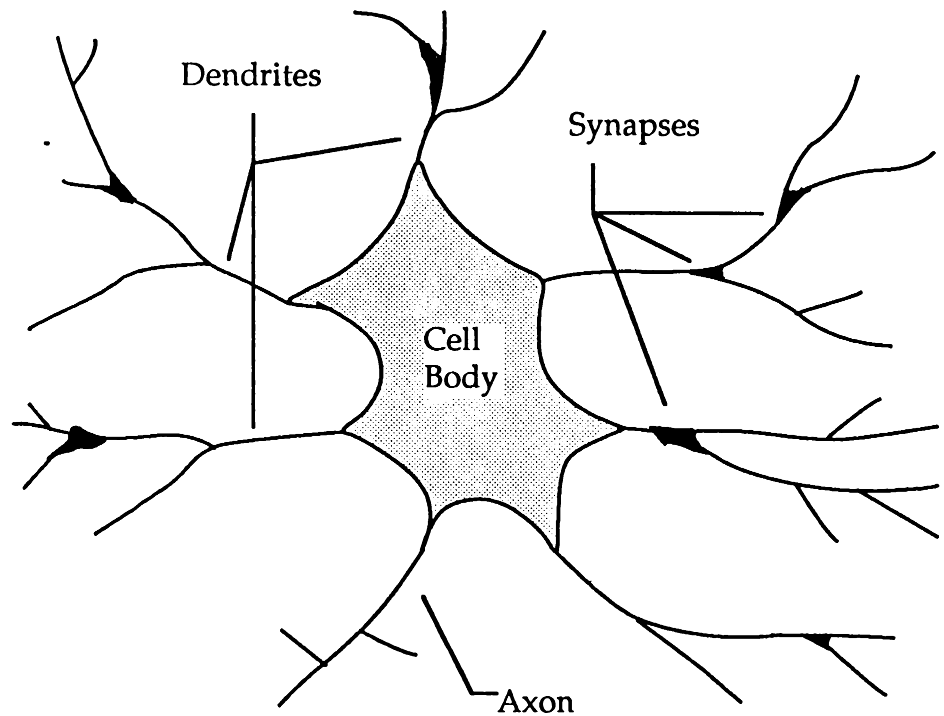


FIGURE (2-1) : BIOLOGICAL NEURON STRUCTURE.

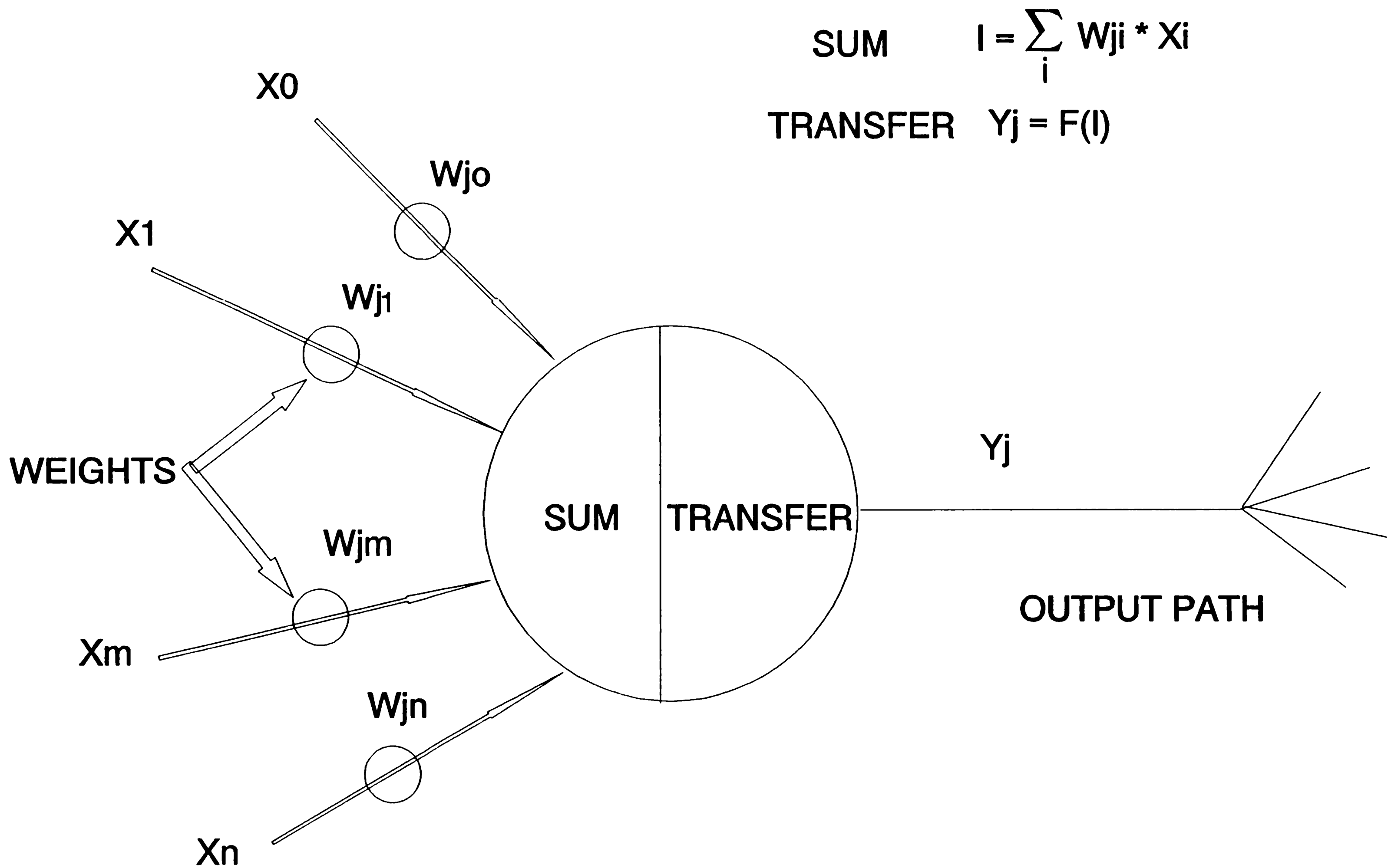


FIGURE (2-2) : PROCESSING ELEMENT STRUCTURE .

BPN is one of the most widely used neural networks. BPN is used in the following applications:

1) Encoding and data compression;

2) Signal processing;

3) Noise analysis;

4) Stock market predictions;

5) Converting English letters to phonemes;

6) Pattern classification; and

7) Non-linear adaptive control. [9]

Network Operation

In this discussion a fully connected, feed-forward, three-layered network is assumed (see Figure 2-3). A sigmoidal function of the form shown in Figure 2-4 is also assumed for the nodes at the hidden and output layers. The training of the network takes place at two stages, forward pass and reverse pass.

Forward Pass

The input vector is fanned out from the input layer and distributed to all the nodes in the hidden layer. Each node at the hidden layer receives a modified input vector. The operation between the input layer and the hidden layer is shown in Figure 2-5. A net weighted sum is calculated as follows:

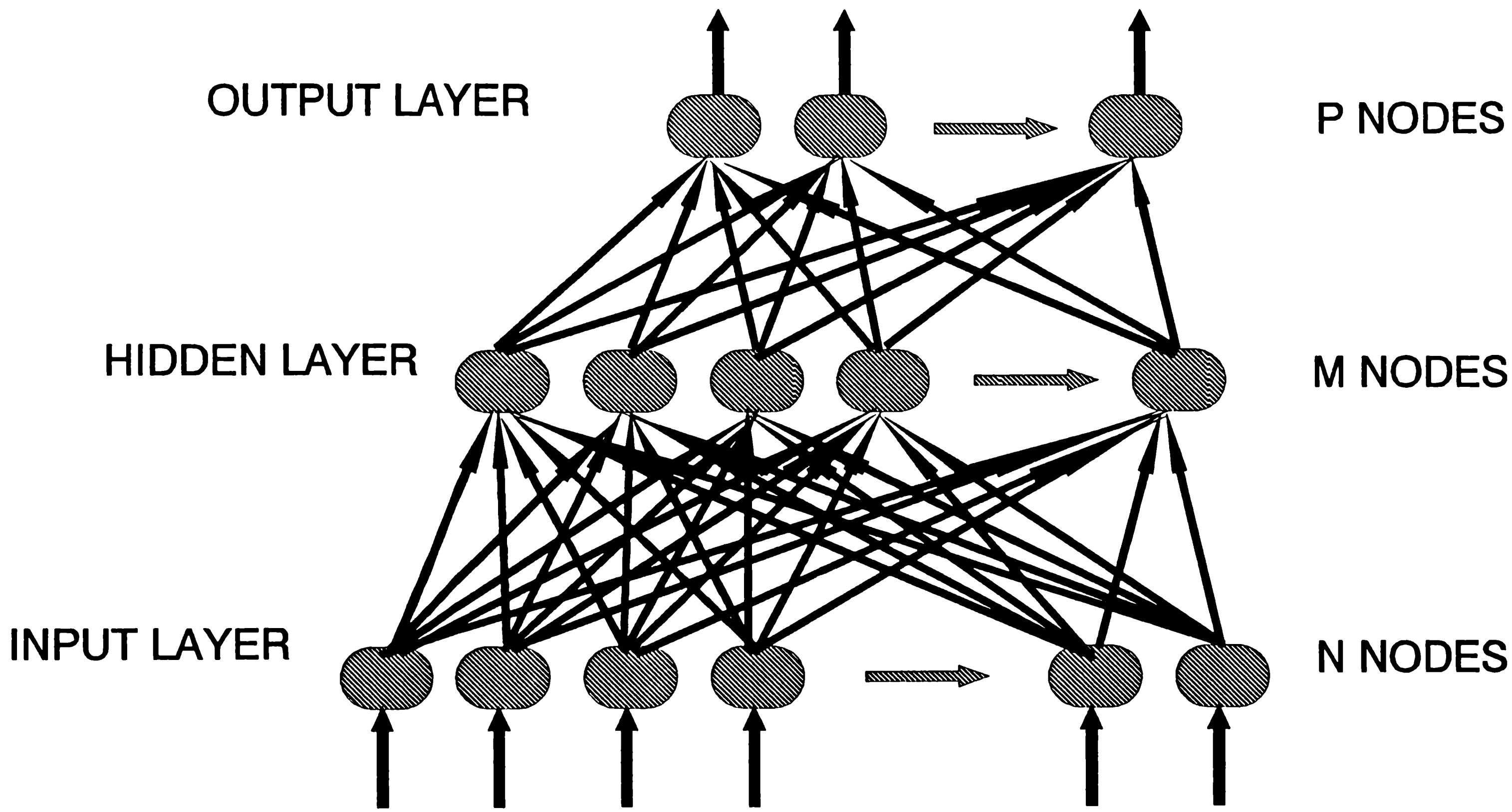


FIGURE (2-3) : NETWORK STRUCTURE.

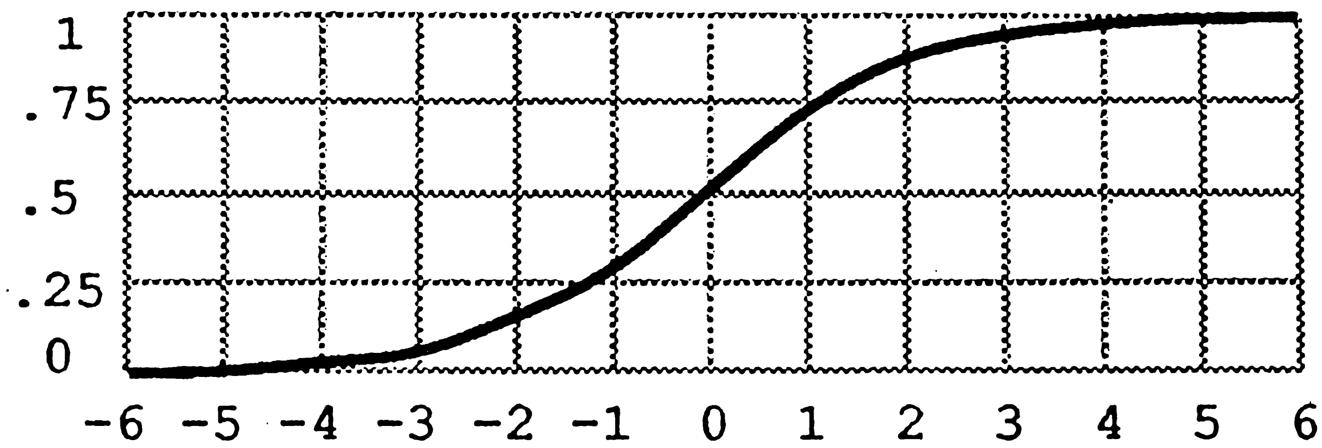


FIGURE (2-4) : SIGMOIDAL TRANSFER FUNCTION .

(Source: BrainMaker User's Guide and Reference Manual)

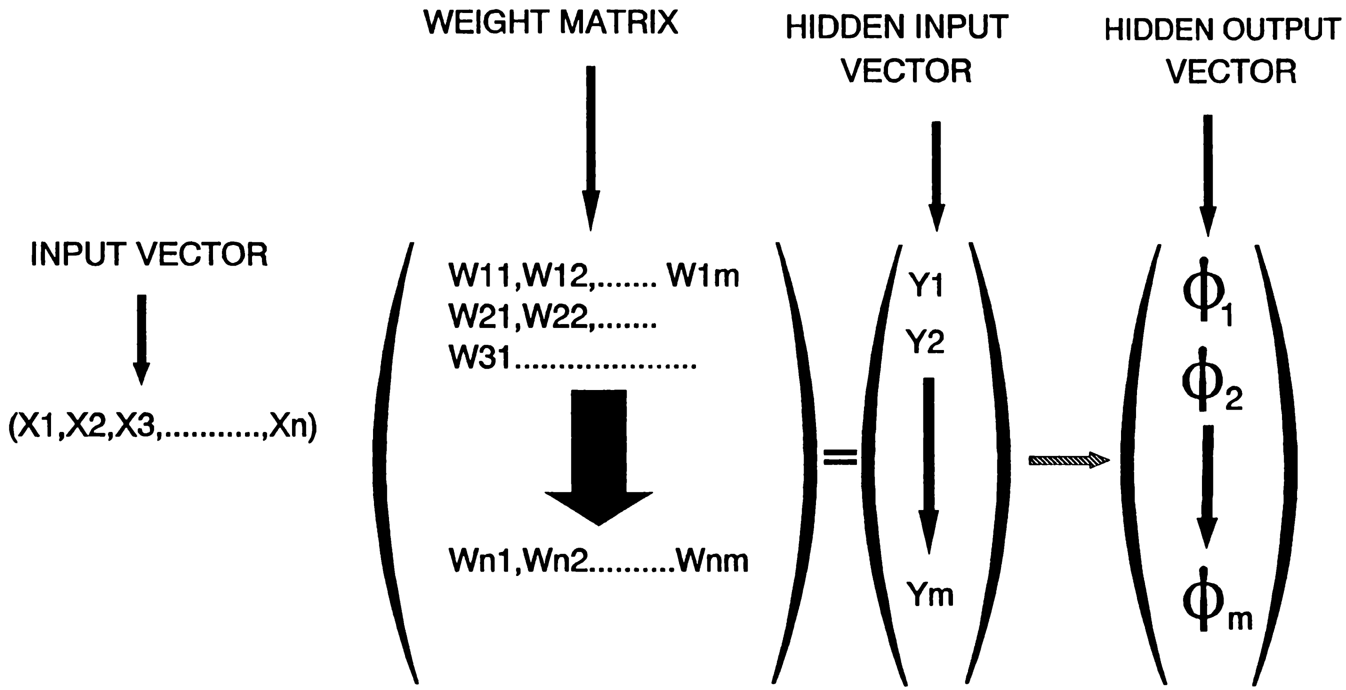


FIGURE (2-5) : INPUT TO HIDDEN LAYER OPERATION.

$$Y_j = \sum_i X_i W_{ij}$$

where i = the ith node at the input layer;

j = the jth node at the hidden layer;

X_i = the ith component of the input vector;

W_{ij} = the weight connection between the ith node and the jth node.

The net weighted sum is an input to the transfer function at the jth node. Y_j is operated on by the sigmoidal function which is defined as follows:

$$\phi_j = \frac{1}{1 + e^{-Y_j}}$$

where ϕ_j = the output of the jth node

This procedure is followed for all the nodes in the hidden layer. The output vector is transmitted to all the nodes in the output layer. The operation between the hidden layer and the output layer is shown in Figure 2-6. The same procedure is followed for the output layer nodes.

Reverse Pass

At the output layer, an error vector is obtained. This error vector is calculated as follows:

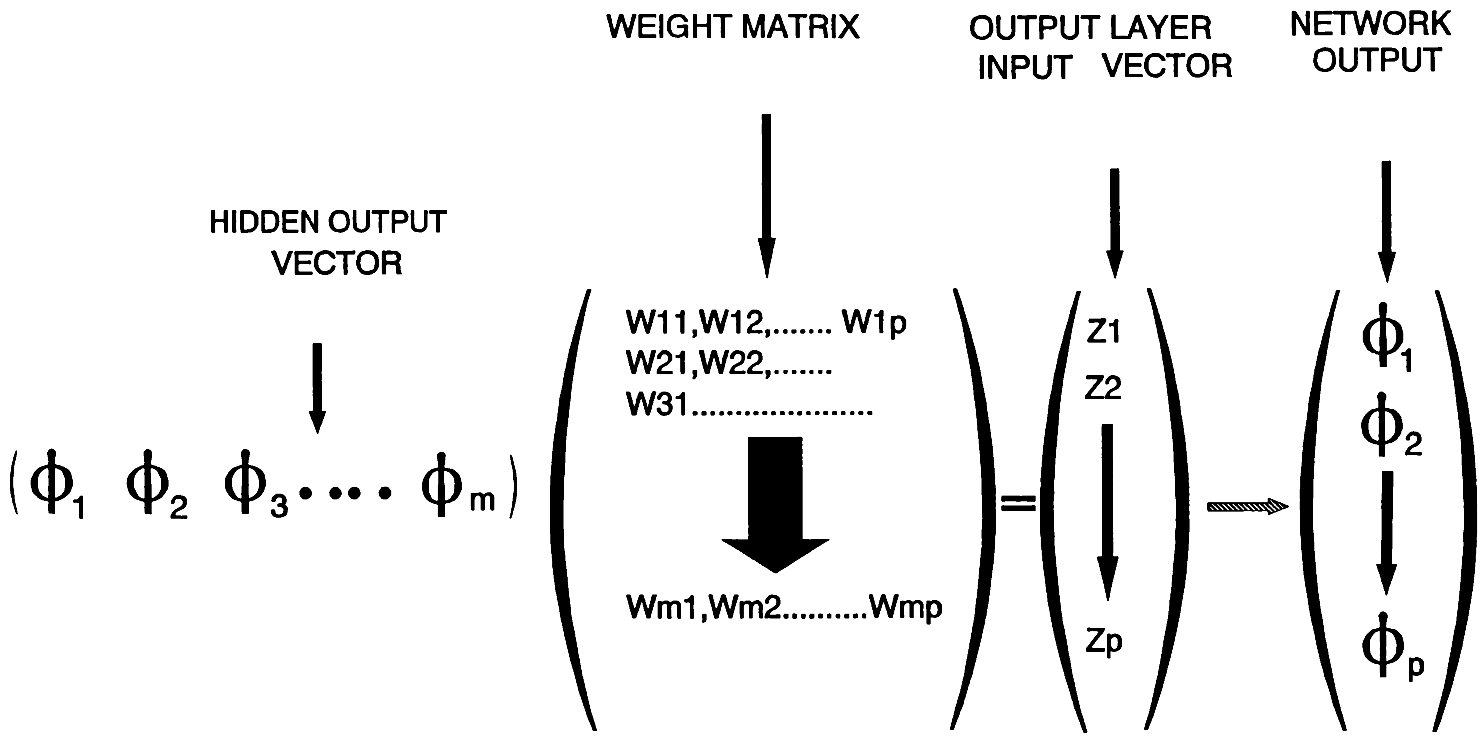


FIGURE (2-6) : HIDDEN TO OUTPUT LAYER OPERATION.

$$\vec{e} = \vec{t} - \vec{\Phi}$$

where $\vec{t}$ = the desired output vector; and

$\vec{\Phi}$ = the actual output vector.

The weights between layers are modified based on the generalized delta rule. This rule is a descent gradient method where the weights are modified in the direction of minimizing the network error. An error function is obtained from the error vector:

$$E = \frac{1}{2}\sum_{k} e_k^2$$

where e_k = the error at node k of the output layer.

Applying the Chain Rule, the error function is differentiated with respect to the connection weight as follows:

$$\frac{\partial E}{\partial W_{jk}} = \frac{\partial E}{\partial \Phi_k}\frac{\partial \Phi_k}{\partial Z_k}\frac{\partial Z_k}{\partial W_{jk}} = -\delta_k \, \Phi_j$$

where ϕ_k = the output of the kth node;

Z_k = the input to the kth node;

W_{jk} = the connection weight between the jth and kth nodes;

ϕ_j = the output of the jth node of the hidden layer;

and

$$\delta_k = \phi_k (1 - \phi_k)\, e_k$$

The change in the weight connection between the jth and kth nodes is evaluated as follows:

$$\Delta W_{jk} = -\beta \frac{\partial E}{\partial W_{jk}} = \beta\, \delta_k\, \phi_j$$

where $\beta =$ the learning parameter.

The weights are modified by the following relationship:

$$W_{jk}^{new} = W_{jk}^{old} + \beta\, \delta_k\, \phi_j$$

The weights between the hidden and input layers must be treated differently than in the above method. Because no target vector exists at the hidden layer, the error cannot be calculated as previously done for the output layer. The error at the hidden nodes is evaluated by propagating the error calculated at the output layer back to the hidden nodes:

$$\delta_j = \left[\sum_k \delta_k\, W_{jk} \right] \phi_j (1 - \phi_j).$$

The above equation can also be written as

$$\delta_j = e_j \, \phi_j \, (1 - \phi_j)$$

where e_j = the error at node j of the hidden layer.

The change in the weight connection between the ith and jth nodes is evaluated as follows:

$$W_{ij}^{new} = W_{ij}^{old} + \beta \, \delta_j \, X_i$$

where X_i = the ith component of the input vector.

In the above discussion, it is assumed that the weight modification is performed after every input-output vector presentation to the network. In other words, every pattern sees a different weight matrix. Another method can be used where an overall error function is defined as the summation of all the global errors (a global error in this context is defined for each pattern). In this method, all patterns see the same weight matrix between each layer. The modification of the weights is performed after presenting the last input-output pattern. Once training is completed, the network can be tested on a set of new patterns which it has never seen before. Training is complete once the constrained error (user dependent) is achieved.

Network Pitfalls

Some problems exist with the backpropagation algorithm. These include local minima and network paralysis. The local minima occur due to the use of the descent gradient method. The surface of the error function is a very complex one, consisting of hills and valleys. The network can be trapped inside a local minimum, and the corresponding weight change will then be so small that it does not contribute to any weight modification. The remedy for this problem is to add a fraction of the change of the weight in the previous cycle and in the same direction. For example, a momentum term can be added to reflect the changes (memory term). The momentum coefficient is a number between zero and one. The best value to use is 0.9. [10]

Network paralysis is caused by the derivative of the output of the node with respect to its input. If the derivative is close to zero, it means that the function input lies in the region where the function range is flat. A remedy for this problem is to randomize the weights again and to retrain.

Data Treatment

Raw data is manipulated before it is presented to the network. Some advantages of performing the manipulation include reduction of training time and prevention of the exponential growth of the transfer function of the neurode. Normalization and scaling are the most widely used manipulation schemes. Each data file is treated at two different levels: 1) a global level where the whole file is treated as one unit, and 2) a partial level where the data file is treated as a data base. At the partial level, the manipulation scheme is applied to each field or to each record. Different methods of normalization and scaling exist. One method of normalization used in the ANSIM software is to calculate the average of the treated data and then to subtract this average from each component of the treated data. Thus, the average of the modified data is approximately equal to zero. [11] One method of scaling is to determine the maximum and the minimum of the data and to find a range where the user wants to insert the values (e.g., between 0.5 and -0.5). A slope of the straight line can be determined and the data components can be mapped to values on the straight line.

Some disadvantages exist to using these methods. One disadvantage is the loss of details from the data. Other methods exist wherein details of the data can be preserved. One of these methods is the extended code, where data is treated in binary code form.

CHAPTER III

LEOPARD AND RPM MODELING

Introduction

In this chapter, a backpropagation network is implemented to approximate a mapping between the fuel assembly local parameters and the fuel assembly multiplication factor. It is also used to relate the global interaction of fuel assemblies in order to measure relative power distribution based on the multiplication factors of the fuel assemblies.

Problem Statement

The objective of this study is to measure the infinite medium multiplication factor, K-INF, as a function of fuel assembly burnup and other assembly local properties, such as burnable poison and soluble poison. When these assemblies are loaded to the reactor core, the relative power distribution is calculated, given assembly description and location. The purpose of the study is thus based on individual specifications of the fuel assemblies and on the interaction of all the assemblies when they are inside the reactor core. The backpropagation network is used to replicate neutronic software with neural networks.

Methodology

A set of different architectures of networks is designed to relate K-INF to the assembly descriptors and to relate assembly relative power at that value of K-INF. In this research, the LEOPARD and RPM codes are used to generate data sets for the neural network.

The use of backpropagation as an approximate method for mapping of $R^m \rightarrow R^n$ has been the subject of research. The proof of such an approximation is given by Cybenko. [12, 13] The question of how many hidden nodes are required can be answered based on the number of training patterns or the number of input nodes. An optimal number of hidden nodes has been suggested by Baum and Haussler [14], but there is no unique set of weights that will satisfy a particular mapping.

A software package called NETS is used in all of the models designed in this research. NETS was developed by a group of engineers at the National Aeronautics and Space Administration (NASA). [15] This software is based wholly on the backpropagation training algorithm. Two types of networks can be designed using this software: a partially connected or a fully connected network. The training files prepared for this software have a specific format, depending on the type of network under consideration. The software allows the user to select the range of weight values, or it can determine a range by default. A choice of adding a bias term is also available. One of the chief advantages of this software is the way it treats the learning parameter. The learning parameter is the fraction of weight change added to the weight matrices during each cycle of training. This parameter changes dynamically during each cycle, based on a polynomial formula. This formula is not mentioned explicitly in the software manual.

Related to the learning parameter is a scaling factor. This scaling factor is a measure of how fast the learning parameter is changing. In each cycle, the learning parameter changes as a function of the scaling factor. NETS also provides as an output the RMS error and the MAX error. The MAX and RMS errors are provided at each cycle, after all patterns proceed through the network. In other words, the modification of the weights occurs after all the input-output patterns pass through the network.

LEOPARD Modeling

Fuel assemblies can be categorized in the following ways: 1) fuel assemblies with burnable poison; 2) fuel assemblies with control rods; 3) fuel assemblies with burnable poison and soluble poison; and 4) fuel assemblies with no burnable poison and no soluble poison. In this research, LEOPARD was used to generate assembly data descriptions for several types of fuel assemblies.

Data Generation

Five data sets were generated for the purpose of training and testing. Two of these sets were generated given soluble poison contents and burnable poison concentration for each burnup step. The other three sets were generated by LEOPARD with no soluble or solid burnable poison. All of these assemblies were depleted for different burnup step lengths for a maximum of 20 burnup steps. Out of each LEOPARD run, the following information was extracted: 1) the burnup at the beginning of each burnup step; 2) the length of each burnup step; 3) the concentration of soluble poison at the beginning of the burnup step (if soluble poison exists); 4) the burnable poison contents at the beginning of the burnup step (if burnable poison exists); 5) the initial value of K-INF associated with the burnup step; and 6) the final value of K-INF of each burnup step. Different models are used to associate final K-INF to descriptors associated with each assembly depth.

Model A

In this model, two data sets are used to train the network. The objective of this model is to associate final K-INF to initial K-INF, initial burnup, change in burnup and poison concentration. The training data consists of five columns. Each column corresponds to a fuel assembly descriptor. Zeros are used to fill the spaces where poison does not exist.

The network structure consists of three layers, as shown in Figure 3-1. The input layer consists of five (5) nodes corresponding to each input parameter of the fuel assembly. Eleven nodes are used in the hidden layer. This number of hidden nodes is not an optimal number, but it is a sufficient number to use to capture the behavior of the fuel assembly. The number is chosen based on Kolomogrove's

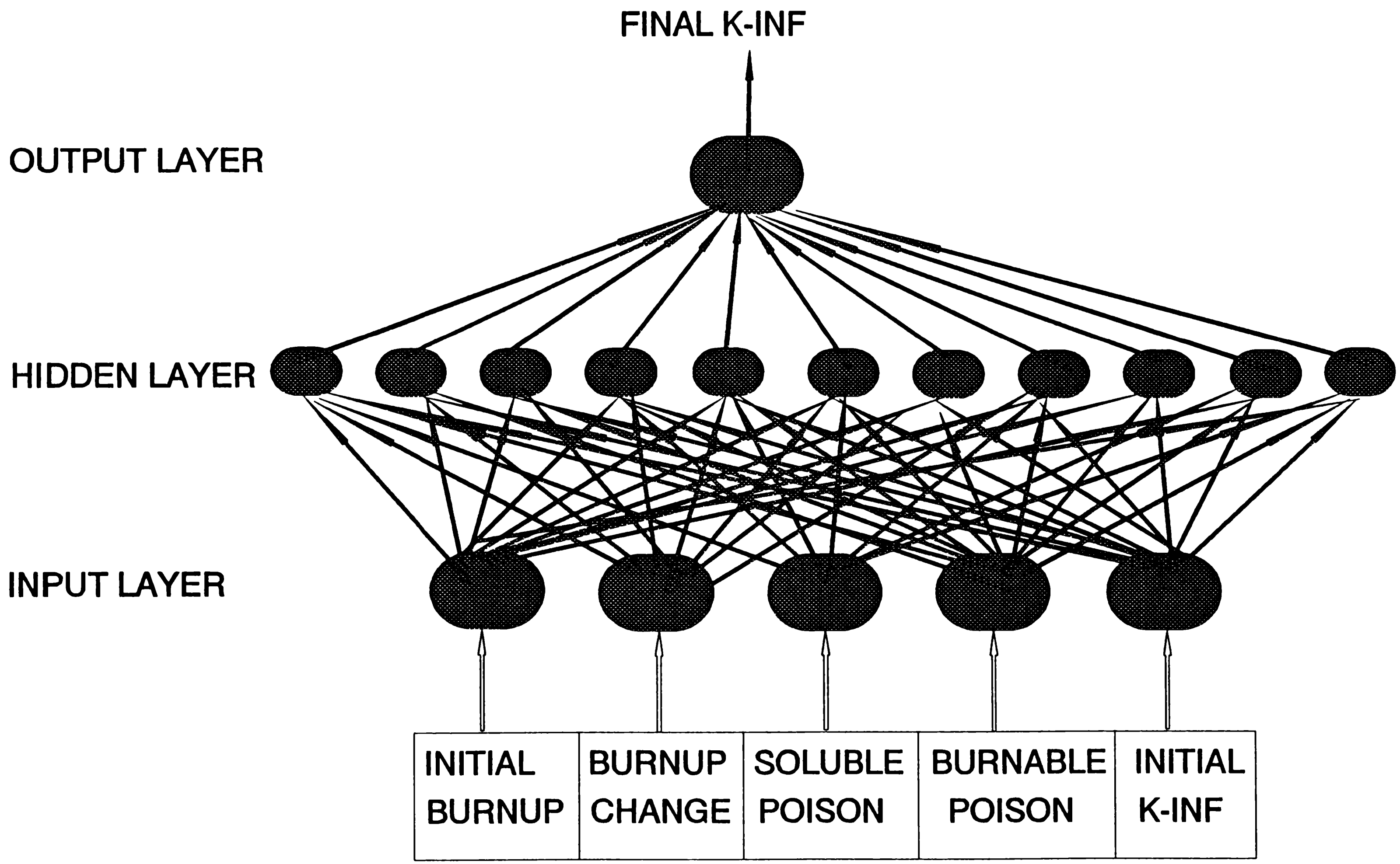


FIGURE (3-1): LEOPARD MODEL A.

Theorem [16], and not on the number of training patterns. At the output layer only one node is used. Biases are introduced between the input layer and the hidden layer, and between the hidden layer and the output layer.

Model B

The objective of this model (see Figure 3-2) is to determine whether a network can behave like a fuel assembly where only three inputs are given: initial burnup, change in burnup, and initial K-INF, to predict the values of K-INF regardless of poison concentration. This model reflects that these three parameters are sufficient to find K-INF, while other parameters are learned implicitly by the network. The same training patterns used in Model A are used here, but the columns corresponding to the poison concentrations are removed.

Three layers are also used here, where three (3) nodes are used in the input layer, seven (7) nodes in the hidden layer, and one (1) unit in the output layer. Biases are introduced between the input and hidden layer, and between the hidden and output layers to ensure stability of the network.

Model C

This model (see Figure 3-3) is used to predict the behavior of fuel assemblies that contain only burnable poison and soluble poison. The purpose of this model is to obtain a better generalization of results when tested with the same type of fuel assemblies.

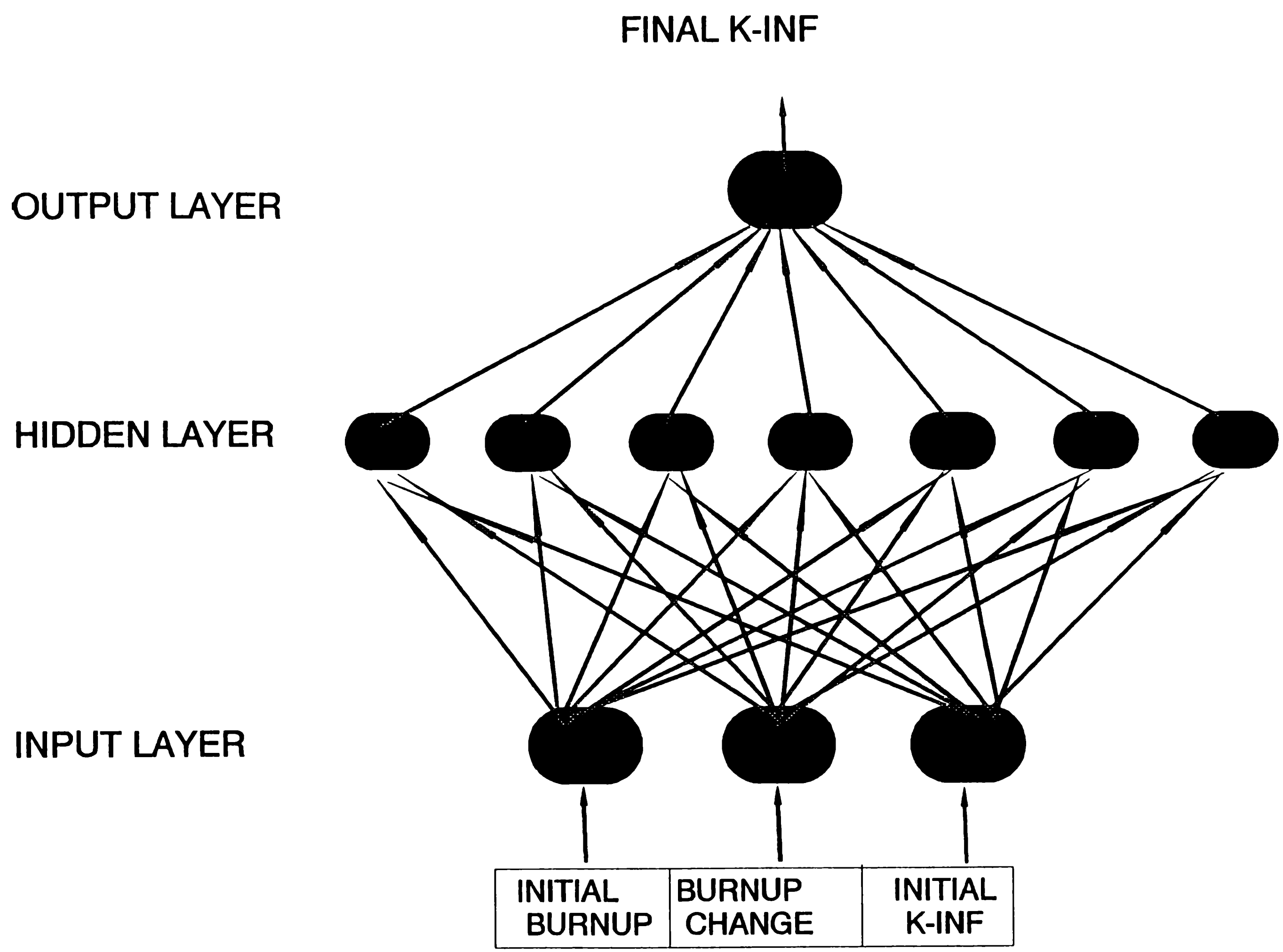


FIGURE (3-2) : LEOPARD MODEL B.

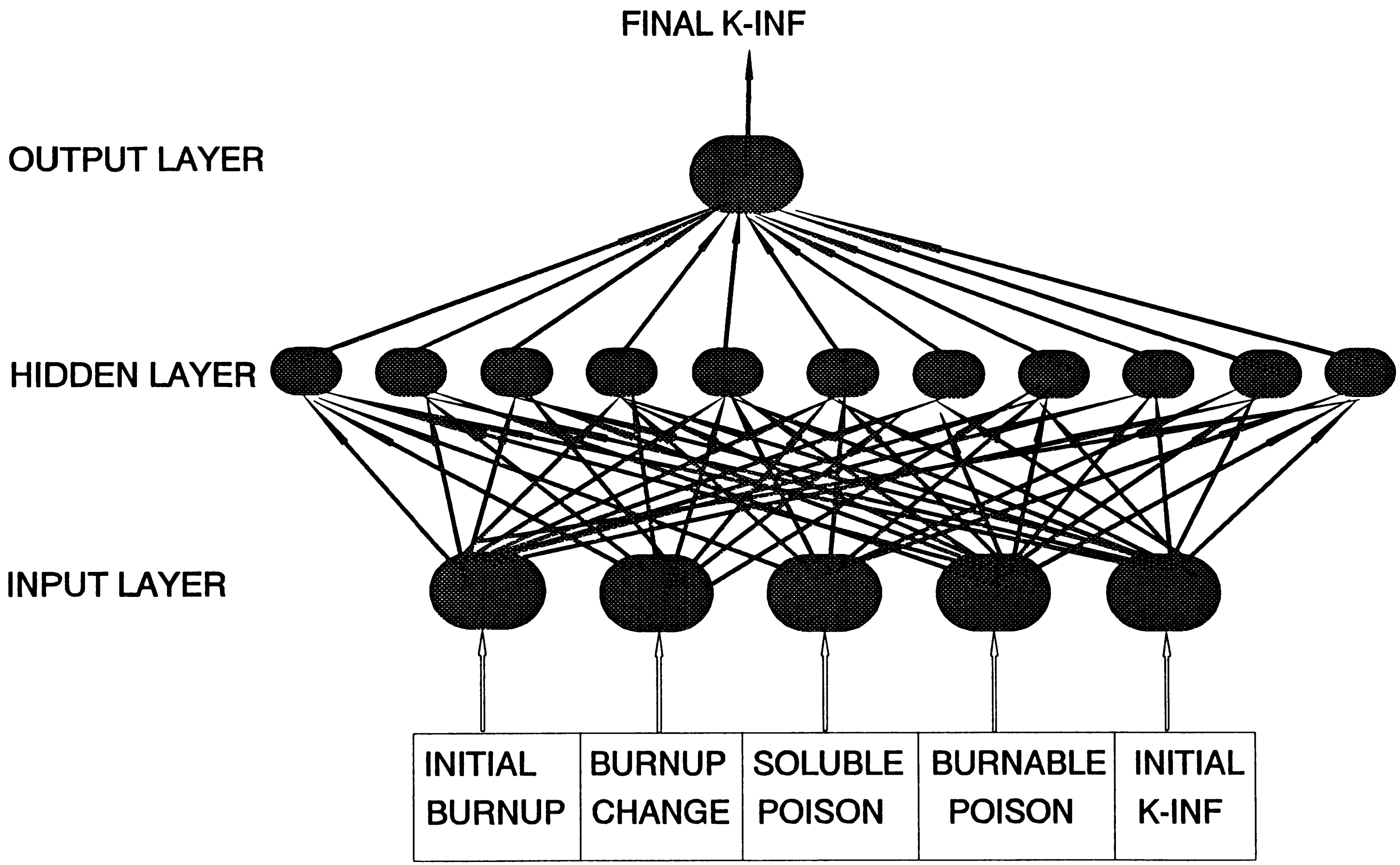


FIGURE (3-3) : LEOPARD MODEL C.

A three-layer network is used in this model. The input layer contains five (5) nodes, while the hidden and the output layer contain eleven (11) and five (5) nodes, respectively. The number of training patterns used in this model is 18.

Model D

Fuel assemblies which contain neither burnable nor soluble poisons are modeled here (see Figure 3-4). This model is used because a general network, as based on Models A and B, performed poorly in predicting assemblies of this type.

The network structure consists of three layers. The input layer contains three (3) nodes, the hidden layer contains seven (7) nodes, and the output layer consists of one (1) node. A bias is used between the hidden and output layers. The learning, scaling, and momentum parameters are used globally between the layers. In other words, the same value of each parameter is used in every layer.

RPM Modeling

In all of the models developed for the RPM code, one-eighth (1/8) core symmetry is assumed. All of the fuel assemblies have the same properties, except for the amount of potential reactivity that exists in all of the fuel assemblies. (More information concerning RPM modeling is given by Driscoll. [2]

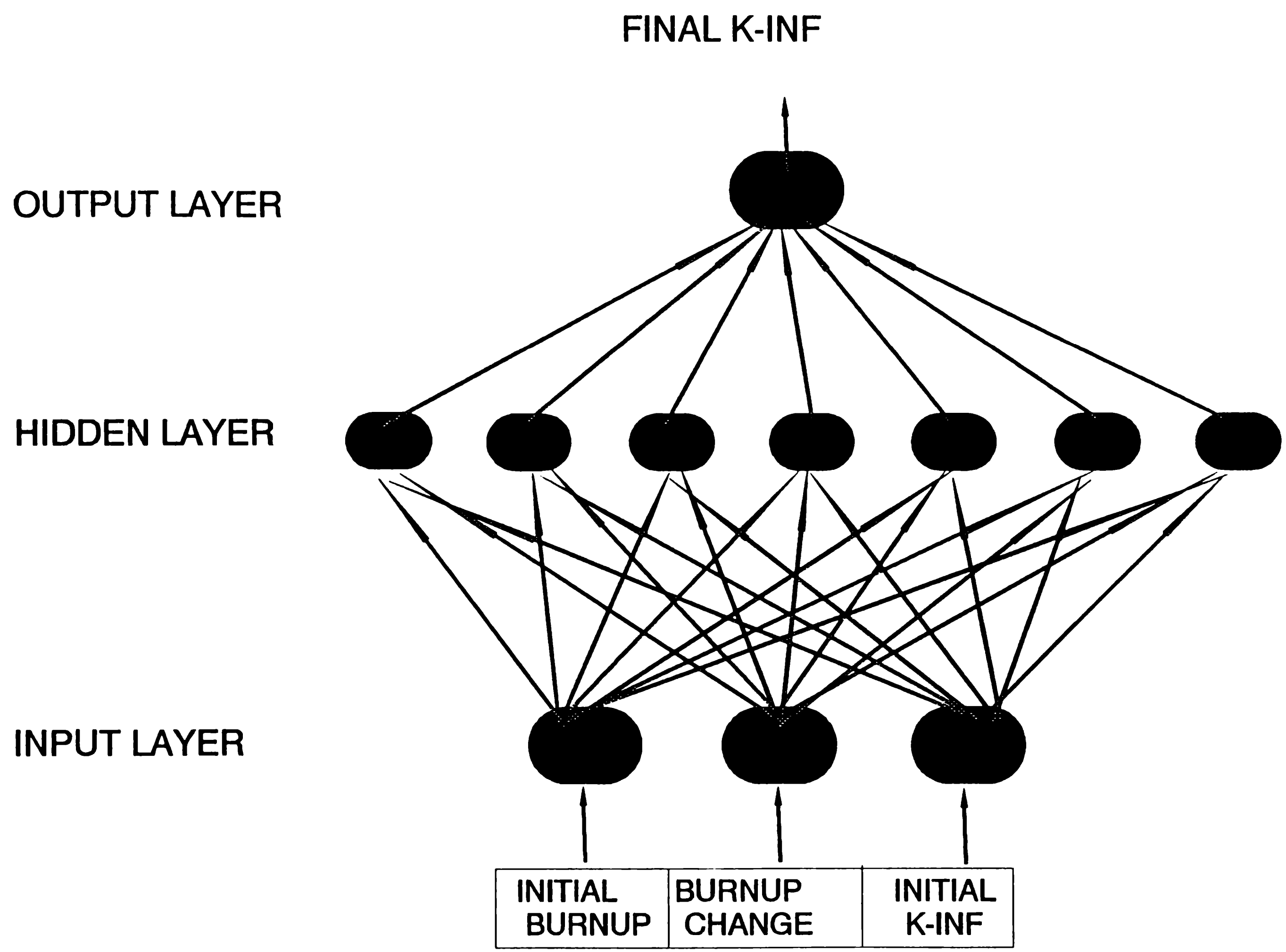


FIGURE (3-4) : LEOPARD MODEL D.

Data Generation

A set of thirty-one (31) fuel assemblies was input to the RPM code. The values of reactivity potential for these assemblies are different. Thirty-one fuel assemblies are reflected with respect to the 1/8 symmetry line to have a reactor core containing 193 fuel assemblies. The relative power distributions are calculated at beginning of cycle (BOC) and end of cycle (EOC), and are placed in a file. The fuel assemblies are shuffled and relative power distribution is recalculated. A set of 110 shuffling patterns were obtained to respond to the RPM software.

The potential reactivity, ρ, is the amount of reactivity produced by the fuel assemblies in the absence of poison or leakage. Potential reactivity of the fuel assemblies is mapped into K-INF using the following formula:

$$k = \frac{1}{1 - \rho},$$

and the relative power is scaled by the equation

$$y = \log_{10} (2 + x),$$

where x = Assembly relative power; and

y = Scaled assembly relative power.

A linear scaling was used in this work, but the scaled values accumulated at about a point of 0.2 - 0.25; in this region the sigmoidal function performs poorly.

Model A

In this model (see Figure 3-5), a three-layered, feed-forward, fully connected

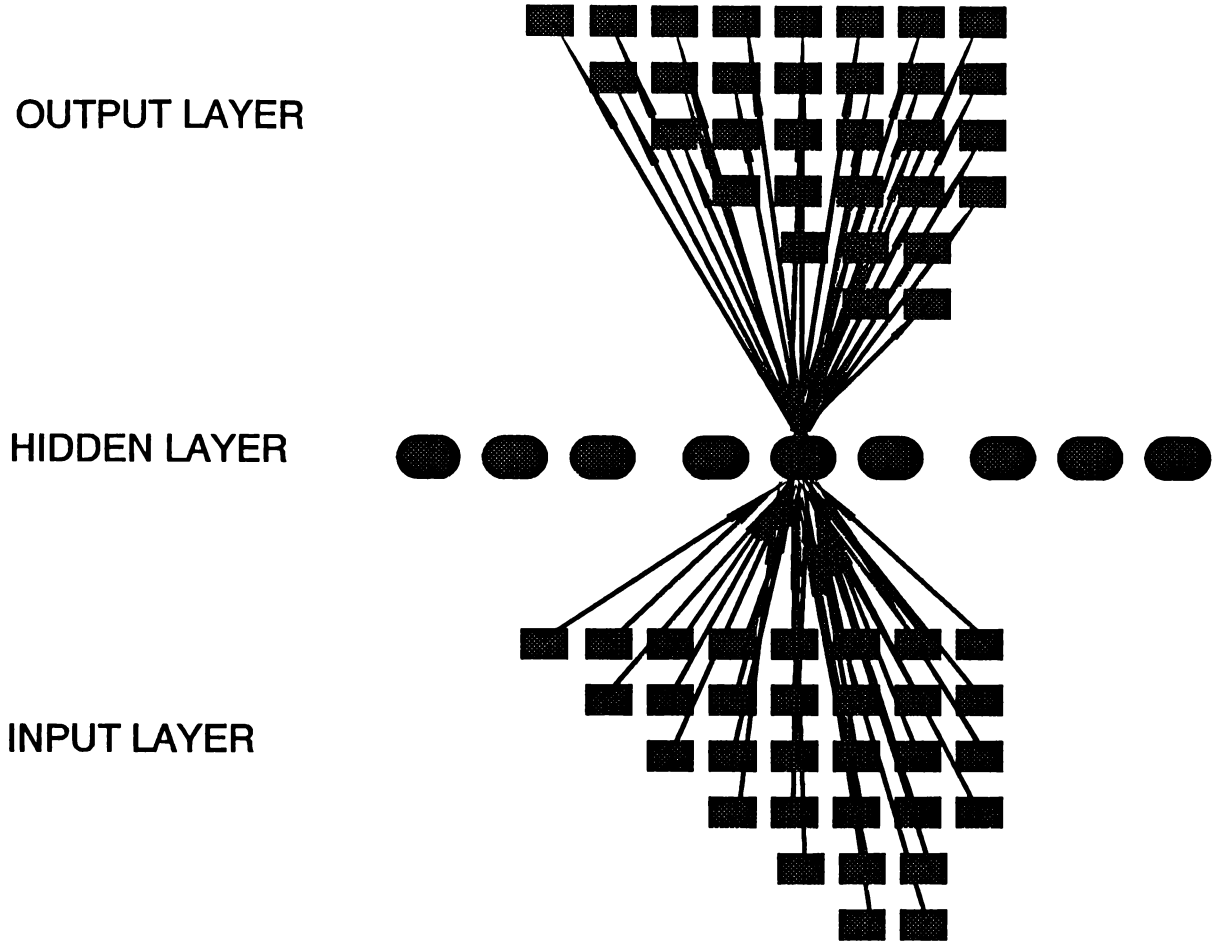


FIGURE (3-5) : NETWORK STRUCTURE FOR

RPM MODEL A.

backpropagation network is used. The first layer contains thirty-one (31) nodes, one node per fuel assembly. The hidden layer has sixty-three (63) nodes, and the output layer consists of thirty-one (31) nodes, one node per fuel assembly corresponding to relative power. The idea behind this design is to give the hidden nodes a global view of all of the 31 fuel assemblies. In other words, each of the hidden nodes will accept modified values from each core shuffling, or behave like global nodes to see if such a modeling can capture the interaction of the fuel assemblies to generate a power distribution. Ten training patterns are used in this model. The network parameters are selected globally, where the same learning, scaling, and momentum parameters are used between each layer.

Next-Door Neighbor Model

The motivation behind this model (see Figure 3-6) is the design of a two-dimensional grid used in numerical methods of solving the diffusion equation. Each fuel assembly has a top neighbor, a bottom neighbor, a left neighbor, and a right neighbor. The K-INF of these assemblies are given and a grid layer of all fuel assemblies in the core is designed in the same way.

The network structure consists of three layers. The input to the hidden layer is partially connected, while the hidden layer to the output layer is fully connected. The input layer consists of a set of (5 x 31) nodes. The hidden layer has a set of 31 nodes, and the output layer contains 31 units.

Ten training patterns are used for this network. The network learned these

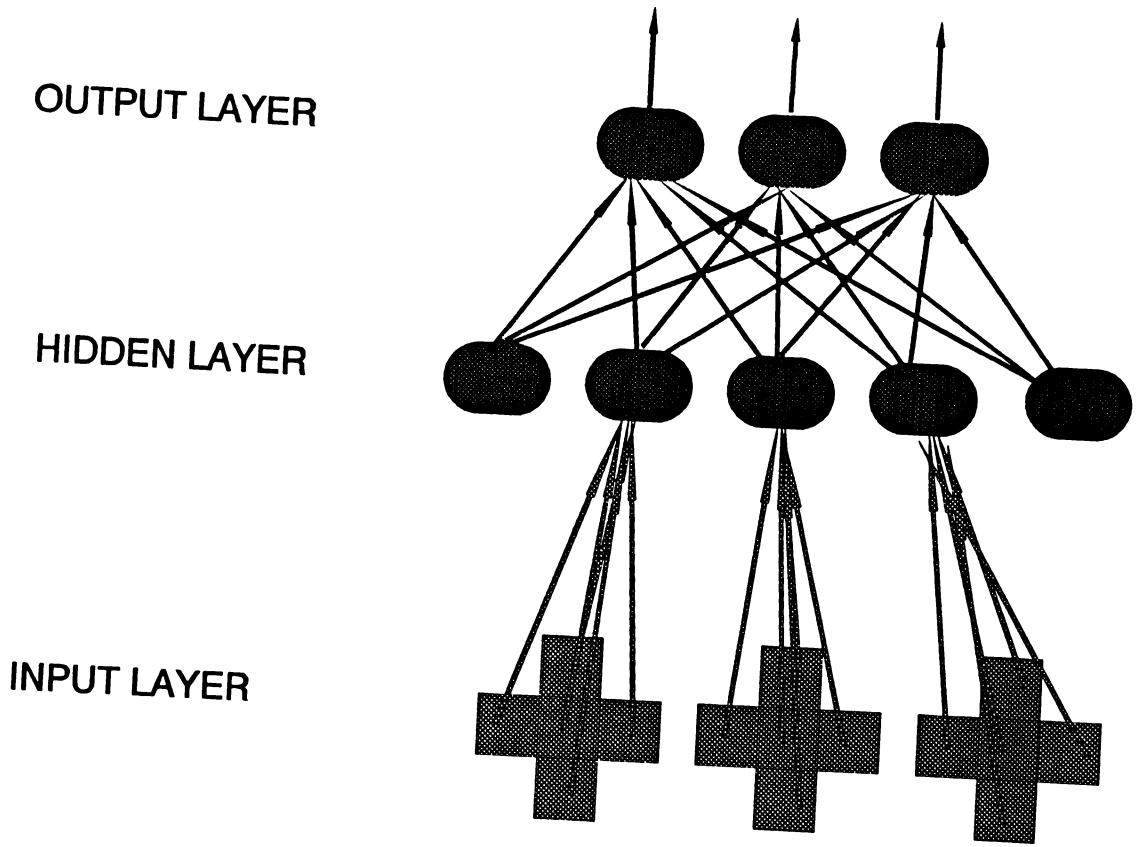


FIGURE (3-6) : NEXT-DOOR NEIGHBOR NETWORK STRUCTURE.

examples after 50 cycles, achieving a maximum error of 0.064 % and a RMS error of 0.019 %. Global parameters are used in this network. The learning parameter used is 0.484, and the scaling factor is 0.065. The momentum term is approximately 0.9.

Patterned Network

In this model (see Figure 3-7), the idea is to allow the nodes in the hidden layer to get a local view of each region. This analysis is similar to the analysis of pattern recognition, where the input is divided into regions and the network learns the importance of each pattern by considering partial patterns of the input layer.

The input grid of this network consists of (9 x 10) nodes. The hidden layer consists of 56 nodes, and the output layer has 56 nodes. The output layer nodes are imposed on the network due to the design of the input grid. Each pattern consists of a (3 x 3) matrix, with one node overlapping for each pattern.

The network is trained on a set of 100 patterns. After 500 training cycles, the network converged with a maximum error of 0.054 % and a RMS error of 0.011 %. Global network parameters are used in this design. The learning parameter is approximately 0.268, the scaling factor is 0.072, and a momentum term of 0.9 is used.

Results

The training results for the LEOPARD models are given in Table 3-1. The

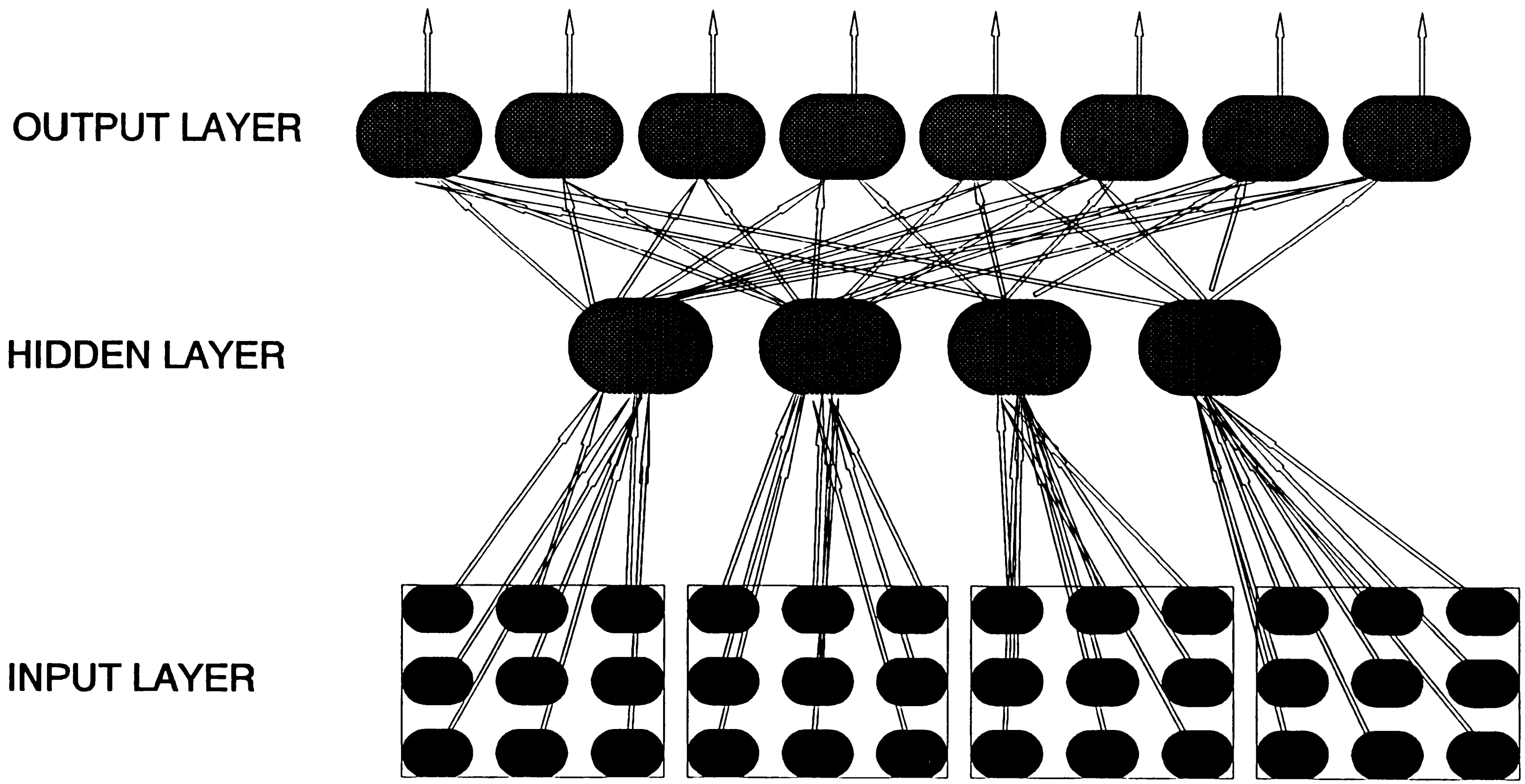


FIGURE (3-7) : PATTERNED NETWORK DESIGN.

TABLE 3-1: TRAINING RESULTS OF ALL LEOPARD MODELS

MODEL	A	B	C	D
INPUT LAYER	5	3	5	3
HIDDEN LAYER	11	7	11	7
OUTPUT LAYER	1	1	1	1
LEARNING PARAMETER	1.36363	2.142857	1.36363	2.14
SCALING FACTOR	0.036852	0.011582	0.036852	0.012846
MOMENTUM TERM	0.9	0.9	0.9	0.9
TRAINING CYCLES	9	12	10	5
MAXIMUM ERROR	0.06805	0.03312	0.03306	0.023138
RMS ERROR	0.033556	0.01513	0.016672	0.012846

training results for the RPM models are given in Table 3-2. The training data sets for LEOPARD Models A-D are shown in Appendix A, in Tables A-1 through A-4. Training data sets for the RPM models are shown in Tables A-19 and A-20. After training is completed, these models are tested on a set of test data.

Testing of Leopard Models

LEOPARD test data are constructed based on each of the models discussed above. Three sets of data are generated by LEOPARD. Test set (1) is based on a different enrichment and soluble poison schedule. The burnable poison concentration is also different from the training data set of Models A and C. The other two test data sets are built based on two different enrichments and no poison present inside the assembly.

Model A is tested on data set (1) and data set (2), as shown in Tables A-5 and A-6. Test results are given in Tables A-12 and A-13. For data set (1), the maximum error approached is 12.35 %, and the minimum error achieved is 0.23 %. For data set (2), the maximum error obtained is 34.36 %, and the minimum error is 8.10 %.

Model B is tested on the same sets of data as Model A, except poison concentrations are now eliminated from the data sets (see Tables A-7 and A-8). Test results are shown in Tables A-14 and A-15. For data set (1), the maximum error is 15.94 %, and the minimum error is 2.20 %. For data set (2), the maximum error obtained is 10.42 %, and the minimum error is 5.25 %.

Model C is tested on data set (1), as shown in Table A-9. The testing results

TABLE 3-2: TRAINING RESULTS OF ALL RPM MODELS

MODEL	MODEL A	NEXT-DOOR NETWORK	PATTERNED NETWORK
INPUT LAYER	31	155	90
HIDDEN LAYER	63	31	56
OUTPUT LAYER	31	31	56
LEARNING PARAMETER	0.483871	0.483871	0.267857
SCALING FACTOR	0.065382	0.065382	0.072388
MOMENTUM TERM	0.9	0.9	0.9
TRAINING CYCLES	245	219	412
MAXIMUM ERROR	0.074958	0.0640475	0.053974
RMS ERROR	0.023363	0.019234	0.01133

are shown in Table A-16. The maximum error obtained for this network is 4.48 %, and the minimum relative error is 2.31 %.

Finally, Model D is tested on data sets (3) and (4), as shown in Tables A-10 and A-11. The testing results are shown in Tables A-17 and A-18. The maximum relative error obtained for data set (3) is 7.93 %, and the minimum error is 0.52 %. For data set (4), the maximum error obtained is 5.46 %, and the minimum error is 0.73 %.

Testing of RPM Models

The first model is tested on 10 patterns, the second model is tested on 5 patterns, and the third model is tested on 10 patterns. Testing data sets for the three RPM models are given in Tables A-21 through A-23.

Results of testing for Model A are shown in Table A-24. The maximum relative error obtained is 24.19 %, and the minimum error achieved is 0.01 %. However, the mean relative error obtained is less than 10 %.

Results of testing for the next-door neighbor network structure are given in Table A-25. The maximum relative error is 43.02 %, and the minimum relative error is 0.5 %. The mean relative error is around 15 %.

Results of testing for the patterned network are tabulated in Table A-26. The maximum relative error obtained is 16.64 %, and the minimum relative error is 0.06 %.

Conclusions

LEOPARD Models

All of the LEOPARD models have learned that the higher the burnup of fuel assemblies, the lower the multiplication factor of the assemblies. The testing errors that appear in every pattern are dependent upon the distance of the points from the hyper surface built by the networks during training. The implicit learning of certain assembly parameters is exposed to a larger error in the network. This fact is apparent in Model B.

All of these LEOPARD models suggest that a general assembly network cannot be achieved using these parameters. On the other hand, a set of networks can be implemented to behave like a certain type of fuel assembly.

RPM Models

The different models of RPM are selected based on the following criteria: 1) the effect of all fuel assemblies (or the global interaction of the fuel assemblies on each other, which is represented by Model A); 2) the local changes that occur in the vicinity of a fuel assembly; and 3) the summation of those local changes to measure the global effects on each fuel assembly at a certain location (represented by the next-door neighbor model and the patterned network). The different sizes of training data for each model are selected based on the ability of the network to converge. In Model A, using 100 patterns for training is not an easy matter, and the network may never converge.

CHAPTER IV

AN EXPERT SYSTEM FOR FUEL SHUFFLING

Background

The determination of a core reload pattern for a PWR is a significant investment in terms of money and time. Once the PWR core is loaded, the in-core fuel management group starts predicting the EOC inventory distribution, power distribution and what fuel assemblies should be removed. At EOC, the core conditions may or may not match the predictions made. Replanning may be needed, and fast decision making capability is required. For every day of shutdown, 1 million dollars of income may be lost by the utility.

An expert system can assist in the coordination of the core reload designs. Experts utilize past experience to find reload configurations, and this knowledge is based on a heuristic set of rules the human expert applies. An expert system is a rule based system. The advantage of using an expert system is that it speeds up the decision-making process faced by human experts. The rules of experience can also be preserved and used by the expert system.

The Electric Power Research Institute (EPRI) developed an expert system that is capable of fuel shuffling based on a set of rules extracted from an OUT-IN strategy. [17] The expert system developed by EPRI has a graphical interface to assist the user in the process. Once a core reload design is selected, PDQ, an evaluator neutronic code, can test it. The testing process is evaluated in conjunction with thermal-hydraulic, safety and economic constraints.

Problem Statement

The objectives of this problem are to apply the OUT-IN fuel strategy to a PWR core at EOC and to find a reload core design that will satisfy thermal-hydraulic and safety constraints.

Methodology

The fuel strategy chosen in this research is the OUT-IN technique. Other fuel shuffling strategies exist in the industry (e.g. IN-OUT, etc.). The selection of this strategy is based on the flat power distribution which this strategy produces. A flat power distribution optimizes the thermal hydraulics performance of the reactor. The amount of control materials used in this strategy is minimized compared to other methods. In a low leakage core, for example, one concern is the power peaking that this strategy produces due to the loading of the fresh fuel at the center region of the core. In the OUT-IN scheme power peaking is minimum compared to other methods. [2]

A general strategy for shuffling the assemblies (as extracted from a study performed by the Electric Power Research Institute) is as follows: [17]

1) The most burned out assemblies are removed from the core,

2) The new fuel assemblies are loaded around the edge, and

3) The used assemblies are moved towards the center.

The specific rules are:

1) Remove all fuel assemblies that are to be removed (i.e., the third of the assemblies in the reactor that are spent). The criteria for removing assemblies are that the assemblies are spent, and whatever reactivity they have remaining is asymmetrically distributed.

2) Fill the center and the centerlines dividing the quarters.

   2a) Take the least burned-out assembly of those to be discarded and do not discard it, but put it in the center.

   2b) Take those assemblies formerly on centerlines and move them towards the center on the centerlines.

   2c) Take those assemblies with the flattest power distribution and put them on the centerlines to fill out the centerlines. Note that one of the reasons for filling out the center lines is so that the evaluation programs can simply work on a quarter of the core at a time. The goal is to use symmetric assemblies on the centerlines to reduce problems generated when the single quadrant is reflected to the remaining quadrants.

3) Fill the diagonal.

3a) Migrate the octant center line assemblies (on the diagonal line) towards the center without moving them off these lines.

3b) Fill the remaining diagonal line locations with assemblies with their hot corners either all pointing towards the center or all towards the outside.

4) Maintain a "quasi-checkerboard" pattern of high and low density.

5) Maintain one-eighth core symmetry.

6) Fill the interior of the quarter core. Move assemblies with hot channel corners (i.e., which have a large amount of unburned fuel).

6a) Put these next to the outside baffle (i.e., as close to the outside as possible, but having no edge adjacent to the outside).

6b) Put them adjoining the center assembly.

6c) Put them near the center of the quadrant with the hot corner pointing outward.

6d) Put them anywhere, as long as the other three corners are relatively burned up (cold). Two hot corners next to each other is probably too hot.

The idea is to put the hot corners in locations of low neutron importance or depressed power, or else next to cold corners.

7) Look at the gradients and rotate or reflect the assemblies (without moving them) to adjust the gradient relationships as follows: A gradient can be represented by an arrow from the coldest fuel cells to

the hottest fuel cells within an assembly. Gradients can be thought of as existing along an edge and diagonally through the center of the assembly.

7a) On adjacent edges, the gradients should be in opposite directions (i.e., the hot and the cold will balance each other).

7b) The diagonal gradients should be in the same direction, towards the center if possible. (This avoids two gradients pointing towards each other and putting two hot corners in the same corner.)

8) Make allowance for fresh fuel enrichment. Adjust the evaluation of hot versus cold corners in accordance with the amount of fuel enrichment of an assembly, noting that the higher the enrichment, the higher the peaking.

The research performed at the University of Tennessee, Knoxville assumes the following conditions about the reactor core:

1) A 1/8 core symmetry.
2) Each fuel assembly has an average multiplication factor.
3) The basic unit of the problem is a fuel assembly. No assembly corners are analyzed.
4) No poison is allowed in the shuffling rules.
5) A three batch core is assumed. Fuel assemblies can belong to one of

the three batches. These batches are designated first, second and third.

6) The fresh batch fuel assemblies have the same amount of potential reactivity.

The following general rules are implemented in the expert system:

1) One third of the one-eighth core of the fuel assemblies are discharged. Discard those which have the lowest multiplication factor.

2) Out of these discharged assemblies, the assembly with the largest multiplication factor is retained and placed at the center of the core.

3) Fuel assemblies living along the horizontal line are moved toward the center of the core, leaving outside locations empty.

4) Fuel assemblies dwelling on the diagonal line are moved towards the center of the core.

5) Fresh fuel assemblies are placed at the core boundary.

6) No two hot assemblies are allowed to live adjacent to each other.

7) A pattern of high and low in the region between the horizontal line and the diagonal line is utilized. This rule is relaxed as the core boundary is approached.

Tool Description

OPS5 (Official Production System 5) is a knowledge engineering language developed at Carnegie-Mellon University. [18] It incorporates a pattern matcher and an interpreter which includes a forward-chaining mechanism. The basic structure of OPS5 consists of a working memory and a production memory. The working memory contains the description of the state of the universe (the description of the problem). The production memory contains all the rules that control the behavior of the problem. The data types used to describe the state of the universe are called working memory elements (WME). There are two types of working memory elements, a class working memory element and a scalar working memory element. A class working memory element (also called element class) consists of a class name and a set of attributes. These attributes can have one value or a multivalued attribute (vector-attribute). The attributes are specific descriptions of an entity. In a logical sense, they are variables with values. Only one vector-attribute is allowed per element class. For example, the following is an element class:

```
(OBJECT    ^color red
           ^size large
           ^weight 10)
```

OBJECT is the name of the element class. Color, size and weight are the attributes associated with OBJECT. A scalar working memory element is an element with no attributes associated with it (e.g., START).

The production rules have the following form:

(P RULE_NAME (LHS) --> (RHS))

where the P stands for production, and is then followed by a rule name. The (LHS) contains the condition elements for the rule to fire. Condition elements are instants of working memory elements. The interpreter tries to match these condition elements with what is in the working memory (thus the name pattern matching process). The (RHS) consists of all the modification actions affecting the working memory elements. These modification actions include updating, creating, or deleting working memory elements. Most of the logical operators are provided in OPS5 (e.g., AND, OR, etc.).

Once all the condition elements in a rule match the corresponding working memory elements, then the rule is ready to fire. Which rule is ready to fire or which rule should fire first or next is the task of the interpreter. The interpreter performs its task based on a RECOGNIZE-ACT-CYCLE. In the RECOGNIZE-ACT-CYCLE, the interpreter looks for a match between condition elements and working memory. If only one rule matches, then this rule fires. If more than one match exists, then the interpreter puts all instantiations in a conflict set. The conflict resolution selects only one rule based on a strategy selected by the programmer. OPS5 contains two types of strategies, MEA and LEX. Both strategies have the same policy. This policy consists of REFRACTION, RECENCY, SPECIFICITY and PSEUDO-SELECTION. REFRACTION is the exclusion of any rule which has been fired. If the conflict set ends up with one rule, then that rule fires next. If more than one rule remains, then RECENCY comes to the picture. The rule with the most recent time tags is selected. Time tags are numbers associated with each working memory, created either by the user or the system. If more than one rule has the same time tags then SPECIFICITY takes control. The most detailed rule is chosen. If the application of SPECIFICITY results in more than one rule, then one rule is selected arbitrarily. The difference between MEA and LEX lies in the second step of the conflict resolution. In MEA the recency of the first condition element is the most important one, whereas in LEX, the recency of each condition element on the left-hand side of a rule is compared to that of its competitors.

System Design

The first step in designing an expert system is obtaining the domain knowledge, followed by a description of world state. Three working memory elements are utilized: an element class describing the fuel assembly, a core location element class, and a control element class. The fuel assembly element class has the following form:

```
(ASSEMBLY name
          batch
          position
          knf
          hs
```

vs)

Six attributes are used. The choice of these attributes is based on the knowledge rules under consideration. The name attribute is an identification of a fuel assembly. The batch to which a fuel assembly belongs is designated by (batch). The core location of a fuel assembly at EOC is described by (position). The multiplication factor associated with a fuel assembly is described by (knf). The symbols (hs) and (vs) are two control attributes utilized to prevent the logic of the checkerboard from cycling indefinitely. The values of these attributes can be either zero or one. Zero means the assembly has not been shuffled. The assembly has been shuffled if the value is equal to one.

The core element class reflects the properties of each location inside the reactor core. The form of this class is as follows:

```
(CORE    position
         class
         assembly
         right
         left
         top
         bottom
         distance
```

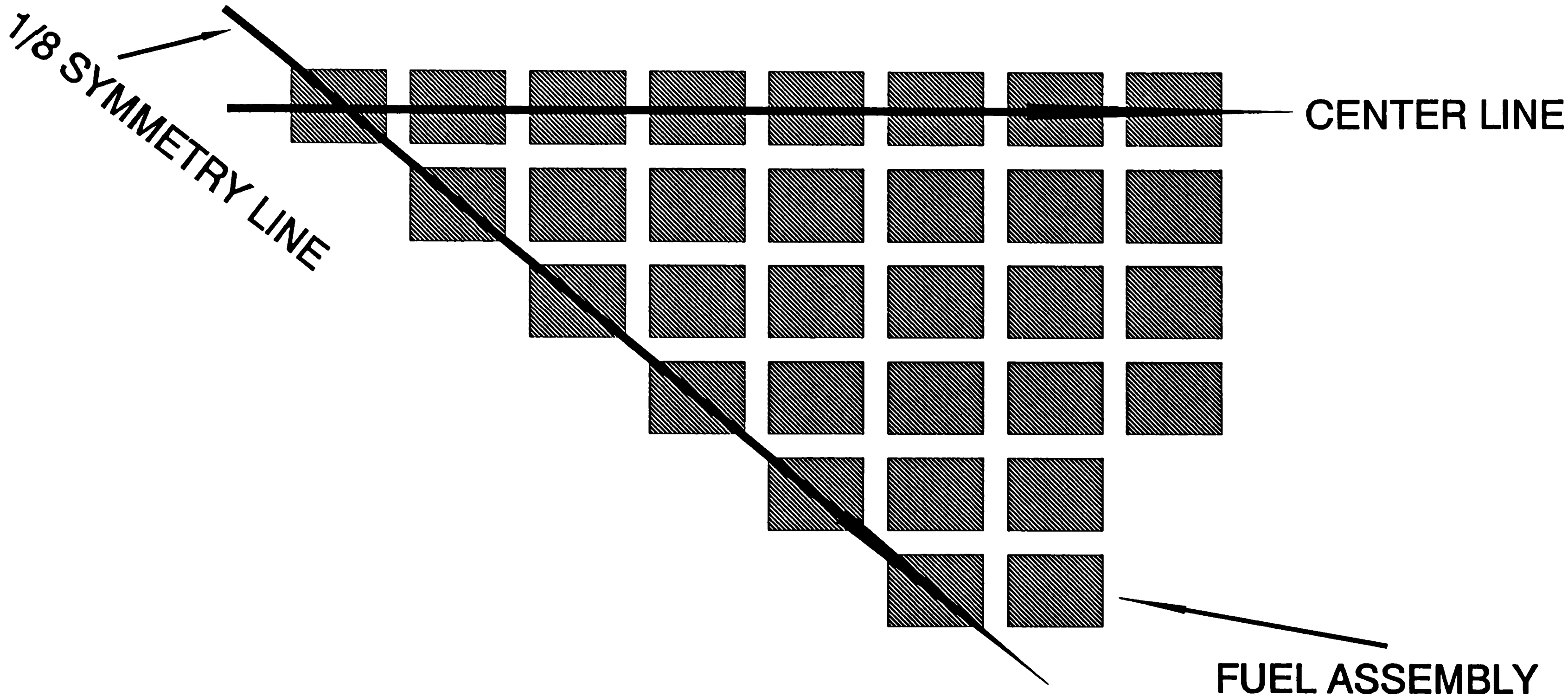
status)

This number of attributes is necessary for the rules or the way the rules are designed. The position attribute is the position of the location in the core. The class attributes can be horizontal, diagonal or in-between. Assembly is the assembly located at that position. Left, right, top, and bottom are the neighbor locations of the position attribute. The (distance) attribute is the distance from the center location of the core. (Status) is the location status where the values of that location are either empty or full. The third working memory element is the goal element. This element has two attributes, a name and a status. The name attribute is the name of the task to be executed next. The status attribute can be active or inactive, and is added to reflect the scheduling process in the nature of the execution of some of the subtasks.

The description of all core locations are described in a file designated CORE.MAP (as shown in Appendix B). Each row of this file is a description of a core location. Thirty-one locations are described based on the 1/8 core map as depicted in Figure 4-1.

The description of fuel assemblies is a file provided by the user and has the format shown in Table B-2.

Three types of rules are implemented in this design: input-output, knowledge and control rules. Input-output rules are implemented to interact with the user. Knowledge rules are those rules implemented based on the fuel shuffling strategy. Control rules are rules implemented to drive the total task from one subproblem to



FIGURE(4-1) : 1/8 REACTOR CORE.

another until all necessary rules are instantiated based on the core configuration under consideration.

Input-Output Rules

These rules include obtaining the assembly description file, getting the core location description file, and producing core reload file. These rules are implemented at the beginning of the code. Rules can be implemented any where in the program. This is one of the advantages of OPS5, where the order of rules is not important.

Knowledge Rules

Knowledge rules can be grouped into six sets based on the division of the fuel shuffling problem into six regions:

1) The discharge of fuel assemblies,

2) The center assembly selection,

3) The horizontal line shuffling,

4) The diagonal line shuffling,

5) The allowance of fresh fuel, and

6) The checkerboard pattern of full fuel assemblies.

The six regions are described below.

1) The discharge of fuel assemblies:

At EOC, certain fuel assemblies are discharged. The following rule performs the task of putting discharged fuel assemblies in a discharge list.

```
(p discharge-assembly
        (goal ^name discharge
                ^status active)
        {<the-count> (counter {<i> >0})}
        {<assembly> (assembly ^name <name>
                ^batch {<x> <<third second first>>}
                ^knf <k>)}
        {<core> (core ^position <pos>
                        ^assembly <name>)}
        - (assembly ^batch <<third second first>>
                        ^knf < <k>)
                -->
        (modify <assembly> ^batch discharged)
        (modify <core> ^assembly no
      ^status empty)
        (modify <the-count> counter (compute
    <i> - 1)))
```

This rule can be summarized in English form as follows: IF (there is an active goal named discharge) AND (a counter with a value greater than zero exists) AND (an assembly, belonging to a second, third or first batch, named <name>, having a value of knf <k> exists) AND (the assembly is at position <pos> in the core) AND (there is no assembly, belonging to a third, second or first batch with a lower k-inf than <k>),

THEN

(modify the assembly batch into discharged) AND (modify the core position into empty) AND (modify the counter working memory into a number less than its original value by one).

The above rule is repeated ten times. The number of times is based on the 1/3 number suggested by the fuel strategy. The last condition element is a negative condition element. A negative condition element is not allowed to be the first condition element in the rule. For this rule to fire, none of working memory elements may match this condition element. Once these fuel assemblies are put in the discharged list, the center fuel assembly is retained from the discharge assembly list.

2) The center assembly selection:

The fuel assembly with the maximum multiplication factor is retained from the discharged list. The following rule picks the center assembly:

```
(p pick-center-assembly
    (goal ^name pick-center
            ^status active)
    {<assembly> (assembly ^name <name>
                    ^batch discharged
                    ^position <pos>
                    ^knf <knf>)}
      (counter 0)
 {<core> (core ^position 11
             ^status empty)}
 - (assembly ^batch discharged
           ^knf > <k>)
 -->
 (write (crfl) ¦ The new center assembly is
¦ <name>)
(modify <core> ^assembly <name>
                ^status full)
(modify <assembly> ^batch old
                    ^position 11
                    ^knf <k>)
                      (remove 3))
```

The English form of this rule as follows:

IF (a goal named pick-center is active) AND (an assembly called <name> belonging to batch discharged located at position <pos> and having a value of knf <k>) AND (a counter with a value of zero exists) AND (the core location of the center assembly is empty) AND (there is no assembly belonging to the discharged batch, with a value of knf greater than <K>)

THEN

(prompt user with the name of the new center assembly) AND (modify the center location to a status full and assign the new name of the new assembly to the attribute assembly) AND (modify the batch of the center assembly to old) AND (remove the working memory element counter).

This rule fires if the center assembly location is empty. Otherwise, the rule doesn't fire. This rule fires only once. When the center assembly is chosen, the discharged list is removed from working memory.

3) The horizontal shuffling along the center line:

The rule implemented to perform this task is as follows.

```
(p move-fuel-along-horizontal-line
(goal ^name move-horizontal
^status active)
```

```
{ <core> (core ^position <pos>
        ^class horizontal
        ^assembly no
        ^right <rpos>
        ^status empty)}
{ <core1> (core ^position <rpos>
        ^class horizontal
        ^assembly {<assembly <> no}
        ^status full)}
    {<assembly1> (assembly ^position <rpos>
            ^name <assembly>)}
    -->
(modify <core> ^assembly <assembly>
        ^status full)
    (modify <core1> ^assembly no
        ^status empty)
    (modify <assembly1> ^position <pos>))
```

The IF statement of the rule contains four condition elements. The first condition element is a control element. Its function is to contribute in the environment necessary for this rule to fire. The other three condition elements function can be summarized as follows:

IF there is a core position at the horizontal line with no assembly AND there is a right neighbor with a fuel assembly,

THEN

modify that position AND insert the right neighbor assembly in it AND modify the position of the right neighbor to empty.

This rule fires on any two positions along the horizontal line which fit the required description. The number of instantiations of this rule is controlled by the state of the assemblies along the horizontal line. Once the fuel assemblies have no empty positions between each other, this rule stops firing and control is handed into another rule to trigger another task. The only empty places along the horizontal line are at the boundary positions of the core. Figure 4-2 depicts the operation of this task.

4) Fuel shuffling along the diagonal line:

This subproblem is built by a rule similar to the rule for horizontal shuffling. The rule fills out all positions along the diagonal line except the boundary positions. This rule exploits the idea that any two diagonal assemblies have the same neighbor, as shown in Figure 4-3. The rule which is implemented to perform this subtask is as follows:

```
(p move-fuel-along-line
```

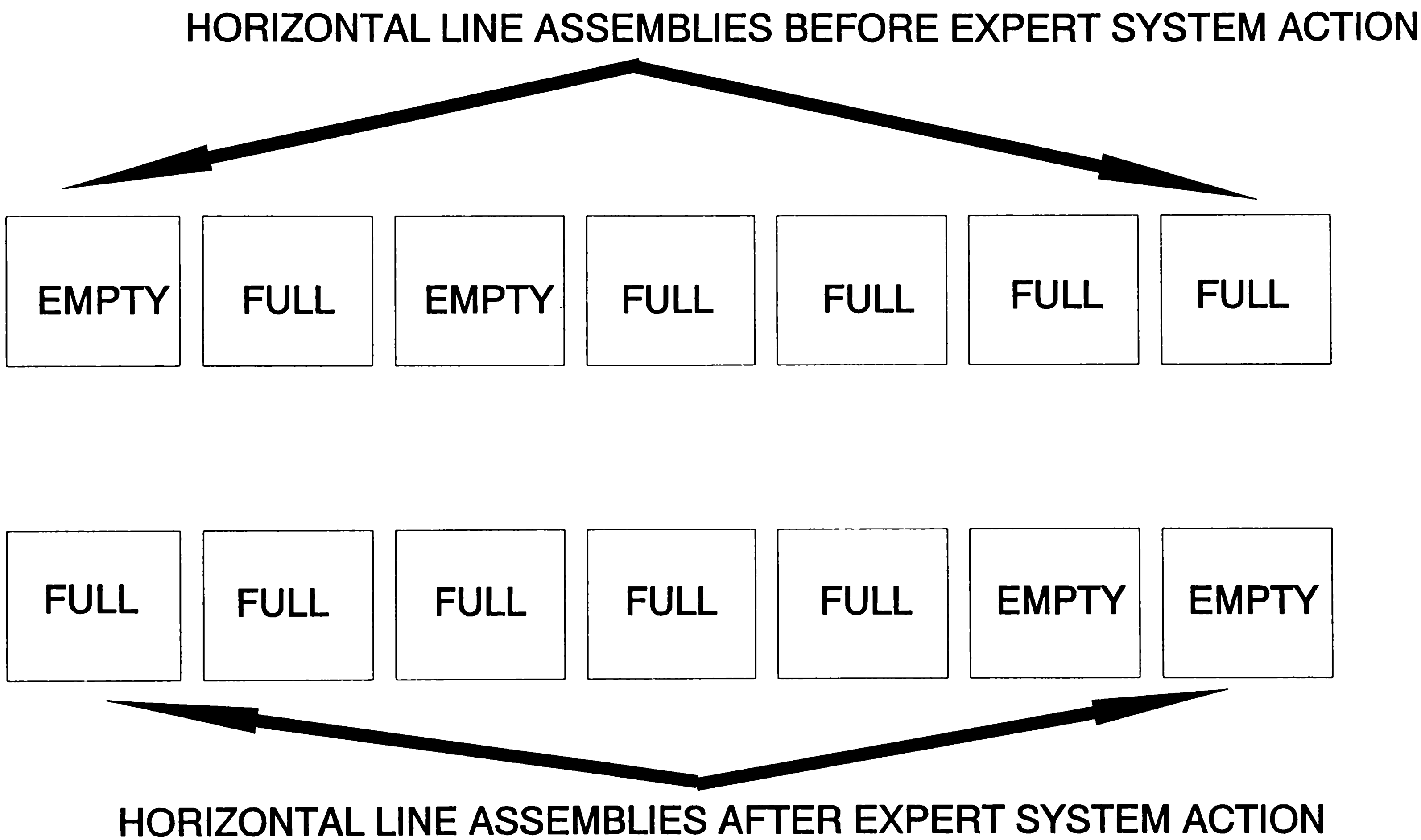


FIGURE (4-2) : HORIZONTAL LINE SHUFFLE.

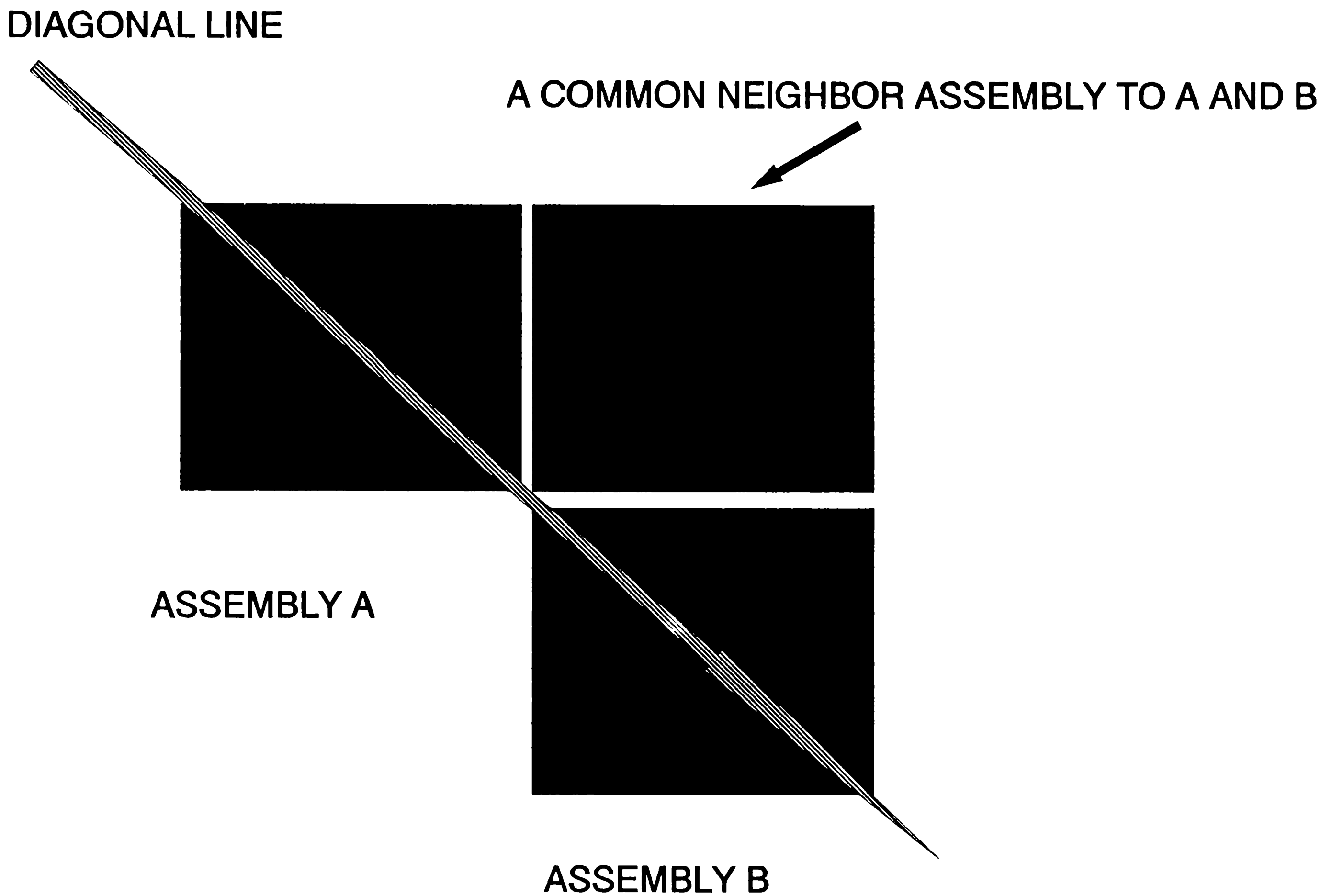


FIGURE (4-3) : LOGIC BEHIND SHUFFLING ALONG DIAGONAL LINE.

```
(goal ^name move-diagonal
      ^status active)
{<core> (core ^position <pos>
      ^class diagonal
      ^assembly no
      ^right <rpos>
      ^status empty)}
{<core1> (core ^position <pos1>
      ^class diagonal
      ^assembly {<assembly <> no}
      ^top <rpos>
      ^status full)}
{<assembly1> (assembly ^position <pos1>
      ^name <assembly>)}
-->
(modify <core> ^assembly <assembly>
      ^status full)
(modify <core1> ^assembly no
      ^status empty)
(modify <assembly1> ^position <pos>))
```

The number of instantiations of this rule is controlled by the number of empty positions along the diagonal line. The result of this task is shown in Figure 4-4.

5) Fresh fuel loading:

The loading of the fresh fuel includes the loading of the remaining empty locations at the horizontal centerline, the loading along the diagonal line, and loading inside the in-between region. A set of rules are written to perform the task. A complete listing of the code is available in the Department of Nuclear Engineering.

6) Checkerboard implementation:

In the checkerboard design, each assembly with a low K-INF should be surrounded with assemblies of high multiplication factor, as shown in Figure 4-5. The reason for doing this is to create a uniform power distribution and to prevent power peaking at a certain region in the core. The method used to perform the task is as follows:

The core is divided into three concentric regions: the inner region, the middle region, and the outer region. In the inner region assemblies of the second and the first batch are loaded based on their batch name in a checkerboard form. The middle region is permitted to have first batch and second batch assemblies where only certain locations are allowed for the second batch assemblies. The outer

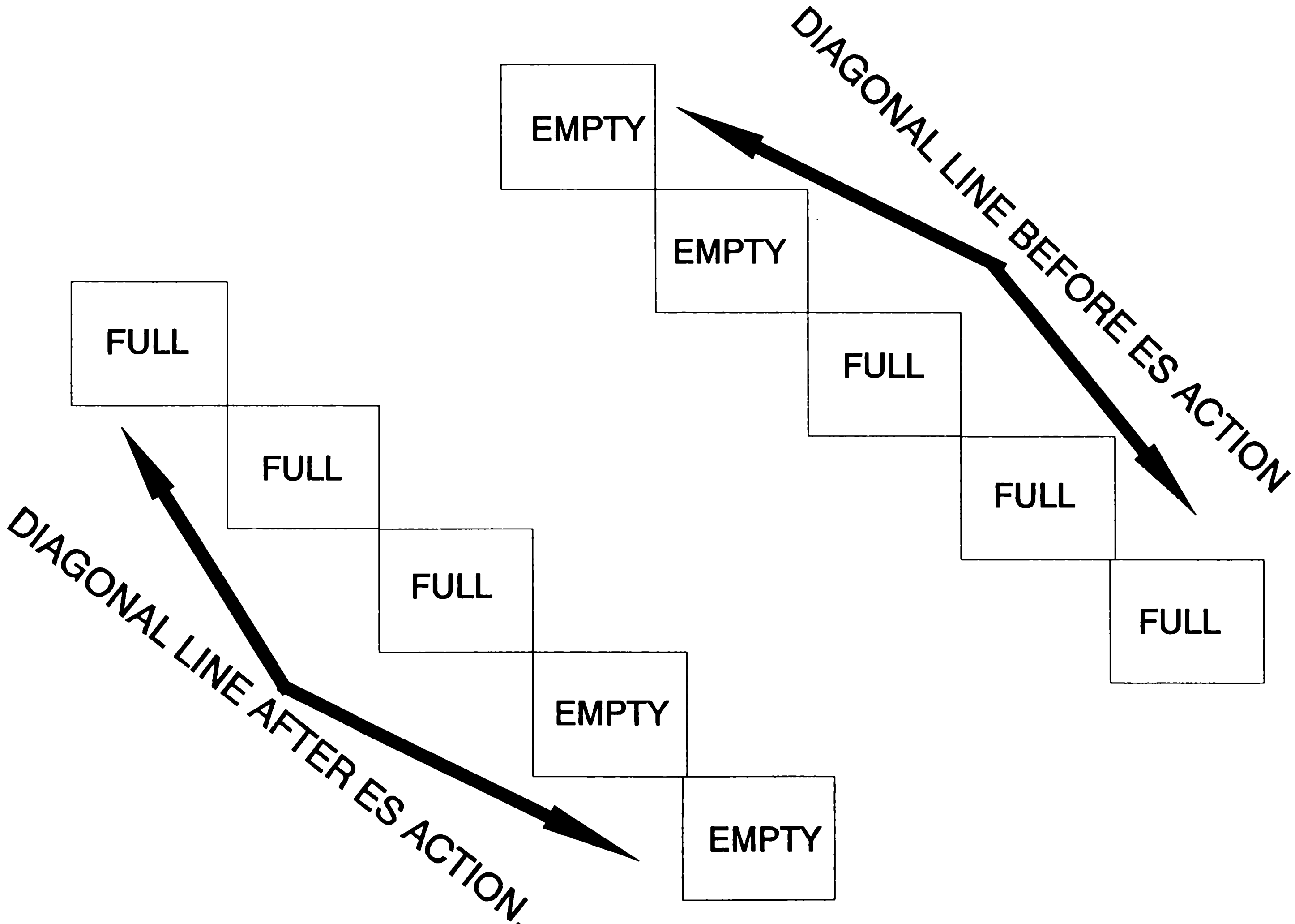


FIGURE (4-4) : DIAGONAL LINE SHUFFLING.

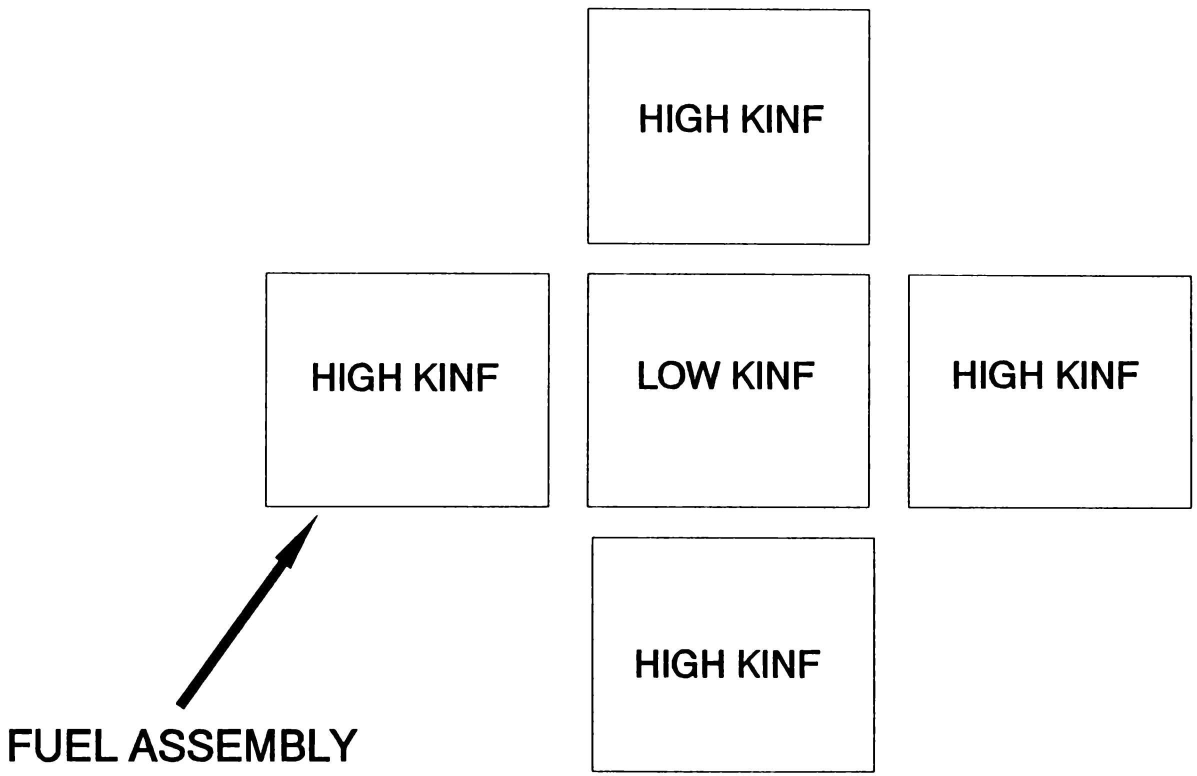


FIGURE (4-5) : GOAL OF CHECKERBOARD TASK.

region is allowed to have fresh and first batch assemblies. The rules coded for this task are similar to the rules mentioned above.

The method used in the implementation does not reflect the amount of how high is or how low is the value of K-INF. A linguistic variable called (KINF) can be defined and a range of the values of K-INF can be defined. A set of three membership functions can be defined as well, where each function reflects the degree of high, low and medium for each set of fuel assembly multiplication factors. This method helps in constructing the checkerboard pattern.

Another method is to generate a set of possible locations for each fuel assembly, and then to apply certain pruning rules that reflect the forbidden position. This method includes a generation of configurations for the in-between region and then tests these configurations based on the rules mentioned above.

Control Rules

The control rules have the following form:

```
(p remove-in-between
    {<goal> (goal ^name1 move-in-between ^status active)}
    -->
    (modify <goal> ^name1 shuffle))
```

The IF side of the rule contains the move-in-between goal. Once this goal is satisfied, the THEN side signals the shuffle task to start. Most of the control rules have the above format.

System Operation

The operation of the program is depicted in Figure 4-6. The first step in running this program is to design a file in the format specified in Table B-2. Each record contains the assembly type, the batch, the position and the fuel assembly K-INF. The user can provide the name of the input file to the program. He or she, while running the code, is permitted to supply the fresh batch assembly K-INF. The user is also allowed to supply the name of the output file of core configuration.

A working memory element called START is the spark of the whole operation. After the firing of the first rule, the following path is taken by the expert system:

1) It obtains the EOC core configuration file from the user,
2) The program assigns a WME for each of the fuel assemblies,
3) The expert system maps each assembly provided in the description file into a core location,
4) It puts the assemblies to be discharged in a list,
5) The program selects the new center fuel assembly and then removes the rest of the discharged list,
6) It asks the user to provide the value of K-INF of the fresh batch fuel

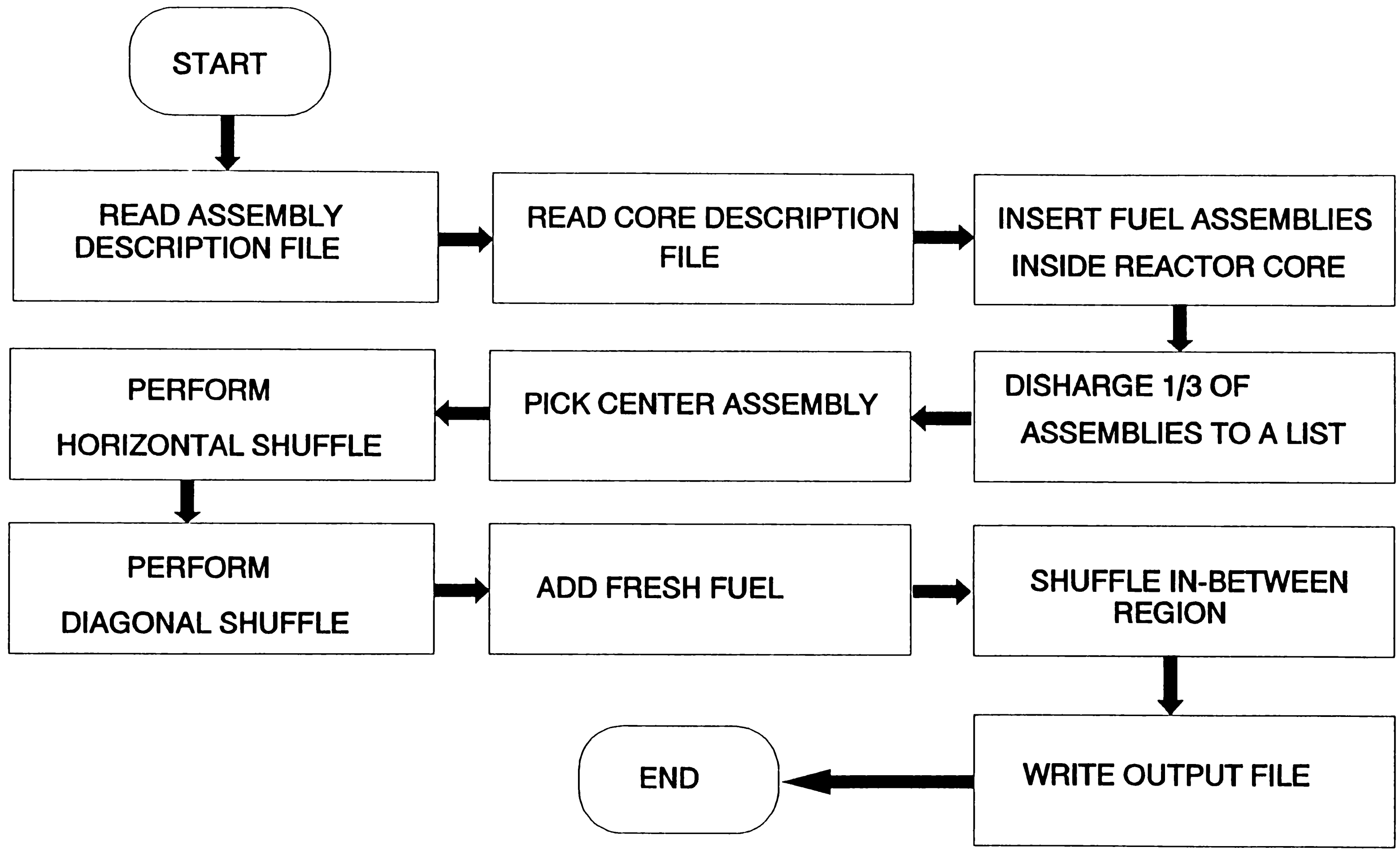


FIGURE (4-6) : EXPERT SYSTEM OPERATION.

assembly, and

7) The expert system shuffles the fuel based on the shuffling rules implemented.

Results

The expert system is tested on a core data with 1/8 core symmetry. The EOC configuration is shown in Figure 4-7. The expert system output is shown in Figure 4-8. This core can be tested using a neutronic code such as RPM, and relative power distribution can be evaluated.

Conclusions

The shuffling rules are implemented. The total number of rules implemented is thirty-one rules. A MEA strategy is utilized. The expert system can be extended to include all core constraints (e.g., power peaking constraint, batch size constraint, etc.). Burnable poison and control rod assemblies can be incorporated into the expert system.

0.811	1.123	1.013	1.140	0.982	1.100	1.210	1.360
	1.200	1.150	1.170	1.340	1.250	1.300	1.260
		1.200	1.025	1.026	1.100	1.120	1.230
			1.018	0.876	0.967	1.130	1.142
				1.220	1.023	1.160	
					1.223	1.290	

KINF

FIGURE (4-7) : CASE STUDY INPUT.

1.026	1.123	1.140	1.100	1.210	1.360	1.380	1.380
	1.200	1.150	1.250	1.120	1.300	1.170	1.260
		1.220	1.100	1.340	1.130	1.380	1.380
			1.223	1.230	1.140	1.380	1.380
				1.380	1.160	1.380	
					1.380	1.290	

KINF

FIGURE (4-8) : CASE STUDY OUTPUT.

CHAPTER V

GRAPHICAL INTERFACE USING MICROSOFT EXCEL

Background

The work performed in this branch of the research has arisen from the desire to have a graphical interface for the expert system. During development of the whole research, new goals were added to the original goal. One of these goals is the interaction between the graphical interface and an evaluator neutronic code. The neutronic code (RPM) was modified to fit the output of this software. Another new goal which was added is the interaction of the neural network code (NETS). Configuration, training, and testing files are created using the software. The user is also allowed to compare results coming from the RPM code and a trained network. This is one of the features of the software.

EPRI has developed a graphical interface with the shuffling rules it has implemented, which utilizes icon images in the design of the software. [18]

Software Objectives

The objectives of this work are to design a manual shuffling capability using a graphical interface, to construct an interaction between RPM and the user, and to create an interface between NETS and the operator.

Tool Description

MicroSoft Excel is the developmental tool of the graphical interface. It is chosen because the features that it offers are capable of representing most of the tasks proposed in the construction of the graphical interface. MicroSoft Excel has three features: (1) Macros, which are divided into two categories: (a) Function Macros, which can only perform calculations on a worksheet; (b) Command Macros, which are capable of performing actions; (2) Worksheets, which are composed of cells. Each cell can represent a value of a parameter of the fuel assembly, and can be used to display the 1/8 core map of the reactor core; and (3) Charts, which can be used to graph data (i.e., graphing the relative power distribution of the fuel assemblies). [18, 19]

Software Operation

The graphical interface developed in this research is contained in a MicroSoft Excel file called RPMMAIN1.XLM. The steps involved in operating the software are listed as follows:

1) In the Disk Operating System (DOS) mode, at the C:\ prompt, type WIN. This command activates the MicroSoft WINDOWS environment.
2) In the WINDOWS environment, select the MicroSoft Excel application

from the menu. This selection activates MicroSoft Excel.

3) Using the FILE command from the menu bar, select the OPEN command to retrieve the RPMMAIN1.XLM file.

4) Using the MACRO command from the menu bar, select the RUN command to execute the RPMMAIN1.XLM file.

5) The menu bar containing the commands for the software appears at the top of the screen, replacing the Excel menu bar.

The path of the software operation is dependent upon which type of command the user chooses.

Software Design

The input of this software and the RPM code are equivalent. There are two types of inputs, core input and fuel assembly input. The core input consists of: 1) the core reactivity at end of cycle; 2) the radial leakage coefficient; 3) the axial leakage cofficient; 4) the power sharing factor; 5) the number of fuel assembly types; and 6) the number of iterations necessary to calculate power fractions. The fuel assembly parameters are: 1) the assembly type; 2) the slope of the reactivity-burnup relation, which is measured in kilograms per megawatt-day (KG/MWD); 3) Fuel assembly reactivity potential; 4) burnable poison reactivity; 5) batch ID; and 6) total number of fuel assemblies of the designated type.

The data manipulation performed by the user is utilized by a worksheet. This worksheet contains two cards, an inventory card and a 1/8 core loading map as shown in Figure 5-1. The inventory card contains all information provided by the user about the fuel assembly and contains a set of two rows at the bottom. These two rows are called LOADED and UNLOADED. The LOADED row contains the number of fuel assemblies of each type which are loaded. The UNLOADED row contains the number of fuel assemblies of each type which remain after loading. The two rows are not updated automatically; rather the user must select the submenu INVENTORY, and then choose one of the update commands. The other card is a grid of the 1/8 core loading map. Each fuel assembly is represented by a set of cells. Each cell contains one of the assembly parameters. A group of four cells is used, and the group is formatted as one square on the worksheet. A set of squares are constructed, creating the 1/8 core loading map.

The 1/8 core loading map is initially empty. The user must fill the core from the inventory card. The process of loading is performed in two steps. First, the user must select the assembly from the inventory pool using the command MARK-ASSEMBLY. Next, the core location must be selected. This is performed by setting the cursor on the top cell of one of the core locations. Finally, the user chooses the LOAD-ASSEMBLY command from the CORE submenu.

Once the core is loaded, the operator can select a WRITE-TO-FILE command, where a file called CORE.INP is produced. This file is readable by the RPM code. The RPM code can evaluate power fractions based on the input data provided by the user.

INVENTORY CARD				
Batch ID=	111	111	112	113
Assy,m Type	1	2	3	4
Current RHO	0	0.12	0.24	0.24
A(kg/MWD)	0.009	0.009	0.009	0.009
BP RHO	0	0	0	0
Total # =	65	64	60	4
Loaded =	0	0	0	0
Unloaded =	65	64	60	4

CORE LOADING MAP

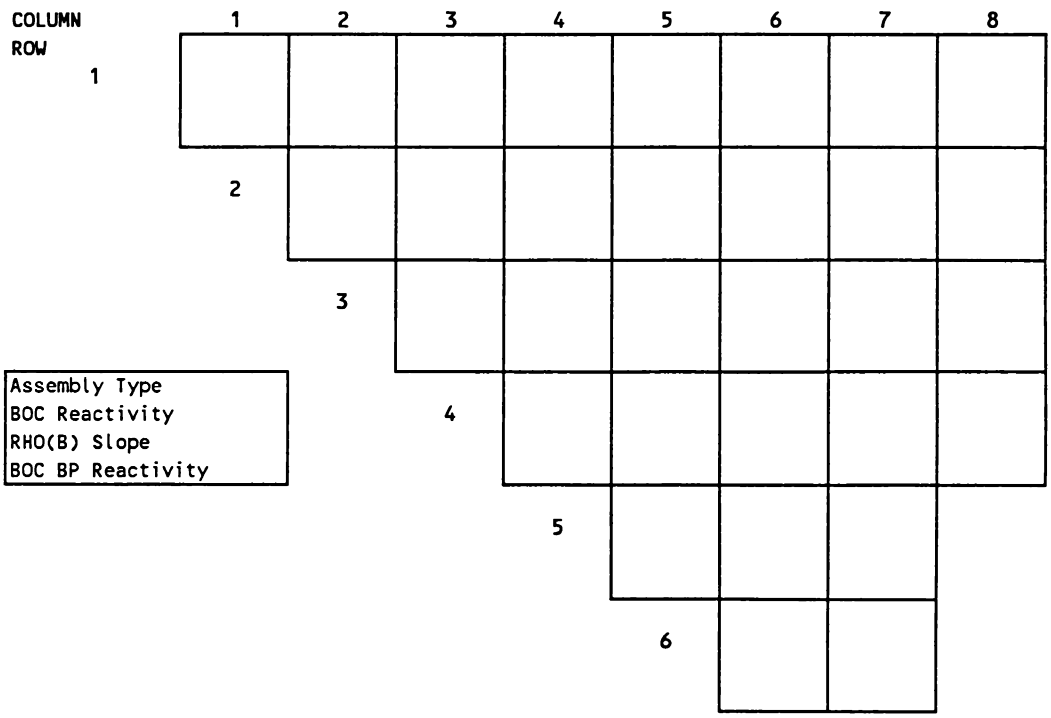


FIGURE 5-1: INVENTORY CARD AND 1/8 CORE LOADING MAP

The menu bar of the software as depicted in figure 5-2 contains the following submenus: 1) CORE; 2) RPM; 3) SHUFFLE; 4) NEURAL NET; 5) INVENTORY; 6) OUTPUT; and 7) HELP. Figure 5-1 illustrates the arrangement of the submenus within the main menu. All of these submenus are created using Macros.

1) CORE Submenu:

This submenu contains the following commands: NEW-CORE, OLD-CORE, MARK-ASSEMBLY, LOAD-ASSEMBLY, MOVE-ASSEMBLY, REMOVE-ASSEMBLY and EXIT. This section describes each command and the purpose of each.

1a) NEW-CORE:

The user can select this command to load a reactor core initially. Once this command is selected, the code asks the user to insert the core input and fuel assembly input.

1b) OLD-CORE:

If the user has saved the work done in a previous session, he or she can retrieve the work again and operate on the data using other commands.

1c) MARK-ASSEMBLY:

This command is necessary before loading, discharging or moving an assembly. The user can set the cursor on the fuel assembly and drag the mouse to contain all the fuel assembly boundaries. After doing this, the user can select this command

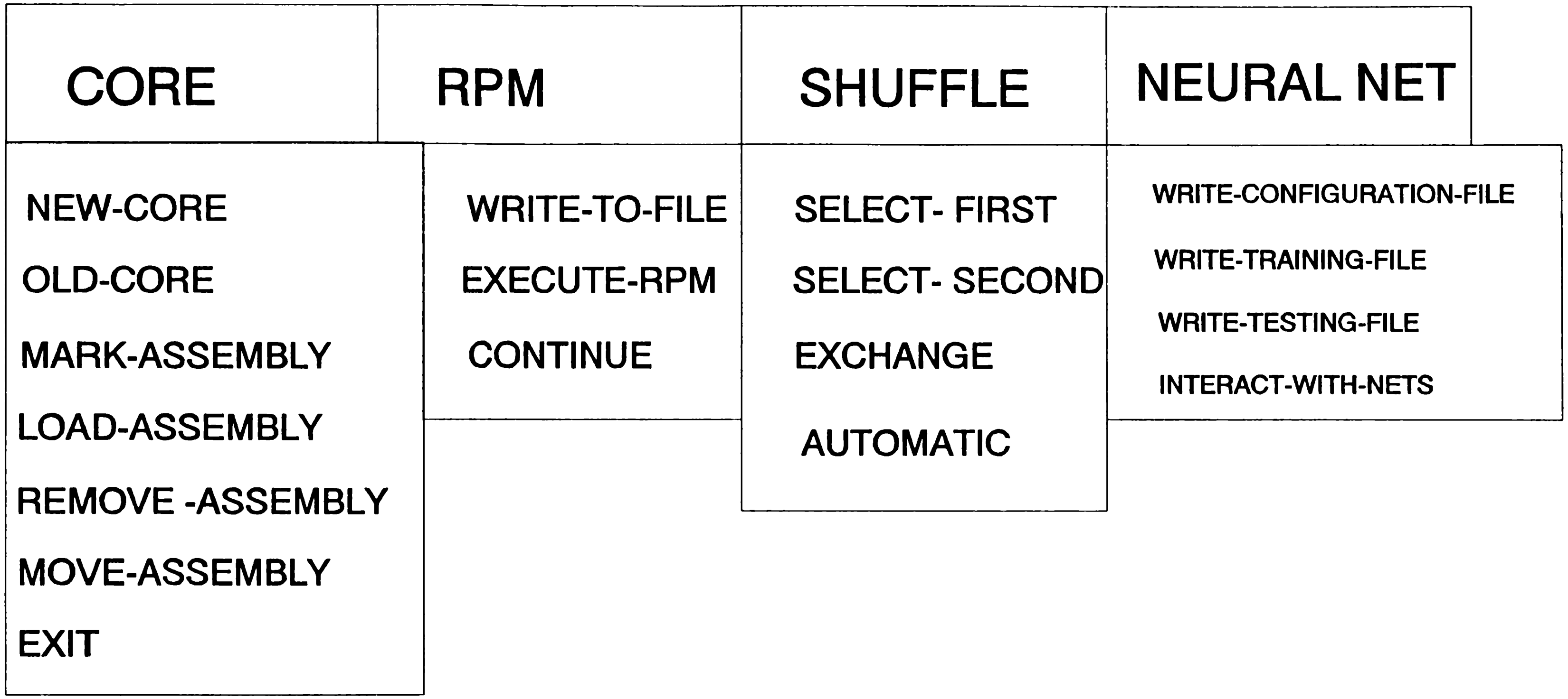


FIGURE (5-2) : SOFTWARE MAIN MENU.

INVENTORY	OUTPUT	HELP
UPDATE-ONE	ERROR %	ABOUT-SOFTWARE
UPDATE-ALL	RPM-OUTPUT	ABOUT-RPM
ADD-FRESH-FUEL	NETS-OUTPUT	ABOUT-NETS

FIGURE (5-2) : SOFTWARE MAIN MENU (CONT).

and an on-off box appears, also called a marquee.

1d) LOAD-ASSEMBLY:

This command performs the task of loading a fuel assembly to the reactor core. MARK-ASSEMBLY must first be chosen, and then a core location is selected on the core loading map. This selection is made by setting the cursor on the top cell of the fuel assembly. Finally, the LOAD-ASSEMBLY command is selected.

1e) MOVE-ASSEMBLY:

This command is used during the shuffling task where the assembly is moved from one location to another empty location. The first step is to select a fuel assembly (using the mouse and pressing the left button while dragging the cursor to cover all the fuel assemblies). The selection of the destination location is the second step, and is performed by positioning the cursor in the top cell of the core location. The last step is the selection of the MOVE-ASSEMBLY command.

1f) REMOVE-ASSEMBLY:

The purpose of this command is the manual discharging of the fuel assemblies. The action is performed by first selecting the fuel assembly to be discharged, as done before in the above- mentioned commands. Once the fuel assembly is chosen, this command can be selected to remove the fuel assembly.

1g) EXIT:

This command transfers control from the software back to Excel, where the user can obtain a hard copy of the results of the session with the software.

2) RPM Submenu:

This submenu has the following commands: WRITE-TO-FILE, EXECUTE-RPM, and CONTINUE.

2a) WRITE-TO-FILE:

This command must be selected before the selection of EXECUTE-RPM command. The purpose of it is to write a file readable by the RPM code.

2b) EXECUTE-RPM:

The execution of the RPM code is performed using this command.

2c) CONTINUE:

CONTINUE functions as a path back to the RPM code once modifications are made to the input of reactor core (i.e., shuffling).

3) SHUFFLE Submenu:

The purpose of this submenu is to assist in the manual shuffling or automatic shuffling process. During shuffling, exchanging the positions of two fuel assemblies is one of the tools used to shuffle. Commands are written to perform the exchange task. The following commands comprise the SHUFFLE submenu: SELECT-FIRST, SELECT-SECOND, EXCHANGE, and AUTOMATIC.

3a) SELECT-FIRST:

This command marks an assembly to be exchanged. The selection of the fuel assembly is necessary to perform this task. The process of selecting an assembly is discussed above. The fuel assembly is selected by positioning the cursor on the top cell of the fuel assembly, and then dragging the cursor down to encompass the fuel assembly. The SELECT-FIRST command is then chosen.

3b) SELECT-SECOND:

The purpose of this command is to select the next assembly to be exchanged. The same steps are performed as in the SELECT-FIRST command. The last step in this sequence is the selection of the SELECT-SECOND command.

3c) EXCHANGE:

This command is selected only after the two previous commands are selected. EXCHANGE exchanges the location of the two fuel assemblies chosen in the SELECT-FIRST and

SELECT-SECOND commands.

3d) AUTOMATIC:

This command is a bridge between the graphical interface and the expert system discussed in Chapter IV. At this point, the interaction has not been made. However, this command can be activated in two stages:

First, an assembly description file readable by the expert system would be designed. The second stage would involve execution of the expert system from the software environment.

4) NEURAL NET:

The NEURAL NET submenu is designed to assist the user in building a configuration file for designing the network, creating a training file for the network, generating a testing file for the network, and interacting with the NETS software.

4a) WRITE-CONFIGURATION-FILE:

This command creates a file readable by NETS software. The name of the file is user dependent. A necessary condition for the name of this file is that it must contain the extension NET (e.g., FILENAME.NET). This file contains information about the number of layers in the network and how many nodes are in each layer. The file produced is for a fully connected, three-layered network.

4b) WRITE-TRAINING-FILE:

The output file produced by this command contains the fuel assembly reactivity potentials of the loading core map. This file is designed only for a fully connected, three- layered network.

4c) WRITE-TESTING-FILE:

The testing file is produced once the network has been trained. This command creates a testing file readable by NETS.

4d) INTERACT-WITH-NETS:

The interaction between the graphical interface and the neural network software is performed using this command. This command is selected after the creation of the configuration and training files.

A set of computer programs written in C language are provided to produce training and testing files for a patterned network. These files are available in the Department of Nuclear Engineering.

5) INVENTORY Submenu:

The purpose of this command is to keep track of the loading process. It is assumed that a 1/8 core symmetry exists. During loading of the core, each assembly loaded on the centerlines is worth four assemblies (half assemblies) distributed over other the centerlines in the core. This is done due to the assumption of symmetry in the reactor core. The UPDATE commands indicate how many fuel assemblies remain in the inventory (e.g., unloaded assemblies), and how many assemblies have been loaded. The actions of the UPDATE commands are reflected in the LOADED and UNLOADED rows in the inventory card as shown in Figure 5-2. The numbers appearing in the unloaded column can be either negative or zero. A negative number indicates that the operator has loaded more assemblies than actually exist in the inventory card. A zero value means that all assemblies of a particular type have been loaded, and none remain. For a correct loading, the UNLOADED row must consist entirely of zero values.

The following commands are contained in the INVENTORY submenu: UPDATE-ONE, UPDATE-ALL, and ADD-FRESH-FUEL.

5a) UPDATE-ONE:

This command updates only one assembly type. Once the command is selected, the user is prompted by an input card, in which the assembly type which he or she wants to track is inserted.

5b) UPDATE-ALL:

The purpose of this command is to inform the user of the whole core state. This command, once selected, provides the number of loaded and unloaded fuel assemblies in the inventory card at the time of the command selection.

5c) ADD-FRESH-FUEL:

This command is necessary if an EOC analysis is performed. After the discharge of fuel assemblies, this command can be used to provide fresh fuel for the next cycle.

6) OUTPUT Submenu:

This submenu is created to provide an indication of the difference between values predicted by the neural network and the values produced by RPM. It contains ERROR, RPM-OUTPUT, and NETS-OUTPUT.

6a) RPM-OUTPUT:

The user can display the output of RPM on a worksheet by selecting RPM-OUTPUT. The user is prompted to insert the name of the output file and he or she can examine this output.

6b) NETS-OUTPUT:

This command has function similar to the previous command (RPM-OUTPUT). The output of the network can be examined by the user. The user is instructed to provide the name of the network file.

6c) ERROR:

When the ERROR command is chosen, the user is asked to provide the name of the network output file and the desired file. The ERROR command then calculates the difference and places it in a file named by the user.

7) HELP submenu:

This submenu contains three help commands: ABOUT-SOFTWARE, ABOUT-RPM, and ABOUT-NETS. The help files have not been generated to date.

Results

The software was used in producing some of the RPM Training, Testing data used in the neural network research performed earlier. In figure 5-3, a 1/8 core map is shown with the inventory card containing all fuel assemblies. The 1/8 core is not shuffled yet. Figure 5-4 shows the 1/8 core map loaded and ready to be tested by the RPM code where relative power distribution of fuel assemblies can be obtained.

Conclusions

The objectives of the software are satisfied. The user can load a core at BOC or at EOC. He or she can also evaluate a loaded core using the RPM code. The operator can test a loaded core with a neural network. A construction of a neural network is also available using this software.

The help files can be incorporated in the software using some of the macro

INVENTORY CARD				
Batch ID=	111	111	112	113
Assy,m Type	1	2	3	4
Current RHO	0	0.12	0.24	0.24
A(kg/MWD)	0.009	0.009	0.009	0.009
BP RHO	0	0	0	0
Total # =	65	64	60	4
Loaded =	65	64	60	4
Unloaded =	0	0	0	0

CORE LOADING MAP

COLUMN / ROW	1	2	3	4	5	6	7	8
1	1 0 0.009 0	2 0.12 0.009 0	4 0.24 0.009 0	1 0 0.009 0	2 0.12 0.009 0	3 0.24 0.009 0	1 0 0.009 0	2 0.12 0.009 0
2		1 0 0.009 0	2 0.12 0.009 0	3 0.24 0.009 0	1 0 0.009 0	2 0.12 0.009 0	3 0.24 0.009 0	1 0 0.009 0
3			1 0 0.009 0	1 0 0.009 0	3 0.24 0.009 0	1 0 0.009 0	2 0.12 0.009 0	3 0.24 0.009 0
4				2 0.12 0.009 0	2 0.12 0.009 0	3 0.24 0.009 0	1 0 0.009 0	2 0.12 0.009 0
5					1 0 0.009 0	2 0.12 0.009 0	3 0.24 0.009 0	
6						1 0 0.009 0	3 0.24 0.009 0	

Assembly Type
BOC Reactivity
RHO(B) Slope
BOC BP Reactivity

FIGURE 5-3: UNSHUFFLED 1/8 REACTOR CORE

INVENTORY CARD				
Batch ID=	111	111	112	113
Assy,m Type	1	2	3	4
Current RHO	0	0.12	0.24	0.24
A(kg/MWD)	0.009	0.009	0.009	0.009
BP RHO	0	0	0	0
Total # =	65	64	60	4
Loaded =	65	64	60	4
Unloaded =	0	0	0	0

CORE LOADING MAP

COLUMN / ROW	1	2	3	4	5	6	7	8
	1	2	4	1	2	1	2	3
1	0	0.12	0.24	0	0.12	0	0.12	0.24
	0.009	0.009	0.009	0.009	0.009	0.009	0.009	0.009
	0	0	0	0	0	0	0	0
		1	2	2	1	2	1	3
2		0	0.12	0.12	0	0.12	0	0.24
		0.009	0.009	0.009	0.009	0.009	0.009	0.009
		0	0	0	0	0	0	0
			1	1	3	1	2	3
3			0	0	0.24	0	0.12	0.24
			0.009	0.009	0.009	0.009	0.009	0.009
			0	0	0	0	0	0
				2	2	3	1	3
4				0.12	0.12	0.24	0	0.24
				0.009	0.009	0.009	0.009	0.009
				0	0	0	0	0
					1	2	3	
5					0	0.12	0.24	
					0.009	0.009	0.009	
					0	0	0	
						1	3	
6						0	0.24	
						0.009	0.009	
						0	0	

Assembly Type
BOC Reactivity
RHO(B) Slope
BOC BP Reactivity

FIGURE 5-4: SHUFFLED 1/8 REACTOR CORE

function capabilities. The set of computer programs written can be accommodated under NEURAL NET submenu and the user can construct testing, training files for a patterned network.

CHAPTER VI

CONCLUSIONS AND FUTURE WORK

Introduction

This chapter contains the conclusions and future work concerning the research performed at the University of Tennessee at Knoxville. Some suggestions are also made for others who would like to continue research in the area of in-core fuel management.

LEOPARD Models

We were unsuccessful in utilizing a feed-forward neural network to represent a general fuel assembly and to obtain high accuracy. A recurrent network structure may obtain the required accuracy. Two networks can be designed, where one of the networks is a control network, and the other is a model network. The model network can relate K-INF to initial K-INF, initial burnup, and change in burnup. The control network can be designed to provide the amount of poison control necessary to reach a certain value of K-INF as an output. The input of the model network would be connected to the control network, and the output of the control network could be connected to the model network. The control network would behave like an inverse controller.

RPM Models

The different models of RPM were chosen based on the following criteria: 1) the effect of all fuel assemblies, or the global interactions of the fuel assemblies on each other, which is represented by a fully connected network, and 2) the local changes that occur in the vicinity of a fuel assembly and the summation of those changes to measure the global effects on each fuel assembly at a certain location, which are represented by the next-door neighbor model and the patterned network. The different sizes of training data for each model are selected based on the ability of the network to converge. In model A, using 100 patterns for training is a difficult task, and the network may never converge.

For future work, the use of recurrent networks may increase the ability of the network to predict the relative power distribution below 5%. The inclusion of other assembly descriptors may also enhance the prediction capabilities of the RPM models. A model can be designed to relate the relative power distribution in a two-dimensional mesh point grid, where the grid consists of five assemblies, four neighbor assemblies surrounding an assembly in the middle. The input layer consists of four nodes, and the output layer consists of one node. The four nodes represent the four assembly relative powers next to the middle assembly, whose relative power is unknown. The network relates the relative power of the middle assembly to its four neighbor assemblies.

Expert System

The representation of knowledge as OBJECT-ATTRIBUTE-VALUE (O-A-V) has decreased the number of rules implemented, compared to the rules previously implemented in the Personal Consultant Plus Shell (PC Plus), in which the fuel shuffling rules were originally coded. This is a result of the use of the O-A-V representation by OPS5. In PC Plus, knowledge is represented by a frame structure, where a default value exists. The default value expresses the most probable value of a variable if the inference engine cannot obtain a value using the other methods present in the frame structure. This type of parameter fails to give a real-world representation of the knowledge.

The expert system can be extended to include other core constraints (e.g., power peaking constraints, batch size constraints, etc.). The interaction between the expert system and a neutronic code can be achieved. Burnable poison and control rod assemblies can be incorporated into the expert system. Since real-life applications have pre-designed locations for such assemblies, the implementation of these rules is more simple than the rules implemented earlier. The checkerboard rules need to be examined more closely. One method to model the logic of the checkerboard pattern is the use of a pre-specified K-INF value for each concentric region, suggested in Chapter IV.

Manual Shuffling

The objectives of the software are satisfied. The user can load a core at BOC or EOC. He or she can also evaluate a loaded core using the RPM code. The operator can test a loaded core with a neural network. Construction of a neural network is also possible using this software. The tool used to develop this software is inexpensive compared to other tools.

The help files can be incorporated in the software by using the Macro function capabilities. The set of computer programs written can be accommodated under the NEURAL NET submenu, and the user can construct testing and training files for a patterned network.

LIST OF REFERENCES

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APPENDICES

APPENDIX A

LEOPARD AND RPM DATA

TABLE A-1: TRAINING SET FOR LEOPARD MODEL A

INITIAL BURNUP GWD/MTU	BURNUP CHANGE GWD/MTU	SOLUBLE POISON PPM	BURNABLE POISON PPM	INITIAL K-inf	FINAL K-inf
0.00250	0.00250	0.00000	0.00000	1.29760	0.63364
0.00500	0.00250	0.00000	0.00000	1.26728	0.62797
0.00750	0.00250	0.00000	0.00000	1.25594	0.62661
0.01000	0.00010	0.00000	0.00000	1.25322	0.62598
0.01000	0.01000	0.00000	0.00000	1.25195	0.62598
0.02000	0.01500	0.00000	0.00000	1.25195	0.62412
0.03500	0.01500	0.00000	0.00000	1.24823	0.62192
0.05000	0.00010	0.00000	0.00000	1.24384	0.62038
0.05000	0.05000	0.00000	0.00000	1.24075	0.62038
0.10000	0.10000	0.00000	0.00000	1.24075	0.61690
0.20000	0.20000	0.00000	0.00000	1.23380	0.61012
0.40000	0.20000	0.00000	0.00000	1.22023	0.59535
0.60000	0.20000	0.00000	0.00000	1.19070	0.58063
0.80000	0.20000	0.00000	0.00000	1.16125	0.56677
1.00000	0.20000	0.00000	0.00000	1.13354	0.55382
1.20000	0.20000	0.00000	0.00000	1.10764	0.54174
1.40000	0.20000	0.00000	0.00000	1.08347	0.53041
1.60000	0.00010	0.00000	0.00000	1.06081	0.51972
1.60000	0.25000	0.00000	0.00000	1.03944	0.51972
0.00250	0.00250	0.50000	1.40900	1.10765	0.54767
0.00500	0.00250	0.49900	1.31700	1.09535	0.54766
0.00750	0.00250	0.49800	1.22600	1.09532	0.55073
0.01000	0.00001	0.49800	1.21600	1.10146	0.55087
0.01000	0.01000	0.49700	1.21600	1.10175	0.55087
0.02000	0.01500	0.49500	1.20600	1.10174	0.55025
0.03500	0.01500	0.49000	1.19600	1.10050	0.54946
0.05000	0.00001	0.48500	1.18600	1.09893	0.54911
0.05000	0.05000	0.48500	1.18600	1.09823	0.54911
0.10000	0.10000	0.46900	1.17600	1.09823	0.54807

TABLE A-1 (CONTINUED)

0.20000	0.20000	0.43600	1.06600	1.09614	0.55010
0.40000	0.20000	0.37400	1.05600	1.10021	0.54355
0.60000	0.20000	0.31500	0.93600	1.08711	0.54039
0.80000	0.20000	0.26100	0.71500	1.08078	0.54116
1.00000	0.20000	0.21200	0.50400	1.08232	0.54162
1.20000	0.24000	0.16900	0.31100	1.08325	0.54144
1.44000	0.20000	0.12600	0.19200	1.08289	0.53656
1.64000	0.20000	0.09600	0.09600	1.07313	0.53252
1.84000	0.00001	0.07200	0.03800	1.06505	0.53252

TABLE A-2: TRAINING SET FOR LEOPARD MODEL B

INITIAL BURNUP GWD/MTU	BURNUP CHANGE GWD/MTU	INITIAL K-inf	FINAL K-inf
0.00250	0.00250	1.29760	0.63364
0.00500	0.00250	1.26728	0.62797
0.00750	0.00250	1.25594	0.62661
0.01000	0.00010	1.25322	0.62598
0.01000	0.01000	1.25195	0.62598
0.02000	0.01500	1.25195	0.62412
0.03500	0.01500	1.24823	0.62192
0.05000	0.00010	1.24384	0.62038
0.05000	0.05000	1.24075	0.62038
0.10000	0.10000	1.24075	0.61690
0.20000	0.20000	1.23380	0.61012
0.40000	0.20000	1.22023	0.59535
0.60000	0.20000	1.19070	0.58063
0.80000	0.20000	1.16125	0.56677
1.00000	0.20000	1.13354	0.55382
1.20000	0.20000	1.10764	0.54174
1.40000	0.20000	1.08347	0.53041
1.60000	0.00010	1.06081	0.51972
1.60000	0.25000	1.03944	0.51972
0.00250	0.00250	1.10765	0.54767
0.00500	0.00250	1.09535	0.54766
0.00750	0.00250	1.09532	0.55073
0.01000	0.00001	1.10146	0.55087
0.01000	0.01000	1.10175	0.55087
0.02000	0.01500	1.10174	0.55025
0.03500	0.01500	1.10050	0.54946
0.05000	0.00001	1.09893	0.54911
0.05000	0.05000	1.09823	0.54911
0.10000	0.10000	1.09823	0.54807

TABLE A-2 (CONTINUED)

0.20000	0.20000	1.09614	0.55010
0.40000	0.20000	1.10021	0.54355
0.60000	0.20000	1.08711	0.54039
0.80000	0.20000	1.08078	0.54116
1.00000	0.20000	1.08232	0.54162
1.20000	0.24000	1.08325	0.54144
1.44000	0.20000	1.08289	0.53656
1.64000	0.20000	1.07313	0.53252
1.84000	0.00001	1.06505	0.53252

TABLE A-3: TRAINING SET FOR LEOPARD MODEL C

INITIAL BURNUP GWD/MTU	BURNUP CHANGE GWD/MTU	SOLUBLE POISON PPM	BURNABLE POISON PPM	INITIAL K-inf	FINAL K-inf
0.02500	0.02500	0.50000	1.40900	1.10765	0.54767
0.05000	0.02500	0.49900	1.31700	1.09535	0.54766
0.07500	0.02500	0.49800	1.22600	1.09532	0.55073
0.10000	0.00010	0.49800	1.21600	1.10146	0.55087
0.10000	0.10000	0.49700	1.21600	1.10175	0.55087
0.20000	0.15000	0.49500	1.20600	1.10174	0.55025
0.35000	0.15000	0.49000	1.19600	1.10050	0.54946
0.50000	0.00010	0.48500	1.18600	1.09893	0.54911
0.50000	0.50000	0.48500	1.18600	1.09823	0.54911
1.00000	1.00000	0.46900	1.17600	1.09823	0.54807
2.00000	2.00000	0.43600	1.06600	1.09614	0.55010
4.00000	2.00000	0.37400	1.05600	1.10021	0.54355
6.00000	2.00000	0.31500	0.93600	1.08711	0.54039
8.00000	2.00000	0.26100	0.71500	1.08078	0.54116
10.00000	2.00000	0.21200	0.50400	1.08232	0.54162
12.00000	2.40000	0.16900	0.31100	1.08325	0.54144
14.40000	2.00000	0.12600	0.19200	1.08289	0.53656
16.40000	2.00000	0.09600	0.09600	1.07313	0.53252
18.40000	0.00010	0.07200	0.03800	1.06505	0.53252

TABLE A-4: TRAINING SET FOR LEOPARD MODEL D

INITIAL BURNUP GWD/MTU	BURNUP CHANGE GWD/MTU	INITIAL K-inf	FINAL K-inf
0.00250	0.00250	1.29760	0.63364
0.00500	0.00250	1.26728	0.62797
0.00750	0.00250	1.25594	0.62661
0.01000	0.00010	1.25322	0.62598
0.01000	0.01000	1.25195	0.62598
0.02000	0.01500	1.25195	0.62412
0.03500	0.01500	1.24823	0.62192
0.05000	0.00010	1.24384	0.62038
0.05000	0.05000	1.24075	0.62038
0.10000	0.10000	1.24075	0.61690
0.20000	0.20000	1.23380	0.61012
0.40000	0.20000	1.22023	0.59535
0.60000	0.20000	1.19070	0.58063
0.80000	0.20000	1.16125	0.56677
1.00000	0.20000	1.13354	0.55382
1.20000	0.20000	1.10764	0.54174
1.40000	0.20000	1.08347	0.53041
1.60000	0.00010	1.06081	0.51972
1.60000	0.25000	1.03944	0.51972

TABLE A-5: TESTING SET (1) FOR LEOPARD MODEL A

INITIAL BURNUP GWD/MTU	BURNUP CHANGE GWD/MTU	SOLUBLE POISON PPM	BURNABLE POISON PPM	INITIAL K-inf
0.00250	0.00250	0.00000	0.00000	1.34661
0.00500	0.00250	0.00000	0.00000	1.31844
0.00750	0.00250	0.00000	0.00000	1.30621
0.01000	0.00010	0.00000	0.00000	1.30336
0.01000	0.01000	0.00000	0.00000	1.30217
0.02000	0.01500	0.00000	0.00000	1.30217
0.03500	0.01500	0.00000	0.00000	1.29876
0.05000	0.00010	0.00000	0.00000	1.29429
0.05000	0.05000	0.00000	0.00000	1.29081
0.10000	0.10000	0.00000	0.00000	1.29081
0.20000	0.20000	0.00000	0.00000	1.28317
0.40000	0.20000	0.00000	0.00000	1.27060
0.60000	0.20000	0.00000	0.00000	1.24454
0.80000	0.20000	0.00000	0.00000	1.21857
1.00000	0.20000	0.00000	0.00000	1.19393
1.20000	0.20000	0.00000	0.00000	1.17084
1.40000	0.20000	0.00000	0.00000	1.14920
1.60000	0.00010	0.00000	0.00000	1.12891

TABLE A-6: TESTING SET (2) FOR LEOPARD MODEL A

INITIAL BURNUP GWD/MTU	BURNUP CHANGE GWD/MTU	SOLUBLE POISON PPM	BURNABLE POISON PPM	INITIAL K-inf
0.00250	0.00250	0.60000	1.40900	0.99514
0.00500	0.00250	0.59900	1.31700	0.98530
0.00750	0.00250	0.59700	1.22600	0.98760
0.01000	0.00001	0.59500	1.21600	0.99491
0.01000	0.01000	0.59500	1.21600	0.99548
0.02000	0.01500	0.59200	1.20600	0.99548
0.03500	0.01500	0.58600	1.19600	0.99510
0.05000	0.00010	0.58000	1.18600	0.99500
0.05000	0.05000	0.58000	1.18600	0.99546
0.10000	0.10000	0.56000	1.17600	0.99546
0.20000	0.20000	0.52100	1.06600	0.99667
0.40000	0.20000	0.44700	1.05600	1.00494
0.60000	0.20000	0.37600	0.93600	0.99585
0.80000	0.20000	0.31200	0.71500	0.99315
1.00000	0.20000	0.25300	0.50400	0.99794
1.20000	0.24000	0.20200	0.31100	1.00180
1.44000	0.24000	0.15000	0.19200	1.00405
1.64000	0.24000	0.11400	0.09600	0.99633
1.84000	0.00001	0.08500	0.03800	0.98968

TABLE A-7: TESTING SET (1) FOR LEOPARD MODEL B

INITIAL BURNUP GWD/MTU	BURNUP CHANGE GWD/MTU	INITIAL K-inf
0.00250	0.00250	1.34661
0.00500	0.00250	1.31844
0.00750	0.00250	1.30621
0.01000	0.00010	1.30336
0.01000	0.01000	1.30217
0.02000	0.01500	1.30217
0.03500	0.01500	1.29876
0.05000	0.00010	1.29429
0.05000	0.05000	1.29081
0.10000	0.10000	1.29081
0.20000	0.20000	1.28317
0.40000	0.20000	1.27060
0.60000	0.20000	1.24454
0.80000	0.20000	1.21857
1.00000	0.20000	1.19393
1.20000	0.20000	1.17084
1.40000	0.20000	1.14920
1.60000	0.00010	1.12891

TABLE A-8: TESTING SET (2) FOR LEOPARD MODEL B

INITIAL BURNUP GWD/MTU	BURNUP CHANGE GWD/MTU	INITIAL K-inf
0.00250	0.00250	0.99514
0.00500	0.00250	0.98530
0.00750	0.00250	0.98760
0.01000	0.00001	0.99491
0.01000	0.01000	0.99548
0.02000	0.01500	0.99548
0.03500	0.01500	0.99510
0.05000	0.00010	0.99500
0.05000	0.05000	0.99546
0.10000	0.10000	0.99546
0.20000	0.20000	0.99667
0.40000	0.20000	1.00494
0.60000	0.20000	0.99585
0.80000	0.20000	0.99315
1.00000	0.20000	0.99794
1.20000	0.24000	1.00180
1.44000	0.24000	1.00405
1.64000	0.24000	0.99633
1.84000	0.00001	0.98968

TABLE A-9: TESTING SET FOR LEOPARD MODEL C

INITIAL BURNUP GWD/MTU	BURNUP CHANGE GWD/MTU	SOLUBLE POISON PPM	BURNABLE POISON PPM	INITIAL K-inf
0.02500	0.02500	0.60000	1.40900	0.99514
0.05000	0.02500	0.59900	1.31700	0.98530
0.07500	0.02500	0.59700	1.22600	0.98760
0.10000	0.00010	0.59500	1.21600	0.99491
0.10000	0.10000	0.59500	1.21600	0.99548
0.20000	0.15000	0.59200	1.20600	0.99548
0.35000	0.15000	0.58600	1.19600	0.99510
0.50000	0.00100	0.58000	1.18600	0.99500
0.50000	0.50000	0.58000	1.18600	0.99546
1.00000	1.00000	0.56000	1.17600	0.99546
2.00000	2.00000	0.52100	1.06600	0.99667
4.00000	2.00000	0.44700	1.05600	1.00494
6.00000	2.00000	0.37600	0.93600	0.99585
8.00000	2.00000	0.31200	0.71500	0.99315
10.00000	2.00000	0.25300	0.50400	0.99794
12.00000	2.40000	0.20200	0.31100	1.00180
14.40000	2.40000	0.15000	0.19200	1.00405
16.40000	2.40000	0.11400	0.09600	0.99633
18.40000	0.00010	0.08500	0.03800	0.98968

TABLE A-10: TESTING SET (1) FOR LEOPARD MODEL D

INITIAL BURNUP GWD/MTU	BURNUP CHANGE GWD/MTU	INITIAL K-inf
0.00250	0.00250	1.34661
0.00500	0.00250	1.31844
0.00750	0.00250	1.30621
0.01000	0.00010	1.30336
0.01000	0.01000	1.30217
0.02000	0.01500	1.30217
0.03500	0.01500	1.29876
0.05000	0.00010	1.29429
0.05000	0.05000	1.29081
0.10000	0.10000	1.29081
0.20000	0.20000	1.28317
0.40000	0.20000	1.27060
0.60000	0.20000	1.24454
0.80000	0.20000	1.21857
1.00000	0.20000	1.19393
1.20000	0.20000	1.17084
1.40000	0.20000	1.14920
1.60000	0.00010	1.12891

TABLE A-11: TESTING SET (2) FOR LEOPARD MODEL D

INITIAL BURNUP GWD/MTU	BURNUP CHANGE GWD/MTU	INITIAL K-inf
0.00140	0.00250	1.29760
0.00390	0.00500	1.27789
0.00890	0.00800	1.25865
0.01690	0.01000	1.24931
0.02690	0.01000	1.24599
0.03690	0.01000	1.24337
0.05190	0.01500	1.24043
0.06690	0.01500	1.23811
0.08690	0.02000	1.23541
0.13690	0.05000	1.22890
0.23690	0.10000	1.21492
0.34690	0.11000	1.19862
0.46690	0.12000	1.16111
0.60190	0.13500	1.13345
0.80190	0.20000	1.13218
0.81190	0.01000	1.12949
0.83190	0.02000	1.12481

TABLE A-12: TESTING SET (1) OUTPUT FOR LEOPARD MODEL A

Desired K-inf	Network Output	Error Difference	Relative Error	Percentage Error
0.659220	0.577830	0.081390	0.123464	12.346410
0.653105	0.577128	0.075977	0.116332	11.633200
0.651680	0.576822	0.074858	0.114869	11.486930
0.651085	0.576760	0.074325	0.114156	11.415560
0.651085	0.576691	0.074394	0.114262	11.426160
0.649380	0.576666	0.072714	0.111974	11.197450
0.647145	0.576569	0.070576	0.109057	10.905750
0.645405	0.576518	0.068887	0.106735	10.673450
0.645405	0.576164	0.069241	0.107283	10.728300
0.641585	0.575707	0.065878	0.102680	10.268010
0.635300	0.573998	0.061302	0.096493	9.649300
0.622270	0.571682	0.050588	0.081296	8.129590
0.609285	0.568212	0.041073	0.067412	6.741180
0.596965	0.564009	0.032956	0.055206	5.520592
0.585420	0.559120	0.026300	0.044925	4.492501
0.574600	0.553581	0.021019	0.036580	3.658023
0.564455	0.547448	0.017007	0.030130	3.012995
0.554875	0.553622	0.001253	0.002258	0.225817

TABLE A-13: TESTING SET (2) OUTPUT FOR LEOPARD MODEL A

Desired K-inf	Network Output	Error Difference	Relative Error	Percentage Error
0.497560	0.668523	-0.170960	-0.343600	-34.360300
0.492650	0.664191	-0.171540	-0.348200	-34.820100
0.493790	0.659137	-0.165350	-0.334850	-33.485300
0.497450	0.658246	-0.160800	-0.323240	-32.324100
0.497740	0.657928	-0.160190	-0.321830	-32.183100
0.497740	0.656980	-0.159240	-0.319930	-31.992600
0.497550	0.656042	-0.158490	-0.318540	-31.854500
0.497500	0.655530	-0.158030	-0.317650	-31.764800
0.497720	0.654086	-0.156370	-0.314160	-31.416500
0.497720	0.650880	-0.153160	-0.307720	-30.772300
0.498330	0.640287	-0.141960	-0.284870	-28.486500
0.502470	0.635949	-0.133480	-0.265650	-26.564600
0.497920	0.627732	-0.129810	-0.260710	-26.070900
0.496570	0.613679	-0.117110	-0.235840	-23.583600
0.498970	0.597044	-0.098070	-0.196550	-19.655300
0.500900	0.574750	-0.073850	-0.147430	-14.743500
0.502020	0.556626	-0.054610	-0.108770	-10.877300
0.498160	0.538506	-0.040350	-0.080990	-8.099000
0.494840	0.543666	-0.048830	-0.098670	-9.867030

TABLE A-14: TESTING SET (1) OUTPUT FOR LEOPARD MODEL B

Desired K-inf	Network Output	Error Difference	Relative Error	Percentage Error
0.659220	0.554138	0.105082	0.159404	15.940354
0.653105	0.553134	0.099971	0.153070	15.307033
0.651680	0.552706	0.098974	0.151875	15.187515
0.651085	0.552606	0.098479	0.151254	15.125368
0.651085	0.552725	0.098360	0.151071	15.107090
0.649380	0.553025	0.096355	0.148380	14.837999
0.647145	0.553205	0.093940	0.145161	14.516067
0.645405	0.553083	0.092322	0.143045	14.304506
0.645405	0.553811	0.091594	0.141917	14.191709
0.641585	0.555716	0.085869	0.133839	13.383885
0.635300	0.559103	0.076197	0.119939	11.993861
0.622270	0.561361	0.060909	0.097882	9.788195
0.609285	0.562031	0.047254	0.077556	7.755648
0.596965	0.561540	0.035425	0.059342	5.934184
0.585420	0.559802	0.025618	0.043760	4.376004
0.574600	0.556680	0.017920	0.031187	3.118691
0.564455	0.552035	0.012420	0.022004	2.200353
0.554875	0.541233	0.013642	0.024586	2.458572

TABLE A-15: TESTING SET (2) OUTPUT FOR LEOPARD MODEL B

Desired K-inf	Network Output	Error Difference	Relative Error	Percentage Error
0.497560	0.533354	-0.035794	-0.071939	-7.193906
0.492650	0.532573	-0.039923	-0.081037	-8.103725
0.493790	0.532893	-0.039103	-0.079190	-7.918953
0.497450	0.533618	-0.036168	-0.072707	-7.270680
0.497740	0.533832	-0.036092	-0.072512	-7.251175
0.497740	0.534335	-0.036595	-0.073522	-7.352232
0.497550	0.534917	-0.037367	-0.075102	-7.510200
0.497500	0.535270	-0.037770	-0.075920	-7.591960
0.497720	0.536080	-0.038360	-0.077071	-7.707145
0.497720	0.538594	-0.040874	-0.082122	-8.212248
0.498330	0.542793	-0.044463	-0.089224	-8.922401
0.502470	0.547217	-0.044747	-0.089054	-8.905407
0.497920	0.548382	-0.050462	-0.101346	-10.134560
0.496570	0.548295	-0.051725	-0.104165	-10.416457
0.498970	0.547204	-0.048234	-0.096667	-9.666713
0.500900	0.544749	-0.043849	-0.087540	-8.754043
0.502020	0.539461	-0.037441	-0.074581	-7.458069
0.498160	0.532436	-0.034276	-0.068805	-6.880520
0.494840	0.520805	-0.025965	-0.052472	-5.247151

TABLE A-16: TESTING SET OUTPUT FOR LEOPARD MODEL C

Desired K-inf	Network Output	Error Difference	Relative Error	Percentage Error
0.497560	0.510670	-0.013110	-0.026349	-2.634858
0.492650	0.511666	-0.019016	-0.038599	-3.859941
0.493790	0.512677	-0.018887	-0.038249	-3.824905
0.497450	0.513354	-0.015904	-0.031971	-3.197105
0.497740	0.513318	-0.015578	-0.031297	-3.129746
0.497740	0.515300	-0.017560	-0.035279	-3.527946
0.497550	0.517492	-0.019942	-0.040080	-4.008039
0.497500	0.519445	-0.021945	-0.044111	-4.411055
0.497720	0.518996	-0.021276	-0.042747	-4.274693
0.497720	0.520046	-0.022326	-0.044857	-4.485655
0.498330	0.518137	-0.019807	-0.039747	-3.974675
0.502470	0.515016	-0.012546	-0.024969	-2.496865
0.497920	0.514248	-0.016328	-0.032792	-3.279242
0.496570	0.514013	-0.017443	-0.035127	-3.512697
0.498970	0.513874	-0.014904	-0.029870	-2.986953
0.500900	0.513701	-0.012801	-0.025556	-2.555600
0.502020	0.513624	-0.011604	-0.023115	-2.311462
0.498160	0.513584	-0.015424	-0.030962	-3.096194
0.494840	0.513784	-0.018944	-0.038283	-3.828308

TABLE A-17: TESTING SET (1) OUTPUT FOR LEOPARD MODEL D

Desired K-inf	Network Output	, Error Difference	Relative Error	Percentage Error
0.610732	0.659220	-0.048490	-0.079390	-7.939000
0.609371	0.653105	-0.043730	-0.071770	-7.177000
0.608764	0.651680	-0.042920	-0.070500	-7.050000
0.608640	0.651085	-0.042450	-0.069740	-6.974000
0.608546	0.651085	-0.042540	-0.069900	-6.990000
0.608591	0.649380	-0.040790	-0.067020	-6.702000
0.608495	0.647145	-0.038650	-0.063520	-6.352000
0.608379	0.645405	-0.037030	-0.060860	-6.086000
0.608046	0.645405	-0.037360	-0.061440	-6.144000
0.608064	0.641585	-0.033520	-0.055130	-5.513000
0.607201	0.635300	-0.028100	-0.046280	-4.628000
0.604964	0.622270	-0.017310	-0.028610	-2.861000
0.599837	0.609285	-0.009450	-0.015750	-1.575000
0.592347	0.596965	-0.004620	-0.007800	-0.780000
0.582373	0.585420	-0.003050	-0.005230	-0.523000
0.569787	0.574600	-0.004810	-0.008450	-0.845000
0.554523	0.564455	-0.009930	-0.017910	-1.791000
0.534714	0.554875	-0.020160	-0.037700	-3.770000

TABLE A-18: TESTING SET (2) OUTPUT FOR LEOPARD MODEL D

Desired K-inf	Network Output	Error Difference	Relative Error	Percentage Error
0.638945	0.608276	0.030669	0.047999	4.799944
0.629325	0.607227	0.022098	0.035114	3.511381
0.624655	0.606179	0.018476	0.029578	2.957793
0.622995	0.605695	0.017300	0.027769	2.776908
0.621685	0.605575	0.016110	0.025913	2.591344
0.620215	0.605490	0.014725	0.023742	2.374177
0.619055	0.605391	0.013664	0.022072	2.207235
0.617705	0.605334	0.012371	0.020027	2.002736
0.614450	0.605244	0.009206	0.014983	1.498250
0.607460	0.604873	0.002587	0.004259	0.425872
0.599310	0.603682	-0.004372	-0.007295	-0.729506
0.580555	0.601833	-0.021278	-0.036651	-3.665114
0.566725	0.597685	-0.030960	-0.054630	-5.462967
0.566090	0.592691	-0.026601	-0.046991	-4.699076
0.564745	0.585615	-0.020870	-0.036955	-3.695473
0.562405	0.585845	-0.023440	-0.041678	-4.167815
0.556065	0.584682	-0.028617	-0.051463	-5.146341

TABLE A-19: TRAINING DATA FOR RPM MODEL A

(1.010101 1.020408 1.030928 1.408451 1.333333 1.351351
1.369863 1.388889 1.204819 1.234568 1.250000 1.265823 1.282051
1.298701 1.315789 1.041667 1.052632 1.063830 1.075269 1.086957
1.219512 1.092896 1.098901 1.104972 1.111111 1.123595 1.136364
1.149425 1.162791 1.176471 1.190476
0.436799 0.459392 0.508664 0.624076 0.650016 0.651084
0.613313 0.527501 0.491222 0.517460 0.566084 0.589838 0.590396
0.557387 0.485579 0.470998 0.466719 0.469822 0.465234 0.443732
0.408579 0.427973 0.411620 0.398808 0.379306 0.355260 0.384712
0.365862 0.346353 0.345178 0.328176)
(1.010101 1.030928 1.020408 1.408451 1.333333 1.351351
1.369863 1.388889 1.204819 1.234568 1.250000 1.265823 1.282051
1.298701 1.315789 1.041667 1.052632 1.063830 1.075269 1.086957
1.219512 1.092896 1.098901 1.104972 1.111111 1.123595 1.136364
1.149425 1.162791 1.176471 1.190476
0.438067 0.460748 0.506911 0.623456 0.649821 0.651278
0.613525 0.527759 0.491502 0.516932 0.565730 0.589838 0.590619
0.557627 0.485863 0.470557 0.466423 0.469822 0.465383 0.443889
0.408579 0.427973 0.411620 0.398981 0.379306 0.355260 0.384712
0.365862 0.346549 0.345178 0.328380)
(1.010101 1.030928 1.020408 1.190476 1.333333 1.351351
1.369863 1.388889 1.204819 1.234568 1.250000 1.265823 1.282051
1.298701 1.315789 1.041667 1.052632 1.063830 1.075269 1.086957
1.219512 1.092896 1.098901 1.104972 1.111111 1.123595 1.136364
1.149425 1.162791 1.176471 1.408451
0.422426 0.441695 0.474216 0.552668 0.633973 0.662286
0.636488 0.550840 0.471585 0.493597 0.536685 0.582972 0.601843
0.577951 0.505692 0.455910 0.455758 0.469233 0.474070 0.457276
0.421604 0.425045 0.414639 0.406540 0.388634 0.362482 0.390759
0.374382 0.355068 0.355834 0.342225)
(1.010101 1.030928 1.020408 1.190476 1.333333 1.219512
1.369863 1.388889 1.204819 1.234568 1.250000 1.265823 1.282051
1.298701 1.315789 1.041667 1.052632 1.063830 1.075269 1.086957
1.351351 1.092896 1.098901 1.104972 1.111111 1.123595 1.136364
1.149425 1.162791 1.176471 1.408451
0.430881 0.450557 0.480725 0.552790 0.618780 0.616895
0.621384 0.549739 0.481586 0.501744 0.539578 0.576802 0.585799
0.572639 0.510411 0.462548 0.459995 0.469675 0.472025 0.461499
0.442323 0.429591 0.418467 0.409764 0.393575 0.371437 0.395501
0.378761 0.359076 0.360215 0.345962)
(1.010101 1.030928 1.020408 1.190476 1.333333 1.219512
1.369863 1.388889 1.204819 1.234568 1.250000 1.162791 1.282051
1.298701 1.315789 1.041667 1.052632 1.063830 1.075269 1.086957
1.351351 1.092896 1.098901 1.104972 1.111111 1.123595 1.136364
1.149425 1.265823 1.176471 1.408451
0.431525 0.450249 0.477121 0.542078 0.601408 0.615319
0.631951 0.563244 0.480438 0.497483 0.526727 0.546666 0.581608
0.581267 0.522053 0.458940 0.454235 0.460597 0.472318 0.468643
0.451786 0.427648 0.418467 0.414137 0.401401 0.377306 0.400020
0.386856 0.372912 0.369030 0.355452)

TABLE A-19 (CONTINUED)

(1.010101 1.030928 1.020408 1.190476 1.333333 1.219512
1.369863 1.388889 1.204819 1.234568 1.250000 1.162791 1.123595
1.298701
1.315789 1.041667 1.052632 1.063830 1.075269 1.086957 1.351351
1.092896 1.098901 1.104972 1.111111 1.282051 1.136364 1.149425
1.265823 1.176471 1.408451
0.450711 0.470263 0.494015 0.551572 0.594945 0.590173
0.619824 0.560624 0.502837 0.516403 0.536432 0.536811 0.536053
0.566084 0.519697 0.473487 0.462997 0.459392 0.459543 0.464936
0.456214 0.435367 0.423246 0.415808 0.406710 0.394101 0.406540
0.393224 0.379306 0.376029 0.361917)
(1.010101 1.030928 1.020408 1.190476 1.333333 1.219512
1.176471 1.388889 1.204819 1.234568 1.250000 1.162791 1.123595
1.298701 1.315789 1.041667 1.052632 1.063830 1.075269 1.086957
1.351351 1.092896 1.098901 1.104972 1.111111 1.282051 1.136364
1.149425 1.265823 1.369863 1.408451
0.473487 0.494572 0.516139 0.568319 0.595606 0.559548
0.533772 0.505692 0.530328 0.541829 0.555094 0.541080 0.518382
0.522314 0.482874 0.494294 0.478855 0.467460 0.456062 0.449015
0.437751 0.450557 0.436481 0.425045 0.408070 0.388634 0.426023
0.417472 0.396025 0.423082 0.390228)
(1.010101 1.030928 1.020408 1.190476 1.149425 1.219512
1.176471 1.388889 1.204819 1.234568 1.250000 1.162791 1.123595
1.298701 1.315789 1.041667 1.052632 1.063830 1.075269 1.086957
1.351351 1.092896 1.098901 1.104972 1.111111 1.282051 1.136364
1.333333 1.265823 1.369863 1.408451
0.448706 0.466571 0.482159 0.516668 0.510813 0.517328
0.512151 0.492201 0.498586 0.508126 0.516139 0.498862 0.493458
0.507451 0.473779 0.470557 0.462248 0.458487 0.457276 0.451786
0.438701 0.454082 0.460597 0.463744 0.435526 0.399501 0.490099
0.516668 0.458638 0.522966 0.460898)
(1.010101 1.030928 1.020408 1.190476 1.149425 1.219512
1.176471 1.388889 1.204819 1.234568 1.086957 1.162791 1.123595
1.298701 1.315789 1.041667 1.052632 1.063830 1.075269 1.250000
1.351351 1.092896 1.098901 1.104972 1.111111 1.282051 1.136364
1.333333 1.265823 1.369863 1.408451
0.405005 0.417804 0.430075 0.459995 0.486430 0.522835
0.538574 0.522705 0.441066 0.447468 0.446071 0.474653 0.501880
0.540830 0.505964 0.426511 0.429106 0.449478 0.474508 0.505828
0.476107 0.438859 0.461048 0.478711 0.462548 0.423574 0.499275
0.533136 0.476397 0.540204 0.475381)
(1.010101 1.204819 1.020408 1.190476 1.149425 1.219512
1.176471 1.388889 1.030928 1.234568 1.086957 1.162791 1.123595
1.298701 1.315789 1.041667 1.052632 1.063830 1.075269 1.250000
1.351351 1.092896 1.098901 1.104972 1.111111 1.282051 1.136364
1.333333 1.265823 1.369863 1.408451
0.418633 0.431525 0.430075 0.458789 0.486147 0.523356
0.539452 0.523746 0.424228 0.441066 0.443889 0.474070 0.502291
0.541704 0.506911 0.422918 0.427648 0.449170 0.475090 0.506640
0.476832 0.438384 0.461348 0.479431 0.463296 0.424228 0.500099
0.534280 0.477411 0.541454 0.476397)

TABLE A-20: TRAINING DATA FOR NEXT-DOOR NEIGHBOR MODEL

```
(1.020408 1.020408 1.010101 1.020408 1.020408
1.204819 1.010101 1.020408 1.030928 1.204819
1.234568 1.020408 1.030928 1.408451 1.234568
1.250000 1.030928 1.408451 1.333333 1.250000
1.265823 1.408451 1.333333 1.351351 1.265823
1.282051 1.333333 1.351351 1.369863 1.282051
1.298701 1.351351 1.369863 1.388889 1.190476
1.315789 1.369863 1.388889 0.001000 1.315789
1.020408 1.020408 1.204819 1.234568 1.234568
1.030928 1.204819 1.234568 1.250000 1.041667
1.408451 1.234568 1.250000 1.265823 1.052632
1.333333 1.250000 1.265823 1.282051 1.063830
1.351351 1.265823 1.282051 1.298701 1.075269
1.369863 1.282051 1.298701 1.315789 1.086957
1.388889 1.298701 1.315789 0.001000 1.219512
1.234568 1.234568 1.041667 1.052632 1.052632
1.250000 1.041667 1.052632 1.063830 1.092896
1.265823 1.052632 1.063830 1.075269 1.098901
1.282051 1.063830 1.075269 1.086957 1.104972
1.298701 1.075269 1.086957 1.219512 1.111111
1.315789 1.086957 1.219512 0.001000 1.123595
1.052632 1.052632 1.092896 1.098901 1.098901
1.063830 1.092896 1.098901 1.104972 1.136364
1.075269 1.098901 1.104972 1.111111 1.149425
1.086957 1.104972 1.111111 1.123595 1.162791
1.219512 1.111111 1.123595 0.001000 0.001000
1.098901 1.098901 1.136364 1.149425 1.149425
1.104972 1.136364 1.149425 1.162791 1.176471
1.111111 1.149425 1.162791 0.001000 1.190476
1.149425 1.149425 1.176471 1.190476 0.001000
1.162791 1.176471 1.190476 0.001000 0.000000
0.436799 0.459392 0.508664 0.624076 0.650016 0.651084
0.613313 0.527501 0.491222 0.517460 0.566084 0.589838
0.590396 0.557387 0.485579 0.470998 0.466719 0.469822
0.465234 0.443732 0.408579 0.427973 0.411620 0.398808
0.379306 0.355260 0.384712 0.365862 0.346353 0.345178
0.328176)
(1.030928 1.030928 1.010101 1.030928 1.030928
1.204819 1.010101 1.030928 1.020408 1.204819
1.234568 1.030928 1.020408 1.408451 1.234568
1.250000 1.020408 1.408451 1.333333 1.250000
1.265823 1.408451 1.333333 1.351351 1.265823
1.282051 1.333333 1.351351 1.369863 1.282051
1.298701 1.351351 1.369863 1.388889 1.190476
1.315789 1.369863 1.388889 0.001000 1.315789
1.030928 1.030928 1.204819 1.234568 1.234568
1.020408 1.204819 1.234568 1.250000 1.041667
1.408451 1.234568 1.250000 1.265823 1.052632
1.333333 1.250000 1.265823 1.282051 1.063830
1.351351 1.265823 1.282051 1.298701 1.075269
1.369863 1.282051 1.298701 1.315789 1.086957
```

TABLE A-20 (CONTINUED)

```
1.388889 1.298701 1.315789 0.001000 1.219512
1.234568 1.234568 1.041667 1.052632 1.052632
1.250000 1.041667 1.052632 1.063830 1.092896
1.265823 1.052632 1.063830 1.075269 1.098901
1.282051 1.063830 1.075269 1.086957 1.104972
1.298701 1.075269 1.086957 1.219512 1.111111
1.315789 1.086957 1.219512 0.001000 1.123595
1.052632 1.052632 1.092896 1.098901 1.098901
1.063830 1.092896 1.098901 1.104972 1.136364
1.075269 1.098901 1.104972 1.111111 1.149425
1.086957 1.104972 1.111111 1.123595 1.162791
1.219512 1.111111 1.123595 0.001000 0.001000
1.098901 1.098901 1.136364 1.149425 1.149425
1.104972 1.136364 1.149425 1.162791 1.176471
1.111111 1.149425 1.162791 0.001000 1.190476
1.149425 1.149425 1.176471 1.190476 0.001000
1.162791 1.176471 1.190476 0.001000 1.298701
0.438067 0.460748 0.506911 0.623456 0.649821 0.651278
0.613525 0.527759 0.491502 0.516932 0.565730 0.589838
0.590619 0.557627 0.485863 0.470557 0.466423 0.469822
0.465383 0.443889 0.408579 0.427973 0.411620 0.398981
0.379306 0.355260 0.384712 0.365862 0.346549 0.345178
0.328380)
(1.030928 1.030928 1.010101 1.030928 1.030928
1.204819 1.010101 1.030928 1.020408 1.204819
1.234568 1.030928 1.020408 1.190476 1.234568
1.250000 1.020408 1.190476 1.333333 1.250000
1.265823 1.190476 1.333333 1.351351 1.265823
1.282051 1.333333 1.351351 1.369863 1.282051
1.298701 1.351351 1.369863 1.388889 1.408451
1.315789 1.369863 1.388889 0.001000 1.315789
1.030928 1.030928 1.204819 1.234568 1.234568
1.020408 1.204819 1.234568 1.250000 1.041667
1.190476 1.234568 1.250000 1.265823 1.052632
1.333333 1.250000 1.265823 1.282051 1.063830
1.351351 1.265823 1.282051 1.298701 1.075269
1.369863 1.282051 1.298701 1.315789 1.086957
1.388889 1.298701 1.315789 0.001000 1.219512
1.234568 1.234568 1.041667 1.052632 1.052632
1.250000 1.041667 1.052632 1.063830 1.092896
1.265823 1.052632 1.063830 1.075269 1.098901
1.282051 1.063830 1.075269 1.086957 1.104972
1.298701 1.075269 1.086957 1.219512 1.111111
1.315789 1.086957 1.219512 0.001000 1.123595
1.052632 1.052632 1.092896 1.098901 1.098901
1.063830 1.092896 1.098901 1.104972 1.136364
1.075269 1.098901 1.104972 1.111111 1.149425
1.086957 1.104972 1.111111 1.123595 1.162791
1.219512 1.111111 1.123595 0.001000 0.001000
```

1.098901 1.098901 1.136364 1.149425 1.149425
1.104972 1.136364 1.149425 1.162791 1.176471
1.111111 1.149425 1.162791 0.001000 1.408451
1.149425 1.149425 1.176471 1.408451 0.001000
1.162791 1.176471 1.408451 0.001000 1.298701
0.422426 0.441695 0.474216 0.552668 0.633973 0.662286
0.636488 0.550840 0.471585 0.493597 0.536685 0.582972
0.601843 0.577951 0.505692 0.455910 0.455758 0.469233
0.474070 0.457276 0.421604 0.425045 0.414639 0.406540
0.388634 0.362482 0.390759 0.374382 0.355068 0.355834
0.342225)
(1.030928 1.030928 1.010101 1.030928 1.030928
1.204819 1.010101 1.030928 1.020408 1.204819
1.234568 1.030928 1.020408 1.190476 1.234568
1.250000 1.020408 1.190476 1.333333 1.250000
1.265823 1.190476 1.333333 1.219512 1.265823
1.282051 1.333333 1.219512 1.369863 1.282051
1.298701 1.219512 1.369863 1.388889 1.408451
1.315789 1.369863 1.388889 0.001000 1.315789
1.030928 1.030928 1.204819 1.234568 1.234568
1.020408 1.204819 1.234568 1.250000 1.041667
1.190476 1.234568 1.250000 1.265823 1.052632
1.333333 1.250000 1.265823 1.282051 1.063830
1.219512 1.265823 1.282051 1.298701 1.075269
1.369863 1.282051 1.298701 1.315789 1.086957
1.388889 1.298701 1.315789 0.001000 1.351351
1.234568 1.234568 1.041667 1.052632 1.052632
1.250000 1.041667 1.052632 1.063830 1.092896
1.265823 1.052632 1.063830 1.075269 1.098901
1.282051 1.063830 1.075269 1.086957 1.104972
1.298701 1.075269 1.086957 1.351351 1.111111
1.315789 1.086957 1.351351 0.001000 1.123595
1.052632 1.052632 1.092896 1.098901 1.098901
1.063830 1.092896 1.098901 1.104972 1.136364
1.075269 1.098901 1.104972 1.111111 1.149425
1.086957 1.104972 1.111111 1.123595 1.162791
1.351351 1.111111 1.123595 0.001000 0.001000
1.098901 1.098901 1.136364 1.149425 1.149425
1.104972 1.136364 1.149425 1.162791 1.176471
1.111111 1.149425 1.162791 0.001000 1.408451
1.149425 1.149425 1.176471 1.408451 0.001000
1.162791 1.176471 1.408451 0.001000 1.298701
0.430881 0.450557 0.480725 0.552790 0.618780 0.616895
0.621384 0.549739 0.481586 0.501744 0.539578 0.576802
0.585799 0.572639 0.510411 0.462548 0.459995 0.469675
0.472025 0.461499 0.442323 0.429591 0.418467 0.409764
0.393575 0.371437 0.395501 0.378761 0.359076 0.360215
0.345962)
(1.030928 1.030928 1.010101 1.030928 1.030928

TABLE A-20 (CONTINUED)

1.204819 1.010101 1.030928 1.020408 1.204819
1.234568 1.030928 1.020408 1.190476 1.234568
1.250000 1.020408 1.190476 1.333333 1.250000
1.162791 1.190476 1.333333 1.219512 1.162791
1.282051 1.333333 1.219512 1.369863 1.282051
1.298701 1.219512 1.369863 1.388889 1.408451
1.315789 1.369863 1.388889 0.001000 1.315789
1.030928 1.030928 1.204819 1.234568 1.234568
1.020408 1.204819 1.234568 1.250000 1.041667
1.190476 1.234568 1.250000 1.162791 1.052632
1.333333 1.250000 1.162791 1.282051 1.063830
1.219512 1.162791 1.282051 1.298701 1.075269
1.369863 1.282051 1.298701 1.315789 1.086957
1.388889 1.298701 1.315789 0.001000 1.351351
1.234568 1.234568 1.041667 1.052632 1.052632
1.250000 1.041667 1.052632 1.063830 1.092896
1.162791 1.052632 1.063830 1.075269 1.098901
1.282051 1.063830 1.075269 1.086957 1.104972
1.298701 1.075269 1.086957 1.351351 1.111111
1.315789 1.086957 1.351351 0.001000 1.123595
1.052632 1.052632 1.092896 1.098901 1.098901
1.063830 1.092896 1.098901 1.104972 1.136364
1.075269 1.098901 1.104972 1.111111 1.149425
1.086957 1.104972 1.111111 1.123595 1.265823
1.351351 1.111111 1.123595 0.001000 0.001000
1.098901 1.098901 1.136364 1.149425 1.149425
1.104972 1.136364 1.149425 1.265823 1.176471
1.111111 1.149425 1.265823 0.001000 1.408451
1.149425 1.149425 1.176471 1.408451 0.001000
1.265823 1.176471 1.408451 0.001000 1.298701
0.431525 0.450249 0.477121 0.542078 0.601408 0.615319
0.631951 0.563244 0.480438 0.497483 0.526727 0.546666
0.581608 0.581267 0.522053 0.458940 0.454235 0.460597
0.472318 0.468643 0.451786 0.427648 0.418467 0.414137
0.401401 0.377306 0.400020 0.386856 0.372912 0.369030
0.355452)
(1.030928 1.030928 1.010101 1.030928 1.030928
1.204819 1.010101 1.030928 1.020408 1.204819
1.234568 1.030928 1.020408 1.190476 1.234568
1.250000 1.020408 1.190476 1.333333 1.250000
1.162791 1.190476 1.333333 1.219512 1.162791
1.123595 1.333333 1.219512 1.369863 1.123595
1.298701 1.219512 1.369863 1.388889 1.408451
1.315789 1.369863 1.388889 0.001000 1.315789
1.030928 1.030928 1.204819 1.234568 1.234568
1.020408 1.204819 1.234568 1.250000 1.041667
1.190476 1.234568 1.250000 1.162791 1.052632
1.333333 1.250000 1.162791 1.123595 1.063830
1.219512 1.162791 1.123595 1.298701 1.075269

TABLE A-20 (CONTINUED)

1.063830 1.092896 1.098901 1.104972 1.136364
1.075269 1.098901 1.104972 1.111111 1.149425
1.086957 1.104972 1.111111 1.282051 1.265823
1.351351 1.111111 1.282051 0.001000 0.001000
1.098901 1.098901 1.136364 1.149425 1.149425
1.104972 1.136364 1.149425 1.265823 1.176471
1.111111 1.149425 1.265823 0.001000 1.408451
1.149425 1.149425 1.176471 1.408451 0.001000
1.265823 1.176471 1.408451 0.001000 1.298701
0.450711 0.470263 0.494015 0.551572 0.594945 0.590173
0.619824 0.560624 0.502837 0.516403 0.536432 0.536811
0.536053 0.566084 0.519697 0.473487 0.462997 0.459392
0.459543 0.464936 0.456214 0.435367 0.423246 0.415808
0.406710 0.394101 0.406540 0.393224 0.379306 0.376029
0.361917)
(1.030928 1.030928 1.010101 1.030928 1.030928
1.204819 1.010101 1.030928 1.020408 1.204819
1.234568 1.030928 1.020408 1.190476 1.234568
1.250000 1.020408 1.190476 1.333333 1.250000
1.162791 1.190476 1.333333 1.219512 1.162791
1.123595 1.333333 1.219512 1.176471 1.123595
1.298701 1.219512 1.176471 1.388889 1.408451
1.315789 1.176471 1.388889 0.001000 1.315789
1.030928 1.030928 1.204819 1.234568 1.234568
1.020408 1.204819 1.234568 1.250000 1.041667
1.190476 1.234568 1.250000 1.162791 1.052632
1.333333 1.250000 1.162791 1.123595 1.063830
1.219512 1.162791 1.123595 1.298701 1.075269
1.176471 1.123595 1.298701 1.315789 1.086957
1.388889 1.298701 1.315789 0.001000 1.351351
1.234568 1.234568 1.041667 1.052632 1.052632
1.250000 1.041667 1.052632 1.063830 1.092896
1.162791 1.052632 1.063830 1.075269 1.098901
1.123595 1.063830 1.075269 1.086957 1.104972
1.298701 1.075269 1.086957 1.351351 1.111111
1.315789 1.086957 1.351351 0.001000 1.282051
1.052632 1.052632 1.092896 1.098901 1.098901
1.063830 1.092896 1.098901 1.104972 1.136364
1.075269 1.098901 1.104972 1.111111 1.149425
1.086957 1.104972 1.111111 1.282051 1.265823
1.351351 1.111111 1.282051 0.001000 0.001000
1.098901 1.098901 1.136364 1.149425 1.149425
1.104972 1.136364 1.149425 1.265823 1.369863
1.111111 1.149425 1.265823 0.001000 1.408451
1.149425 1.149425 1.369863 1.408451 0.001000
1.265823 1.369863 1.408451 0.001000 1.298701
0.473487 0.494572 0.516139 0.568319 0.595606 0.559548
0.533772 0.505692 0.530328 0.541829 0.555094 0.541080
0.518382 0.522314 0.482874 0.494294 0.478855 0.467460

TABLE A-20 (CONTINUED)

```
0.456062 0.449015 0.437751 0.450557 0.436481 0.425045
0.408070 0.388634 0.426023 0.417472 0.396025 0.423082
0.390228)
(1.030928 1.030928 1.010101 1.030928 1.030928
1.204819 1.010101 1.030928 1.020408 1.204819
1.234568 1.030928 1.020408 1.190476 1.234568
1.250000 1.020408 1.190476 1.149425 1.250000
1.162791 1.190476 1.149425 1.219512 1.162791
1.123595 1.149425 1.219512 1.176471 1.123595
1.298701 1.219512 1.176471 1.388889 1.408451
1.315789 1.176471 1.388889 0.001000 1.315789
1.030928 1.030928 1.204819 1.234568 1.234568
1.020408 1.204819 1.234568 1.250000 1.041667
1.190476 1.234568 1.250000 1.162791 1.052632
1.149425 1.250000 1.162791 1.123595 1.063830
1.219512 1.162791 1.123595 1.298701 1.075269
1.176471 1.123595 1.298701 1.315789 1.086957
1.388889 1.298701 1.315789 0.001000 1.351351
1.234568 1.234568 1.041667 1.052632 1.052632
1.250000 1.041667 1.052632 1.063830 1.092896
1.162791 1.052632 1.063830 1.075269 1.098901
1.123595 1.063830 1.075269 1.086957 1.104972
1.298701 1.075269 1.086957 1.351351 1.111111
1.315789 1.086957 1.351351 0.001000 1.282051
1.052632 1.052632 1.092896 1.098901 1.098901
1.063830 1.092896 1.098901 1.104972 1.136364
1.075269 1.098901 1.104972 1.111111 1.333333
1.086957 1.104972 1.111111 1.282051 1.265823
1.351351 1.111111 1.282051 0.001000 0.001000
1.098901 1.098901 1.136364 1.333333 1.333333
1.104972 1.136364 1.333333 1.265823 1.369863
1.111111 1.333333 1.265823 0.001000 1.408451
1.333333 1.333333 1.369863 1.408451 0.001000
1.265823 1.369863 1.408451 0.001000 1.298701
0.448706 0.466571 0.482159 0.516668 0.510813 0.517328
0.512151 0.492201 0.498586 0.508126 0.516139 0.498862
0.493458 0.507451 0.473779 0.470557 0.462248 0.458487
0.457276 0.451786 0.438701 0.454082 0.460597 0.463744
0.435526 0.399501 0.490099 0.516668 0.458638 0.522966
0.460898)
(1.030928 1.030928 1.010101 1.030928 1.030928
1.204819 1.010101 1.030928 1.020408 1.204819
1.234568 1.030928 1.020408 1.190476 1.234568
1.086957 1.020408 1.190476 1.149425 1.086957
1.162791 1.190476 1.149425 1.219512 1.162791
1.123595 1.149425 1.219512 1.176471 1.123595
1.298701 1.219512 1.176471 1.388889 1.408451
1.315789 1.176471 1.388889 0.001000 1.315789
1.030928 1.030928 1.204819 1.234568 1.234568
```

TABLE A-20 (CONTINUED)

```
1.020408 1.204819 1.234568 1.086957 1.041667
1.190476 1.234568 1.086957 1.162791 1.052632
1.149425 1.086957 1.162791 1.123595 1.063830
1.219512 1.162791 1.123595 1.298701 1.075269
1.176471 1.123595 1.298701 1.315789 1.250000
1.388889 1.298701 1.315789 0.001000 1.351351 1.234568
1.234568 1.041667 1.052632 1.052632
1.086957 1.041667 1.052632 1.063830 1.092896
1.162791 1.052632 1.063830 1.075269 1.098901
1.123595 1.063830 1.075269 1.250000 1.104972
1.298701 1.075269 1.250000 1.351351 1.111111
1.315789 1.250000 1.351351 0.001000 1.282051
1.052632 1.052632 1.092896 1.098901 1.098901
1.063830 1.092896 1.098901 1.104972 1.136364
1.075269 1.098901 1.104972 1.111111 1.333333
1.250000 1.104972 1.111111 1.282051 1.265823
1.351351 1.111111 1.282051 0.001000 0.001000
1.098901 1.098901 1.136364 1.333333 1.333333
1.104972 1.136364 1.333333 1.265823 1.369863
1.111111 1.333333 1.265823 0.001000 1.408451
1.333333 1.333333 1.369863 1.408451 0.001000
1.265823 1.369863 1.408451 0.001000 1.298701
0.405005 0.417804 0.430075 0.459995 0.486430 0.522835
0.538574 0.522705 0.441066 0.447468 0.446071 0.474653
0.501880 0.540830 0.505964 0.426511 0.429106 0.449478
0.474508 0.505828 0.476107 0.438859 0.461048 0.478711
0.462548 0.423574 0.499275 0.533136 0.476397 0.540204
0.475381)
(1.204819 1.204819 1.010101 1.204819 1.204819
1.030928 1.010101 1.204819 1.020408 1.030928
1.234568 1.204819 1.020408 1.190476 1.234568
1.086957 1.020408 1.190476 1.149425 1.086957
1.162791 1.190476 1.149425 1.219512 1.162791
1.123595 1.149425 1.219512 1.176471 1.123595
1.298701 1.219512 1.176471 1.388889 1.408451
1.315789 1.176471 1.388889 0.001000 1.315789
1.204819 1.204819 1.030928 1.234568 1.234568
1.020408 1.030928 1.234568 1.086957 1.041667
1.190476 1.234568 1.086957 1.162791 1.052632
1.149425 1.086957 1.162791 1.123595 1.063830
1.219512 1.162791 1.123595 1.298701 1.075269
1.176471 1.123595 1.298701 1.315789 1.250000
1.388889 1.298701 1.315789 0.001000 1.351351
1.234568 1.234568 1.041667 1.052632 1.052632
1.086957 1.041667 1.052632 1.063830 1.092896
1.162791 1.052632 1.063830 1.075269 1.098901
1.123595 1.063830 1.075269 1.250000 1.104972
1.298701 1.075269 1.250000 1.351351 1.111111
1.315789 1.250000 1.351351 0.001000 1.282051
```

TABLE A-20 (CONTINUED)

```
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        1.063830 1.092896 1.098901 1.104972 1.136364
        1.075269 1.098901 1.104972 1.111111 1.333333
        1.250000 1.104972 1.111111 1.282051 1.265823
        1.351351 1.111111 1.282051 0.001000 0.001000
        1.098901 1.098901 1.136364 1.333333 1.333333
        1.104972 1.136364 1.333333 1.265823 1.369863
        1.111111 1.333333 1.265823 0.001000 1.408451
        1.333333 1.333333 1.369863 1.408451 0.001000
        1.265823 1.369863 1.408451 0.001000 1.298701
0.418633 0.431525 0.430075 0.458789 0.486147 0.523356 0.539452
0.523746 0.424228 0.441066 0.443889 0.474070 0.502291 0.541704
0.506911 0.422918 0.427648 0.449170 0.475090 0.506640 0.476832
0.438384 0.461348 0.479431 0.463296 0.424228 0.500099 0.534280
0.477411 0.541454 0.476397)
```

TABLE A-21: TESTING DATA FOR RPM MODEL A

(1.010101 1.020408 1.030928 1.052632 1.104972 1.351351
1.369863 1.388889 1.063830 1.234568 1.250000 1.265823 1.282051
1.298701 1.315789 1.041667 1.408451 1.204819 1.075269 1.086957
1.219512 1.092896 1.098901 1.333333 1.111111 1.123595 1.136364
1.149425 1.162791 1.176471 1.190476)
(1.010101 1.020408 1.030928 1.052632 1.104972 1.351351
1.369863 1.388889 1.063830 1.234568 1.250000 1.086957 1.282051
1.298701 1.315789 1.041667 1.408451 1.204819 1.075269 1.265823
1.219512 1.092896 1.098901 1.333333 1.111111 1.123595 1.136364
1.149425 1.162791 1.176471 1.190476)
(1.010101 1.020408 1.030928 1.052632 1.104972 1.351351
1.369863 1.388889 1.063830 1.234568 1.250000 1.086957 1.041667
1.298701 1.315789 1.282051 1.408451 1.204819 1.075269 1.265823
1.219512 1.092896 1.098901 1.333333 1.111111 1.123595 1.136364
1.149425 1.162791 1.176471 1.190476)
(1.020408 1.010101 1.030928 1.052632 1.104972 1.351351
1.369863 1.388889 1.063830 1.234568 1.250000 1.086957 1.041667
1.298701 1.315789 1.282051 1.408451 1.204819 1.075269 1.265823
1.219512 1.092896 1.098901 1.333333 1.111111 1.123595 1.136364
1.149425 1.162791 1.176471 1.190476)
(1.030928 1.010101 1.020408 1.052632 1.104972 1.351351
1.369863 1.388889 1.063830 1.234568 1.250000 1.086957 1.041667
1.298701 1.315789 1.282051 1.408451 1.204819 1.075269 1.265823
1.219512 1.092896 1.098901 1.333333 1.111111 1.123595 1.136364
1.149425 1.162791 1.176471 1.190476)
(1.010101 1.030928 1.020408 1.052632 1.104972 1.351351
1.369863 1.388889 1.063830 1.234568 1.250000 1.086957 1.041667
1.298701 1.315789 1.282051 1.408451 1.204819 1.075269 1.265823
1.219512 1.092896 1.098901 1.333333 1.111111 1.123595 1.136364
1.149425 1.162791 1.176471 1.190476)
(1.010101 1.030928 1.020408 1.234568 1.104972 1.351351
1.369863 1.388889 1.063830 1.052632 1.250000 1.086957 1.041667
1.298701 1.315789 1.282051 1.408451 1.204819 1.075269 1.265823
1.219512 1.092896 1.098901 1.333333 1.111111 1.123595 1.136364
1.149425 1.162791 1.176471 1.190476)
(1.010101 1.030928 1.020408 1.234568 1.104972 1.351351
1.369863 1.388889 1.063830 1.052632 1.250000 1.086957 1.041667
1.298701 1.315789 1.282051 1.408451 1.204819 1.075269 1.123595
1.219512 1.092896 1.098901 1.333333 1.111111 1.265823 1.136364
1.149425 1.162791 1.176471 1.190476)
(1.010101 1.030928 1.020408 1.234568 1.104972 1.351351
1.369863 1.388889 1.063830 1.052632 1.250000 1.086957 1.041667
1.298701 1.315789 1.282051 1.176471 1.204819 1.075269 1.123595
1.219512 1.092896 1.098901 1.333333 1.111111 1.265823 1.136364
1.149425 1.162791 1.408451 1.190476)
(1.010101 1.030928 1.020408 1.234568 1.104972 1.351351
1.369863 1.388889 1.063830 1.052632 1.250000 1.086957 1.041667
1.298701 1.092896 1.282051 1.176471 1.204819 1.075269 1.123595
1.219512 1.315789 1.098901 1.333333 1.111111 1.265823 1.136364
1.149425 1.162791 1.408451 1.190476)

TABLE A-22: TESTING SET FOR RPM NEXT-DOOR NEIGHBOR MODEL

(1.010101 1.010101 1.020408 1.010101 1.010101
1.204819 1.020408 1.010101 1.123595 1.204819
1.234568 1.010101 1.123595 1.298701 1.234568
1.250000 1.123595 1.298701 1.333333 1.250000
1.265823 1.298701 1.333333 1.092896 1.265823
1.369863 1.333333 1.092896 1.052632 1.369863
1.030928 1.092896 1.052632 1.388889 1.190476
1.315789 1.052632 1.388889 0.001000 1.315789
1.010101 1.010101 1.204819 1.234568 1.234568
1.123595 1.204819 1.234568 1.250000 1.075269
1.298701 1.234568 1.250000 1.265823 1.282051
1.333333 1.250000 1.265823 1.369863 1.149425
1.092896 1.265823 1.369863 1.030928 1.041667
1.052632 1.369863 1.030928 1.315789 1.104972
1.388889 1.030928 1.315789 0.001000 1.408451
1.234568 1.234568 1.075269 1.282051 1.282051
1.250000 1.075269 1.282051 1.149425 1.111111
1.265823 1.282051 1.149425 1.041667 1.098901
1.369863 1.149425 1.041667 1.104972 1.063830
1.030928 1.041667 1.104972 1.408451 1.219512
1.315789 1.104972 1.408451 0.001000 1.351351
1.282051 1.282051 1.111111 1.098901 1.098901
1.149425 1.111111 1.098901 1.063830 1.136364
1.041667 1.098901 1.063830 1.219512 1.086957
1.104972 1.063830 1.219512 1.351351 1.162791
1.408451 1.219512 1.351351 0.001000 0.001000
1.098901 1.098901 1.136364 1.086957 1.086957
1.063830 1.136364 1.086957 1.162791 1.176471
1.219512 1.086957 1.162791 0.001000 1.190476
1.086957 1.086957 1.176471 1.190476 0.001000
1.162791 1.176471 1.190476 0.001000 1.030928)

(1.010101 1.010101 1.020408 1.010101 1.010101
1.204819 1.020408 1.010101 1.123595 1.204819
1.234568 1.010101 1.123595 1.298701 1.234568
1.250000 1.123595 1.298701 1.162791 1.250000
1.265823 1.298701 1.162791 1.092896 1.265823
1.369863 1.162791 1.092896 1.052632 1.369863
1.030928 1.092896 1.052632 1.388889 1.190476
1.315789 1.052632 1.388889 0.001000 1.315789
1.010101 1.010101 1.204819 1.234568 1.234568
1.123595 1.204819 1.234568 1.250000 1.075269
1.298701 1.234568 1.250000 1.265823 1.282051

TABLE A-22 (CONTINUED)

1.162791	1.250000	1.265823	1.369863	1.149425
1.092896	1.265823	1.369863	1.030928	1.041667
1.052632	1.369863	1.030928	1.315789	1.104972
1.388889	1.030928	1.315789	0.001000	1.408451
1.234568	1.234568	1.075269	1.282051	1.282051
1.250000	1.075269	1.282051	1.149425	1.111111
1.265823	1.282051	1.149425	1.041667	1.098901
1.369863	1.149425	1.041667	1.104972	1.063830
1.030928	1.041667	1.104972	1.408451	1.219512
1.315789	1.104972	1.408451	0.001000	1.351351
1.282051	1.282051	1.111111	1.098901	1.098901
1.149425	1.111111	1.098901	1.063830	1.136364
1.041667	1.098901	1.063830	1.219512	1.086957
1.104972	1.063830	1.219512	1.351351	1.333333
1.408451	1.219512	1.351351	0.001000	0.001000
1.098901	1.098901	1.136364	1.086957	1.086957
1.063830	1.136364	1.086957	1.333333	1.176471
1.219512	1.086957	1.333333	0.001000	1.190476
1.086957	1.086957	1.176471	1.190476	0.001000
1.333333	1.176471	1.190476	0.001000	1.030928)

(1.010101	1.010101	1.020408	1.010101	1.010101
1.204819	1.020408	1.010101	1.123595	1.204819
1.234568	1.010101	1.123595	1.190476	1.234568
1.250000	1.123595	1.190476	1.162791	1.250000
1.265823	1.190476	1.162791	1.092896	1.265823
1.369863	1.162791	1.092896	1.052632	1.369863
1.030928	1.092896	1.052632	1.388889	1.298701
1.315789	1.052632	1.388889	0.001000	1.315789
1.010101	1.010101	1.204819	1.234568	1.234568
1.123595	1.204819	1.234568	1.250000	1.075269
1.190476	1.234568	1.250000	1.265823	1.282051
1.162791	1.250000	1.265823	1.369863	1.149425
1.092896	1.265823	1.369863	1.030928	1.041667
1.052632	1.369863	1.030928	1.315789	1.104972
1.388889	1.030928	1.315789	0.001000	1.408451
1.234568	1.234568	1.075269	1.282051	1.282051
1.250000	1.075269	1.282051	1.149425	1.111111
1.265823	1.282051	1.149425	1.041667	1.098901
1.369863	1.149425	1.041667	1.104972	1.063830
1.030928	1.041667	1.104972	1.408451	1.219512
1.315789	1.104972	1.408451	0.001000	1.351351

TABLE A-22 (CONTINUED)

1.282051 1.282051 1.111111 1.098901 1.098901
1.149425 1.111111 1.098901 1.063830 1.136364
1.041667 1.098901 1.063830 1.219512 1.086957
1.104972 1.063830 1.219512 1.351351 1.333333
1.408451 1.219512 1.351351 0.001000 0.001000
1.098901 1.098901 1.136364 1.086957 1.086957
1.063830 1.136364 1.086957 1.333333 1.176471
1.219512 1.086957 1.333333 0.001000 1.298701
1.086957 1.086957 1.176471 1.298701 0.001000
1.333333 1.176471 1.298701 0.001000 1.030928)

(1.010101 1.010101 1.020408 1.010101 1.010101
1.204819 1.020408 1.010101 1.123595 1.204819
1.234568 1.010101 1.123595 1.190476 1.234568
1.250000 1.123595 1.190476 1.162791 1.250000
1.265823 1.190476 1.162791 1.092896 1.265823
1.176471 1.162791 1.092896 1.052632 1.176471
1.030928 1.092896 1.052632 1.388889 1.298701
1.315789 1.052632 1.388889 0.001000 1.315789
1.010101 1.010101 1.204819 1.234568 1.234568
1.123595 1.204819 1.234568 1.250000 1.075269
1.190476 1.234568 1.250000 1.265823 1.282051
1.162791 1.250000 1.265823 1.176471 1.149425
1.092896 1.265823 1.176471 1.030928 1.041667
1.052632 1.176471 1.030928 1.315789 1.104972
1.388889 1.030928 1.315789 0.001000 1.408451
1.234568 1.234568 1.075269 1.282051 1.282051
1.250000 1.075269 1.282051 1.149425 1.111111
1.265823 1.282051 1.149425 1.041667 1.098901
1.176471 1.149425 1.041667 1.104972 1.063830
1.030928 1.041667 1.104972 1.408451 1.219512
1.315789 1.104972 1.408451 0.001000 1.351351
1.282051 1.282051 1.111111 1.098901 1.098901
1.149425 1.111111 1.098901 1.063830 1.136364
1.041667 1.098901 1.063830 1.219512 1.086957
1.104972 1.063830 1.219512 1.351351 1.333333
1.408451 1.219512 1.351351 0.001000 0.001000
1.098901 1.098901 1.136364 1.086957 1.086957
1.063830 1.136364 1.086957 1.333333 1.369863
1.219512 1.086957 1.333333 0.001000 1.298701
1.086957 1.086957 1.369863 1.298701 0.001000
1.333333 1.369863 1.298701 0.001000 1.030928)

TABLE A-22 (CONTINUED)

(1.010101	1.010101	1.020408	1.010101	1.010101
1.204819	1.020408	1.010101	1.123595	1.204819
1.234568	1.010101	1.123595	1.190476	1.234568
1.250000	1.123595	1.190476	1.162791	1.250000
1.111111	1.190476	1.162791	1.092896	1.111111
1.176471	1.162791	1.092896	1.052632	1.176471
1.030928	1.092896	1.052632	1.388889	1.298701
1.315789	1.052632	1.388889	0.001000	1.315789
1.010101	1.010101	1.204819	1.234568	1.234568
1.123595	1.204819	1.234568	1.250000	1.075269
1.190476	1.234568	1.250000	1.111111	1.282051
1.162791	1.250000	1.111111	1.176471	1.149425
1.092896	1.111111	1.176471	1.030928	1.041667
1.052632	1.176471	1.030928	1.315789	1.104972
1.388889	1.030928	1.315789	0.001000	1.408451
1.234568	1.234568	1.075269	1.282051	1.282051
1.250000	1.075269	1.282051	1.149425	1.265823
1.111111	1.282051	1.149425	1.041667	1.098901
1.176471	1.149425	1.041667	1.104972	1.063830
1.030928	1.041667	1.104972	1.408451	1.219512
1.315789	1.104972	1.408451	0.001000	1.351351
1.282051	1.282051	1.265823	1.098901	1.098901
1.149425	1.265823	1.098901	1.063830	1.136364
1.041667	1.098901	1.063830	1.219512	1.086957
1.104972	1.063830	1.219512	1.351351	1.333333
1.408451	1.219512	1.351351	0.001000	0.001000
1.098901	1.098901	1.136364	1.086957	1.086957
1.063830	1.136364	1.086957	1.333333	1.369863
1.219512	1.086957	1.333333	0.001000	1.298701
1.086957	1.086957	1.369863	1.298701	0.001000
1.333333	1.369863	1.298701	0.001000	1.030928)

TABLE A-23: TESTING DATA FOR PATTERNED NETWORK MODEL

(1.063830 1.020408 1.063830 1.234568 1.250000 1.265823
1.282051 1.298701 1.315789 0.000000
1.020408 1.010101 1.020408 1.030928 1.052632 1.104972 1.351351
1.369863 1.388889 0.000000
1.063830 1.020408 1.063830 1.234568 1.250000 1.265823 1.282051
1.298701 1.315789 0.000000
1.234568 1.030928 1.234568 1.041667 1.408451 1.204819 1.075269
1.086957 1.219512 0.000000
1.250000 1.052632 1.250000 1.408451 1.092896 1.098901 1.333333
1.111111 1.123595 0.000000
1.265823 1.104972 1.265823 1.204819 1.098901 1.136364 1.149425
1.162791 0.000000 0.000000
1.282051 1.351351 1.282051 1.075269 1.333333 1.149425 1.176471
1.190476 0.000000 0.000000
1.298701 1.369863 1.298701 1.086957 1.111111 1.162791 1.190476
0.000000 0.000000 0.000000
1.315789 1.388889 1.315789 1.219512 1.123595 0.000000 0.000000
0.000000 0.000000 0.000000)

(1.063830 1.020408 1.063830 1.234568 1.250000 1.086957
1.282051 1.298701 1.315789 0.000000
1.020408 1.010101 1.020408 1.030928 1.052632 1.104972 1.351351
1.369863 1.388889 0.000000
1.063830 1.020408 1.063830 1.234568 1.250000 1.086957 1.282051
1.298701 1.315789 0.000000
1.234568 1.030928 1.234568 1.041667 1.408451 1.204819 1.075269
1.265823 1.219512 0.000000
1.250000 1.052632 1.250000 1.408451 1.092896 1.098901 1.333333
1.111111 1.123595 0.000000
1.086957 1.104972 1.086957 1.204819 1.098901 1.136364 1.149425
1.162791 0.000000 0.000000
1.282051 1.351351 1.282051 1.075269 1.333333 1.149425 1.176471
1.190476 0.000000 0.000000
1.298701 1.369863 1.298701 1.265823 1.111111 1.162791 1.190476
0.000000 0.000000 0.000000
1.315789 1.388889 1.315789 1.219512 1.123595 0.000000 0.000000
0.000000 0.000000 0.000000)

(1.063830 1.020408 1.063830 1.234568 1.250000 1.086957
1.041667 1.298701 1.315789 0.000000
1.020408 1.010101 1.020408 1.030928 1.052632 1.104972 1.351351
1.369863 1.388889 0.000000
1.063830 1.020408 1.063830 1.234568 1.250000 1.086957 1.041667
1.298701 1.315789 0.000000
1.234568 1.030928 1.234568 1.282051 1.408451 1.204819 1.075269
1.265823 1.219512 0.000000
1.250000 1.052632 1.250000 1.408451 1.092896 1.098901 1.333333
1.111111 1.123595 0.000000
1.086957 1.104972 1.086957 1.204819 1.098901 1.136364 1.149425
1.162791 0.000000 0.000000
1.041667 1.351351 1.041667 1.075269 1.333333 1.149425 1.176471

TABLE A-23 (CONTINUED)

1.190476 0.000000 0.000000
1.298701 1.369863 1.298701 1.265823 1.111111 1.162791 1.190476
0.000000 0.000000 0.000000
1.315789 1.388889 1.315789 1.219512 1.123595 0.000000 0.000000
0.000000 0.000000 0.000000)

(1.063830 1.010101 1.063830 1.234568 1.250000 1.086957
1.041667 1.298701 1.315789 0.000000
1.010101 1.020408 1.010101 1.030928 1.052632 1.104972 1.351351
1.369863 1.388889 0.000000
1.063830 1.010101 1.063830 1.234568 1.250000 1.086957 1.041667
1.298701 1.315789 0.000000
1.234568 1.030928 1.234568 1.282051 1.408451 1.204819 1.075269
1.265823 1.219512 0.000000
1.250000 1.052632 1.250000 1.408451 1.092896 1.098901 1.333333
1.111111 1.123595 0.000000
1.086957 1.104972 1.086957 1.204819 1.098901 1.136364 1.149425
1.162791 0.000000 0.000000
1.041667 1.351351 1.041667 1.075269 1.333333 1.149425 1.176471
1.190476 0.000000 0.000000
1.298701 1.369863 1.298701 1.265823 1.111111 1.162791 1.190476
0.000000 0.000000 0.000000
1.315789 1.388889 1.315789 1.219512 1.123595 0.000000 0.000000
0.000000 0.000000 0.000000)

(1.063830 1.010101 1.063830 1.234568 1.250000 1.086957
1.041667 1.298701 1.315789 0.000000
1.010101 1.030928 1.010101 1.020408 1.052632 1.104972 1.351351
1.369863 1.388889 0.000000
1.063830 1.010101 1.063830 1.234568 1.250000 1.086957 1.041667
1.298701 1.315789 0.000000
1.234568 1.020408 1.234568 1.282051 1.408451 1.204819 1.075269
1.265823 1.219512 0.000000
1.250000 1.052632 1.250000 1.408451 1.092896 1.098901 1.333333
1.111111 1.123595 0.000000
1.086957 1.104972 1.086957 1.204819 1.098901 1.136364 1.149425
1.162791 0.000000 0.000000
1.041667 1.351351 1.041667 1.075269 1.333333 1.149425 1.176471
1.190476 0.000000 0.000000
1.298701 1.369863 1.298701 1.265823 1.111111 1.162791 1.190476
0.000000 0.000000 0.000000
1.315789 1.388889 1.315789 1.219512 1.123595 0.000000 0.000000
0.000000 0.000000 0.000000)

(1.063830 1.030928 1.063830 1.234568 1.250000 1.086957
1.041667 1.298701 1.315789 0.000000
1.030928 1.010101 1.030928 1.020408 1.052632 1.104972 1.351351
1.369863 1.388889 0.000000
1.063830 1.030928 1.063830 1.234568 1.250000 1.086957 1.041667
1.298701 1.315789 0.000000
1.234568 1.020408 1.234568 1.282051 1.408451 1.204819 1.075269

TABLE A-23 (CONTINUED)

1.265823 1.219512 0.000000
1.250000 1.052632 1.250000 1.408451 1.092896 1.098901 1.333333
1.111111 1.123595 0.000000
1.086957 1.104972 1.086957 1.204819 1.098901 1.136364 1.149425
1.162791 0.000000 0.000000
1.041667 1.351351 1.041667 1.075269 1.333333 1.149425 1.176471
1.190476 0.000000 0.000000
1.298701 1.369863 1.298701 1.265823 1.111111 1.162791 1.190476
0.000000 0.000000 0.000000
1.315789 1.388889 1.315789 1.219512 1.123595 0.000000 0.000000
0.000000 0.000000 0.000000)

(1.063830 1.030928 1.063830 1.052632 1.250000 1.086957
1.041667 1.298701 1.315789 0.000000
1.030928 1.010101 1.030928 1.020408 1.234568 1.104972 1.351351
1.369863 1.388889 0.000000
1.063830 1.030928 1.063830 1.052632 1.250000 1.086957 1.041667
1.298701 1.315789 0.000000
1.052632 1.020408 1.052632 1.282051 1.408451 1.204819 1.075269
1.265823 1.219512 0.000000
1.250000 1.234568 1.250000 1.408451 1.092896 1.098901 1.333333
1.111111 1.123595 0.000000
1.086957 1.104972 1.086957 1.204819 1.098901 1.136364 1.149425
1.162791 0.000000 0.000000
1.041667 1.351351 1.041667 1.075269 1.333333 1.149425 1.176471
1.190476 0.000000 0.000000
1.298701 1.369863 1.298701 1.265823 1.111111 1.162791 1.190476
0.000000 0.000000 0.000000
1.315789 1.388889 1.315789 1.219512 1.123595 0.000000 0.000000
0.000000 0.000000 0.000000)

(1.063830 1.030928 1.063830 1.052632 1.250000 1.086957
1.041667 1.298701 1.315789 0.000000
1.030928 1.010101 1.030928 1.020408 1.234568 1.104972 1.351351
1.369863 1.388889 0.000000
1.063830 1.030928 1.063830 1.052632 1.250000 1.086957 1.041667
1.298701 1.315789 0.000000
1.052632 1.020408 1.052632 1.282051 1.408451 1.204819 1.075269
1.123595 1.219512 0.000000
1.250000 1.234568 1.250000 1.408451 1.092896 1.098901 1.333333
1.111111 1.265823 0.000000
1.086957 1.104972 1.086957 1.204819 1.098901 1.136364 1.149425
1.162791 0.000000 0.000000
1.041667 1.351351 1.041667 1.075269 1.333333 1.149425 1.176471
1.190476 0.000000 0.000000
1.298701 1.369863 1.298701 1.123595 1.111111 1.162791 1.190476
0.000000 0.000000 0.000000
1.315789 1.388889 1.315789 1.219512 1.265823 0.000000 0.000000
0.000000 0.000000 0.000000)

(1.063830 1.030928 1.063830 1.052632 1.250000 1.086957

TABLE A-23 (CONTINUED)

1.041667 1.298701 1.315789 0.000000
1.030928 1.010101 1.030928 1.020408 1.234568 1.104972 1.351351
1.369863 1.388889 0.000000
1.063830 1.030928 1.063830 1.052632 1.250000 1.086957 1.041667
1.298701 1.315789 0.000000
1.052632 1.020408 1.052632 1.282051 1.176471 1.204819 1.075269
1.123595 1.219512 0.000000
1.250000 1.234568 1.250000 1.176471 1.092896 1.098901 1.333333
1.111111 1.265823 0.000000
1.086957 1.104972 1.086957 1.204819 1.098901 1.136364 1.149425
1.162791 0.000000 0.000000
1.041667 1.351351 1.041667 1.075269 1.333333 1.149425 1.408451
1.190476 0.000000 0.000000
1.298701 1.369863 1.298701 1.123595 1.111111 1.162791 1.190476
0.000000 0.000000 0.000000
1.315789 1.388889 1.315789 1.219512 1.265823 0.000000 0.000000
0.000000 0.000000 0.000000)

(1.063830 1.030928 1.063830 1.052632 1.250000 1.086957
1.041667 1.298701 1.092896 0.000000
1.030928 1.010101 1.030928 1.020408 1.234568 1.104972 1.351351
1.369863 1.388889 0.000000
1.063830 1.030928 1.063830 1.052632 1.250000 1.086957 1.041667
1.298701 1.092896 0.000000
1.052632 1.020408 1.052632 1.282051 1.176471 1.204819 1.075269
1.123595 1.219512 0.000000
1.250000 1.234568 1.250000 1.176471 1.315789 1.098901 1.333333
1.111111 1.265823 0.000000
1.086957 1.104972 1.086957 1.204819 1.098901 1.136364 1.149425
1.162791 0.000000 0.000000
1.041667 1.351351 1.041667 1.075269 1.333333 1.149425 1.408451
1.190476 0.000000 0.000000
1.298701 1.369863 1.298701 1.123595 1.111111 1.162791 1.190476
0.000000 0.000000 0.000000
1.092896 1.388889 1.092896 1.219512 1.265823 0.000000 0.000000
0.000000 0.000000 0.000000)

TABLE A-24: TESTING SET OUTPUT FOR RPM MODEL A
(for ten testing patterns)

DESIRED OUTPUT LOGARITHMICALLY SCALED RELATIVE POWER

0.400365	0.417472	0.456821	0.499962	0.542327	0.601734
0.585799	0.511081	0.442166	0.494015	0.540204	0.558108
0.567379	0.54133	0.47509	0.503927	0.556061	0.5214
0.484727	0.448397	0.408579	0.498999	0.465829	0.457579
0.401401	0.362294	0.429268	0.403464	0.366796	0.370883
0.343015					

NETWORK OUTPUT

0.441308	0.463482	0.491853	0.568493	0.619509	0.614261
0.610198	0.539758	0.490451	0.508464	0.537594	0.560904
0.566647	0.565221	0.503562	0.465135	0.465789	0.465498
0.463219	0.457168	0.430364	0.432135	0.422085	0.423876
0.394617	0.366638	0.398834	0.382587	0.373494	0.373203
0.358782					

ERROR DIFFERENCE

-0.040943	-0.04601	-0.035032	-0.068531	-0.077182	-0.012527
-0.024399	-0.028677	-0.048285	-0.014449	0.00261	-0.002796
0.000732	-0.023891	-0.028472	0.038792	0.090272	0.055902
0.021508	-0.008771	-0.021785	0.066864	0.043744	0.033703
0.006784	-0.004344	0.030434	0.020877	-0.006698	-0.00232
-0.015767					

RELATIVE ERROR

-10.23%	-11.02%	-7.67%	-13.71%	-14.23%	-2.08%
-4.17%	-5.61%	-10.92%	-2.92%	0.48%	-0.50%
0.13%	-4.41%	-5.99%	7.70%	16.23%	10.72%
4.44%	-1.96%	-5.33%	13.40%	9.39%	7.37%
1.69%	-1.20%	7.09%	5.17%	-1.83%	-0.63%
-4.60%					

TABLE A-24 (CONTINUED)

DESIRED OUTPUT LOGARITHMICALLY SCALED RELATIVE POWER

0.392873	0.40824	0.44295	0.478711	0.514681	0.600319
0.604766	0.533264	0.43072	0.477411	0.513484	0.509471
0.563244	0.563125	0.497483	0.489114	0.538448	0.505286
0.492481	0.491922	0.43361	0.489537	0.462997	0.467164
0.420945	0.376394	0.431846	0.410609	0.376212	0.377306
0.34811					

NETWORK OUTPUT

0.44058	0.463356	0.486584	0.553239	0.601688	0.597844
0.598631	0.536616	0.48627	0.501354	0.526251	0.547001
0.555226	0.559978	0.50255	0.462828	0.463911	0.461992
0.461972	0.461618	0.43609	0.432738	0.427435	0.431631
0.404562	0.373644	0.410806	0.401685	0.386716	0.395587
0.37677					

ERROR DIFFERENCE

-0.047707	-0.055116	-0.043634	-0.074528	-0.087007	0.002475
0.006135	-0.003352	-0.05555	-0.023943	-0.012767	-0.03753
0.008018	0.003147	-0.005067	0.026286	0.074537	0.043294
0.030509	0.030304	-0.00248	0.056799	0.035562	0.035533
0.016383	0.00275	0.02104	0.008924	-0.010504	-0.018281
-0.02866					

RELATIVE ERROR

-12.14%	-13.50%	-9.85%	-15.57%	-16.91%	0.41%
1.01%	-0.63%	-12.90%	-5.02%	-2.49%	-7.37%
1.42%	0.56%	-1.02%	5.37%	13.84%	8.57%
6.19%	6.16%	-0.57%	11.60%	7.68%	7.61%
3.89%	0.73%	4.87%	2.17%	-2.79%	-4.85%
-8.23%					

TABLE A-24 (CONTINUED)

DESIRED OUTPUT LOGARITHMICALLY SCALED RELATIVE POWER

0.432649	0.453318	0.493179	0.507451	0.499275	0.53199
0.539954	0.483872	0.486289	0.548635	0.557146	0.501059
0.481443	0.503109	0.454997	0.602277	0.60401	0.521922
0.468052	0.459242	0.40824	0.5325	0.480007	0.463445
0.409257	0.365301	0.442166	0.412796	0.373831	0.378943
0.348305					

NETWORK OUTPUT

0.441021	0.465175	0.482628	0.544481	0.588472	0.584986
0.58811	0.533878	0.485064	0.500258	0.51405	0.53459
0.546344	0.555517	0.503961	0.456576	0.459602	0.461264
0.461259	0.463579	0.43998	0.432801	0.434614	0.43783
0.411736	0.382179	0.415631	0.420477	0.398591	0.411822
0.390213					

ERROR DIFFERENCE

-0.008372	-0.011857	0.010551	-0.03703	-0.089197	-0.052996
-0.048156	-0.050006	0.001225	0.048377	0.043096	-0.033531
-0.064901	-0.052408	-0.048964	0.145701	0.144408	0.060658
0.006793	-0.004337	-0.03174	0.099699	0.045393	0.025615
-0.002479	-0.016878	0.026535	-0.007681	-0.02476	-0.032879
-0.041908					

RELATIVE ERROR

-1.94%	-2.62%	2.14%	-7.30%	-17.87%	-9.96%
-8.92%	-10.33%	0.25%	8.82%	7.74%	-6.69%
-13.48%	-10.42%	-10.76%	24.19%	23.91%	11.62%
1.45%	-0.94%	-7.77%	18.72%	9.46%	5.53%
-0.61%	-4.62%	6.00%	-1.86%	-6.62%	-8.68%
-12.03%					

TABLE A-24 (CONTINUED)

DESIRED OUTPUT LOGARITHMICALLY SCALED RELATIVE POWER

0.431846	0.451172	0.492481	0.507181	0.499412	0.532245
0.540329	0.4843	0.485011	0.548144	0.556905	0.501196
0.481729	0.503518	0.455302	0.601951	0.603902	0.521922
0.468347	0.459543	0.408579	0.5325	0.480151	0.463744
0.409426	0.365488	0.442323	0.412964	0.374015	0.379124
0.348305					

NETWORK OUTPUT

0.441016	0.465285	0.482568	0.544577	0.588478	0.585012
0.588047	0.533824	0.48504	0.500244	0.513908	0.53459
0.546394	0.555501	0.503936	0.456495	0.459554	0.46125
0.461179	0.463535	0.439916	0.432675	0.434575	0.437792
0.41175	0.382244	0.415411	0.420527	0.398517	0.411747
0.390181					

ERROR DIFFERENCE

-0.00917	-0.014113	0.009913	-0.037396	-0.089066	-0.052767
-0.047718	-0.049524	-2.9E-05	0.0479	0.042997	-0.033394
-0.064665	-0.051983	-0.048634	0.145456	0.144348	0.060672
0.007168	-0.003992	-0.031337	0.099825	0.045576	0.025952
-0.002324	-0.016756	0.026912	-0.007563	-0.024502	-0.032623
-0.041876					

RELATIVE ERROR

-2.12%	-3.13%	2.01%	-7.37%	-17.83%	-9.91%
-8.83%	-10.23%	-0.01%	8.74%	7.72%	-6.66%
-13.42%	-10.32%	-10.68%	24.16%	23.90%	11.62%
1.53%	-0.87%	-7.67%	18.75%	9.49%	5.60%
-0.57%	-4.58%	6.08%	-1.83%	-6.55%	-8.60%
-12.02%					

TABLE A-24 (CONTINUED)

DESIRED OUTPUT LOGARITHMICALLY SCALED RELATIVE POWER

0.432328	0.450403	0.490099	0.506505	0.499275	0.532627
0.54108	0.484869	0.484157	0.547036	0.556423	0.501059
0.482016	0.504063	0.455758	0.601408	0.603686	0.522053
0.468643	0.459995	0.408918	0.532372	0.480294	0.464042
0.409764	0.365675	0.442637	0.4133	0.374198	0.379306
0.3485					

NETWORK OUTPUT

0.441117	0.465327	0.482511	0.544674	0.588577	0.585235
0.588046	0.533721	0.485068	0.500402	0.513914	0.534669
0.546575	0.555612	0.503934	0.456339	0.459533	0.461349
0.461206	0.463607	0.43992	0.432727	0.434561	0.437677
0.411572	0.382295	0.415259	0.42052	0.398437	0.411576
0.389938					

ERROR DIFFERENCE

-0.008789	-0.014924	0.007588	-0.038169	-0.089302	-0.052608
-0.046966	-0.048852	-0.000911	0.046634	0.042509	-0.03361
-0.064559	-0.051549	-0.048176	0.145069	0.144153	0.060704
0.007437	-0.003612	-0.031002	0.099645	0.045733	0.026365
-0.001808	-0.01662	0.027378	-0.00722	-0.024239	-0.03227
-0.041438					

RELATIVE ERROR

-2.03%	-3.31%	1.55%	-7.54%	-17.89%	-9.88%
-8.68%	-10.08%	-0.19%	8.52%	7.64%	-6.71%
-13.39%	-10.23%	-10.57%	24.12%	23.88%	11.63%
1.59%	-0.79%	-7.58%	18.72%	9.52%	5.68%
-0.44%	-4.55%	6.19%	-1.75%	-6.48%	-8.51%
-11.89%					

TABLE A-24 (CONTINUED)

DESIRED OUTPUT LOGARITHMICALLY SCALED RELATIVE POWER

0.43393	0.454692	0.491502	0.506911	0.499137	0.532117
0.540204	0.484157	0.486572	0.548144	0.556785	0.501059
0.481586	0.503382	0.45515	0.601951	0.603794	0.521922
0.4682	0.459392	0.40841	0.532372	0.480007	0.463594
0.409426	0.365488	0.442323	0.412964	0.374015	0.378943
0.348305					

NETWORK OUTPUT

0.441126	0.465106	0.482633	0.54448	0.588565	0.585184
0.588174	0.53383	0.485117	0.500428	0.514201	0.534669
0.546476	0.555646	0.503984	0.456504	0.459631	0.461378
0.461368	0.463696	0.44005	0.432982	0.434642	0.437754
0.411544	0.382164	0.415702	0.420418	0.398584	0.411727
0.390001					

ERROR DIFFERENCE

-0.007196	-0.010414	0.008869	-0.037569	-0.089428	-0.053067
-0.04797	-0.049673	0.001455	0.047716	0.042584	-0.03361
-0.06489	-0.052264	-0.048834	0.145447	0.144163	0.060544
0.006832	-0.004304	-0.03164	0.09939	0.045365	0.02584
-0.002118	-0.016676	0.026621	-0.007454	-0.024569	-0.032784
-0.041696					

RELATIVE ERROR

-1.66%	-2.29%	1.80%	-7.41%	-17.92%	-9.97%
-8.88%	-10.26%	0.30%	8.71%	7.65%	-6.71%
-13.47%	-10.38%	-10.73%	24.16%	23.88%	11.60%
1.46%	-0.94%	-7.75%	18.67%	9.45%	5.57%
-0.52%	-4.56%	6.02%	-1.80%	-6.57%	-8.65%
-11.97%					

TABLE A-24 (CONTINUED)

DESIRED OUTPUT LOGARITHMICALLY SCALED RELATIVE POWER

0.40637	0.422754	0.462997	0.529943	0.512684	0.551206
0.563837	0.505014	0.442637	0.488974	0.545307	0.504471
0.494155	0.522966	0.472756	0.565139	0.58872	0.521269
0.476542	0.473195	0.420286	0.525563	0.481443	0.471145
0.417804	0.371991	0.446226	0.418798	0.379306	0.383995
0.351989					

NETWORK OUTPUT

0.442057	0.465748	0.484971	0.554788	0.599883	0.597114
0.594815	0.534921	0.488066	0.506375	0.52084	0.543849
0.555356	0.559711	0.504894	0.456469	0.45992	0.464628
0.46235	0.461215	0.436941	0.432975	0.431257	0.43133
0.403752	0.378806	0.406923	0.409412	0.389713	0.396153
0.376409					

ERROR DIFFERENCE

-0.035687	-0.042994	-0.021974	-0.024845	-0.087199	-0.045908
-0.030978	-0.029907	-0.045429	-0.017401	0.024467	-0.039378
-0.061201	-0.036745	-0.032138	0.10867	0.1288	0.056641
0.014192	0.01198	-0.016655	0.092588	0.050186	0.039815
0.014052	-0.006815	0.039303	0.009386	-0.010407	-0.012158
-0.02442					

RELATIVE ERROR

-8.78%	-10.17%	-4.75%	-4.69%	-17.01%	-8.33%
-5.49%	-5.92%	-10.26%	-3.56%	4.49%	-7.81%
-12.38%	-7.03%	-6.80%	19.23%	21.88%	10.87%
2.98%	2.53%	-3.96%	17.62%	10.42%	8.45%
3.36%	-1.83%	8.81%	2.24%	-2.74%	-3.17%
-6.94%					

TABLE A-24 (CONTINUED)

DESIRED OUTPUT LOGARITHMICALLY SCALED RELATIVE POWER

0.413467	0.43072	0.471878	0.539703	0.517064	0.548512
0.554368	0.496238	0.451479	0.499137	0.55582	0.509203
0.490661	0.510009	0.462997	0.578066	0.600755	0.526469
0.47041	0.444981	0.409087	0.534407	0.485721	0.46938
0.410271	0.375664	0.449015	0.419129	0.377306	0.384353
0.351603					

NETWORK OUTPUT

0.443092	0.466252	0.484741	0.550751	0.596936	0.593021
0.592732	0.534292	0.489932	0.507597	0.518035	0.53887
0.553895	0.560371	0.507108	0.454504	0.45882	0.465912
0.463218	0.461679	0.440605	0.436036	0.434873	0.433726
0.403367	0.379125	0.409992	0.41411	0.39516	0.400391
0.380323					

ERROR DIFFERENCE

-0.029625	-0.035532	-0.012863	-0.011048	-0.079872	-0.044509
-0.038364	-0.038054	-0.038453	-0.00846	0.037785	-0.029667
-0.063234	-0.050362	-0.044111	0.123562	0.141935	0.060557
0.007192	-0.016698	-0.031518	0.098371	0.050848	0.035654
0.006904	-0.003461	0.039023	0.005019	-0.017854	-0.016038
-0.02872					

RELATIVE ERROR

-7.17%	-8.25%	-2.73%	-2.05%	-15.45%	-8.11%
-6.92%	-7.67%	-8.52%	-1.69%	6.80%	-5.83%
-12.89%	-9.87%	-9.53%	21.38%	23.63%	11.50%
1.53%	-3.75%	-7.70%	18.41%	10.47%	7.60%
1.68%	-0.92%	8.69%	1.20%	-4.73%	-4.17%
-8.17%					

TABLE A-24 (CONTINUED)

DESIRED OUTPUT LOGARITHMICALLY SCALED RELATIVE POWER

0.39585	0.408918	0.443263	0.510813	0.517196	0.583199
0.610128	0.549984	0.423082	0.457276	0.508664	0.497759
0.512551	0.55594	0.507991	0.500374	0.500236	0.495406
0.479863	0.473487	0.438701	0.476687	0.470557	0.483302
0.431203	0.395152	0.45515	0.444045	0.398634	0.437433
0.378761					

NETWORK OUTPUT

0.440036	0.463466	0.482536	0.533948	0.573907	0.571704
0.579283	0.533	0.486953	0.498778	0.506773	0.521309
0.538842	0.54915	0.506743	0.454109	0.455357	0.460549
0.462967	0.46296	0.446878	0.43491	0.443072	0.44043
0.419095	0.389377	0.425989	0.440301	0.410917	0.429666
0.403999					

ERROR DIFFERENCE

-0.044186	-0.054548	-0.039273	-0.023135	-0.056711	0.011495
0.030845	0.016984	-0.063871	-0.041502	0.001891	-0.02355
-0.026291	0.00679	0.001248	0.046265	0.044879	0.034857
0.016896	0.010527	-0.008177	0.041777	0.027485	0.042872
0.012108	0.005775	0.029161	0.003744	-0.012283	0.007767
-0.025238					

RELATIVE ERROR

-11.16%	-13.34%	-8.86%	-4.53%	-10.97%	1.97%
5.06%	3.09%	-15.10%	-9.08%	0.37%	-4.73%
-5.13%	1.22%	0.25%	9.25%	8.97%	7.04%
3.52%	2.22%	-1.86%	8.76%	5.84%	8.87%
2.81%	1.46%	6.41%	0.84%	-3.08%	1.78%
-6.66%					

TABLE A-24 (CONTINUED)

DESIRED OUTPUT LOGARITHMICALLY SCALED RELATIVE POWER

0.40671	0.421604	0.458487	0.525434	0.515741	0.557026
0.559188	0.483302	0.438542	0.477411	0.5302	0.503518
0.495822	0.511215	0.432969	0.533645	0.539954	0.516006
0.479143	0.452859	0.405688	0.554126	0.504199	0.496238
0.428135	0.382557	0.478855	0.457731	0.403464	0.449941
0.38507					

NETWORK OUTPUT

0.443501	0.46807	0.477652	0.538947	0.578012	0.577558
0.577673	0.529812	0.48584	0.505177	0.502032	0.523912
0.542371	0.553983	0.507298	0.446282	0.453311	0.464224
0.462117	0.466022	0.444703	0.435108	0.44266	0.440562
0.413492	0.392383	0.416593	0.44014	0.409367	0.422542
0.396786					

ERROR DIFFERENCE

-0.036791	-0.046466	-0.019165	-0.013513	-0.062271	-0.020532
-0.018485	-0.04651	-0.047298	-0.027766	0.028168	-0.020394
-0.046549	-0.042768	-0.074329	0.087363	0.086643	0.051782
0.017026	-0.013163	-0.039015	0.119018	0.061539	0.055676
0.014643	-0.009826	0.062262	0.017591	-0.005903	0.027399
-0.011716					

RELATIVE ERROR

-9.05%	-11.02%	-4.18%	-2.57%	-12.07%	-3.69%
-3.31%	-9.62%	-10.79%	-5.82%	5.31%	-4.05%
-9.39%	-8.37%	-17.17%	16.37%	16.05%	10.04%
3.55%	-2.91%	-9.62%	21.48%	12.21%	11.22%
3.42%	-2.57%	13.00%	3.84%	-1.46%	6.09%
-3.04%					

TABLE A-25: TESTING SET OUTPUT FOR NEXT-DOOR NEIGHBOR MODEL
(for five testing patterns)

DESIRED OUTPUT LOGARITHMICALLY SCALED RELATIVE POWER

0.49485	0.52009	0.565848	0.591065	0.565021	0.507451
0.432649	0.414973	0.563837	0.589391	0.602819	0.577262
0.532245	0.432007	0.406881	0.564784	0.574263	0.518119
0.456062	0.412796	0.397245	0.511482	0.45894	0.414137
0.394977	0.372175	0.420451	0.386677	0.373831	0.366049
0.349472					

NETWORK OUTPUT

0.443404	0.459454	0.482735	0.538599	0.598819	0.622818
0.610438	0.546975	0.475005	0.503634	0.523505	0.549102
0.56789	0.563535	0.517978	0.484215	0.459956	0.483762
0.471185	0.446603	0.441766	0.435726	0.426639	0.403833
0.404467	0.390206	0.425102	0.3718	0.379787	0.387366
0.376682					

ERROR DIFFERENCE

0.051446	0.060636	0.083113	0.052466	-0.033798	-0.115367
-0.177789	-0.132002	0.088832	0.085757	0.079314	0.02816
-0.035645	-0.131528	-0.111097	0.080569	0.114307	0.034357
-0.015123	-0.033807	-0.044521	0.075756	0.032301	0.010304
-0.00949	-0.018031	-0.004651	0.014877	-0.005956	-0.021317
-0.02721					

RELATIVE ERROR

10.40%	11.66%	14.69%	8.88%	-5.98%	-22.73%
-41.09%	-31.81%	15.75%	14.55%	13.16%	4.88%
-6.70%	-30.45%	-27.30%	14.27%	19.90%	6.63%
-3.32%	-8.19%	-11.21%	14.81%	7.04%	2.49%
-2.40%	-4.84%	-1.11%	3.85%	-1.59%	-5.82%
-7.79%					

TABLE A-25 (CONTINUED)

DESIRED OUTPUT LOGARITHMICALLY SCALED RELATIVE POWER

0.513218	0.539327	0.583765	0.601082	0.557267	0.475526
0.411451	0.399501	0.585235	0.608633	0.613419	0.567144
0.479719	0.40841	0.392697	0.581495	0.586925	0.518514
0.441381	0.402261	0.388989	0.522444	0.465383	0.415474
0.394977	0.369772	0.430236	0.398981	0.382917	0.39585
0.364926					

NETWORK OUTPUT

0.441998	0.454743	0.480322	0.526448	0.566634	0.590527
0.579297	0.530154	0.478701	0.501998	0.51362	0.522526
0.540014	0.543396	0.513468	0.480224	0.4552	0.476479
0.468874	0.454694	0.44748	0.441853	0.441353	0.426691
0.423297	0.401395	0.448981	0.41802	0.41166	0.436087
0.407431					

ERROR DIFFERENCE

0.07122	0.084584	0.103443	0.074634	-0.009367	-0.115001
-0.167846	-0.130653	0.106534	0.106635	0.099799	0.044618
-0.060295	-0.134986	-0.120771	0.101271	0.131725	0.042035
-0.027493	-0.052433	-0.058491	0.080591	0.02403	-0.011217
-0.02832	-0.031623	-0.018745	-0.019039	-0.028743	-0.040237
-0.042505					

RELATIVE ERROR

13.88%	15.68%	17.72%	12.42%	-1.68%	-24.18%
-40.79%	-32.70%	18.20%	17.52%	16.27%	7.87%
-12.57%	-33.05%	-30.75%	17.42%	22.44%	8.11%
-6.23%	-13.03%	-15.04%	15.43%	5.16%	-2.70%
-7.17%	-8.55%	-4.36%	-4.77%	-7.51%	-10.16%
-11.65%					

TABLE A-25 (CONTINUED)

DESIRED OUTPUT LOGARITHMICALLY SCALED RELATIVE POWER

0.519303	0.545183	0.586475	0.592954	0.52866	0.45667
0.402777	0.394802	0.591732	0.613207	0.606919	0.523486
0.459392	0.400711	0.389343	0.591621	0.601517	0.515211
0.437592	0.401056	0.388811	0.57066	0.484157	0.423246
0.399847	0.372175	0.445604	0.409426	0.390759	0.407051
0.37236					

NETWORK OUTPUT

0.441832	0.458799	0.479354	0.52438	0.560806	0.582716
0.576047	0.531173	0.483063	0.504803	0.51532	0.516369
0.531396	0.542598	0.516411	0.479152	0.455593	0.474524
0.467165	0.457251	0.452575	0.444921	0.442885	0.426901
0.422751	0.404718	0.451017	0.422477	0.415206	0.436732
0.411076					

ERROR DIFFERENCE

0.077471	0.086384	0.107121	0.068574	-0.032146	-0.126046
-0.17327	-0.136371	0.108669	0.108404	0.091599	0.007117
-0.072004	-0.141887	-0.127068	0.112469	0.145924	0.040687
-0.029573	-0.056195	-0.063764	0.125739	0.041272	-0.003655
-0.022904	-0.032543	-0.005413	-0.013051	-0.024447	-0.029681
-0.038716					

RELATIVE ERROR

14.92%	15.84%	18.27%	11.56%	-6.08%	-27.60%
-43.02%	-34.54%	18.36%	17.68%	15.09%	1.36%
-15.67%	-35.41%	-32.64%	19.01%	24.26%	7.90%
-6.76%	-14.01%	-16.40%	22.03%	8.52%	-0.86%
-5.73%	-8.74%	-1.21%	-3.19%	-6.26%	-7.29%
-10.40%					

TABLE A-25 (CONTINUED)

DESIRED OUTPUT: LOGARITHMICALLY SCALED RELATIVE POWER

0.490099	0.517196	0.575303	0.63809	0.626853	0.52621
0.43361	0.40824	0.559428	0.589838	0.616581	0.596927
0.538951	0.429429	0.399154	0.561101	0.571709	0.517724
0.452247	0.40432	0.386677	0.503927	0.450095	0.403292
0.380211	0.36135	0.407221	0.370698	0.349278	0.348889
0.330617					

NETWORK OUTPUT

0.443711	0.464509	0.500499	0.563432	0.618566	0.632729
0.60362	0.538173	0.485071	0.516619	0.536211	0.559207
0.574207	0.558286	0.510636	0.488587	0.46384	0.480044
0.466991	0.445154	0.43776	0.435447	0.421485	0.405294
0.400828	0.383192	0.414951	0.364212	0.368083	0.377489
0.362334					

ERROR DIFFERENCE

0.046388	0.052687	0.074804	0.074658	0.008287	-0.106519
-0.17001	-0.129933	0.074357	0.073219	0.08037	0.03772
-0.035256	-0.128857	-0.111482	0.072514	0.107869	0.03768
-0.014744	-0.040834	-0.051083	0.06848	0.02861	-0.002002
-0.020617	-0.021842	-0.00773	0.006486	-0.018805	-0.0286
-0.031717					

RELATIVE ERROR

9.47%	10.19%	13.00%	11.70%	1.32%	-20.24%
-39.21%	-31.83%	13.29%	12.41%	13.03%	6.32%
-6.54%	-30.01%	-27.93%	12.92%	18.87%	7.28%
-3.26%	-10.10%	-13.21%	13.59%	6.36%	-0.50%
-5.42%	-6.04%	-1.90%	1.75%	-5.38%	-8.20%
-9.59%					

TABLE A-25 (CONTINUED)

DESIRED OUTPUT LOGARITHMICALLY SCALED RELATIVE POWER

0.498311	0.524915	0.578181	0.625518	0.575072	0.506911
0.428621	0.408918	0.568202	0.595827	0.613842	0.580583
0.529559	0.427486	0.400883	0.567497	0.575996	0.5168
0.452247	0.407391	0.390935	0.509874	0.45515	0.408918
0.388456	0.366796	0.414973	0.380211	0.366236	0.357935
0.339253					

NETWORK OUTPUT

0.435123	0.449604	0.481577	0.546925	0.595153	0.623173
0.593711	0.534552	0.465286	0.496289	0.515585	0.54743
0.568146	0.555625	0.506918	0.478278	0.456443	0.479401
0.472867	0.455629	0.437099	0.435782	0.431982	0.413866
0.409412	0.389887	0.432977	0.390912	0.391611	0.406985
0.384853					

ERROR DIFFERENCE

0.063188	0.075311	0.096604	0.078593	-0.020081	-0.116262
-0.16509	-0.125634	0.102916	0.099538	0.098257	0.033153
-0.038587	-0.128139	-0.106035	0.089219	0.119553	0.037399
-0.02062	-0.048238	-0.046164	0.074092	0.023168	-0.004948
-0.020956	-0.023091	-0.018004	-0.010701	-0.025375	-0.04905
-0.0456					

RELATIVE ERROR

12.68%	14.35%	16.71%	12.56%	-3.49%	-22.94%
-38.52%	-30.72%	18.11%	16.71%	16.01%	5.71%
-7.29%	-29.98%	-26.45%	15.72%	20.76%	7.24%
-4.56%	-11.84%	-11.81%	14.53%	5.09%	-1.21%
-5.39%	-6.30%	-4.34%	-2.81%	-6.93%	-13.70%
-13.44%					

TABLE A-26: TESTING SET OUTPUT FOR PATTERNED NETWORK
(for ten testing patterns)

DESIRED OUTPUT: LOGARITHMICALLY SCALED RELATIVE POWER

0.400365	0.417472	0.456821	0.499962	0.542327	0.601734	0.585799	0.511081
0.417472	0.442166	0.494015	0.540204	0.558108	0.567379	0.54133	0.47509
0.456821	0.494015	0.503927	0.556061	0.5214	0.484727	0.448397	0.408579
0.499962	0.540204	0.556061	0.498999	0.465829	0.457579	0.401401	0.362294
0.542327	0.558108	0.5214	0.465829	0.429268	0.403464	0.366796	0
0.601734	0.567379	0.484727	0.457579	0.403464	0.370883	0.343015	0
0.585799	0.54133	0.448397	0.401401	0.366796	0.343015	0	0

NETWORK OUTPUT: RELATIVE POWER

0.359163	0.369968	0.414594	0.471986	0.558823	0.619175	0.590487	0.512485
0.371568	0.404167	0.467167	0.535924	0.544483	0.554158	0.545454	0.481745
0.414098	0.46698	0.490199	0.540786	0.509196	0.480873	0.474601	0.444269
0.472625	0.534011	0.542799	0.494461	0.470554	0.473526	0.449326	0.408641
0.559747	0.545074	0.508988	0.470159	0.442865	0.422721	0.401436	0.000976
0.6199	0.554935	0.484939	0.475459	0.421118	0.391753	0.360177	0.000807
0.58863	0.544955	0.474328	0.449351	0.405932	0.360614	0.001267	0.000809

ERROR DIFFERENCE

0.041202	0.047504	0.042227	0.027976	-0.016496	-0.017441	-0.004688	-0.001404
0.045904	0.037999	0.026848	0.00428	0.013625	0.013221	-0.004124	-0.006655
0.042723	0.027035	0.013728	0.015275	0.012204	0.003854	-0.026204	-0.03569
0.027337	0.006193	0.013262	0.004538	-0.004725	-0.015947	-0.047925	-0.046347
-0.01742	0.013034	0.012412	-0.00433	-0.013597	-0.019257	-0.03464	-0.000976
-0.018166	0.012444	-0.000212	-0.01788	-0.017654	-0.02087	-0.017162	-0.000807
-0.002831	-0.003625	-0.025931	-0.04795	-0.039136	-0.017599	-0.001267	-0.000809

RELATIVE ERROR

10.29%	11.38%	9.24%	5.60%	-3.04%	-2.90%	-0.80%	-0.27%
11.00%	8.59%	5.43%	0.79%	2.44%	2.33%	-0.76%	-1.40%
9.35%	5.47%	2.72%	2.75%	2.34%	0.80%	-5.84%	-8.74%
5.47%	1.15%	2.38%	0.91%	-1.01%	-3.49%	-11.94%	-12.79%
-3.21%	2.34%	2.38%	-0.93%	-3.17%	-4.77%	-9.44%	
-3.02%	2.19%	-0.04%	-3.91%	-4.38%	-5.63%	-5.00%	
-0.48%	-0.67%	-5.78%	-11.95%	-10.67%	-5.13%		

TABLE A-26 (CONTINUED)

DESIRED OUTPUT: LOGARITHMICALLY SCALED RELATIVE POWER

0.392873	0.40824	0.44295	0.478711	0.514681	0.600319	0.604766	0.533264
0.40824	0.43072	0.477411	0.513484	0.509471	0.563244	0.563125	0.497483
0.44295	0.477411	0.489114	0.538448	0.505286	0.492481	0.491922	0.43361
0.478711	0.513484	0.538448	0.489537	0.462997	0.467164	0.420945	0.376394
0.514681	0.509471	0.505286	0.462997	0.431846	0.410609	0.376212	0
0.600319	0.563244	0.492481	0.467164	0.410609	0.377306	0.34811	0
0.604766	0.563125	0.491922	0.420945	0.376212	0.34811	0	0

NETWORK OUTPUT:

0.35646	0.365464	0.405137	0.449539	0.524763	0.609909	0.584904	0.510655
0.367594	0.404252	0.462377	0.519422	0.513245	0.540608	0.545034	0.485492
0.40523	0.462862	0.489856	0.542059	0.497015	0.479859	0.485977	0.456991
0.449999	0.518385	0.543702	0.497225	0.476529	0.491562	0.468892	0.423142
0.52606	0.513795	0.496628	0.47662	0.45735	0.443067	0.420968	0.000798
0.611472	0.541043	0.485853	0.49459	0.440659	0.414276	0.375788	0.000655
0.583757	0.544866	0.485492	0.470442	0.425585	0.376848	0.001041	0.000703

ERROR DIFFERENCE

0.036413	0.042776	0.037813	0.029172	-0.010082	-0.00959	0.019862	0.022609
0.040646	0.026468	0.015034	-0.005938	-0.003774	0.022636	0.018091	0.011991
0.03772	0.014549	-0.000742	-0.003611	0.008271	0.012622	0.005945	-0.023381
0.028712	-0.004901	-0.005254	-0.007688	-0.013532	-0.024398	-0.047947	-0.046748
-0.011379	-0.004324	0.008658	-0.013623	-0.025504	-0.032458	-0.044756	-0.000798
-0.011153	0.022201	0.006628	-0.027426	-0.03005	-0.03697	-0.027678	-0.000655
0.021009	0.018259	0.00643	-0.049497	-0.049373	-0.028738	-0.001041	-0.000703

RELATIVE ERROR

9.27%	10.48%	8.54%	6.09%	-1.96%	-1.60%	3.28%	4.24%
9.96%	6.15%	3.15%	-1.16%	-0.74%	4.02%	3.21%	2.41%
8.52%	3.05%	-0.15%	-0.67%	1.64%	2.56%	1.21%	-5.39%
6.00%	-0.95%	-0.98%	-1.57%	-2.92%	-5.22%	-11.39%	-12.42%
-2.21%	-0.85%	1.71%	-2.94%	-5.91%	-7.90%	-11.90%	
-1.86%	3.94%	1.35%	-5.87%	-7.32%	-9.80%	-7.95%	
3.47%	3.24%	1.31%	-11.76%	-13.12%	-8.26%		

TABLE A-26 (CONTINUED)

DESIRED OUTPUT: LOGARITHMICALLY SCALED RELATIVE POWER

0.432649	0.453318	0.493179	0.507451	0.499275	0.53199	0.539954	0.483872
0.453318	0.486289	0.548635	0.557146	0.501059	0.481443	0.503109	0.454997
0.493179	0.548635	0.602277	0.60401	0.521922	0.468052	0.459242	0.40824
0.507451	0.557146	0.60401	0.5325	0.480007	0.463445	0.409257	0.365301
0.499275	0.501059	0.521922	0.480007	0.442166	0.412796	0.373831	0
0.53199	0.481443	0.468052	0.463445	0.412796	0.378943	0.348305	0
0.539954	0.503109	0.459242	0.409257	0.373831	0.348305	0	0

NETWORK OUTPUT:

0.376822	0.38952	0.445048	0.456871	0.527265	0.578938	0.554567	0.489833
0.391625	0.429162	0.493088	0.532778	0.515447	0.493393	0.515884	0.46902
0.44607	0.493867	0.519559	0.559265	0.506587	0.46484	0.462634	0.440902
0.456738	0.53299	0.561244	0.508663	0.483915	0.486129	0.456441	0.415119
0.528611	0.515321	0.506203	0.483832	0.467622	0.451609	0.421421	0.000971
0.580714	0.49342	0.472011	0.488292	0.4491	0.426638	0.379835	0.000817
0.552979	0.515975	0.46234	0.458006	0.424567	0.379832	0.001279	0.000931

ERROR DIFFERENCE

0.055827	0.063798	0.048131	0.05058	-0.02799	-0.046948	-0.014613	-0.005961
0.061693	0.057127	0.055547	0.024368	-0.014388	-0.01195	-0.012775	-0.014023
0.047109	0.054768	0.082718	0.044745	0.015335	0.003212	-0.003392	-0.032662
0.050713	0.024156	0.042766	0.023837	-0.003908	-0.022684	-0.047184	-0.049818
-0.029336	-0.014262	0.015719	-0.003825	-0.025456	-0.038813	-0.04759	-0.000971
-0.048724	-0.011977	-0.003959	-0.024847	-0.036304	-0.047695	-0.03153	-0.000817
-0.013025	-0.012866	-0.003098	-0.048749	-0.050736	-0.031527	-0.001279	-0.000931

RELATIVE ERROR

12.90%	14.07%	9.76%	9.97%	-5.61%	-8.82%	-2.71%	-1.23%
13.61%	11.75%	10.12%	4.37%	-2.87%	-2.48%	-2.54%	-3.08%
9.55%	9.98%	13.73%	7.41%	2.94%	0.69%	-0.74%	-8.00%
9.99%	4.34%	7.08%	4.48%	-0.81%	-4.89%	-11.53%	-13.64%
-5.88%	-2.85%	3.01%	-0.80%	-5.76%	-9.40%	-12.73%	
-9.16%	-2.49%	-0.85%	-5.36%	-8.79%	-12.59%	-9.05%	
-2.41%	-2.56%	-0.67%	-11.91%	-13.57%	-9.05%		

TABLE A-26 (CONTINUED)

DESIRED OUTPUT: LOGARITHMICALLY SCALED RELATIVE POWER

0.431846	0.451172	0.492481	0.507181	0.499412	0.532245	0.540329	0.4843
0.451172	0.485011	0.548144	0.556905	0.501196	0.481729	0.503518	0.455302
0.492481	0.548144	0.601951	0.603902	0.521922	0.468347	0.459543	0.408579
0.507181	0.556905	0.603902	0.5325	0.480151	0.463744	0.409426	0.365488
0.499412	0.501196	0.521922	0.480151	0.442323	0.412964	0.374015	0
0.532245	0.481729	0.468347	0.463744	0.412964	0.379124	0.348305	0
0.540329	0.503518	0.459543	0.409426	0.374015	0.348305	0	0

NETWORK OUTPUT:

0.371086	0.383516	0.442051	0.456325	0.527868	0.578768	0.555154	0.490755
0.385659	0.423665	0.491274	0.532413	0.515143	0.493414	0.516527	0.470288
0.443003	0.491987	0.518601	0.559234	0.506464	0.464806	0.463848	0.442636
0.456283	0.532553	0.561405	0.508436	0.48487	0.488889	0.459423	0.417366
0.52932	0.515016	0.506142	0.484592	0.469008	0.45308	0.423451	0.000946
0.580442	0.493438	0.471988	0.491047	0.45061	0.427633	0.380711	0.000795
0.553492	0.516507	0.463769	0.460982	0.426831	0.380864	0.001263	0.000908

ERROR DIFFERENCE

0.06076	0.067656	0.05043	0.050856	-0.028456	-0.046523	-0.014825	-0.006455
0.065513	0.061346	0.05687	0.024492	-0.013947	-0.011685	-0.013009	-0.014986
0.049478	0.056157	0.08335	0.044668	0.015458	0.003541	-0.004305	-0.034057
0.050898	0.024352	0.042497	0.024064	-0.004719	-0.025145	-0.049997	-0.051878
-0.029908	-0.01382	0.01578	-0.004441	-0.026685	-0.040116	-0.049436	-0.000946
-0.048197	-0.011709	-0.003641	-0.027303	-0.037646	-0.048509	-0.032406	-0.000795
-0.013163	-0.012989	-0.004226	-0.051556	-0.052816	-0.032559	-0.001263	-0.000908

RELATIVE ERROR

14.07%	15.00%	10.24%	10.03%	-5.70%	-8.74%	-2.74%	-1.33%
14.52%	12.65%	10.38%	4.40%	-2.78%	-2.43%	-2.58%	-3.29%
10.05%	10.24%	13.85%	7.40%	2.96%	0.76%	-0.94%	-8.34%
10.04%	4.37%	7.04%	4.52%	-0.98%	-5.42%	-12.21%	-14.19%
-5.99%	-2.76%	3.02%	-0.92%	-6.03%	-9.71%	-13.22%	
-9.06%	-2.43%	-0.78%	-5.89%	-9.12%	-12.80%	-9.30%	
-2.44%	-2.58%	-0.92%	-12.59%	-14.12%	-9.35%		

TABLE A-26 (CONTINUED)

DESIRED OUTPUT: LOGARITHMICALLY SCALED RELATIVE POWER

0.432328	0.450403	0.490099	0.506505	0.499275	0.532627	0.54108	0.484869
0.450403	0.484157	0.547036	0.556423	0.501059	0.482016	0.504063	0.455758
0.490099	0.547036	0.601408	0.603686	0.522053	0.468643	0.459995	0.408918
0.506505	0.556423	0.603686	0.532372	0.480294	0.464042	0.409764	0.365675
0.499275	0.501059	0.522053	0.480294	0.442637	0.4133	0.374198	0
0.532627	0.482016	0.468643	0.464042	0.4133	0.379306	0.3485	0
0.54108	0.504063	0.459995	0.409764	0.374198	0.3485	0	0

NETWORK OUTPUT :

0.363905	0.375464	0.43333	0.451963	0.526496	0.579844	0.558538	0.495046
0.377631	0.415812	0.486083	0.530286	0.513502	0.494345	0.519883	0.473951
0.434282	0.486809	0.515511	0.5582	0.505718	0.465443	0.467083	0.445894
0.451979	0.53034	0.560487	0.507798	0.485657	0.491759	0.463004	0.420269
0.527985	0.513439	0.505482	0.485264	0.470432	0.455218	0.425716	0.000906
0.581651	0.494382	0.472862	0.494039	0.452584	0.429248	0.382032	0.000758
0.556827	0.519858	0.467062	0.464619	0.429328	0.382264	0.001235	0.000867

ERROR DIFFERENCE

0.068423	0.074939	0.056769	0.054542	-0.027221	-0.047217	-0.017458	-0.010177
0.072772	0.068345	0.060953	0.026137	-0.012443	-0.012329	-0.01582	-0.018193
0.055817	0.060227	0.085897	0.045486	0.016335	0.0032	-0.007088	-0.036976
0.054526	0.026083	0.043199	0.024574	-0.005363	-0.027717	-0.05324	-0.054594
-0.02871	-0.01238	0.016571	-0.00497	-0.027795	-0.041918	-0.051518	-0.000906
-0.049024	-0.012366	-0.004219	-0.029997	-0.039284	-0.049942	-0.033532	-0.000758
-0.015747	-0.015795	-0.007067	-0.054855	-0.05513	-0.033764	-0.001235	-0.000867

RELATIVE ERROR

15.83%	16.64%	11.58%	10.77%	-5.45%	-8.86%	-3.23%	-2.10%
16.16%	14.12%	11.14%	4.70%	-2.48%	-2.56%	-3.14%	-3.99%
11.39%	11.01%	14.28%	7.53%	3.13%	0.68%	-1.54%	-9.04%
10.77%	4.69%	7.16%	4.62%	-1.12%	-5.97%	-12.99%	-14.93%
-5.75%	-2.47%	3.17%	-1.03%	-6.28%	-10.14%	-13.77%	
-9.20%	-2.57%	-0.90%	-6.46%	-9.50%	-13.17%	-9.62%	
-2.91%	-3.13%	-1.54%	-13.39%	-14.73%	-9.69%		

TABLE A-26 (CONTINUED)

DESIRED OUTPUT: LOGARITHMICALLY SCALED RELATIVE POWER

0.43393	0.454692	0.491502	0.506911	0.499137	0.532117	0.540204	0.484157
0.454692	0.486572	0.548144	0.556785	0.501059	0.481586	0.503382	0.45515
0.491502	0.548144	0.601951	0.603794	0.521922	0.4682	0.459392	0.40841
0.506911	0.556785	0.603794	0.532372	0.480007	0.463594	0.409426	0.365488
0.499137	0.501059	0.521922	0.480007	0.442323	0.412964	0.374015	0
0.532117	0.481586	0.4682	0.463594	0.412964	0.378943	0.348305	0
0.540204	0.503382	0.459392	0.409426	0.374015	0.348305	0	0

NETWORK OUTPUT:

0.375404	0.387494	0.439296	0.453059	0.525256	0.580199	0.557372	0.493239
0.389588	0.426836	0.489693	0.530986	0.514077	0.494307	0.518611	0.471439
0.440387	0.490551	0.517386	0.55826	0.505933	0.465504	0.464666	0.442419
0.45289	0.531184	0.560158	0.508255	0.483713	0.486178	0.456992	0.415736
0.526532	0.514017	0.505569	0.483714	0.467621	0.45225	0.421623	0.000955
0.582211	0.494352	0.472897	0.488469	0.449538	0.427238	0.380272	0.0008
0.555811	0.518814	0.46421	0.45862	0.424762	0.380191	0.001267	0.00091

ERROR DIFFERENCE

0.058526	0.067198	0.052206	0.053852	-0.026119	-0.048082	-0.017168	-0.009082
0.065104	0.059736	0.058451	0.025799	-0.013018	-0.012721	-0.015229	-0.016289
0.051115	0.057593	0.084565	0.045534	0.015989	0.002696	-0.005274	-0.034009
0.054021	0.025601	0.043636	0.024117	-0.003706	-0.022584	-0.047566	-0.050248
-0.027395	-0.012958	0.016353	-0.003707	-0.025298	-0.039286	-0.047608	-0.000955
-0.050094	-0.012766	-0.004697	-0.024875	-0.036574	-0.048295	-0.031967	-0.0008
-0.015607	-0.015432	-0.004818	-0.049194	-0.050747	-0.031886	-0.001267	-0.00091

RELATIVE ERROR

13.49%	14.78%	10.62%	10.62%	-5.23%	-9.04%	-3.18%	-1.88%
14.32%	12.28%	10.66%	4.63%	-2.60%	-2.64%	-3.03%	-3.58%
10.40%	10.51%	14.05%	7.54%	3.06%	0.58%	-1.15%	-8.33%
10.66%	4.60%	7.23%	4.53%	-0.77%	-4.87%	-11.62%	-13.75%
-5.49%	-2.59%	3.13%	-0.77%	-5.72%	-9.51%	-12.73%	
-9.41%	-2.65%	-1.00%	-5.37%	-8.86%	-12.74%	-9.18%	
-2.89%	-3.07%	-1.05%	-12.02%	-13.57%	-9.15%		

TABLE A-26 (CONTINUED)

DESIRED OUTPUT: LOGARITHMICALLY SCALED RELATIVE POWER

0.40637	0.422754	0.462997	0.529943	0.512684	0.551206	0.563837	0.505014
0.422754	0.442637	0.488974	0.545307	0.504471	0.494155	0.522966	0.472756
0.462997	0.488974	0.565139	0.58872	0.521269	0.476542	0.473195	0.420286
0.529943	0.545307	0.58872	0.525563	0.481443	0.471145	0.417804	0.371991
0.512684	0.504471	0.521269	0.481443	0.446226	0.418798	0.379306	0
0.551206	0.494155	0.476542	0.471145	0.418798	0.383995	0.351989	0
0.563837	0.522966	0.473195	0.417804	0.379306	0.351989	0	0

NETWORK OUTPUT:

0.441757	0.463373	0.527367	0.560585	0.59035	0.581631	0.53408	0.462659
0.463903	0.490921	0.532356	0.564917	0.556909	0.505135	0.494128	0.439787
0.527417	0.532585	0.538844	0.551566	0.52084	0.469564	0.43106	0.399693
0.560335	0.565635	0.551401	0.4977	0.463481	0.433421	0.398046	0.368513
0.590839	0.555774	0.52019	0.465399	0.435339	0.411063	0.376993	0.001536
0.580457	0.505157	0.47091	0.432861	0.412047	0.390816	0.354767	0.001405
0.533954	0.494373	0.43065	0.398431	0.375347	0.352419	0.001866	0.001624

ERROR DIFFERENCE

-0.035387	-0.040619	-0.06437	-0.030642	-0.077666	-0.030425	0.029757	0.042355
-0.041149	-0.048284	-0.043382	-0.01961	-0.052438	-0.01098	0.028838	0.032969
-0.06442	-0.043611	0.026295	0.037154	0.000429	0.006978	0.042135	0.020593
-0.030392	-0.020328	0.037319	0.027863	0.017962	0.037724	0.019758	0.003478
-0.078155	-0.051303	0.001079	0.016044	0.010887	0.007735	0.002313	-0.001536
-0.029251	-0.011002	0.005632	0.038284	0.006751	-0.006821	-0.002778	-0.001405
0.029883	0.028593	0.042545	0.019373	0.003959	-0.00043	-0.001866	-0.001624

RELATIVE ERROR

-8.71%	-9.61%	-13.90%	-5.78%	-15.15%	-5.52%	5.28%	8.39%
-9.73%	-10.91%	-8.87%	-3.60%	-10.39%	-2.22%	5.51%	6.97%
-13.91%	-8.92%	4.65%	6.31%	0.08%	1.46%	8.90%	4.90%
-5.73%	-3.73%	6.34%	5.30%	3.73%	8.01%	4.73%	0.93%
-15.24%	-10.17%	0.21%	3.33%	2.44%	1.85%	0.61%	
-5.31%	-2.23%	1.18%	8.13%	1.61%	-1.78%	-0.79%	
5.30%	5.47%	8.99%	4.64%	1.04%	-0.12%		

TABLE A-26 (CONTINUED)

DESIRED OUTPUT: LOGARITHMICALLY SCALED RELATIVE POWER

0.413467	0.43072	0.471878	0.539703	0.517064	0.548512	0.554368	0.496238
0.43072	0.451479	0.499137	0.55582	0.509203	0.490661	0.510009	0.462997
0.471878	0.499137	0.578066	0.600755	0.526469	0.47041	0.444981	0.409087
0.539703	0.55582	0.600755	0.534407	0.485721	0.46938	0.410271	0.375664
0.517064	0.509203	0.526469	0.485721	0.449015	0.419129	0.377306	0
0.548512	0.490661	0.47041	0.46938	0.419129	0.384353	0.351603	0
0.554368	0.510009	0.444981	0.410271	0.377306	0.351603	0	0

NETWORK OUTPUT:

0.44186	0.463589	0.530579	0.562452	0.591455	0.579224	0.532988	0.461887
0.464191	0.494078	0.536749	0.567495	0.560835	0.504554	0.492306	0.439492
0.530758	0.536785	0.541149	0.551275	0.522579	0.467352	0.427625	0.398024
0.562396	0.567938	0.55153	0.497561	0.463594	0.432141	0.396908	0.370966
0.592002	0.5597	0.52184	0.46528	0.434889	0.409597	0.377873	0.001562
0.57787	0.504652	0.468248	0.431672	0.411099	0.391695	0.356656	0.001425
0.53277	0.492425	0.427079	0.396658	0.376518	0.354341	0.001886	0.001641

ERROR DIFFERENCE

-0.028393	-0.032869	-0.058701	-0.022749	-0.074391	-0.030712	0.02138	0.034351
-0.033471	-0.042599	-0.037612	-0.011675	-0.051632	-0.013893	0.017703	0.023505
-0.05888	-0.037648	0.036917	0.04948	0.00389	0.003058	0.017356	0.011063
-0.022693	-0.012118	0.049225	0.036846	0.022127	0.037239	0.013363	0.004698
-0.074938	-0.050497	0.004629	0.020441	0.014126	0.009532	-0.000567	-0.001562
-0.029358	-0.013991	0.002162	0.037708	0.00803	-0.007342	-0.005053	-0.001425
0.021598	0.017584	0.017902	0.013613	0.000788	-0.002738	-0.001886	-0.001641

RELATIVE ERROR

-6.87%	-7.63%	-12.44%	-4.22%	-14.39%	-5.60%	3.86%	6.92%
-7.77%	-9.44%	-7.54%	-2.10%	-10.14%	-2.83%	3.47%	5.08%
-12.48%	-7.54%	6.39%	8.24%	0.74%	0.65%	3.90%	2.70%
-4.20%	-2.18%	8.19%	6.89%	4.56%	7.93%	3.26%	1.25%
-14.49%	-9.92%	0.88%	4.21%	3.15%	2.27%	-0.15%	
-5.35%	-2.85%	0.46%	8.03%	1.92%	-1.91%	-1.44%	
3.90%	3.45%	4.02%	3.32%	0.21%	-0.78%		

TABLE A-26 (CONTINUED)

DESIRED OUTPUT: LOGARITHMICALLY SCALED RELATIVE POWER

0.39585	0.408918	0.443263	0.510813	0.517196	0.583199	0.610128	0.549984
0.408918	0.423082	0.457276	0.508664	0.497759	0.512551	0.55594	0.507991
0.443263	0.457276	0.500374	0.500236	0.495406	0.479863	0.473487	0.438701
0.510813	0.508664	0.500236	0.476687	0.470557	0.483302	0.431203	0.395152
0.517196	0.497759	0.495406	0.470557	0.45515	0.444045	0.398634	0
0.583199	0.512551	0.479863	0.483302	0.444045	0.437433	0.378761	0
0.610128	0.55594	0.473487	0.431203	0.398634	0.378761	0	0

NETWORK OUTPUT:

0.427589	0.447026	0.508674	0.549662	0.569219	0.572917	0.539595	0.46542
0.446869	0.477443	0.516552	0.546463	0.538874	0.505388	0.503192	0.446258
0.507983	0.514741	0.525689	0.514083	0.511242	0.476802	0.441103	0.410564
0.54854	0.545098	0.514797	0.479819	0.467044	0.453408	0.414079	0.382999
0.569261	0.538334	0.509954	0.467494	0.451435	0.43891	0.402716	0.001269
0.572077	0.505495	0.475633	0.453786	0.440266	0.432175	0.381674	0.001224
0.538711	0.503893	0.439558	0.413739	0.401721	0.379415	0.001546	0.001476

ERROR DIFFERENCE

-0.031739	-0.038108	-0.065411	-0.038849	-0.052023	0.010282	0.070533	0.084564
-0.037951	-0.054361	-0.059276	-0.037799	-0.041115	0.007163	0.052748	0.061733
-0.06472	-0.057465	-0.025315	-0.013847	-0.015836	0.003061	0.032384	0.028137
-0.037727	-0.036434	-0.014561	-0.003132	0.003513	0.029894	0.017124	0.012153
-0.052065	-0.040575	-0.014548	0.003063	0.003715	0.005135	-0.004082	-0.001269
0.011122	0.007056	0.00423	0.029516	0.003779	0.005258	-0.002913	-0.001224
0.071417	0.052047	0.033929	0.017464	-0.003087	-0.000654	-0.001546	-0.001476

RELATIVE ERROR

-8.02%	-9.32%	-14.76%	-7.61%	-10.06%	1.76%	11.56%	15.38%
-9.28%	-12.85%	-12.96%	-7.43%	-8.26%	1.40%	9.49%	12.15%
-14.60%	-12.57%	-5.06%	-2.77%	-3.20%	0.64%	6.84%	6.41%
-7.39%	-7.16%	-2.91%	-0.66%	0.75%	6.19%	3.97%	3.08%
-10.07%	-8.15%	-2.94%	0.65%	0.82%	1.16%	-1.02%	
1.91%	1.38%	0.88%	6.11%	0.85%	1.20%	-0.77%	
11.71%	9.36%	7.17%	4.05%	-0.77%	-0.17%		

TABLE A-26 (CONTINUED)

DESIRED OUTPUT: LOGARITHMICALLY SCALED RELATIVE POWER

0.40671	0.421604	0.458487	0.525434	0.515741	0.557026	0.559188	0.483302
0.421604	0.438542	0.477411	0.5302	0.503518	0.495822	0.511215	0.432969
0.458487	0.477411	0.533645	0.539954	0.516006	0.479143	0.452859	0.405688
0.525434	0.5302	0.539954	0.554126	0.504199	0.496238	0.428135	0.382557
0.515741	0.503518	0.516006	0.504199	0.478855	0.457731	0.403464	0
0.557026	0.495822	0.479143	0.496238	0.457731	0.449941	0.38507	0
0.559188	0.511215	0.452859	0.428135	0.403464	0.38507	0	0

NETWORK OUTPUT:

0.436249	0.455377	0.510911	0.557102	0.575928	0.586514	0.550355	0.456697
0.45617	0.484083	0.521086	0.553917	0.551135	0.526236	0.505012	0.432128
0.510227	0.518667	0.533941	0.534422	0.524091	0.486212	0.440568	0.396624
0.556692	0.552293	0.534196	0.496047	0.468761	0.448359	0.411514	0.375503
0.57655	0.550852	0.523215	0.470254	0.438207	0.418042	0.3877	0.001373
0.58686	0.525485	0.486698	0.450359	0.417268	0.404915	0.362981	0.001321
0.551217	0.505894	0.439999	0.412052	0.387036	0.362494	0.001677	0.001609

ERROR DIFFERENCE

-0.029539	-0.033773	-0.052424	-0.031668	-0.060187	-0.029488	0.008833	0.026605
-0.034566	-0.045541	-0.043675	-0.023717	-0.047617	-0.030414	0.006203	0.000841
-0.05174	-0.041256	-0.000296	0.005532	-0.008085	-0.007069	0.012291	0.009064
-0.031258	-0.022093	0.005758	0.058079	0.035438	0.047879	0.016621	0.007054
-0.060809	-0.047334	-0.007209	0.033945	0.040648	0.039689	0.015764	-0.001373
-0.029834	-0.029663	-0.007555	0.045879	0.040463	0.045026	0.022089	-0.001321
0.007971	0.005321	0.01286	0.016083	0.016428	0.022576	-0.001677	-0.001609

RELATIVE ERROR

-7.26%	-8.01%	-11.43%	-6.03%	-11.67%	-5.29%	1.58%	5.50%
-8.20%	-10.38%	-9.15%	-4.47%	-9.46%	-6.13%	1.21%	0.19%
-11.28%	-8.64%	-0.06%	1.02%	-1.57%	-1.48%	2.71%	2.23%
-5.95%	-4.17%	1.07%	10.48%	7.03%	9.65%	3.88%	1.84%
-11.79%	-9.40%	-1.40%	6.73%	8.49%	8.67%	3.91%	
-5.36%	-5.98%	-1.58%	9.25%	8.84%	10.01%	5.74%	
1.43%	1.04%	2.84%	3.76%	4.07%	5.86%		

APPENDIX B

EXPERT SYSTEM FILES

TABLE B-1: CORE DESCRIPTION FILE

Position	Class	Right	Left	Top	Bottom	Status	Distance
11	center	12	nil	nil	nil	empty	0
12	horizontal	13	11	nil	22	empty	1
13	horizontal	14	12	nil	23	empty	2
14	horizontal	15	13	nil	24	empty	3
15	horizontal	16	14	nil	25	empty	4
16	horizontal	17	15	nil	26	empty	5
17	horizontal	18	16	nil	27	empty	6
18	horizontal	rf	17	nil	28	empty	7
22	diagonal	23	nil	12	nil	empty	1
33	diagonal	34	nil	23	nil	empty	2
44	diagonal	45	nil	34	nil	empty	3
55	diagonal	56	nil	45	nil	empty	4
66	diagonal	67	nil	56	nil	empty	5
23	in-between	24	22	13	33	empty	2
24	in-between	25	23	14	34	empty	3
25	in-between	26	24	15	35	empty	4
26	in-between	27	25	16	36	empty	5
27	in-between	28	26	17	37	empty	6
28	in-between	rf	27	18	38	empty	7
34	in-between	35	33	24	44	empty	3
35	in-between	36	34	25	45	empty	4
36	in-between	37	35	26	46	empty	5
37	in-between	38	36	27	47	empty	6
38	in-between	rf	37	28	48	empty	7
45	in-between	46	44	35	55	empty	4
46	in-between	47	45	36	56	empty	5
47	in-between	48	46	37	57	empty	6
48	in-between	rf	47	38	rf	empty	7
56	in-between	57	55	46	66	empty	5
57	in-between	rf	56	47	67	empty	6
67	in-between	rf	66	57	rf	empty	6

TABLE B-2: INPUT FILE FOR EXPERT SYSTEM

Assembly ID	Batch	Location	K-INF
a1	third	11	0.811
a2	second	12	2.002
a8	first	18	3.00
a3	third	13	1.13
a4	second	14	2.0
a5	third	15	1.45
a6	second	16	1.1
a7	first	17	3.21
b1	third	22	0.987
c1	second	33	1.2
d1	third	44	0.78
e1	first	55	2.7
f1	first	66	2.98
b2	second	23	1.35
b3	second	24	2.03
b4	first	25	2.34
b5	first	26	2.45
b6	first	27	2.75
b8	first	28	2.80
c2	third	34	1.25
c3	third	35	1.26
c4	second	36	1.45
c5	second	37	1.54
c6	first	38	2.023
d2	third	45	0.876
d4	third	46	0.967
d5	second	47	2.356
d6	second	48	2.42
e2	third	56	1.23
e3	second	57	2.76
f2	first	67	3.05

APPENDIX C

THE RPM CODE

APPENDIX C

THE RPM CODE

In this appendix the equations used in the RPM code are discussed.

BACKGROUND:

The RPM code is based on the linear reactivity model. [2] In this model the basic relationship between reactivity and burnup is a linear one:

$$\rho = \rho_o - AB, \qquad \text{(C.1)}$$

where B is burnup.

Reactivity, ρ_o, is measured by extrapolation when xenon and samarium have come to equilbrium. The slope A is a strong function of the fuel conversion ratio and hence unique for each combination of initial fuel enrichment and fuel-to-moderator ratio.

Equation (C.1) can be used with a batch-by-batch analysis or an assembly-by-assembly analysis. In the RPM code, the analysis is performed based on a fuel assembly.

REACTIVITY-BASED POWER-SHARING RELATION:

The method used in the construction of the RPM program is the group-and-one-half diffusion equation. Applying the two-group diffusion equation for any space under consideration yields, for the fast group, the following:

$$-D_1\nabla^2\phi_1+\Sigma_{a1}\phi_1+\Sigma_{12}\phi_1-\frac{1}{k}(\nu\Sigma_{f1}\phi_1+\nu\Sigma_{f2}\phi_2)=0, \tag{C.2}$$

where

D_1 is fast group diffusion coefficient,

ϕ_1 is fast group flux,

ϕ_2 is thermal group flux,

Σ_{a1} is fast group absorption cross section,

Σ_{12} is fast group scattering cross section,

Σ_{f1} is fast group fission cross section,

Σ_{f2} is thermal group fission cross section,

ν is average number of neutrons released per fission, and

k is effective multiplication factor.

For the thermal group,

$$-D_2\nabla^2\phi_2+\Sigma_{a2}\phi_2-\Sigma_{12}\phi_1=0, \tag{C.3}$$

where

D_2 is thermal group diffusion coefficient, and

Σ_{a2} is fast group absorption cross section.

The group-and-one-half model is obtained by assuming the thermal leakage to be zero. This is a valid assumption, since the thermal leakage is typically less than

5% of thermal absorption. This reduces equation (C.3) to:

$$\Sigma_{a2}\phi_2 = \Sigma_{12}\phi_1$$

or

$$\phi_2 = \frac{\Sigma_{12}\phi_1}{\Sigma_{a2}}. \tag{C.4}$$

The corresponding two-group reactivity, ρ, is given by:

$$\rho = \frac{(\nu\Sigma_{f1}\phi_1+\nu\Sigma_{f2}\phi_2)-(\Sigma_{a1}\phi_1+\Sigma_{a2}\phi_2)}{(\nu\Sigma_{f1}\phi_1+\nu\Sigma_{f2}\phi_2)}. \tag{C.5}$$

Combining Eqs. (C.2), (C.4) and (C.5) yields, for a critical system (k = 1.0):

$$\nabla^2\phi_1+\frac{1}{M^2}\left(\frac{\rho}{1-\rho}\right) = 0, \tag{C.6}$$

where M^2 is the migration area, defined as:

$$M^2 = \frac{D_1}{\Sigma_{12}+\Sigma_{a1}}. \tag{C.7}$$

The fast flux can be related to the local power density, q, since:

$$q = \kappa(\Sigma_{f1}\phi_1+\Sigma_{f2}\phi_2), \tag{C.8}$$

where κ is energy yield per fission (MeV/fission),

or using Eq. (C.4) for ϕ_2 ,

$$q=\kappa(\Sigma_{f1}+\Sigma_{f2}\frac{\Sigma_{12}}{\Sigma_{a2}})\phi_1. \tag{C.9}$$

Combining Eqs. (C.5), (C.6), and (C.9) after some manipulation,

$$\nabla^2[q(1-\rho)]+\frac{\rho q}{M^2}=0. \tag{C.10}$$

Normalizing by total power, Q, yields the following equation for each mesh point:

$$\nabla^2[f_i(1-\rho_i)]+\frac{\rho_i f_i}{M^2}=0. \tag{C.11}$$

where

f_i is assembly i power fraction.

ALGORITHMS USED IN RPM PROGRAM:

The application of numerical methods to equation (C.11) can permit a computer to solve the equation for a set of fuel assemblies loaded to the reactor core. The number of fuel assemblies used in this model is 193. The backward finitedifference approximation for each mesh point i and its four neighbors can be evaluated as follows:

$$f_i = \frac{\frac{1}{(4-R)} \sum_{j=1}^{4-R} f_j \left[1 - \left(\frac{3-\theta}{2}\right) \rho_j\right]}{1 - \left[\theta + \frac{R(R+1)}{4} (\theta - 1)\right] [\rho_i - R . \rho_L]}, \tag{C.12}$$

where

f_i is power fraction; power of fuel assembly i relative to that of core-average assembly,

f_j is power fraction; power of fuel assembly j relative to that of core-average assembly,

ρ_L is leakage reactivity,

ρ_i is reactivity of the ith fuel assembly,

ρ_j is reactivity of the jth fuel assembly adjacent to the ith assembly,

R is the number of neighbors that are reflector nodes (R = 0,1,2), and

θ is the coupling constant, which can be obtained as follows:

$$\theta = 1 + \frac{1}{6} \frac{h^2}{M^2}, \tag{C.13}$$

where

h is assembly width, and

M^2 is the migration area.

Once this has been accomplished, the mean potential reactivity of the core is given by the power-weighted relation:

$$\overline{\rho_c}=\sum_{i=1}^{N}\frac{f_i(\rho_i-\rho_{BPi}-A_i\overline{f_i}B_c)}{\sum_{i=1}^{N}f_i}, \tag{C.14}$$

where

ρ_{BP} is burnable poison reactivity, and

B_c is cycle burnup.

The quantity f_i is the cycle average power of the assembly i:

$$\overline{f_i}=\frac{f_{i,BOC}+f_{i,EOC}}{2}. \tag{C.15}$$

The leakage reactivity is given by

$$\overline{\rho_L}=\frac{\sum_{i=1}^{N}f_i.NF.RQ}{\sum_{i=1}^{N}f_i}, \tag{C.16}$$

where

NF is the number of assembly faces (0,1, or 2) exposed to the reflector, and

RQ is the fraction of assembly-born neutrons leaking per reflected face.

The required soluble poison (SP) reactivity is given by

$$\rho_{sp} = \overline{\rho_c} - \overline{\rho_L}. \qquad (C.17)$$

The thermal leakage correction is applied at BOC and EOC to the converged set of power fractions, f_i :

$$\frac{\Delta f_i}{f_i} = -TL.\rho_i. \qquad (C.18)$$

where

TL = 4L/h, the thermal leakage correction,

where

L is diffusion length, and

h is the assembly width.

DESCRIPTION OF PROGRAM:

The user starts the program by typing RPM. Two different sets of inputs are needed to run the program core parameters and assembly parameters. The core parameters are as follows:

1) specified end of cycle reactivity
2) power sharing factor
3) thermal leakage correction factor
4) radial leakage factor
5) number of different assembly types

6) number of iterations

The assembly parameters are as follows:

1) assembly type
2) assembly potential reactivity
3) slope, A (Kg/MWd)
4) burnable poison reactivity

The RPM code evaluates the following:

1) relative power distribution at BOC
2) poisoned reactivity required to keep the system critical
3) relative power distribution at EOC
4) assembly cycle burnup
5) core average power
6) core average cycle burnup
7) leakage reactivity

The program also permits the user to coastdown the reactor core. Coastdown is one of the methods used to strech out the reactor cycle. In coastdown, the extra reactivity is obtained by reducing the core power (hence, mean fuel temperature and xenon concentration) and/or moderator temperature. The code asks the user if he or she wishes to coastdown the reactor core. The user provides the code with a negative amount of reactivity. Then the code evaluates the assembly relative power and burnup.

APPENDIX D

LEOPARD CODE

APPENDIX D

LEOPARD CODE

LEOPARD (Lifetime Evaluating Operations Pertinent to the Analysis of Reactor Design) is a zero-dimensional neutronic code. The code performs neutronic calculations, including fast and thermal spectra and fuel depletion analysis. It utilizes the MUFT-SOFOCATE model. [21] This appendix describes geometry and initial isotopic treatment, thermal spectrum calculations, fast spectrum calculations and fuel depletion analysis performed by LEOPARD.

GEOMETRY AND ISOTOPIC TREATMENT:

LEOPARD views the reactor core as a large array of identical cylindrical fuel cells arranged in a square or a hexadiagonal lattice. Each fuel cell contains four regions: pellet region, clad and void region, moderator region, and an extra region. The extra region represents the percent of the core comprised of control rod followers, water slots, assembly cans and structure. Each region is provided by the user in the form of a volumetric percentage. A typical description might be:

a. pellet	100% UO2
b. clad and void	85% ss 304,15% void
c. moderator	100% H2O
d. extra	40% ss 304, 40% H2O, 20% Zr-2

The user is also allowed to supply a non-lattice fraction. The non-lattice fraction is the fraction of the total core which is not unit fuel cells.

The lattice dimensions are supplied by the user. These include pellet radius, clad outer radius, and the lattice pitch. Other dimensions not provided by the user are inferred by the code from geometry. The user is allowed to enter the dimensions as cold or hot. The code corrects these dimensions if they are cold, based on the effects of temperature on materials using elemental thermal expansion coefficients.

ISOTOPIC TREATMENT:

For each one of the regions discussed, a number density vector is evaluated by

$$N_{i,j}=\frac{f_{i,j}B_i}{[1+\alpha(T_j-68F)]^3} \qquad \text{(D.1)}$$

where i denotes an element or pseudo element,

j denotes a region,

f is the user's supplied regional volume fraction for the element or pseudo element,

B is the reference elemental number density (atoms per cubic angstrom),

T is the regional temperature (°F),

α is the elemental thermal expansion coefficient, (inch/inch °F), and

N is the resultant number density (atoms per cubic angstrom)

The homogenized number densities can be calculated by:

$$\overline{N_i} = \frac{\sum_{J=1}^{4} N_{i,j} V_j}{\sum_{J=1}^{4} V_j} \qquad \text{(D.2)}$$

where V_j is the regional volume or volume fraction.

THERMAL SPECTRUM CALCULATIONS:

The SOFOCATE model is used to calculate thermal constants averaged over the Wigner-Wilkins spectrum using 172 energy groups [21]. The thermal energy extends from 0.625 eV to zero eV. The thermal constants incude disadvantage factors and macroscopic cross sections. Each energy group is homogenized using the ABH method. [21] One difference between the calculation of disadvantage factors using LEOPARD and using the SOFOCATE model is that, in LEOPARD, the disadvantage factors are energy-dependent and inherent in the spectrum calculation, where in the SOFOCATE model, they must be determined *a priori.* A Maxwellian distribution is also available in LEOPARD.

FAST SPECTRUM CALCULATIONS:

The MUFT model is used to calculate the fast neutron cross section. MUFT is a 54-group, Fourier transform, slowing-down code which utilizes the B_1 and Grueling-Goertzel approximations. [21] The upper limit of the fast group is 10 MeV.

The cutoff energy is 0.625 eV.

BURNUP CALCULATIONS:

In performing burnup calculations, LEOPARD considers only these groups of related elements:

a. Thorium 232 through uranium 236

b. Uranium 238 through plutonium 242

c. Promethium 149 and samarium 149

d. Iodine 135 and xenon 135

e. One pseudo element accounting for all other fission products.

A set of differential equations has been written for all of the above groups, and a solution for the isotopic concentration of each element can be obtained. [21]

VITA

Faisal Husni Al-Gutifan was born in Deraa, Syria on January 16, 1964. He graduated from Deraa High School in June, 1982. He entered the University of Tennessee at Martin in September, 1983. He transferred to the University of Tennessee, Knoxville in June, 1986 and in August, 1988 received the Bachelor of Science degree in Nuclear Engineering. He reentered the University of Tennessee, Knoxville in January, 1989 and in December, 1991 received the Master of Science in Nuclear Engineering.