Key Words: Heat Exchanger Leak
KCTA Code
Radionuclide Relese

Retention: Lifetime

A MODEL FOR RADIONUCLIDE TRANSPORT IN THE COOLING WATER SYSTEM (U)

S. D. Kahook

Issued: August 1992

SRTC

SAVANNAH RIVER TECHNOLOGY CENTER
AIKEN, SC 29808
Westinghouse Savannah River Company
Savannah River Site
Aiken, SC 29808

PREPARED FOR THE U.S. DEPARTMENT OF ENERGY UNDER CONTRACT NO. DE-AC09-89SR18035

Kevin O'Kula 8-7-92

K. R. O'Kula, Authorized Derivative Classifier Date

Document: WSRC-TR-92-261

Title: A MODEL FOR RADIONUCLIDE TRANSPORT IN THE COOLING WATER SYSTEM (U)

Revision Number: 0

Approvals

S. D. Kahook, Author	8/4/92 DATE
T. E. Britt, Technical Reviewer	8/14/92 DATE
A. A. Simpkins, Technical Reviewer	8 14-92 DATE
K. R. O'Kula, Manager	8-14-92 DATE
M. J. Hitchler, Manager	8/17/92 DATE

ABSTRACT

A radionuclide transport model developed to assess radiological levels in the K-reactor Cooling Water System (CWS) in the event of an inadvertent process water (PW) leakage to the cooling water (CW) in the heat exchangers (HX) is described. During and following a process water leak, the radionuclide transport model determines the time-dependent release rates of radionuclide from the cooling water system to the environment via evaporation to the atmosphere and blow-down to the Savannah River. The developed model allows for delay times associated with the transport of the cooling water radioactivity through cooling water system components. Additionally, this model simulates the time-dependent behavior of radionuclides levels in various CWS components. The developed model is incorporated into the **K**-reactor **C**ooling **T**ower **A**ctivity (**KCTA**) code. **KCTA** allows the accident (heat exchanger leak rate) and the cooling tower blow-down and evaporation rates to be described as time-dependent functions. Thus, the postulated leak and the consequence of the assumed leak can be modelled realistically.

This model is the first of three models to be ultimately assembled to form a comprehensive Liquid Pathway Activity System (LPAS). LPAS will offer integrated formation, transport, deposition, and release estimates for radionuclides formed in a SRS facility. Process water and river water modules are forthcoming as input and downstream components, respectively, for **KCTA**.

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND SYMBOLS

ALARA As Low As Reasonably Achievable;

A_i^e initial steady state rate of release of the i^{th} radionuclide to the environment by means of evaporation;

A_i^{Bd} initial steady state rate of release of the i^{th} radionuclide to the environment by means of blow down to the river;

A_i^{rel} inititial total steady state rate of release of the i^{th} radionuclide to the environment by all pathways;

Bd(t) cooling tower blow-down rate (gpm: gallons per minute);

Ci curie which is equal to 3.7×10^{10} disintegrations per second;

$c_i^T(t)$ i^{th} radionuclide concentration in the cooling tower;

Cw Cooling Water;

CV Control Volume;

CWS Cooling Water System;

CY Calendar Year;

DOE Department of Energy;

E(t) cooling tower evaporation rate (gpm);

R(t) recirculation flow rate from the cooling tower to the 186-Basin (gpm);

HX Heat Exchanger;

I/O Input/Output;

KCTA K-reactor Cooling Tower Activity code;

$N_i^m(t)$ activity level of the i^{th} radionuclide in the m^{th} CV;

$N_i^{m \leftarrow n}(t)$ activity level of the i^{th} radionuclide transported from the n^{th} to the m^{th} CV;

$N^{m}_{i\leftarrow j}(t)$ activity level of the i^{th} radionuclide's parent (the j^{th} parent);

LPAS Liquid Pathway Activity System;

$f^{m\leftarrow n}$ ratio of radionuclides that reach the n^{th} CV to the radionuclides that left the m^{th} CV;

λ_i decay constant of the i^{th} radionuclide;

τ^{m}_{r} effective residence time of radionuclides in the m^{th} CV;

$\tau^{m\leftarrow n}_{t}$ effective delay time for the transport of radionuclides from the n^{th} to the m^{th} CV;

NF number of control volumes in the system;

NR number of radionuclides in the system;

PC Personal Computer;

PW Process Water;

RHS Right Hand Side;

RW River Water;

S^{Cw}_{i0} initial steady-state cooling water makeup flow;

S^{Pw}_{i0} initial steady-state process water in-leakage;

SAR Safety Analysis Report;

SRS Savannah River Site;

SRTC Savannah River Technology Center;

$T_{½}$ radionuclide's radiological half-life (sec);

V&V Verification and Validation;

WSRC Westinghouse Savannah River Company;

1.0 INTRODUCTION

1.1 Introduction

A thermal discharge mitigation system, the K-reactor cooling tower, is to be tied-in to the cooling water system by end of CY 1992. Previously, environmental discharge of core heat transferred from the process water system (PWS) to the cooling water system (CWS) was directly to the Savannah River via surface streams. Cooling water discharge to the K-011 effluent canal was at a maximum flow of 179,000 gpm and at 171° F for reactor power levels of 2400 - 2500 MW. Implementation of the Cooling Tower in the CWS for the K-reactor reduces the effluent cooling water discharge to a constant flow of 20,000 gpm at a maximum temperature of 90° F. Thus, the Cooling Tower results in a significant reduction in the thermal energy released to the Savannah River.

Additionally, prior to Cooling Tower tie-in, any PW heat exchanger leak is released to the Savannah River (via discharge to the K-011 effluent canal) at the same rate as the process water leakage is introduced to the cooling water. The incorporation of the Cooling Tower makes the cooling water a quasi-closed system, releases of radionuclides to the environment with the Cooling Tower installed needs to be addressed. That is, due to the differences between the two operating conditions, pre- and post-Cooling Tower tie-in, the radiological impacts (occupational and environmental) of leakage to the heat exchangers are different. Therefore, a radionuclide transport code has been developed in order to assess the radiological impact of the Cooling Tower to the public by means of radionuclide releases to the environment (evaporation and blow-down to the river) and to employees by means of radionuclide levels in CWS components as a results of an inadvertent heat exchanger leak.

1.2 Summary

This report describes a radionuclide transport model developed to assess radiological levels in the K-reactor Cooling Water System (CWS) in the event of operational and accidental process water (PW) leaks to the cooling water (CW) in the heat exchangers (HX). During and following a PW leaks the radionuclide transport model determines the time-dependent release rates of radionuclides from the CWS to the environment via evaporation to the atmosphere and blow-dowr to the Savannah River. Additionally, this model simulates the time-dependent behavior of radionuclide levels in various CWS components. Results obtained from this model will be used to determine

occupational radiological exposures and to determine population dose rates as a result of releases of radionuclides via evaporation and blow-down.

Additional models are forthcoming. The model presented in this report will be integrated with additional models. This will allow comprehensive treatment of liquid-borne radionuclide production, deposition, and transport in the process and cooling water systems. Ultimate radiological impacts to workers and the general public will also be predicted upon model completion.

1.3 Expected Radiological Impacts of the Cooling Tower

With regard to radionuclide releases to the environment, there are three main differences between operating with and without a Cooling Tower. They are:

1. **Release Pathways.** In the case of the online Cooling Tower, aqueous radionuclides are released to the environment via evaporation from the cooling tower and blow-down to the river. For the case of the Cooling Tower not implemented, the only pathway to introduce aqueous radionuclides to the environment is by means of cooling water discharge to the river.

2. **Rates of Release.** The rate of radionuclide release to the environment is higher for the case without a Cooling Tower provided that the leak duration is not prolonged. This is due to the fact that the CWS with the Cooling Tower is a quasi-closed loop. Since only a fraction of the CWS water inventory is released to the environment, only a fraction of the radionuclides present in the CWS is released to the environment. However, once the leaking heat exchanger(s) is(are) isolated, the case without the Cooling Tower will cease to release radionuclides to the environment while the CWS with online Cooling Tower continues to discharge radionuclides due to radionuclide inventory buildup in its components during the PW leak.

3. **Amounts of Release.** For short-lived radionuclides ($T_{1/2} \approx$ hours or less), the CWS with the Cooling Tower online discharges less radioactivity to the environment. This is due to holding times in the Cooling Tower System being longer as a result of being a quasi-closed loop and due to long residence times in the CWS components. The residence time in the Cooling Tower System is about 2.6 hours due to both the 25 million gallon basin (186-Basin) and the 3 million gallon cooling tower basin. During the relatively long holding times, a fraction of the short-lived radionuclides are lost by means of radioactive decay. However, for long-lived radionuclides ($T_{1/2} \approx$ days), the CWS with the

online Cooling Tower will eventually release the same amount of radionuclides as the case without a Cooling Tower (provided that a release pathway remains in existence, e.g., evaporation and/or blow-down), except the release is over an extended period of time, as mentioned in item 2 above. An example of this class of radionuclides is tritium (^3H). The delay times may be significant, so that effective precautions are available.

In Section 4.0 of this report, comparisons of the effects of operating with and without a cooling tower are presented for the December 1991 process water leak.

1.4 Report Organization

The report is divided into the following sections:

1.0 INTRODUCTION

A preview of the pre- and post-Cooling Tower conditions is included in this section. A qualitative description of the differences associated with operating the reactor with and without the cooling tower water system is also included in this section.

2.0 MODEL DEVELOPMENT

A description of the CWS radionuclide transport model is included in this section. Assumptions employed during development of this model and limitations of this model are also presented in this section.

3.0 DESCRIPTION OF THE KCTA CODE

This section describes the KCTA (**K**-reactor **C**ooling **T**ower Water System **A**ctivity) code which incorporates the CWS radionuclide transport model. The different modules, execution sequence, and input requirements are described in this section.

4.0 CASE STUDY

This section compares the effect of operating with and without a cooling tower for the December 1991 process water leak.

5.0 LIMITATIONS AND FUTURE WORK

This section summarizes the work performed in this report. Assumptions and limitations employed in developing the model and the **KCTA** code are also presented. Recommendations for future work and modifications to the model are given.

APPENDIX A

The data files connected to the KCTA code during execution are described in this appendix. These files are the input data file, the output data file, and the data base file. A sample input file and the obtained output file are also described in Appendix A.

APPENDIX B

A Fortran listing of the KCTA code is included in Appendix B, and the variables used in the KCTA code are included in the Fortran source file.

2.0 MODEL DEVELOPMENT

2.1 General Radionuclide Transport Model

The equation governing the time dependent behavior of the activity level for the i^{th} radionuclide in the m^{th} control volume (CV) is the following:

$$\frac{d}{dt}N_i^m(t) = \sum_{k\neq m}^{NF} f^{m\leftarrow k}\, N_i^{m\leftarrow k}(t-\tau_t^{m\leftarrow k})\, e^{-\lambda_i \tau_t^{m\leftarrow k}} \Big/ \tau_r^k \;-\; N_i^m(t)\left\{\lambda_i + 1\Big/\tau_r^m\right\}$$

$$+ \sum_{j\neq i}^{NR} \lambda_j \left\{ N_{i\leftarrow j}^m(t) + \sum_{\ell\neq m}^{NF} N_{i\leftarrow j}^{m\leftarrow \ell}(t) \right\} \qquad (2\text{-}1)$$

where

$N_i^m(t)$ activity level of the i^{th} radionuclide in the m^{th} CV;

$N_i^{m\leftarrow k}(t)$ activity level of the i^{th} radionuclide transported from the k^{th} to the m^{th} CV;

$N_{i\leftarrow j}^m(t)$ activity level of the i^{th} radionuclide's parent (the j^{th} parent) in the m^{th} CV;

$N_{i\leftarrow j}^{m\leftarrow \ell}(t)$ activity level of the i^{th} radionuclide's parent (the j^{th} parent) in all loops connected to the m^{th} CV;

$f^{m\leftarrow k}$ fraction of the k^{th} CV radionuclides that are directed to the m^{th} CV;

λ_i decay constant of the i^{th} radionuclide;

τ_r^m effective residence time of radionuclides in the m^{th} CV;

$\tau_t^{m\leftarrow k}$ effective delay time for the transport of radionuclides from the k^{th} to the m^{th} CV;

NF number of control volumes in the system;

NR number of different radionuclides present (or examined) in the system;

t time (sec).

The first term on the right hand side (RHS) of Equation (2-1) describes the rate of inflow of the i^{th} radionuclide into the m^{th} CV from all other control volumes. A correction factor is used in the first term to account for decay of the radionuclides in the loop connecting the k^{th} to the m^{th} CV. The second term on the RHS of Equation (2-1) describes the loss rate of the i^{th} radionuclide as a result of radioactive decay in the m^{th} CV and as a result of outflow from the m^{th} CV. The third term on the RHS of Equation (2-1) describes the production rate of the i^{th} radionuclide from the decay of parent radionuclides in the m^{th} CV and in the loops connecting all other control volumes to the m^{th} CV. Implicit assumptions in Equation (2-1) are the following:

(1) perfect mixing of radionuclides in the control volumes, and

(2) slug flow outside the control volumes (in the connecting loops).

2.2 K-Reactor Cooling Tower Water System

Shown in Figure 2-1 is a block diagram of the K-reactor secondary cooling system. As indicated in the figure, there are only three control volumes that are of interest which may contain radionuclides. The control volumes are the heat exchanger system, the 186-Basin, and the cooling tower. Figure 2-1 also shows two additional potential sources for radionuclides: the cooling water makeup flow, Cw(t), and the process water leakage to the cooling water in the heat exchangers, Pw(t).

Employing Equation (2-1) to the control volumes of the block diagram shown in Figure 2-1 results in the following equations:

$$\frac{d}{dt}N_i^X(t) = N_i^B(t-\tau_t^{X\leftarrow B})\, e^{-\lambda_i \tau_t^{X\leftarrow B}} \Big/ \tau_r^B + N_i^{Pw}(t-\tau_t^{X\leftarrow Pw})\, e^{-\lambda_i \tau_t^{X\leftarrow Pw}} \Big/ \tau_r^{Pw} + \sum_{j\neq i}^{NR} \lambda_j \left\{ N_{i\leftarrow j}^X(t) + N_{i\leftarrow j}^{X\leftarrow B}(t) + N_{i\leftarrow j}^{X\leftarrow Pw}(t) \right\} - N_i^X(t) \left\{ \lambda_i + 1/\tau_r^X \right\} \qquad (2\text{-}2)$$

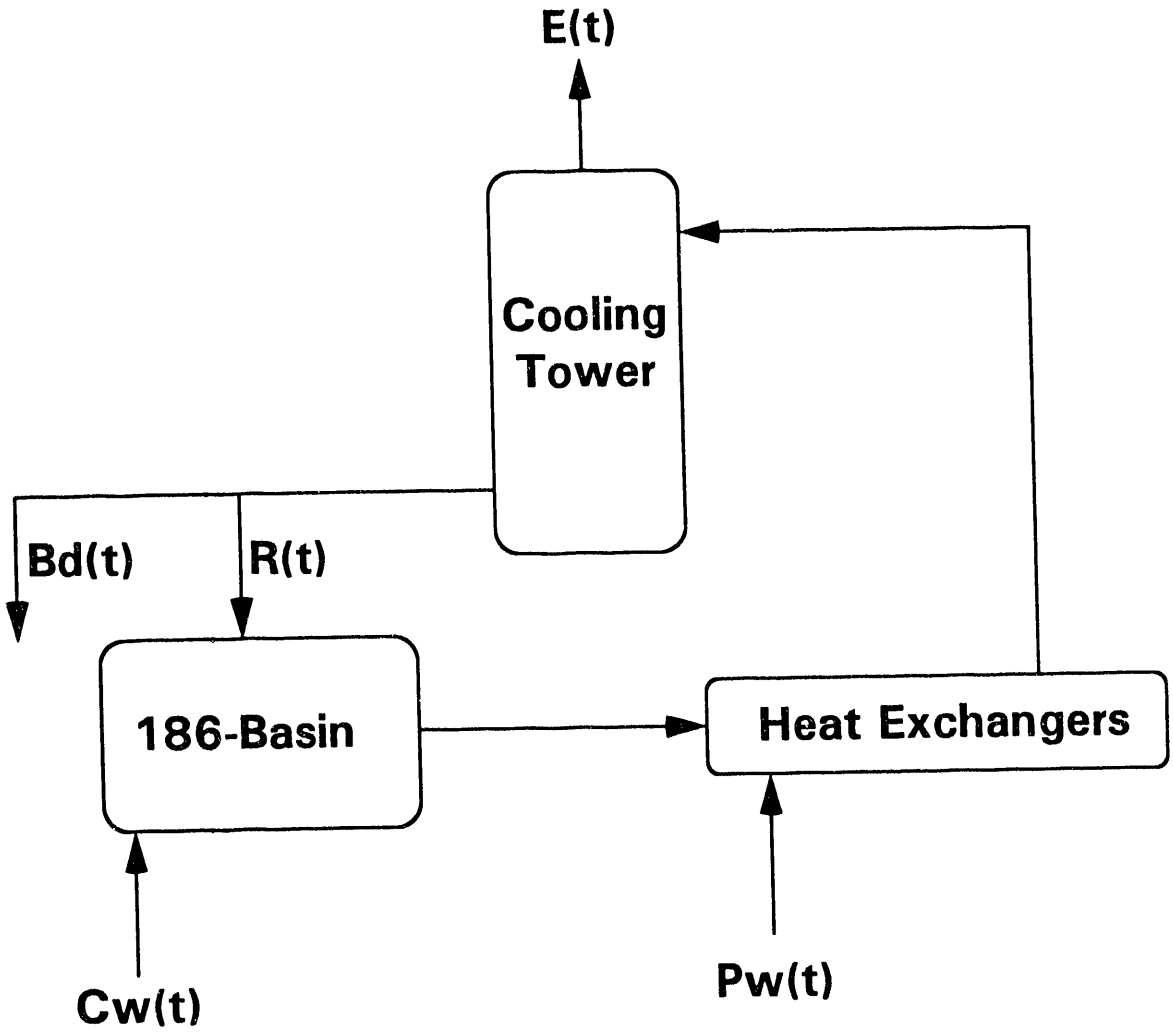

Figure 2-1.

Schematic of the K-Reactor Cooling Tower Water System

$$\frac{d}{dt}N_i^B(t) = f^{B\leftarrow T}\,N_i^T(t-\tau_t^{B\leftarrow T})\,e^{-\lambda_i\tau_i^{B\leftarrow T}}\Big/\tau_r^T + N_i^{Cw}(t-\tau_t^{B\leftarrow Cw})\,e^{-\lambda_i\tau_i^{B\leftarrow Cw}}\Big/\tau_r^{Cw} + \sum_{j\neq i}^{NR}\lambda_j\left\{N_{i\leftarrow j}^B(t) + N_{i\leftarrow j}^{B\leftarrow T}(t) + N_{i\leftarrow j}^{B\leftarrow Cw}(t)\right\} - N_i^B(t)\left\{\lambda_i + 1/\tau_r^B\right\} \quad (2\text{-}3)$$

$$\frac{d}{dt}N_i^T(t) = N_i^X(t-\tau_t^{T\leftarrow X})\,e^{-\lambda_i\tau_i^{T\leftarrow X}}\Big/\tau_r^X - N_i^T(t)\left\{\lambda_i + 1/\tau_r^T\right\} + \sum_{j\neq I}^{NR}\lambda_j\left\{N_{i\leftarrow j}^T(t) + N_{i\leftarrow j}^{T\leftarrow X}(t)\right\} \quad (2\text{-}4)$$

where superscripts "X," "T," "B," "Cw," and "Pw" are used exclusively to denote the heat exchanger system, the cooling tower, the 186-Basin, the cooling water makeup flow, and the process water in-leakage to the heat exchanger(s), respectively. The term N_i^T/τ_r^T in Equation (2-3) denotes the rate at which the i^{th} radionuclide are lost from the cooling tower via all outflow processes and $f^{B\leftarrow T}$ in Equation (2-3) is the fraction of N_i^T/τ_r^T that reaches the 186-Basin. That is

$$N_i^T(t)\Big/\tau_r^T = c_i^T(t)\left\{Bd(t) + E(t) + R(t)\right\} \quad (2\text{-}5)$$

$$f^{B\leftarrow T} = \frac{R(t)}{Bd(t) + E(t) + R(t)} \quad (2\text{-}6)$$

where

$c_i^T(t)$ i^{th} radionuclide concentration in the cooling tower;

Bd(t) cooling tower blow-down rate;

E(t) cooling tower evaporation rate;

R(t) recirculation flow rate of the CW from the cooling tower to the 186-Basin.

If the production of the i^{th} radionuclide from the decay of all its parent(s) radionuclides in all control volumes and connecting loops can be neglected, then Equations (2-2), (2-3), and (2-4) become:

$$\frac{d}{dt} N_i^X(t) = N_i^B(t-\tau_t^{X\leftarrow B})\ \epsilon_i^{X\leftarrow B} - \lambda_i^X\ N_i^X(t) + S_i^{Pw}(t) \tag{2-7}$$

$$\frac{d}{dt} N_i^B(t) = f^{B\leftarrow T}\ N_i^T(t-\tau_t^{B\leftarrow T})\ \epsilon_i^{B\leftarrow T} - \lambda_i^B\ N_i^B(t) + S_i^{Cw}(t) \tag{2-8}$$

$$\frac{d}{dt} N_i^T(t) = N_i^X(t-\tau_t^{T\leftarrow X})\ \epsilon_i^{T\leftarrow X} - \lambda_i^T\ N_i^T(t) \tag{2-9}$$

where in Equations (2-7) through (2-9), the definitions and coefficients used to reduce the complexity of analytical representations are as follows:

$$S_i^k(t) = N_i^k(t-\tau_t^{m\leftarrow k})\ e^{-\lambda_i \tau_i^{m\leftarrow k}} \Big/ \tau_r^k \tag{2-10}$$

$$\epsilon_i^{m\leftarrow k} = e^{-\lambda_i \tau_i^{m\leftarrow k}} \Big/ \tau_r^k \tag{2-11}$$

$$\lambda_i^m = \lambda_i + 1/\tau_r^m \tag{2-12}$$

2.2.1 Steady-State Solution

In order to obtain the steady state conditions for the i^{th} radionuclide activity levels in the relevant control volumes, Equations (2-7) through (2-9) are set to zero. Rearranging terms in the resultant equations and solving in terms of the initial steady-state cooling water makeup flow, S_{i0}^{Cw}, and in terms of the initial steady-state process water in-leakage, S_{i0}^{Pw}, yields the following:

$$N_{i0}^X = \left[\frac{\lambda_i^T \lambda_i^B}{\Lambda_i - \Gamma_i f^{B\leftarrow T}}\right] S_{i0}^{Pw} + \left[\frac{\lambda_i^T \epsilon_i^{X\leftarrow B}}{\Lambda_i - \Gamma_i f^{B\leftarrow T}}\right] S_{i0}^{Cw} \tag{2-13}$$

$$N_{i0}^{T} = \left[\frac{\lambda_i^B \, \epsilon_i^{T \leftarrow X}}{\Lambda_i - \Gamma_i f^{B \leftarrow T}} \right] S_{i0}^{Pw} + \left[\frac{\epsilon_i^{T \leftarrow X} \, \epsilon_i^{X \leftarrow B}}{\Lambda_i - \Gamma_i f^{B \leftarrow T}} \right] S_{i0}^{Cw} \qquad (2\text{-}14)$$

$$N_{i0}^{B} = \left[\frac{f^{B \leftarrow T} \, \epsilon_i^{B \leftarrow T} \, \epsilon_i^{T \leftarrow X}}{\Lambda_i - \Gamma_i f^{B \leftarrow T}} \right] S_{i0}^{Pw} + \left[\frac{\lambda_i^X \, \lambda_i^T}{\Lambda_i - \Gamma_i f^{B \leftarrow T}} \right] S_{i0}^{Cw} \qquad (2\text{-}15)$$

where

$$\Lambda_i = \lambda_i^X \, \lambda_i^B \, \lambda_i^T = \left(\lambda_i \tau_r^X + 1\right)\left(\lambda_i \tau_r^B + 1\right)\left(\lambda_i \tau_r^T + 1\right) \Big/ \left(\tau_r^X \, \tau_r^B \, \tau_r^T\right) \qquad (2\text{-}16)$$

$$\Gamma_i = \epsilon_i^{B \leftarrow T} \, \epsilon_i^{T \leftarrow X} \, \epsilon_i^{X \leftarrow B} = e^{-\lambda_i \left(\tau_i^{B \leftarrow T} + \tau_i^{T \leftarrow X} + \tau_i^{X \leftarrow B}\right)} \Big/ \left(\tau_r^T \, \tau_r^B \, \tau_r^X\right) \qquad (2\text{-}17)$$

where subscripts "0" denote parameters are at initial steady-state values. The initial steady state rate of release of the i^{th} radionuclide to the environment by means of evaporation (A_i^e) and blow down to the river (A_i^{Bd}), and the total release rate to the environment (A_i^{rel}) are given by the following Equations:

$$A_{i0}^{e} = \frac{f^{E \leftarrow T}}{\tau_r^T} N_{i0}^{T} = \frac{E_0 / \tau_r^T}{E_0 + Bd_0 + R_0} N_{i0}^{T} \qquad (2\text{-}18)$$

$$A_{i0}^{Bd} = \frac{f^{Bd \leftarrow T}}{\tau_r^T} N_{i0}^{T} = \frac{Bd_0 / \tau_r^T}{E_0 + Bd_0 + R_0} N_{i0}^{T} \qquad (2\text{-}19)$$

$$A_{i0}^{rel} = \frac{1 - f^{B \leftarrow T}}{\tau_r^T} N_{i0}^{T} = \frac{\left(E_0 + Bd_0\right) / \tau_r^T}{E_0 + Bd_0 + R_0} N_{i0}^{T} \qquad (2\text{-}20)$$

where

$$f^{E \leftarrow T} = \frac{E(t)}{Bd(t) + E(t) + R(t)} \qquad (2\text{-}21)$$

$$f^{Bd \leftarrow T} = \frac{Bd(t)}{Bd(t) + E(t) + R(t)} \tag{2-22}$$

In Equation (2-18), evaporation losses to the environment from the 186-Basin are assumed to be included with the evaporation losses from the cooling tower. Additionally, an inherent assumption in the derivation of the above equations is that the cooling tower water flow rate is constant.

If the i^{th} radionuclide has a half-life that is quite large relative to the control volume's residence time and the delay time associated with the transport of the radionuclides via the connecting loops, then simplifications can be employed to the radionuclide transport model for the K-reactor cooling tower water system if the following is true:

$$\epsilon_i^{m \leftarrow k} = e^{\lambda_i \tau_i^{m \leftarrow k}} \Big/ \tau_r^k \approx 1 \Big/ \tau_r^k \tag{2-23}$$

$$\lambda_i^n = \lambda_i + 1 \Big/ \tau_r^n \approx 1 \Big/ \tau_r^n \tag{2-24}$$

$$\Gamma_i \approx \Lambda_i \approx \left(\tau_r^X \tau_r^B \tau_r^T \right)^{-1} \tag{2-25}$$

Utilizing Equations (2-23) through (2-25) in Equations (2-13) through (2-15) yields the following initial steady state values:

$$N_{i0}^X = \frac{\tau_r^X}{1 - f^{B \leftarrow T}} \left\{ S_{i0}^{Pw} + S_{i0}^{Cw} \right\} \tag{2-26}$$

$$N_{i0}^T = \frac{\tau_r^T}{1 - f^{B \leftarrow T}} \left\{ S_{i0}^{Pw} + S_{i0}^{Cw} \right\} \tag{2-27}$$

$$N_{i0}^B = \frac{\tau_r^B}{1 - f^{B \leftarrow T}} \left\{ f^{B \leftarrow T} S_{i0}^{Pw} + S_{i0}^{Cw} \right\} \tag{2-28}$$

Employing Equation (2-27) for the i^{th} radionuclide activity level in the cooling tower in Equation (2-20) and solving for the total rate of release of the i^{th} radionuclide yields the following:

$$A_{i0}^{rel} = S_{i0}^{Pw} + S_{i0}^{Cw} \qquad (2\text{-}29)$$

The above equation implies, as expected, that once i^{th} radionuclide saturation levels are reached in the control volumes, then the rate of release of that radionuclide into the environment is the same as the rate it is introduced into the K-reactor cooling tower water system. (This is only true for radionuclides with half-lives that are quite large compared with the time constants of the system being considered, e.g., ^{3}H).

Equations (2-7) through (2-20) are incorporated in KCTA (K-reactor Cooling Tower Activity), a code developed as part of this work and described in Section 3. A Fortran listing of the KCTA code is presented in Appendix B.

3.0 DESCRIPTION OF THE KCTA CODE

3.1 Introduction

The **K**-reactor **C**ooling **T**ower **A**ctivity (**KCTA**) code calculates the radionuclide levels in the heat exchangers, the cooling tower, and the 186-Basin (CTW components) of the Department of Energy (DOE) reactors at the Savannah River Site (SRS). The KCTA also calculates the release rates and total release of radionuclides to the environment via evaporation to the atmosphere and blow-down to the Savannah River during and following a postulated PW leak through the heat exchangers.

The KCTA code allows the PW leak and the cooling tower evaporation and blow-down rates to be all time-dependent, thus a realistic simulation of accident (leak) can be performed.

A description of the KCTA code is included in the following section. This includes description of the modules that constitute the KCTA code.

3.2 Description of the KCTA

KCTA is written in standard Fortran-77 and operates on a Personal Computer (PC). KCTA contains six modules: MAIN, REED, STEADY, RITE1, ERRCHK, and TRANS. The Fortran listing of the KCTA code is presented in Appendix B. The variables used in the KCTA code are also described in the Fortran source file (listed in Appendix B). Descriptions of the KCTA modules are included in the following subsections.

3.2.1 The MAIN Module

In addition to controlling the execution sequence of the other modules, the MAIN module performs the following tasks:

1. Checks if the default input file "**KCTA.i**" exist on the current drive. If it does, the file is opened as an old file and assigned to I/O unit 10. Otherwise, the user is prompted to enter the name of the file containing the input data. KCTA will continue to prompt the user until a file with the input filename is found on the current drive. The name of the input file is assigned to the **INP** variable-an A12 format variable. Description

of the required input data along with the format of the input data file are included in Appendix A.

2. Checks if the default output file "**KCTA.o**" exists on the current drive. If it does, the user is prompted to enter a new filename to be used to write the output data to. KCTA will continue to prompt the user for an output file until a name for the output file is selected that does not exist on the current drive. Once a suitable output file is selected, it is opened as a new file and assigned to I/O unit 20. The name of the output file is assigned to the **OUTP** variable-an A12 format variable. The obtained output from the KCTA code is described in Appendix A.

3. Checks if the data base file "**KCTA.d**" exists on the current. If it does, it is opened as an old file and assigned to I/O unit 60. If the file "**KCTA.d**" does not exist on the current drive, the user is informed of that and execution is aborted. This file is also described in Appendix A.

If execution is not aborted the MAIN module calls the remaining modules in the following sequence: **REED**, **STEADY**, **RITE1**, **ERRCHK**, and finally **TRANS**.

3.2.2 The REED Module

The REED module is used exclusively to read in all necessary input data from the file assigned to I/O unit 10 (whose name is contained in the **INP** variable) and to read in the corresponding radionuclide data found in the data base file "**KCTA.d**". Descriptions of the required input data and the data base file are presented in Appendix A.

In addition to reading in the input data, the REED module performs the following:

1. Checks if the number of radionuclides included in the input file is greater than the maximum number allowed (50 radionuclides). If so, REED informs the user if execution is to be continued with only the first 50 radionuclides included in the simulation, or if the user wishes to abort. If the user selects the option to include only 50 radionuclides in the simulation, the remaining data for the radionuclides are ignored.

2. Checks if the radionuclide concentration are entered in units of Ci/gallons or Ci/liter. If the data is in Ci/gallon, REED converts the data to Ci/liter.

3. Searches for and reads in the required data for each radionuclide included in the simulation from the data base file "**KCTA.d.**" If data for a selected radionuclide are not found in the data base file, REED informs the user and aborts execution.

4. Returns execution to the MAIN module.

3.2.3 The STEADY Module

The STEADY module calculates constants and coefficients that are nuclide- and cooling tower parameter-dependent. Initial steady-state radionuclide activity levels in the various CTW system components and initial steady-state release rates to the environment are also calculated by the STEADY module. The following are the tasks performed by the STEADY module:

1. Converts the process water and the cooling water make-up flow rates from gallons per minute to gallons per sec.

2. Calculates both the total cooling water flow rate in the CTW system and the flow fractions from the cooling tower to the atmosphere, to the Savannah River, and to the 186-Basin using Equations (2-21), (2-22), and (2-6), respectively.

3. Calculates the resident and loop time constants using the following Equations:

$$\tau_r^m = V^m / \dot{V}_f^m \tag{3-1}$$

$$\tau_\ell^{m \leftarrow n} = V^{m \leftarrow n} / \dot{V}_f^{m \leftarrow n} \tag{3-2}$$

where V^m and $V^{m \leftarrow n}$ are the volumes of the m^{th} CV and the loop connecting the n^{th} CV to the m^{th} CV, respectively, and $\dot{V}$ is the corresponding cooling water flow rate.

4. Calculates the nuclide-CV-dependent and the nuclide-loop-dependent constants using Equations (2-11) and (2-12).

5. Calculates the initial steady-state radionuclide activity levels in the CTW components using Equations (2-13), (2-14), and (2-15).

6. Calculates the initial steady-state rate of radionuclide release to the environment via evaporation to the atmosphere and blow-down to the Savannah River using Equations (2-18), (2-19), and (2-20).

7. Returns execution to MAIN.

3.2.4 The RITE1 Module

The RITE1 module writes the input data read by the REED module and the constants and coefficients calculated by the STEADY module to the file assigned to I/O unit 20 whose name is contained in the **OUTP** variable. Description of the output obtained from KCTA is presented in Appendix A.

3.2.5 The ERRCHK Module

The ERRCHK module checks the following so that execution errors are minimized:

1. Checks if the pre-set array sizes for storing delayed term data are not exceeded by that required from the obtained loop times and requested step size. If the required array size is larger than that set by KCTA, ERRCHK aborts execution.

2. Checks if the requested time step for the simulation is within the recommended time step. The recommended time step is the smallest of the following:

   a. Half of the smallest time increment between two adjacent points used in defining the leak function.

   b. Half of the smallest of all CV residence times.

   c. Half of the smallest of all loop connection times.

If ERRCHK detects that the requested time step is greater than any of the time steps given in item (a), (b), or (c) above, the user is given the option of continuing with the execution at the requested time step, changing the time step to that recommended by ERRCHK, or aborting the program. If the time step is changed to the value recommended by ERRCHK, then the test described in item (1) above is repeated.

3. Returns execution to MAIN.

3.2.6 The TRANS Module

The TRANS module calculates the time-dependent nuclide activity level in each of the CTW components, the release rates to the environment, and the total release to the environment from t=0 sec up to the current time step for each radionuclide. For each radionuclide included in the simulation and at each time step, the TRANS module performs the following tasks:

1. Calculates the PW leak rate into the heat exchangers using linear interpolation between the points that define the leak function.

2. Obtains values for the delayed terms in Equations (2-7), (2-8), and (2-9) using the following scheme:

   a. if $t - \tau_\ell^{m \leftarrow n} \leq 0$ sec, the delayed term values are set to their initial steady-state values (calculated by the STEADY module ($N_i^{m \leftarrow n}(t-\tau_\ell^{m \leftarrow n}) = N_{i0}^n$).

   b. if $t - \tau_\ell^{m \leftarrow n} \geq 0$ sec, the delayed terms are obtained by searching the delayed term arrays for the corresponding time. That is, since the time step is fixed throughout the simulation, the number of time steps executed from time=0.0 sec to time=$t - \tau_\ell^{m \leftarrow n}$ is equal to $(t - \tau_\ell^{m \leftarrow n})/\Delta t$, where Δt is the time step. The delayed values are then obtained from the delayed term arrays.

3. Calculates the activity levels in heat exchangers, 186-Basin, and the cooling tower by integrating Equation (2-7), (2-8), and (2-9), respectively.

4. Calculates the release rates via blow-down to the Savannah River and evaporation to the atmosphere by use of Equations (2-19) and (2-20), respectively.

5. Calculates the total amount released to the environment since the initiation of the transient (i.e., since t=0 sec).

6. Checks if the calculated values are to be printed for the current time step. If so, these values are written to the output file connected to I/O unit 20.

7. Repeats steps (1) through (6) until the maximum time for the simulation is reached. If so, steps (1) through (6) are repeated for the other radionuclides included in the simulation.

8. Returns execution to MAIN.

Once execution is returned to the MAIN module from the TRANS module, MAIN will then close all I/O ports and terminate execution.

4.0 CASE STUDY

4.1 Introduction

Radionuclides release rates and total releases from the CWS to the environment due to process water leaks are investigated in this section for two CWS operational conditions: with and without an on-line cooling tower. The chosen leak scenario is the PW leak that occurred in December 1991. Although controls are now in place to prevent extended leaks such as this, it is assumed that the leak duration was again 64 hours before being isolated. Since the CWS with the cooling tower is a quasi-closed loop, radionuclides will be present for prolonged periods in CWS components, e.g., the 186-Basin. Therefore, doses to workers due to the presence of tritium in CWS components during the event are also presented in this section.

4.2 Description of Event

Approximately 5,700 Ci of tritium were released from a leaking heat exchanger to the Savannah River during the period of December 22 through December 25, 1991[1] (leak duration was estimated to be 64 hours). For an assumed tritium concentration of 8.6 Ci/liter in the PW, the December 91 leak is a relatively large PW leak: 0.046 gpm or $\approx$550 lb/day. However, current controls preclude such a long leak duration. The leak rate was estimated to be constant during the 64 hour period, i.e., $\approx$89.1 Ci/Hr during the 64 hour event.

4.3 CWS Without an On-Line Cooling Tower

The CWS without an on-line cooling tower is a once-through open system. Thus, any leak releasing PW to the CWS will release the same amount of PW at the same rate to the environment. This indicates that a total of 5,700 Ci of tritium is released to the environment at a constant rate of $\approx$89.1 Ci/Hr (2.47×10^{-2} Ci/sec). Additionally, with the exception of the tritium evaporating as it flows in the canal connecting the CWS to the Savannah River, all the tritium is released in liquid form to the environment.

4.4 CWS With a Cooling Tower On-Line

In order to investigate the radiological effects of a CWS with an on-line cooling tower the following assumptions are employed:

- The reactor is assumed to have been operating at 720 MW. This results in cooling water evaporation and blow-down rates of 6,000 gpm and 14,000 gpm, respectively. The cooling water recirculation rate is assumed to be constant at 160,000 gpm.

- The leak continues for 64 hours. However, after 64 hours the reactor is shutdown and the cooling water evaporation and blow-down rates both drop to 0.0 gpm. The cooling water gamma monitor would indicate process water leakage as well as testing controls before 64 hours elapsed. Nonetheless, the same time length is used in the illustration as occurred in December 1991.

The input file to the **KCTA** code describing this event is listed in Figure 4-1. Appendix A discusses the required input to the **KCTA** code. Results obtained from the **KCTA** code are discussed in the following subsections.

4.4.1 Tritium Concentration Levels in CWS Components

Shown in Figure 4-2 on the following page are the time dependent behavior of the tritium concentration levels in the CWS components (186-Basin, heat exchangers, and the cooling tower) during the 64-hour leak. Also shown in Figure 4-2 are the steady-state tritium concentration levels in the heat exchangers and the cooling tower. The

```
10  2.304+05 1200
87700 3.2+06 2.5+07 1+06 2+06 1.0+6
1.4+04 6.0+03 1.6+05
1
1003   8.6  -1.14-08
1.00-04 2.0+04
3
0.0    4.56-02
2.304e+05 4.56e-02
2.305e+05 0.0e-02
3
0.0    1.4+04
2.304e+05 1.4+04
2.305e+05 0.0
3
0.0    6.0+03
2.304e+05 6.0+03
2.305e+05 0.0
```

Figure 4-1. KCTA Code Input File for December 1991 Event

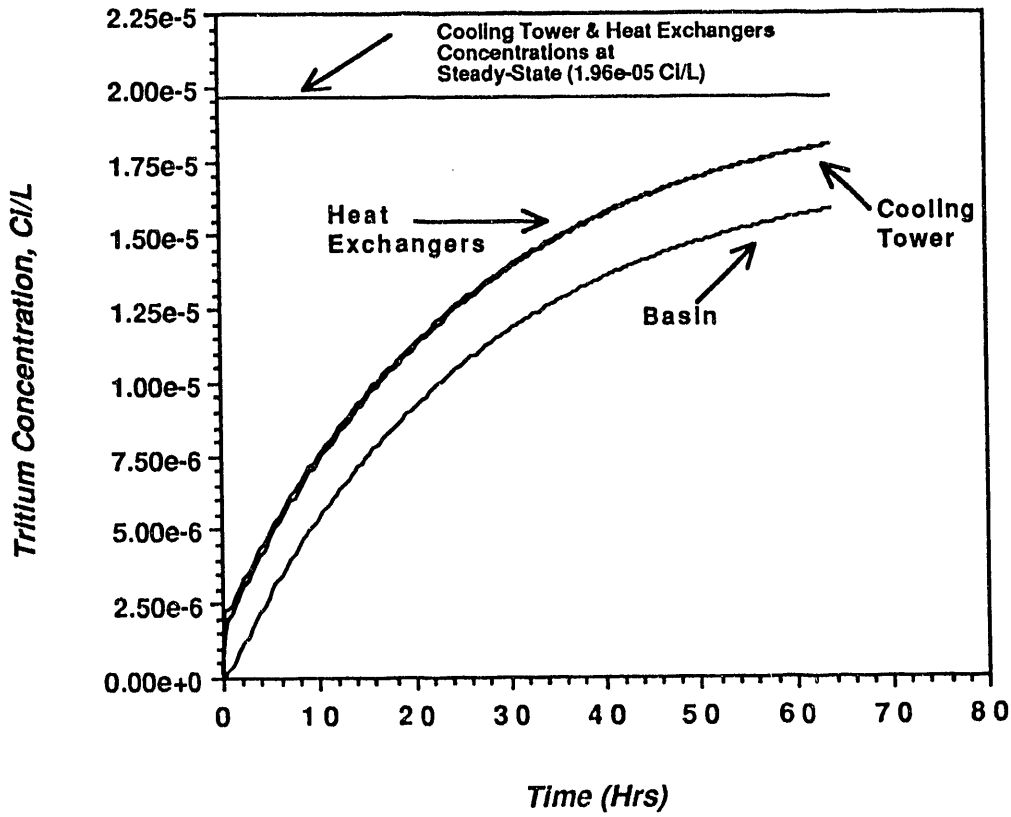

Figure 4-2. Tritium Concentration in CWS Components During the December 1991 Leak

steady-state tritium concentration levels are obtained by allowing the leak to continue at normal CWS operations, i.e., normal cooling water evaporation and blow-down rates. The steady-state tritium level in the cooling tower and heat exchangers is 1.96×10^{-05} Ci/L. This is also shown in Figure 4-2. The steady-state concentration of tritium in the 186-basin is 1.74×10^{-05} Ci/L. The concentration of any radionuclide in the basin is always lower than that in the cooling tower or in the heat exchanger due to the following:

- Decay of short-life radionuclides in the heat exchangers and the cooling tower prior to reaching the basin. However, for long-lived radionuclides, e.g., ^{3}H, the lag time for transporting radionuclides from the heat exchangers to the cooling tower and then to the basin is negligible.

- The basin receives cooling water from two sources: recirculation flow from the cooling water and cooling water make-up from the Savannah River. The make-up cooling water dilutes radionuclides entering the basin from the cooling tower.

The time dependent behavior of tritium concentration levels in CWS components during the first two hours of the December 91 leak are plotted in Figure 4-3. The effect of the lag times associated with transporting radionuclides between the CWS components can be seen in Figure 4-3. Figure 4-3 indicates that the tritium concentration levels in the cooling tower and the basin begin to increase at about six and 20 minutes, respectively, following the initiation of the leak. These are due to the loop connection times between the heat exchangers and the cooling tower and the loop connection time between the cooling tower and the basin. However, in reality, the basin is expected to experience the effect of the leak at a much longer time ($\approx$40 minutes). The longer lag time is due to the residence time of the radionuclides in the heat exchangers ($\approx$0.5 min), loop time between the heat exchangers and the cooling tower ($\approx$6 min), the residence time in the cooling tower ($\approx$18 min), and the loop time between the cooling tower and the 186-Basin ($\approx$11 min). The assumption embedded in the employed model of instantaneous perfect mixing in the CWS components causes the lag time to be underestimated. The effect of shorter lag time predicted by the model due to the perfect mixing assumption is compensated by the fact that tritium at reduced concentrations is transported to the basin.

Figure 4-3 also indicates that the tritium concentration level in the heat exchangers reaches a plateau only after a few minutes following the leak. The plateau only lasts for about 20 minutes and the tritium level in the heat exchanger begins to rise again. The obtained plateau is due to the relatively small volume of the heat exchangers

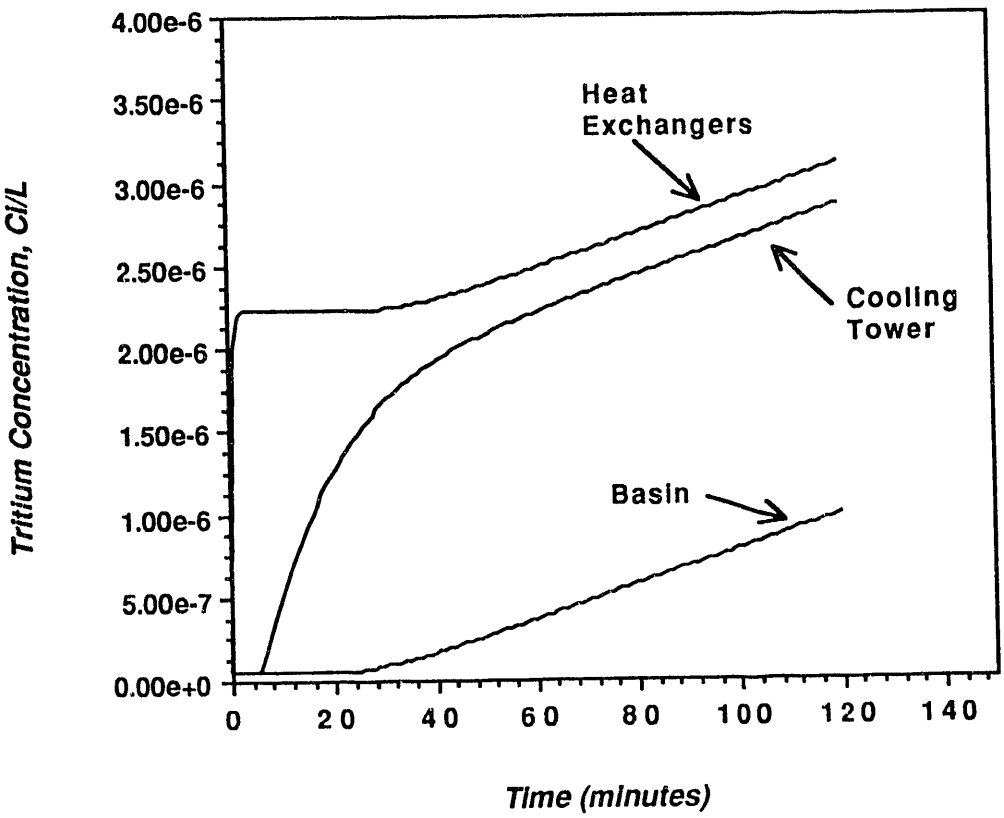

Figure 4-3. Tritium Concentration in CWS Components During the First Two Hours of the December 1991 Leak

which causes a temporary tritium saturation level to be reached quickly. The temporary tritium concentration steady-state level ceases to exist due to the fact that at about 25 minutes into the event, the basin starts to contribute more tritium to the heat exchangers, thereby increasing the source of tritium. In reality, this occurs at about 200 minutes after the leak begins. (Residence time in the 186-Basin alone is about 160 minutes). This is also due to the assumption of perfect mixing in the CWS control volumes.

The effects of instantaneous perfect mixing in the CWS components can be reduced by one of two ways. These are the following:

- Dividing the CWS components into a number of control volumes. Then by employing lag times between the smaller control volumes, a more accurate treatment of lag times associated with transporting radionuclides through CWS components can be obtained. This task, sub-dividing the CWS control volumes into smaller control volumes is recommended for future work.

- Using a "mocked-up" description of the CWS in the input file to allow a better treatment of radionuclide mixing in the CVs. This can be accomplished by reducing the CV's volume and increasing the loop volume connecting the different CWS components. This will allow better treatment of lag times associated with transporting radionuclides through the CWS and reduce the effect of the instantaneous perfect mixing assumption embedded in the **KCTA** code. The input file with the "mocked-up" description of the CWS is presented in Figure 4-4. Table 4-1 list the volumes of the actual and the "mocked-up" CWS. The tritium concentration level in CWS components as a function of time during the even, obtained from performing a **KCTA** run on the "mocked-up" CWS, are presented in Figures 4-5 and 4-6. Figure 4-5 is for the first two hours during the event and Figure 4-6 is for the entire period of the event.

Figures 4-5 and 4-6 indicate that a number of plateaus are obtained for each control volume. Each plateau last for $\approx$200 minutes, which is equal to the loop cycle time. Figure 4-5 also indicates that the 186-Basin begins to experience the effects of the leak at about 40 minutes following the initiation of the leak, indicating that the lag times in the CWS are being accounted for. For the purpose of comparison, Table 4-2 lists the tritium release rates and total releases to the environment at the end of the event (64 hours) for the two different treatments of the CWS using the **KCTA** code.

The results, as shown in Table 4-2, indicate that the "mocked-up" CWS configuration releases $\approx$4% less tritium than the actual CWS configuration using the current model employed in the **KCTA** code. Table 4-2 also indicates that tritium is being released

```
10  2.304+05 1200
87700 2.0+05 2.0+05 1+06 5+06 2.58+07
1.4+04 6.0+03 1.6+05
1
1003    8.6  -1.14-08
1.00-04 2.0+04
3
0.0     4.56-02
2.304e+05 4.56e-02
2.305e+05 0.0e-02
3
0.0     1.4+04
2.304e+05 1.4+04
2.305e+05 0.0
3
0.0     6.0+03
2.304e+05 6.0+03
2.305e+05 0.0
```

Figure 4-4. KCTA Code Input File for December 1991 Event With "Mocked-Up" CWS Description

Table 4-1. Volumes of the Actual and "Mocked-Up" CWS

CWS Components	Actual CWS	"Mocked-up" CWS
Heat Exchangers (gallons)	87,700	87,700
Cooling Tower (gallons)	3,200,000	200,000
186-Basin (gallons)	25,000,000	200,000
HXs-to-CT (gallons)	1,000,000	1,000,000
CT-to-Basin (gallons)	2,000,000	5,000,000
Basin-to-Hxs (gallons)	1,000,000	25,800,000
Total Volume (gallons)	32,287,700	32,287,700

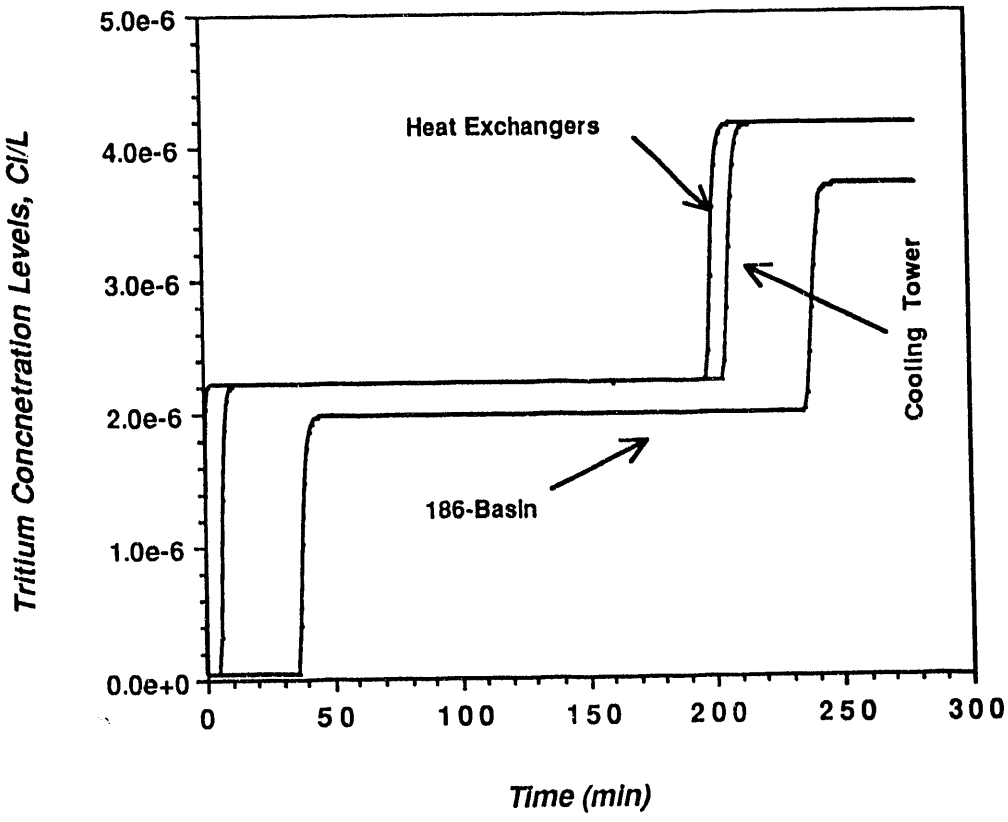

Figure 4-5. Tritium Release Rates from the "Mocked-Up" CWS to the Environment During the First Two-hours of the December 1991 Leak

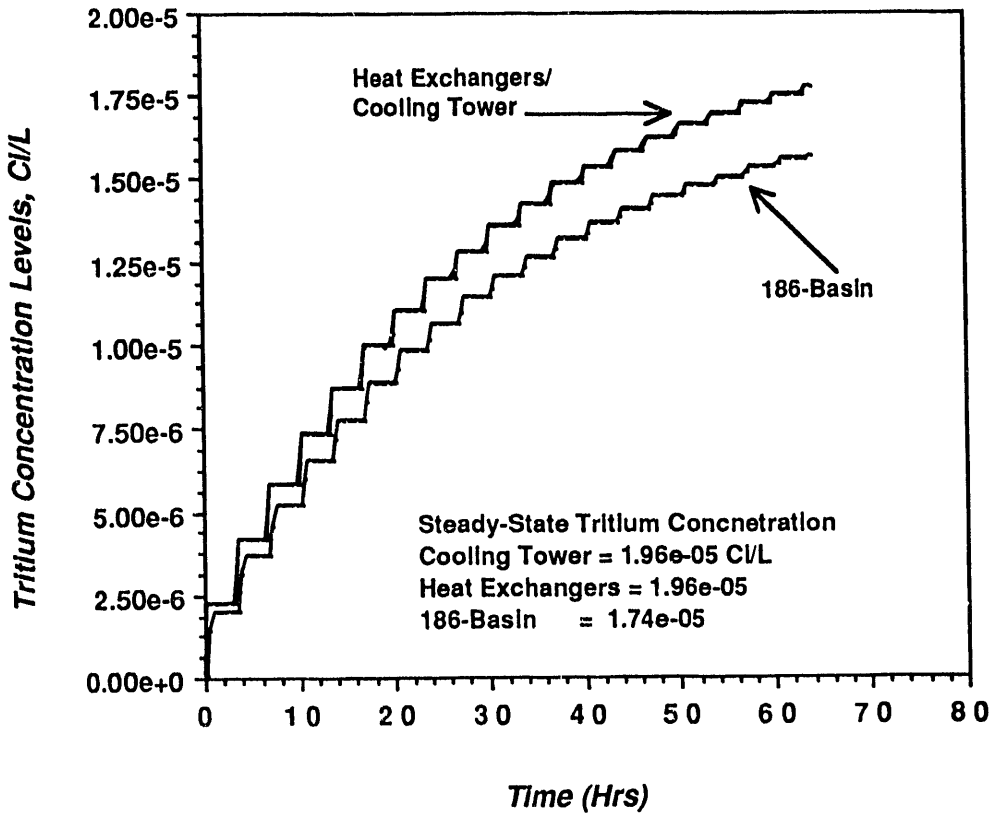

Figure 4-6. Tritium Release Rates from the "Mocked-Up" CWS to the Environment During the December 1991 Leak

Table 4-2. Tritium Release Rates and Cumulative Releases to the Environment at the End of the Event

Parameter	Actual CWS	"Mocked-Up" CWS
Release Rate (Ci/sec)		
Evaporation	6.81×10^{-3}	6.27×10^{-3}
Blow-Down	1.59×10^{-2}	1.57×10^{-2}
Total	2.27×10^{-2}	2.24×10^{-2}
Cumulative Release (Ci)		
Evaporation	1.11×10^{3}	1.07×10^{3}
Blow-Down	2.60×10^{3}	2.50×10^{3}
Total	3.71×10^{3}	3.57×10^{3}

at a lower rate in the "mocked-up" CWS than does the actual CWS. This is due to the fact that a longer effective CWS lag time is obtained using a "mocked-up" CWS configuration.

4.4.2 Tritium Release Rate

Shown in Figure 4-7 is a plot of the time-dependent tritium release rates from the CWS to the environment via evaporation to the atmosphere and blow-down to the Savannah River. Also shown in Figure 4-7 are the tritium steady-state release rates to the environment. Steady-state release rate of tritium is obtained from either the CWS without an on-line cooling tower or if the PW leak in the CWS with an on-line cooling tower is allowed to continue. This can be seen from Figure 4-7 where the total tritium release rate to the environment is approaching its asymptotic value of $\approx 2.5 \times 10^{-2}$ Ci/sec.

The cumulative tritium release to the environment as a function of time is presented in Figure 4-8. Figure 4-8 indicates that at the time the leak is isolated and the reactor is shutdown, 3,714 Ci of tritium has been released to the environment for the case the CWS with an on-line cooling tower versus 5,700 Ci for the CWS without an on-line cooling tower.

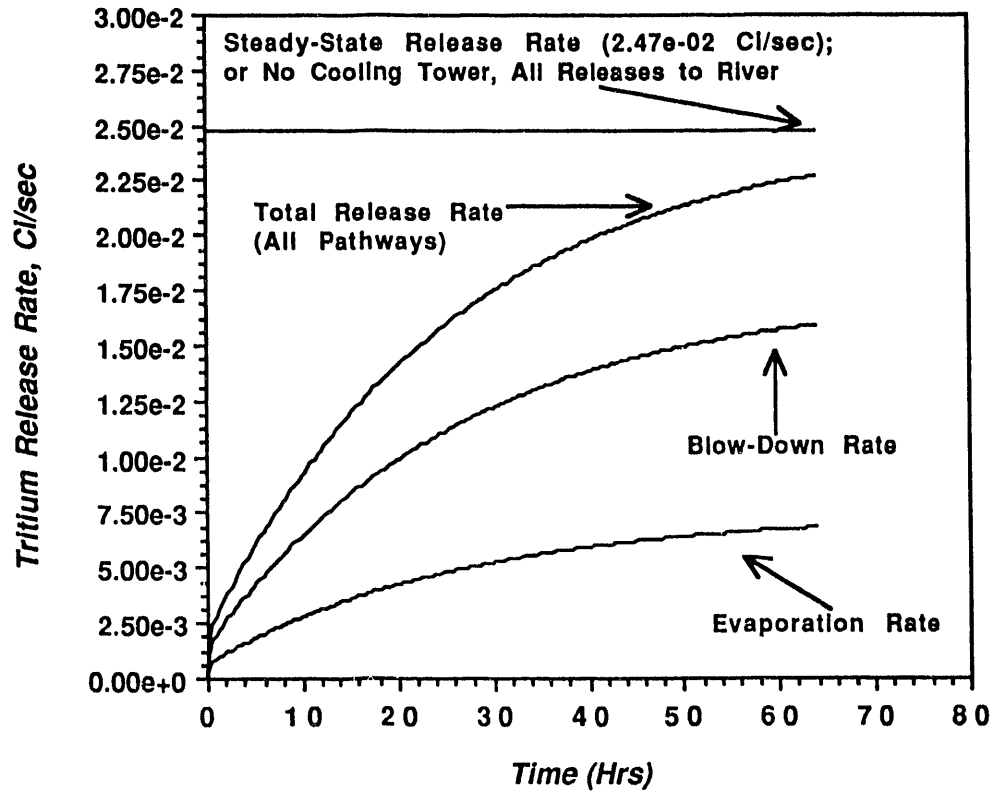

Figure 4-7. Tritium Release Rates from the CWS to the Environment During the December 1991 Leak

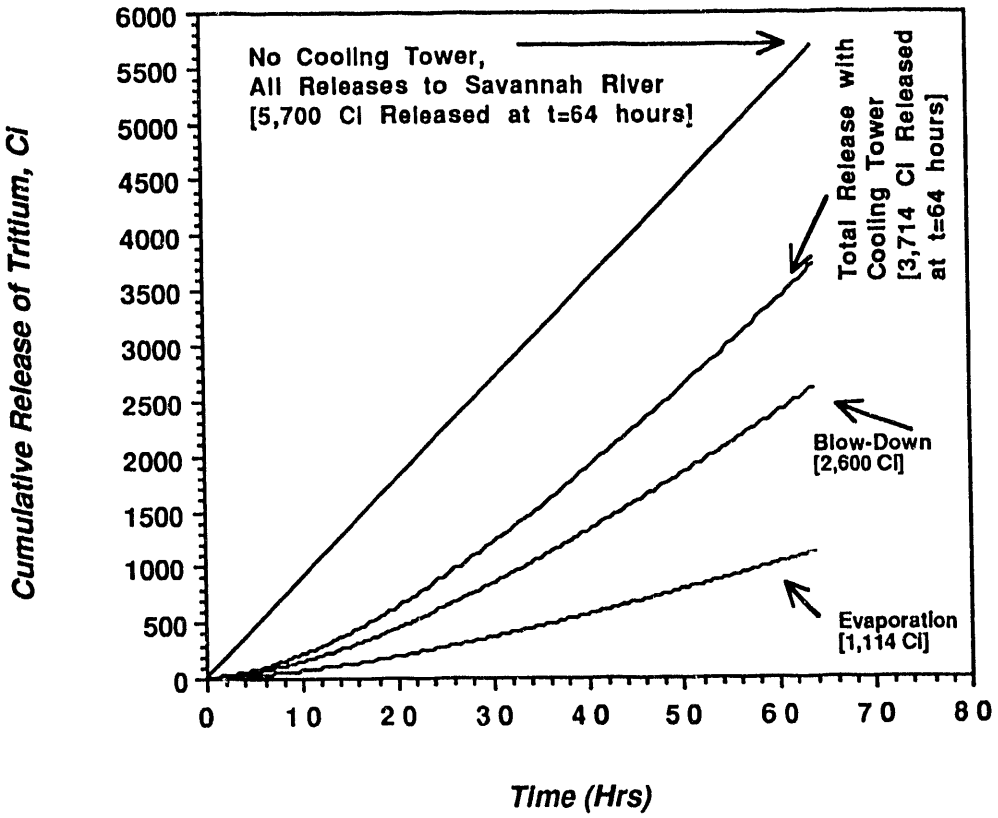

Figure 4-8. Cumulative Tritium Release from the CWS to the Environment During the December 1991 Leak

During the 64 hour leak, 5,700 Ci of tritium have been released through the leaking heat exchanger to the CWS. Of the 5,700 Ci, only 3,714 Ci have been released to the environment. The remaining 1,986 Ci of tritium are stored in the CWS: ≈1,500 Ci in the 186-Basin, ≈6 Ci in the heat exchangers, ≈220 in the cooling tower, and ≈260 Ci in the loop connecting the CWS components. This indicates that the CWS with an on-line cooling tower system is acting as an electric circuit with a capacitor.

4.4.3 Tritium Dose Rates

The dose to workers around the cooling tower following the December 1991 leak as a function of time is presented in Figure 4-9. The given doses are due to inhalation of tritium, absorption of tritium through the skin, and immersion in the tritiated environment. Figure 4-9 also list the doses at the steady-state tritium concentration levels if the leak was allowed to continue. Although the December 1991 leak is a relatively large leak, the resultant dose to workers are relatively small, e.g., $\approx 7 \times 10^{-8}$ rem/Hr. Additionally, the inhalation dose is computed[3] assuming saturated vapor condition for water at 90°F, which yields higher concentration of tritium than would be expected and workers are assumed to be totally surrounded by a tritiated environment.

Since controls have been added to the CWS to prevent such large leaks, than the doses presented in Figure 4-9 are not expected. However, doses to workers at steady-state conditions for PW leaks of 0.5 lb/h and 0.5 lb/day are presented in Table 4-3. These would be the maximum expected doses to workers for continuous leaks.

4.5 References

1. D.M. Hamby, R.P. Addis, D.M. Beals, J.R. Cadieux, W.H. Carlton, D.L. Dunn, G. Hall, D.W. Hayes, R. Lorenzo, M.V. Kantelo, and R.W. Taylor, "Emergency Response Monitoring Activities and Environmental Impact of the K-Reactor Aqueous Tritium Release of December 1991 (U)," WSRC-RP-92-186, Westinghouse Savannah River Company, Aiken, SC, February 7, 1992.

2. DOE-EH-0071, "Internal Dose Conversion Factors for Calculating Dose to the Public," July 1988.

3. J.M. East and K.R. O'Kula, "Tritium Inhalation - Unprotected Doses (U)," SRL-STE-92-0045, Westinghouse Savannah River Company, Aiken, SC, February 26, 1992.

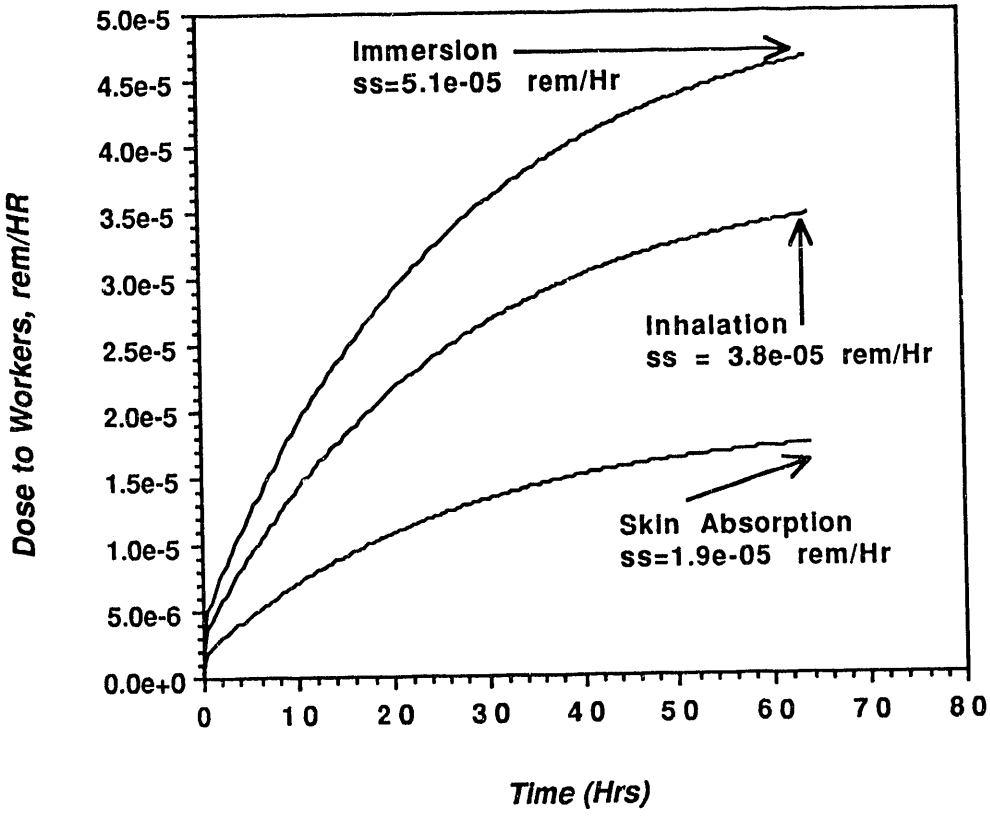

Figure 4-9. Expected Dose to Workers Near the Cooling Tower During the December 1991 Leak

Table 4-3. Maximum Expected Dose to Workers Near The Cooling Tower Due to Continual Process Water Leaks

PATHWAY	0.5 lb/day	0.5 lb/Hr
INHALATION	5.1×10^{-8} rem/Hr	1.2×10^{-6} rem/Hr
SKIN ABSORPTION	2.5×10^{-8} rem/Hr	6.0×10^{-7} rem/Hr
IMMERSION	6.6×10^{-8} rem/Hr	1.6×10^{-6} rem/Hr

5.0 LIMITATIONS AND FUTURE WORK

5.1 Introduction

Assumptions embedded in the development of the CWS radionuclide transport model along with limitations of the **KCTA** code are discussed in the following section. This is followed by a section outlining recommendations for further work.

5.2 Limitations

Assumptions embedded in the development of the radionuclide transport model include the following:

- instantaneous perfect mixing of radionuclides in all control volumes. However, the effects of this assumption can be reduced by employing a "mocked-up" description of CWS control volumes, e.g., Section 4.4.1.
- slug flow outside the control volumes (in the connecting loops);
- radionuclides are introduced to the cooling water system only by the PW leak (through the heat exchangers) and/or by the make-up cooling-water. Production of radionuclides from the decay of their parent(s) radionuclides is neglected;
- cooling tower water flow rate is constant;
- results included in the output file are all in tabular format without any graphical displays.
- all evaporation losses occur only in the cooling tower; and
- radionuclides have the same evaporation characteristics as water. This assumption may only be valid for tritium in the form of DTO, T_2O, or HTO.

5.3 Path Forward

Verification and Validation (V&V) of the **KCTA** code needs to be performed. This step will provide an assurance of the quality of its results is obtained. Following the V&V process, comparison studies can be performed to examine effects of the cooling tower on the environment. This can be achieved by examining effects of various heat exchanger leak scenarios and various operator responses by means of varying the cooling tower blow-down and evaporation rates. Such studies can be useful in establishing procedures so that radionuclide releases to the environment and the consequences of these releases can be minimized.

Additionally, enhancements to the **KCTA** code may be required in the future. Recommended enhancements and modifications to the **KCTA** code include the following:

- Sub-divide the control volumes into smaller control volumes so that the effects of assuming perfect mixing in the control volumes can be reduced.

- Divide the heat exchangers into two control volumes. One CV should simulate the leaking heat exchanger and the other should simulate the remaining heat exchangers. This modification will allow proper accounting of radionuclide levels in all heat exchangers and will allow investigation into the detectability of the leaking heat exchanger if small PW leaks continue for prolonged periods during operations.

- Include the CWS connecting loops as control volumes so that radionuclide levels throughout the CWS can be determined.

- Improve the output format so that other parameters can be printed during the transient. Examples include total amount of radionuclides that have leaked into the CWS and amount of radionuclides present in each CV and in the CWS.

- Allow the cooling water make-up flow to be time-dependent or the concentration of radionuclides entering with the cooling water make-up flow to be time dependent.

- Employ evaporation coefficients for each radionuclide in the data base file or in the input file so that their evaporation relative to the evaporation of water can be accurately accounted for.

- Employ a module that will account for the production of radionuclides through the decay of their parent radionuclides.

- Employ a module to estimate inhalation dose rates due to evaporation of the cooling water from the 186-Basin and the cooling tower basin. This can be accomplished by assuming saturated vapor conditions at 186- and cooling tower basins.

- Employ a module or enhance the TRANS module so that the release rates of radionuclides to the environment are calculated in radiological terms other than Ci, e.g., R/Hr.

- Tie-in the **KCTA** code with other modules to form the SRS Liquid Pathway Activity System (**LPAS**). **LPAS** will offer integrated formation, transport, deposition, and release estimates for radionuclides formed in SRS facilities. Figure 5-1 presents a schematic of a possible SRS **LPAS**.

- Real-time tie-in capabilities could be introduced, with feedback. For example, The WIND system could provide current evaporation conditions at the cooling tower.

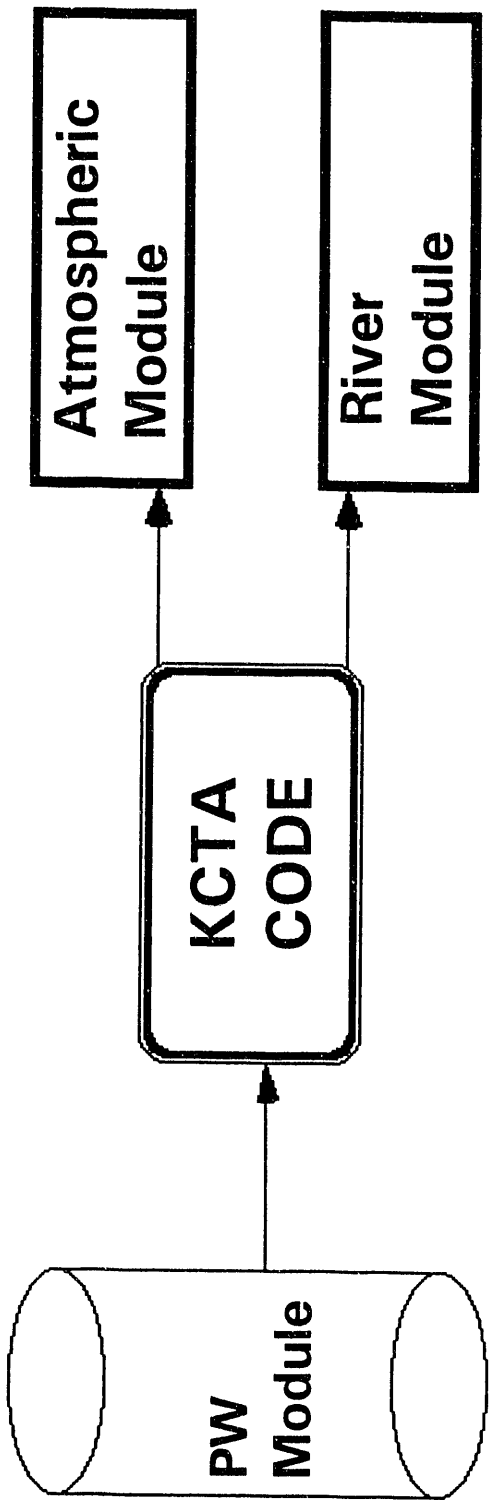

Figure 5-1. Schematic of an Example SRS LPAS

APPENDIX A
DESCRIPTION OF THE DATA FILES USED BY THE KCTA CODE

There are three files connected to the I/O of the KCTA code. They are: the input data file, the output data file, and the data base file. These files are described in the sections that follow.

A.1 Input Data File

Upon execution of the KCTA code, the MAIN module checks for the default input file by the name of "**KCTA.i**" on the current drive (the drive, i.e., directory where the KCTA code is called from). If a file with the default name of "**KCTA.i**" does not exist on the current drive, the user is prompted to enter the name of the file that contains the input data. Once a file is found, input data are read into KCTA by the REED module.

The input data, contained in the input data file, consists of four data blocks: (I) simulation/output data block, (II) CTW specific data block, (III) nuclide-dependent data block, and (IV) function definition data block. These data blocks are described as follows:

A.1.1 Block I, Simulation/Output Data

This block consists of one card (line) with three input values in free format. It contains the following variables:

DT time step size (seconds)

TMX time to terminate simulation (seconds)

TPR time increment at which results are to be printed to the output file (seconds)

A.1.2 Block II, CTW Specific Data

This data block contains cooling tower specific data. It consists of two cards. The first card consists of six variables, as follows:

VX volume of cooling water in all heat exchangers (gallons)

VT volume of cooling water in the cooling tower (gallons)

VB volume of cooling water in the 186-Basin (gallons)

VXT volume of the loop connecting the heat exchangers to the cooling tower (gallons)

VTB volume of the loop connecting the cooling tower to the 186-Basin (gallons)

VBX volume of the loop connecting the 186-Basin to the heat exchangers (gallons)

The second input card consists of three input variables, as follows:

Bd_0 cooling tower blow-down rate to the Savannah River (gallons per minute)

E_0 cooling tower evaporation rate to the atmosphere (gallons per minute)

R_0 cooling water recirculation rate from the cooling tower to the 186-Basin (gallons per minute)

A.1.3 Block III, Nuclide-Dependent Data

This data block consists of two types of input. The first is the number of radionuclides to be included in the problem. This value is read into the variable **NR**. The second type of input consists of **NR** input cards with three input values per card, as follows:

NID(i) radionuclide identification number which has the form of ***ZZZAAA***. Where ***ZZZ*** is the atomic number and ***AAA*** is the mass number. For example, for ^{24}Na ***ZZZ*** is **011** and ***AAA*** is **024**. Thus, the **NID** for ^{24}Na is **11024**. (Table B-1, in Section B.3, lists the available radionuclides and their identification numbers.)

sPw(i) radionuclide activity in the process water

sCw(i) radionuclide activity in the make-up cooling water

If **sPw** and **sCw** are greater than zero, they are read in Ci/liter and then converted to Ci/gallon. If these variables are less than zero, they are read in Ci/gallon and multiplied by -1.

A.1.4 Block IV, Function Definition Data

Three functions are defined in this data block: (1) Heat exchanger PW leak rate, (2) cooling tower blow-down rate, and (3) cooling tower evaporation rate. Input format for these functions are described below:

A.1.4.1 Heat Exchanger Leak Function

Three types of input are needed to define this function. The first contains two variables, as follows:

Pw initial steady-state process water leak rate (gallons/min)

Cw cooling water make-up flow rate (gallons/min)

The second type of input is the number of data point pairs used in to define the time-dependent process water leak function. This value is stored in the variable **NLP**. The third type of input consists of **NLP** data cards with two data points per card, as follows:

TLK(i) time (sec); and

CLK(i) process water leak-rate in gallons per minute at **TLK(i)**.

A.1.4.2 Cooling Tower Blow-Down Rate Function

Only two types of input are needed to define the cooling tower blow-down rate function. The first is the number of data points used in defining this function and is stored in the variable **NBP**. The second type of input consists of **NBP** data cards with two data points per card, as follows:

TBD(i) time (sec); and

BDR(i) blow-down rate in gallons per minute at **TBD(i)**.

A.1.4.3 Cooling Tower Evaporation Rate Function

This function also requires two types of input. The first is the number of data points used in defining this function and is stored in the variable **NEP**. The second type of input consists of **NEP** data cards with two data points per card, as follows:

TEV(i) time (sec); and

EVR(i) blow-down rate in gallons per minute at **TEV(i)**.

A.1.5 Sample Input Data File

An example problem is presented in this section. The input file used to define this sample problem is shown in Figure A-1. It should be pointed out that this problem does not reflect the actual K-reactor cooling tower system. It is used only for illustrative purposes.

The sample input file shown in Figure B-1 assumes the following:

- Request a time-step of 5 seconds, terminate the simulation after 100 minutes, and print the output data at 100 seconds increments.
- The volumes of shell side of all heat exchangers, the cooling tower and its basin, the 186-basin, the loop connecting the heat exchangers to the cooling tower, the loop connecting the cooling tower to the 186-basin, and the loop connecting the 186-basin to the cooling tower are 8.77×10^4, 3.2×10^6, 2.5×10^7, 1.0×10^6, 2.0×10^6, and 1.0×10^6 gallons, respectively.
- The cooling tower blow-down rate to the Savannah River, evaporation rate to the atmosphere, and recirculation rate are 1.4×10^4, 6.0×10^3, 1.6×10^5 gpm, respectively.
- There is only one radionuclide to be processed, namely tritium (^3H). The concentration of ^3H is 8.6 Ci/liter in the PW and 1.14×10^{-8} Ci/gallon in the make-up cooling water.

```
5   6000  100                              Block I, Simulation/Output Data
87700 3.2+06 2.5+07 1+06 2+06 1.0+6        Block II, CTW Specific Data
1.4+04 6.0+03 1.6+05
1                                          Block III, Nuclide-Dependent Data
1003   8.6  -1.14-08
1.00-04 2.0+04                             Block IV, Leak Function Data
6
0.0    4.20-02
50.0   3.80-02
600.0  3.40-02
1200.  3.20-02
2400.  3.10-02
2500   0.0
3                                          Block IV, Blow-Down Function Data
0.0    1.4+04
3600   1.4+04
4000   0.0
3                                          Block IV, Evaporation Function Data
0.0    6.0+03
1500.  6.0+03
1600   0.0
```

Figure A-1. Example of the KCTA Code Input File

- The initial steady-state PW leak rate is 1.0×10^{-4} gallons/minute and the cooling water make-up flow rate is 2.0×10^{4} gallons/minute.
- There are six points used to define the time-dependent PW leak rate function.
- There are three points used to define the time-dependent blow-down rate function.
- There are three points used to define the time-dependent evaporation rate function.
- In defining the time-dependent functions (PW leak, blow-down to the river, and evaporation to the atmosphere), it is assumed that the leak is detected after 20 minutes of its occurrence. The reactor is then shutdown at time=20 minutes (1200 sec) and the evaporation begins to drop to zero at time=1500 sec (assuming 300 second lag for the travel of the hot cooling water from the heat exchangers to the cooling tower). The heat exchanger with the leak is detected at 2400 seconds at which time the operators isolate the heat exchanger. It is also assumed that at one-hour following the initiation of the leak, the operators

have started closing down the necessary valves to stop the blow-down to the river. This process is assumed to take 400 seconds.

A.2 Output Data File

After checking the current directory for the input file, the MAIN module checks if a file with the name "**KCTA.o**" exists on the current drive. If such a file exists, the MAIN module prompts the user to enter a name of a file to be used for writing the output data to. Once a file is selected that does not exist on the current drive, this file is assigned to I/O unit 20 and opened as a new file.

The output file is divided into four parts: (1) the input data and associated time constants, (2) the functions defining the PW leak and the cooling tower evaporation and blow-down rates, (3) the initial steady-state release rates, and (4) the transient data. The different parts of the output data are described in the following subsections.

A.2.1 Output Data File, Part (1)

The input data read by the REED module and the residence and delay loop times calculated by the STEADY module are printed out to the output file. Shown in Figure A-2 is a printout of the first part of the output data for the example input file shown in Figure B-1. Note that the name of the corresponding input file is printed on the first line of the output data. Additionally, the flow rates of make-up cooling water and the initial steady-state process water in-leakage are printed in units of gallons per minute. This part of the output file is printed to assure that the input data have been entered correctly.

A.2.2 Output Data File, Part (2)

The second part of the output data list the function definition data read by the REED module. These are shown in Figure A-3 where the PW leak function and the cooling tower evaporation and blow-down functions in gallons per sec and gallons per minute are printed out to assure that the input data have been entered correctly.

```
 The following data are obtained from the input file <KCTA.I      >
 ================================================================


-------------------------------------------------------------------------
      >>>>>>>>>>>>>>>>>> VOLUMES (gallons) <<<<<<<<<<<<<<<<<<
-------------------------------------------------------------------------
  Control Volume                              Connecting Loop Volume
-------------------------------------------------------------------------
Heat Exchangers = <.8770E+05>             HX's-to-CT      = <.1000E+07>
Cooling Tower   = <.3200E+07>             CT-to-186-Basin= <.2000E+07>
186-Basin       = <.2500E+08>             Basin-to-HX's   = <.1000E+07>
-------------------------------------------------------------------------



-------------------------------------------------------------------------
        >>>>>>>>>>>>>>>>>> TIME CONSTANTS >>>>>>>>>>>>>>>>>>
-------------------------------------------------------------------------
  Residence Time (sec)                        Loop Delay Time (sec)
-------------------------------------------------------------------------
Heat Exchangers = <.2923E+02>             HX's-to-CT      = <.3626E+03>
Cooling Tower   = <.1067E+04>             CT-to-186-Basin= <.1817E+04>
186-Basin       = <.8333E+04>             Basin-to-HX's   = <.8708E+04>
-------------------------------------------------------------------------

        Make-up Water Flow Rate       = <.2000E+05> GPM
        Process Water In-Leakage Rate = <.1000E-03> GPM


        Cooling Tower Blow-down Rate     = <.1400E+05> GPM
        Cooling Tower evaporation Rate   = <.6000E+04> GPM
        Cooling Tower Recirculation Rate = <.1600E+06> GPM
        Total Cooling Water Flow Rate    = <.1800E+06> GPM
```

Figure A-2. First Part of the Output File Produced by KCTA

The following are the data used in defining the process water in-leakage to the heat exchangers at t > 0.

NOTE: ONLY < 6> points are used in defining the Process Water Leak Rate Function, as follows:

Time (sec)	Gallons/min	Gallons/sec
.0000E+00	.4200E-01	.7000E-03
.5000E+02	.3800E-01	.6333E-03
.6000E+03	.3400E-01	.5667E-03
.1200E+04	.3200E-01	.5333E-03
.2400E+04	.3100E-01	.5167E-03
.2500E+04	.0000E+00	.0000E+00

The following are the data used in defining the blow-down rate function at t > 0.

NOTE: ONLY < 3> points are used in defining this Function, as follows:

Time (sec)	Gallons/min	Gallons/sec
.0000E+00	.1400E+05	.2333E+03
.3600E+04	.1400E+05	.2333E+03
.4000E+04	.0000E+00	.0000E+00

The following are the data used in defining the evaporation rate function at t > 0.

NOTE: ONLY < 3> points are used in defining this Function, as follows:

Time (sec)	Gallons/min	Gallons/sec
.0000E+00	.6000E+04	.1000E+03
.1500E+04	.6000E+04	.1000E+03
.1600E+04	.0000E+00	.0000E+00

Figure A-3. Second Part of the Output File Produced by KCTA

A.2.3 Output Data File, Part (3)

The third part of the output data list the output produced by the STEADY module. That is, the initial steady-state release rates to the environment for each radionuclide and all radionuclides combined are listed in units of Ci/sec, Ci/day, and Ci/year. Shown in Figure A-4 is a printout of the second part of the output data for the example input file shown in Figure B-1.

A.2.4 Output Data File, Part (4)

The fourth part of the output file is the data calculated by the TRANS module and is printed by the TRANS module for each radionuclide at the requested print time interval. The printed data consist of the time-dependent radionuclide level in the 186-Basin, all heat exchangers, and the K-reactor cooling tower. Additionally, the radionuclide release rates in Ci/sec and integrated release since the initiation of the transient in Ci are printed out at the requested print time interval. The third part of the output file for the example input data given in Figure B-1 is presented in Figure A-5.

A.3 Data Base File

One of the requirements for a successful execution of the KCTA code is the existence of the data base file by the name of "**KCTA.d**" on the drive where the KCTA code is called from. This file is used to obtain two parameters for each radionuclide: the radiological half-life in seconds (stored in the variable **HLF**) and the symbol denoting the radionuclide (stored in the variable **NME**). The data base file, "**KCTA.d**," contains data for 65 radionuclides. Table B-1 lists the nuclides (**NME**) and their identification numbers (**NID**) currently employed in "**KCTA.d**."

```
>>>>>>>>>>>>>> Initial Steady-State Release <<<<<<<<<<<<<
>>>>>>>>>>>>>> of Radionuclides <Ci/second> <<<<<<<<<<<<<

                    INTAKE BY                    RELEASE PATHWAY
   ISOTOPE          Cw(0) &      Atmosphere          River      TOTAL TO THE
 ID       Name       Pw(0)      (Evaporation)    (Blow-Down)    ENVIRONMENT
------------------------------------------------------------------------------
 1003      3-H     .5805E-04     .1741E-04       .4062E-04      .5803E-04
------------------------------------------------------------------------------
All Nuclides
       <TOTAL>     .5805E-04     .1741E-04       .4062E-04      .5803E-04
------------------------------------------------------------------------------


>>>>>>>>>>>>>> Initial Steady-State Release <<<<<<<<<<<<<
>>>>>>>>>>>>>> of Radionuclides <Ci/day    > <<<<<<<<<<<<<

                    INTAKE BY                    RELEASE PATHWAY
   ISOTOPE          Cw(0) &      Atmosphere          River      TOTAL TO THE
 ID       Name       Pw(0)      (Evaporation)    (Blow-Down)    ENVIRONMENT
------------------------------------------------------------------------------
 1003      3-H     .5016E+01     .1504E+01       .3510E+01      .5014E+01
------------------------------------------------------------------------------
All Nuclides
       <TOTAL>     .5016E+01     .1504E+01       .3510E+01      .5014E+01
------------------------------------------------------------------------------


>>>>>>>>>>>>>> Initial Steady-State Release <<<<<<<<<<<<<
>>>>>>>>>>>>>> of Radionuclides <Ci/year   > <<<<<<<<<<<<<

                    INTAKE BY                    RELEASE PATHWAY
   ISOTOPE          Cw(0) &      Atmosphere          River      TOTAL TO THE
 ID       Name       Pw(0)      (Evaporation)    (Blow-Down)    ENVIRONMENT
------------------------------------------------------------------------------
 1003      3-H     .1831E+04     .5491E+03       .1281E+04      .1830E+04
------------------------------------------------------------------------------
All Nuclides
       <TOTAL>     .1831E+04     .5491E+03       .1281E+04      .1830E+04
------------------------------------------------------------------------------
```

Figure A-4. Third Part of the Output File Produced by KCTA

The following data relate to the 1th nuclide, i.e., ====> 3-H
with the nuclide ID => 1003

TIME (sec)	Activity Levels (Ci/L) 186Basin	Heat-Ex.	K-Tower	Release Rate of ith (Ci/sec) Evapor.	River	Total	Total Released (Ci) Evapor.	River	Total
.0000E+00	.4122E-07	.4600E-07	.4600E-07	.1741E-04	.4062E-04	.5803E-04	.0000E+00	.0000E+00	.0000E+00
.1000E+03	.4122E-07	.1823E-05	.4600E-07	.1741E-04	.4062E-04	.5803E-04	.1741E-02	.4062E-02	.5803E-02
.2000E+03	.4122E-07	.1811E-05	.4600E-07	.1741E-04	.4062E-04	.5803E-04	.3482E-02	.8125E-02	.1161E-01
.3000E+03	.4122E-07	.1777E-05	.4600E-07	.1741E-04	.4062E-04	.5803E-04	.5223E-02	.1219E-01	.1741E-01
.4000E+03	.4122E-07	.1742E-05	.7482E-07	.2832E-04	.6608E-04	.9440E-04	.7155E-02	.1669E-01	.2385E-01
.5000E+03	.4122E-07	.1707E-05	.2272E-06	.8601E-04	.2007E-03	.2867E-03	.1313E-01	.3065E-01	.4378E-01
.6000E+03	.4122E-07	.1672E-05	.3700E-06	.1400E-03	.3267E-03	.4668E-03	.2476E-01	.5777E-01	.8253E-01
.7000E+03	.4122E-07	.1653E-05	.4969E-06	.1881E-03	.4388E-03	.6269E-03	.4145E-01	.9672E-01	.1382E+00
.8000E+03	.4122E-07	.1637E-05	.6092E-06	.2306E-03	.5380E-03	.7686E-03	.6264E-01	.1462E+00	.2088E+00
.9000E+03	.4122E-07	.1621E-05	.7084E-06	.2681E-03	.6256E-03	.8937E-03	.8780E-01	.2049E+00	.2927E+00
.1000E+04	.4122E-07	.1605E-05	.7955E-06	.3011E-03	.7026E-03	.1004E-02	.1165E+00	.2717E+00	.3882E+00
.1100E+04	.4122E-07	.1589E-05	.8728E-06	.3304E-03	.7708E-03	.1101E-02	.1482E+00	.3458E+00	.4940E+00
.1200E+04	.4122E-07	.1573E-05	.9417E-06	.3564E-03	.8317E-03	.1188E-02	.1827E+00	.4263E+00	.6090E+00
.1300E+04	.4122E-07	.1567E-05	.1003E-05	.3796E-03	.8858E-03	.1265E-02	.2196E+00	.5125E+00	.7321E+00
.1400E+04	.4122E-07	.1563E-05	.1057E-05	.4002E-03	.9337E-03	.1334E-02	.2588E+00	.6038E+00	.8625E+00
.1500E+04	.4122E-07	.1559E-05	.1105E-05	.4183E-03	.9761E-03	.1394E-02	.2998E+00	.6995E+00	.9993E+00
.1600E+04	.4123E-07	.1555E-05	.1148E-05	.4344E-04	.1013E-02	.1057E-02	.3193E+00	.7992E+00	.1119E+01
.1700E+04	.4125E-07	.1551E-05	.1185E-05	.0000E+00	.1047E-02	.1047E-02	.3193E+00	.9024E+00	.1222E+01
.1800E+04	.4127E-07	.1547E-05	.1219E-05	.0000E+00	.1077E-02	.1077E-02	.3193E+00	.1009E+01	.1328E+01
.1900E+04	.4123E-07	.1543E-05	.1250E-05	.0000E+00	.1104E-02	.1104E-02	.3193E+00	.1118E+01	.1437E+01
.2000E+04	.4125E-07	.1539E-05	.1277E-05	.0000E+00	.1128E-02	.1128E-02	.3193E+00	.1230E+01	.1549E+01
.2100E+04	.4127E-07	.1535E-05	.1302E-05	.0000E+00	.1150E-02	.1150E-02	.3193E+00	.1344E+01	.1663E+01
.2200E+04	.4129E-07	.1531E-05	.1324E-05	.0000E+00	.1169E-02	.1169E-02	.3193E+00	.1460E+01	.1779E+01
.2300E+04	.4221E-07	.1527E-05	.1344E-05	.0000E+00	.1187E-02	.1187E-02	.3193E+00	.1578E+01	.1897E+01
.2400E+04	.4478E-07	.1523E-05	.1361E-05	.0000E+00	.1202E-02	.1202E-02	.3193E+00	.1697E+01	.2017E+01
.2500E+04	.4882E-07	.3724E-06	.1377E-05	.0000E+00	.1216E-02	.1216E-02	.3193E+00	.1818E+01	.2138E+01
.2600E+04	.5416E-07	.4625E-07	.1391E-05	.0000E+00	.1228E-02	.1228E-02	.3193E+00	.1941E+01	.2260E+01
.2700E+04	.6062E-07	.4130E-07	.1403E-05	.0000E+00	.1239E-02	.1239E-02	.3193E+00	.2064E+01	.2383E+01
.2800E+04	.6804E-07	.4122E-07	.1410E-05	.0000E+00	.1245E-02	.1245E-02	.3193E+00	.2188E+01	.2508E+01
.2900E+04	.7629E-07	.4122E-07	.1335E-05	.0000E+00	.1179E-02	.1179E-02	.3193E+00	.2310E+01	.2629E+01
.3000E+04	.8526E-07	.4122E-07	.1221E-05	.0000E+00	.1078E-02	.1078E-02	.3193E+00	.2422E+01	.2742E+01
.3100E+04	.9486E-07	.4122E-07	.1115E-05	.0000E+00	.9844E-03	.9844E-03	.3193E+00	.2525E+01	.2844E+01
.3200E+04	.1050E-06	.4122E-07	.1018E-05	.0000E+00	.8992E-03	.8992E-03	.3193E+00	.2619E+01	.2938E+01
.3300E+04	.1156E-06	.4122E-07	.9303E-06	.0000E+00	.8216E-03	.8216E-03	.3193E+00	.2704E+01	.3024E+01
.3400E+04	.1265E-06	.4122E-07	.8504E-06	.0000E+00	.7510E-03	.7510E-03	.3193E+00	.2783E+01	.3102E+01
.3500E+04	.1378E-06	.4122E-07	.7776E-06	.0000E+00	.6868E-03	.6868E-03	.3193E+00	.2854E+01	.3173E+01
.3600E+04	.1493E-06	.4122E-07	.7114E-06	.0000E+00	.6283E-03	.6283E-03	.3193E+00	.2919E+01	.3239E+01
.3700E+04	.1613E-06	.4122E-07	.6512E-06	.0000E+00	.4313E-03	.4313E-03	.3193E+00	.2971E+01	.3291E+01
.3800E+04	.1737E-06	.4122E-07	.5964E-06	.0000E+00	.2633E-03	.2633E-03	.3193E+00	.3005E+01	.3324E+01
.3900E+04	.1865E-06	.4122E-07	.5465E-06	.0000E+00	.1207E-03	.1207E-03	.3193E+00	.3023E+01	.3343E+01
.4000E+04	.1998E-06	.4122E-07	.5010E-06	.0000E+00	.1106E-04	.1106E-04	.3193E+00	.3029E+01	.3348E+01
.4100E+04	.2133E-06	.4122E-07	.4597E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.4200E+04	.2269E-06	.4122E-07	.4221E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.4300E+04	.2405E-06	.4122E-07	.3878E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.4400E+04	.2541E-06	.4122E-07	.3567E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.4500E+04	.2677E-06	.4122E-07	.3283E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.4600E+04	.2813E-06	.4122E-07	.3025E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.4700E+04	.2946E-06	.4122E-07	.2790E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.4800E+04	.3065E-06	.4122E-07	.2577E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.4900E+04	.3170E-06	.4122E-07	.2382E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.5000E+04	.3261E-06	.4122E-07	.2205E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.5100E+04	.3340E-06	.4122E-07	.2044E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.5200E+04	.3408E-06	.4122E-07	.1897E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.5300E+04	.3465E-06	.4122E-07	.1764E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.5400E+04	.3514E-06	.4122E-07	.1642E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.5500E+04	.3555E-06	.4122E-07	.1532E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.5600E+04	.3588E-06	.4122E-07	.1431E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.5700E+04	.3614E-06	.4122E-07	.1339E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.5800E+04	.3634E-06	.4122E-07	.1256E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.5900E+04	.3649E-06	.4122E-07	.1180E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01
.6000E+04	.3658E-06	.4122E-07	.1111E-06	.0000E+00	.0000E+00	.0000E+00	.3193E+00	.3029E+01	.3348E+01

Figure A-5. Fourth Part of the Output File Produced by KCTA

Table A-1
Names and Identification Numbers of
The Radionuclides Employed in "KCTA.d"

Nuclide	Nuclide ID	Nuclide	Nuclide ID
3-H	1003	129-Sb	51129
16-N	7016	127-Te	52127
19-O	8019	129-Te	52129
24-Na	11024	131m-Te	52131
52-Cr	24051	132-Te	52132
54-Mn	25054	131-I	53131
59-Fe	26059	132-I	53132
57-Co	27057	133-I	53133
58-Co	27058	134-I	53134
60-Co	27060	135-I	53135
65-Zn	30065	133-Xe	54133
85-Kr	36085	135-Xe	54135
87-Kr	36087	134-Cs	55134
88-Kr	36088	136-Cs	55136
86-Kr	37086	137-Cs	55137
89-Sr	38089	139-Ba	56139
91-Sr	38091	140-Ba	56140
92-Sr	38092	140-La	57140
90-Y	39090	141-La	57141
91-Y	39091	142-La	57142
92-Y	39092	141-Ce	58141
93-Y	39093	143-Ce	58143
95-Zr	40095	144-Ce	58144
97-Zr	40097	147-Nd	60147
95-Nb	41095	237-U	92237
99-Mo	42099	238-Np	93238
99m-Tc	43099	239-Np	93239
103-Ru	44103	238-Pu	94238
105-Ru	44105	239-Pu	94239
105-Rh	45105	241-Am	95241
109-Cd	48109	242-Cm	96242
124-Sb	51124	244-Cm	96244
127-Sb	51127		

APPENDIX B
FORTRAN LISTING OF THE KCTA CODE

B.1 The MAIN Module

```
C-----------------------------------------------------------------------
C----
C----    KK        KK     CCCCCCCCCCC    TTTTTTTTTTTTTT  TT       AAA
C----    KK       KK     CCCCCCCCCCCCC   TT       TT      TT      A A
C----    KK      KK      CC           CC          TT             A   A
C----    KK     KK       CC                       TT            A     A
C----    KK  KK          CC                       TT           A       A
C----    KKKKK           CC                       TT          A         A
C----    KKKKK           CC                       TT         AAAAAAAAAAAAA
C----    KK  KK          CC                       TT         AAAAAAAAAAAAA
C----    KK   KK         CC                       TT         AA          AA
C----    KK     KK       CC           CC          TT         AA          AA
C----    KK      KK      CCCCCCCCCCCCCC           TT         AA          AA
C----    KK       KK      CCCCCCCCCC              TT         AA          AA
C----
C-----------------------------------------------------------------------
C----    PROGRAMMED BY:
C----    ~~~~~~~~~~~~~~
C----                      **************************
C----                      *    SAMER D. KAHOOK     *
C----                      * WSRC/NRT&SC/STS/R&STT *
C----                      *       JULY-1992        *
C----                      **************************
C----                      ~   VERSION R&STT 1.0    ~
C----                      ~~~~~~~~~~~~~~~~~~~~~~~~~~
C----                            ~~~~~~~~~~~~
C----                               ~~~~~~
C----                                 ~~
C-----------------------------------------------------------------------
C----                               KCTA Code
C----                               =========
C----
C----            K-reactor Cooling Tower Activity Code
C-----------------------------------------------------------------------
C----  PROGRAM SUMMARY: This program simulates the activity level of
C----  ~~~~~~~~~~~~~~~  a radionuclide in the control volumes (CV's)
C----                   of the K-reactor Cooling Tower Water System due
C----                   to a Process Water leak into the HEAT EXCHANGERS.
C----
C----                   The KCTA code also calculates the rate of release
C----                   of the ith radionuclide into the environment via
C----                   evaporation and blowdown from the cooling tower.
C----
C----                   The leak can be defined by a number of pair values
C----                   (time dependent).  The time (sec) and the leak rate
C----                   in gpm define the points needed for the leak
C----                   function.
C----
C----           There are six modules in KCTA, as follows:
C----
C----      <MAIN>  Checks for the neccessary files and controls the
C----              flow of the Program's Execution.
```

```
C----
C----      <REED>  Data from the input file on I/O unit 10, defined by INP
C----              are read into KCTA by this module.
C----
C----     <STEADY> Computes coupled nuclide-CV coefficients, initial
C----              steady-state activity levels in the CV's, and initial
C----              rate of radionuclides releases to the environment.
C----
C----      <RITE1> Write the input data along with steady state values
C----              and coefficients to the ouptut file on I/O UNIT 10
C----              defined by the variable OUTP.
C----
C----     <ERRCHK> Checks if the time step increment is large enough
C----              so that the array sizes for storing delayed terms
C----              are sufficient.  Also checks if the step size is
C----              small enough such that the leak function is
C----              accounted for and that dt is less than half of
C----              loop connection and residence times (which ever is
C----              minimum).
C----
C----      <TRANS> Steps into time.  The time-dependent behavior of the
C----              ith radionuclide in the CV's along with the release
C----              rates are computed with TRANS.  TRANS additionaly
C----              write the output to UNIT 20.
C----
C=====================================================================
C=============>  Needed INPUT PARAMETERS  [KCTA.I]  <================
C
C      VX    = cooling water (CW) volume in heat exchangers (HX's) [gallons]
C      VT    = CW volume in Cooling Tower (CT) [gallons]
C      VB    = CW volume in 186-Basin (B) [gallons]
C      VXT   = CW volume in loop connecting HX's to CT [gallons]
C      VTB   = CW volume in loop connecting CT to B [gallons]
C      VBX   = CW volume in loop connecting B to HX's [gallons]
C
C      Bd_0 = tower blow down rate [gallons per minute: gpm]
C      E_0  = tower evaporation rate [gpm]
C      R_0  = tower to 186-basin recirculation rate [gpm]
C
C       Pw   = process water in-leakage flow rate in gpm
C       Cw   = cooling water make-up flow rate in gpm
C
C       DT     = delta time (sec)
C       TMX    = Maximum time to follow transient (sec)
C       TPR    = Print flag, time increment to print results (sec)
C
C       NR   = number of radionuclides to be examined
C     NID(i)= ith radionuclide ID number [I4 format]
C     sPw(i)= ith radionuclide conc. in process water [Ci/gallon]
C     sCw(i)= ith radionuclide conc. in cooling water make-up [Ci/gallon]
C
C      NLP     = NUMBER OF POINTS USED TO DEFINE LEAK FROM T=0 OF PW
C      TLK(j) = TIME OF LEAK POINT DEFINITION (sec),
C      CLK(j) = moderator leak rate at TLK(i), gpm
C
C      NEP     = NUMBER OF POINTS USED TO DEFINE EVAPORATION RATE
C      TEV(j) = TIME OF EVAPORATION POINT DEFINITION (sec),
C      EVR(j) = EVAPORATION rate at TLK(i), gpm
C
C      NBP     = NUMBER OF POINTS USED TO DEFINE BLOW-FOWN RATE
C      TBD(j) = TIME OF BLOW-DOWN POINT DEFINITION (sec),
C      BDR(j) = BLOW-DOWN rate at TLK(i), gpm
```

```
C=============================================================================
C==============>  Needed ISOTOPE DATA [KCTA.D]  <================
C
C     NMD(i)= radionuclide ID number for comparison [I4 format]
C     HLF(i)= half-life of ith radionuclide, [sec]
C     NME(i)= name of ith radionuclide [A6 format]
C     DUMA  = dummy variable for NME(i) search
C=============================================================================
C==============> Constants & Coefficients, CALCULATED <================
C
C     TRPINT= Counter for the print coefficient (sec)
C       NDUM= Used to count the number of nuclides no to be read if > 50.
C
C    LAM1(I)= Decay constant of the ith radionuclide in 1/sec
C      TOTF = total cooling water flow rate= Bd_0 + E_0 + R_0 [gpm]
C      TOTs = totf/60 [gallon/sec]
C      fR_0 = fraction of R_0, R_0/total flow
C      fE_0 = fraction of E_0, E_0/total flow
C      fB_0 = fraction of Bd_0, Bd_0/total flow
C
C      tr_X  = CW residence time in heat exchangers (sec)
C      tr_T  = CW residence time in cooling tower (sec)
C      tr_T  = CW residence time in 186-Basin (sec)
C      tl_XT = CW loop time from HX's to CT  (sec)
C      tl_TB = CW loop time from CT to 186-Basin (sec)
C      tl_BX = CW loop time from 186-Basin to HX's (sec)
C
C     LAMX(i)= Modified ith decay constant in heat exchangers, 1/sec
C     LAMT(i)= Modified ith decay constant in cooling Tower, 1/sec
C     LAMB(i)= Modified ith decay constant in 186-Basin, 1/sec
C
C    EP_BX(i)= Constant for ith decay between B and X, 1/sec
C    EP_XT(i)= Constant for ith decay between X and T, 1/sec
C    EP_TB(i)= Constant for ith decay between T and B, 1/sec
C
C      EPP(I)= Constants for all KCTA loop, ith radionuclide [1/sec])**3
C      LMM(I)= Constants for all KCTA CVs, ith radionuclide [1/sec])**3
C       DD(i)= CONSTANTs
C
C        IDT1= Flag for checking maximum recommended dt
C        IDT2= Flag for checking maximum recommended dt
C        IDT3= Flag for checking maximum recommended dt
C
C       DTMX1= Minimum of TLK(i) and dt
C       DTMX2= Minimum of all loop and residence times and dt
C       DTMX3= Minimum of DTMX1 and DTMX2
C=============================================================================
C==============> Initial Steady-State Parameters  <================
C
C     T_in(i)=steady state rate of i in HX & B [Ci/sec]
C      CPw(i)=steady state rate of in-leakage of i in hx [Ci/sec]
C      CCw(i)=steady state rate of make-up flow of i in B [Ci/sec]
C     R_E0(i)=Initial rate of release of i by evaporation [Ci/sec]
C     R_B0(i)=Initial rate of release of i by Blow-down [Ci/sec]
C     TR_0(i)=Initial rate of release of i total (Ci/sec]
C       T_in0=Total initial rate of all i into HX's & B [CI/sec]
C       CPw_0=Total initial inleakage of all i into HX's [CI/sec]
C       CCw_0=Total initial make-up flow of all i into B [CI/sec]
C        RE_0=Total initial rate of release of all i by evaporation (Ci/sec)
C        RB_0=Total initial rate of release of all i by blow-down (Ci/sec)
C        RT_0=Total initial rate of release of all i all pathways (Ci/sec)
C     NT_0(i)=Initial steady-state content of i in cooling tower [Ci]
```

```
C     NB_0(i)=Initial steady-state content of i in 186-Basin [Ci]
C     NX_0(i)=Initial steady-state content of i in all Heat exchangers [Ci]
C=============================================================================
C=============> Constants & Conversion Factors  <===============
C
C      SEC    = alphanumeric = 'seconds'
C      DAY    = alphanumeric = 'day     '
C      YR     = alphanumeric = 'year    '
C
C      c1     = conversion factor from 1/sec to 1/day
C      c2     = conversion factor from 1/day to 1/year
C      c3     = conversion factor from 1/sec to 1/hour
C=============================================================================
C=============> Transient Variables  <===============
C
C       DREQ = Maximum Allowed step size [sec]
C      RSIZE = Required size of ZB, ZX, and ZT arrays
C
C      SLP1   = Slope of the line defining the leak function
C      IXS1   = Intersection of the line defining the leak function
C      LKR    = Leak rate at a given instant in time, gallons/sec
C
C      SLP2   = Slope of the line defining the evaporation function
C      IXS2   = Intersection of the line defining the evaporation function
C      REV    = Evaporation rate at a given instant in time, gallons/sec
C
C      SLP3   = Slope of the line defining the blow-down function
C      IXS3   = Intersection of the line defining the blow-down function
C      RBD    = Blow-down rate at a given instant in time, gallons/sec
C
C      TME    = Time into the transient (sec)
C      JTN    = Number of steps taken from 0 sec to tme
C      JJ     = Counter for ZX, ZB, & ZT
C
C      IX     = Pointer to ZX at tme - tl_XT
C      IB     = Pointer to ZB at tme - tl_BX
C      IT     = Pointer to ZT at tme - tl_TB
C
C     NT_t(i)=Cooling Tower level of i at tme [Ci]
C     NB_t(i)=186-Basin level of i at tme [Ci]
C     NX_t(i)=Heat Exchangers level of i at tme [Ci]
C
C     NT_d(i)=Cooling Tower level of i at tme-tl_TB [Ci]
C     NB_d(i)=186-Basin level of i at tme-tl_BX [Ci]
C     NX_d(i)=Heat Exchangers level of i at tme-tl_XT [Ci]
C
C     ER_t(i)=total rate of release of i at tme to environ. [Ci/sec]
C     ER_e(i)=rate of release of i at tme to envn. via evapor. [Ci/sec]
C     ER_b(i)=rate of release of i at tme to envn. via blowdown [Ci/sec]
C
C     IR_t(i)=total released of i at tme to environ. [Ci/sec]
C     IR_e(i)=total released of i at tme to envn. via evapor. [Ci/sec]
C     IR_b(i)=total released of i at tme to envn. via blowdown [Ci/sec]
C
C       ZB(i)=Values of NB_t(i) for recall [Ci/sec]
C       ZT(i)=Values of NT_t(i) for recall [Ci/sec]
C       ZX(i)=Values of NX_t(i) for recall [Ci/sec]
C=============================================================
C=============>  DECLARE ALL VARIABLES,   <===============
C=============> CONSTANTS, & COEFFICIENTS <===============
C
      PROGRAM MAIN
```

```
      REAL*8 VX,VT,VB,VXT,VTB,VBX,Bd_0,E_0,R_0,Pw,Cw,sPw(50),DT,
     &       sCw(50),TLK(20),CLK(20),TMX,TPR,CPw(50),HLF(50),LAM1(50)
      REAL*8 fB_0,tr_X,tr_B,tr_T,tl_XT,tl_TB,tl_BX,TOTF,TOTS,
     &       LAMX(50),LAMT(50),LAMB(50),EP_BX(50),EP_XT(50),TPRINT,
     &       EP_TB(50),EPP(50),LMM(50),DD(50),R_E0(50),R_B0(50),
     &       TR_0(50),RE_0,RB_0,RT_0,CPw_0,CCw(50),CCw_0,T_in(50),
     &       T_in0,NT_0(50),NB_0(50),NX_0(50),IXS1,TME,fR_0,fE_0,
     &       SLP1,LKR,NT_t(50),NB_t(50),NX_t(50),NT_d(50),NB_d(50),
     &       NX_d(50),ER_t(50),ER_E(50),ER_B(50),c1,c2,c3,DTMX1,DTMX2,
     &       DTMX3,ZX(1000),ZT(1000),ZB(1000),DREQ,SLP2,SLP3,IXS2,IXS3,
     &       TEV(20),TBD(20),EVR(20),BDR(20),REV,RBD
      INTEGER*4 NR,NID(50),NLP,OPT,NEP,NBP,IFLGE,IFLGB
      INTEGER*4 NMD(50),I1,J1,IFLGL,I2,I3,
     &       NDUM,IX,IB,IT,RSIZE,JTN,JJ,IDT1,IDT2,IDT3
      LOGICAL EXT
      CHARACTER*12 INP,OUTP
      CHARACTER*6  NME(50),DUMA,SEC,DAY,YR
      COMMON /reed10/VX,VT,VB,VXT,VTB,VBX,Bd_0,E_0,R_0,Pw,Cw,DT,TMX,
     &               TPR,LAM1,NR,NID,sPw,sCw,NLP,TLK,CLK,OPT,HLF,
     &               SLP2,SLP3,IXS2,IXS3,TEV,TBD,EVR,
     &               BDR,REV,RBD,NEP,NBP,IFLGE,IFLGB
      COMMON /TRD/fR_0,fE_0,fB_0,tr_X,tr_B,tr_T,tl_XT,tl_TB,
     &       tl_BX,TOTF,TOTS,LAMX,LAMT,LAMB,EP_BX,EP_XT,TPRINT,
     &       EP_TB,EPP,LMM,DD,R_E0,R_B0,TR_0,RE_0,RB_0,RT_0,CPw,CPw_0,
     &       CCw,CCw_0,T_in,T_in0,NT_0,NB_0,NX_0,IXS1,TME,SLP1,
     &       LKR,NT_t,NB_t,NX_t,NT_d,NB_d,NX_d,ER_t,ER_E,ER_B,C1,C2,
     &       C3,DTMX1,DTMX2,DTMX3,ZX,ZT,ZB,DREQ,EXT
      COMMON /INTG/NMD,IFLGL,NDUM,RSIZE,JTN,JJ,IDT1,IDT2,IDT3
      COMMON /CHR/INP,OUTP,NME,DUMA,SEC,DAY,YR
C
C
C
       INP='KCTA.I'
       OUTP='KCTA.O'
       SEC='second'
       day='day    '
       YR='year   '
       RE_0=0.0
       RB_0=0.0
       RT_0=0.0
       CPw_0=0.0
       CCw_0=0.0
       T_in0= 0.0
       c1= 8.64e+04
       c2=3.1536e+07
       c3=3600
       IDT1=-100
       IDT2=-100
       IDT3=-100
       DTMX1=1E4
C-------------------------------------------------------------------------
C----      Inquire about the file "KCTA.i" which contains the input
C----  data.  If it exists, open this file as an old file and assign it
C----  to I/O UNIT 10.  Otherwise, ask the user to enter the name of
C----  input file.
C-------------------------------------------------------------------------
9000  INQUIRE(FILE=INP,EXIST=EXT)
      IF (EXT) THEN
         GOTO 9002
         ELSE
9001     WRITE(6,5001) INP
         READ(6,5002,ERR=9001) INP
```

```
         GOTO 9000
      ENDIF
9002  OPEN (10,FILE=INP,STATUS='OLD')
C-----------------------------------------------------------------------
C----      Check if a file called "KCTA.o" exists under the current
C----  directory.  If it exists, ask the user to enter an alternative
C----  name to be used for an output file and assign it to unit 20.
C----  Otherwise, use the default file for output.
C-----------------------------------------------------------------------
9003  INQUIRE(FILE=OUTP,EXIST=EXT)
      IF (EXT) THEN
9004     WRITE(6,5003) OUTP
         READ(6,5002,ERR=9004) OUTP
         GOTO 9003
      ENDIF
      OPEN(UNIT=20,FILE=OUTP,STATUS='NEW')
C-----------------------------------------------------------------------
C----      Check if the data base file "KCTA.D" exists under the current
C----  directory.  If it exists, open it as an old file and
C----  assign it to unit 60; otherwise, inform the user and abort.
C-----------------------------------------------------------------------
      INQUIRE(FILE='KCTA.D',EXIST=EXT)
      IF (EXT) THEN
          OPEN(UNIT=60,FILE='KCTA.D',STATUS='OLD')
      ELSE
          WRITE(6,6010)
          GOTO 9017
      ENDIF
C-----------------------------------------------------------------------
C----      CALL REED, to input data from I/O unit 10.
C-----------------------------------------------------------------------
       CALL REED
C-----------------------------------------------------------------------
C----      CALL STEADY, to calculate constants, coefficients, and
C----                   steady-state levels in all Control Volumes and
C----                   steady-state releases to the envrionment.
C-----------------------------------------------------------------------
       CALL STEADY
C-----------------------------------------------------------------------
C----      CALL RITE1, to write input data and steady state values to
C----                  the output file given by OUTPon I/O unit 60.
C-----------------------------------------------------------------------
       CALL RITE1
C-----------------------------------------------------------------------
C----      CALL ERRCHK, checks for some errors in the input file
C-----------------------------------------------------------------------
       CALL ERRCHK
C-----------------------------------------------------------------------
C----      CALL TRANS, STARTS THE TRANSIENT
C-----------------------------------------------------------------------
       CALL TRANS
C-----------------------------------------------------------------------
C-----        Format Statements used for I/O
C-----------------------------------------------------------------------
5001  FORMAT(//////T2,'The input file <',A12,'> does not exist on'/T2,
     & 'the current drive. Enter the name of the file'/T2,'containing',
     & ' the input data.  For example: KCTA.in .'//
     & T30,'Name of input file <FILE.EXT>===> ')
5002  FORMAT(A12)
5003  FORMAT(//'  The output file <',A12,'> exists on the'/'  current',
     & ' drive.  Enter a name for a file'/'   to be used for output. ',
     & ' For example: KCTA.out.'//T30,
```

```
     & 'Name of output file <FILE.EXT>===> ')
6010  FORMAT(/////7X,47('*')/7X,4('*'),' Data file "KCTA.D" ',
     &  'does not exist     ****'/7X,4('*'),' on current drive.',
     &  21X,'****'/7X,4('*'),13X,11('*'),15X,4('*')/7X,4('*'),
     &  4X,8('!'),' Aborting KCTA !!!!!!!!    ****'/
     &  7X,4('*'),13X,11('*'),15X,4('*')/7X,47('*')///)
6014  FORMAT(///t10,40('*'),/t10,3('*'),5x,'Error in Time Function',
     &  7x,3('*')/t10,3('*'),10x,'Part of Program',9x,
     &  3('*')/t10,40('*'))
C-------------------------------------------------------------------------
C-----      Close all i/o units and END Program.
C-------------------------------------------------------------------------
9017  CLOSE(10)
      CLOSE(20)
      CLOSE(30)
      CLOSE(60)
123   CONTINUE
      STOP
      END
```

B.2 The REED Module

```
C        ////////////////////////////////////////////////////////
C       /                          SUBROUTINE REED               /
C      /                           ~~~~~~~~~~~~~~~              /
C     / SUBROUTINE SUMMARY: Reads data from Unit 10, i.e,      /
C    /                      from default input file, and from /
C   /                       UNIT 60, i.e., the data base     /
C  /                        "KCTA.D".                       /
C////////////////////////////////////////////////////////
      SUBROUTINE REED
      CHARACTER*12 INP,OUTP
      CHARACTER*6  NME(50),DUMA,SEC,DAY,YR
      INTEGER*4 NMD(50),I1,J1,IFLAG,I2,I3,
     &       NDUM,IX,IB,IT,RSIZE,JTN,JJ,IDT1,IDT2,IDT3
      INTEGER*4 NR,NID(50),NLP,OPT,NEP,NBP,IFLGE,IFLGB
      REAL*8 VX,VT,VB,VXT,VTB,VBX,Bd_0,E_0,R_0,Pw,Cw,sPw(50),DT,
     &       sCw(50),TLK(20),CLK(20),TMX,TPR,CPw(50),HLF(50),
     &       LAM1(50),SLP2,SLP3,IXS2,IXS3,
     &       TEV(20),TBD(20),EVR(20),BDR(20),REV,RBD
      COMMON /CHR/INP,OUTP,NME,DUMA,SEC,DAY,YR
      COMMON /reed10/VX,VT,VB,VXT,VTB,VBX,Bd_0,E_0,R_0,Pw,Cw,DT,TMX,
     &               TPR,LAM1,NR,NID,sPw,sCw,NLP,TLK,CLK,OPT,HLF,
     &               SLP2,SLP3,IXS2,IXS3,TEV,TBD,EVR,
     &               BDR,REV,RBD,NEP,NBP,IFLGE,IFLGB
C-------------------------------------------------------------------------
C----    Read all data from INP
C-------------------------------------------------------------------------
C
C     Number time-increment of solution and Maximum time to
C     follow transient.
C
      READ(10,*) DT,TMX,TPR
C
C      Volumes of HX's, CT, B, and connecting loops in gallons
C
       READ(10,*) VX,VT,VB,VXT,VTB,VBX
C
C     Tower blow down rate, tower evaporation rate, and tower to
C                    186-basin recirculation rate in GPM
C
       READ(10,*) Bd_0,E_0,R_0
C
C      Read number of radionuclides in problem.
C      If number of nuclides exceed maximum nuber allowed, inform
C      the user that the maximum allowed nuclides are 50.  Ask
C      the user if the problem should continue with only the
C      first 50 nuclides included or if the user wishes to abort.
C
       READ(10,*) NR
      IF(NR .GT. 50) THEN
         WRITE(20,6017) INP,NR
9030     WRITE(6,6017) INP,NR
         READ(6,*,ERR=9030) OPT
         IF(OPT .EQ. 1) THEN
             WRITE(6,6018)
             WRITE(20,6018)
             STOP
         ELSE
           IF(OPT .NE. 2) GOTO 9030
           NDUM = NR - 50
```

```
            NR = 50
           WRITE(6,6019)  NDUM
           WRITE(20,6019) NDUM
         ENDIF
       ENDIF
C
C       Read nuclides' ID numbers to be processes by KCTA and their
C        concentrations in moderator (pw) and cooling water (cw)
C
C     if sPw < 0 [Ci/galllons]  else if sPw > 0 [Ci/liter] and convert
C     if cPw < 0 [Ci/galllons]  else if cPw > 0 [Ci/liter] and convert
C
C        Also, if more than <50> nuclides are included in the porblem,
C        Skip the lines containing more than <50> nuclides so that the
C        Heat Exchangers leak function can be probably read.
C
        DO 9005 i1=1,NR
            READ(10,*) NID(i1),sPw(i1),sCw(i1)
            IF(sPw(i1) .GT. 0) sPw(i1) =  3.785*sPw(i1)
            IF(sCw(i1) .GT. 0) sCw(i1) =  3.785*sCw(i1)
            IF(sPw(i1) .LT. 0) sPw(i1) = -sPw(i1)
            IF(sCw(i1) .LT. 0) sCw(i1) = -sCw(i1)
9005    CONTINUE
        IF (NDUM .GE. 1) then
           DO 9035 i1=1,NDUM
 9035      READ(10,*) I2
        ENDIF

C
C       Initial steady state process water leakage and make-up water
c       flow rates in [gpm]
C
        READ(10,*) Pw,Cw
C
C      Number of points used to define leak rate of accident.
C      MAXIMUM allowed points are 20, check if NLP is > 20, if so
C      inform the user the function needs to be modified so that
C      it can be approximated by a maximum of 20 point and THEN ABORT.
C      Otherwise, continue
C
       READ(10,*) NLP
       IF(NLP .GT. 20) THEN
           WRITE(6,6016) INP,NLP
           WRITE(20,6016) INP,NLP
           STOP
       ENDIF
C
C     pairs of time and leak rate to define function.
C     Also, convert from gpm to gallons/sec.
C
       DO 9006 j1=1,NLP
              READ(10,*) TLK(j1),CLK(j1)
9006   CLK(j1) = CLK(j1)/60.0
C
C      Number of points used to define BLOW-DOWN RATE FUNCTION.
C      MAXIMUM allowed points are 20, check if NBP is > 20, if so
C      inform the user the function needs to be modified so that
C      it can be approximated by a maximum of 20 point and THEN ABORT.
C      Otherwise, continue
C
       READ(10,*) NBP
       IF(NLP .GT. 20) THEN
```

```
          WRITE(6,6020) INP,NBP
          WRITE(20,6020) INP,NBP
          STOP
       ENDIF
C
C     pairs of time and blow-down rate to define function.
C     Also, convert from gpm to gallons/sec.
C
       DO 9040 j1=1,NBP
             READ(10,*) TBD(j1),BDR(j1)
9040   BDR(j1) = BDR(j1)/60.0
C
C      Number of points used to define evaporation rate FUNCTION.
C      MAXIMUM allowed points are 20, check if NEP is > 20, if so
C      inform the user the function needs to be modified so that
C      it can be approximated by a maximum of 20 point and THEN ABORT.
C      Otherwise, continue
C
       READ(10,*) NEP
       IF(NLP .GT. 20) THEN
          WRITE(6,6021) INP,NEP
          WRITE(20,6021) INP,NEP
          STOP
       ENDIF
C
C     pairs of time and evaporation rate to define function.
C     Also, convert from gpm to gallons/sec.
C
       DO 9041 j1=1,NEP
             READ(10,*) TEV(j1),EVR(j1)
9041   EVR(j1) = EVR(j1)/60.0
C-------------------------------------------------------------------------
C----     Search for needed data from "KCTA.D" and read them.
C-------------------------------------------------------------------------
       DO 9007 i1 = 1,NR
9008      READ(60,*) NMD(i1),HLF(i1)
          READ(60,6008) NME(i1)
          IF(NMD(i1) .LT. 0) THEN
             WRITE(6,6009) NID(i1)
             WRITE(20,6009) NID(i1)
             STOP
          ENDIF
          IF(NMD(i1) .EQ. NID(i1)) THEN
             IF(NID(i1+1) .LT. NID(i1)) REWIND(60)
             LAM1(i1) = 0.693/HLF(i1)
          ELSE
          GOTO 9008
          ENDIF
9007      CONTINUE
C////////////////////////////////////////////////////////////////////
C///          Format Statements used for I/O in REED              ///
C////////////////////////////////////////////////////////////////////
6021   FORMAT(////T8,32('>'),33('<')/T8,6('>'),3x,'The maximum ',
     & 'allowed number of points to',11x,6('<')/T8,6('>'),3x,'def',
     & 'ine the Evaporation Rate is <20>.',14x,6('<')/T8,6('>'),53x,
     & 6('<')/T8,6('>'),3x,'In the input file <',A12,'>, NEP has a',
     & 7x,6('<')/T8,6('>'),3x,'a value of <',I3,'>.  Modify ',
     & 'the definition so that',2x,6('<')/T8,6('>'),3x,'this funct',
     & 'ion can be defined by only <20> points. ',6('<')/T8,6('>'),
     & 53x,6('<')/T8,6('>'),4x,44('!'),5x,6('<')/T8,6('>'),4x,10('!'),
     & '  Aborting EXECUTION  ',12('!'),5x,6('<')/T8,6('>'),4x,44('!'),
     & 5x,6('<')/T8,6('>'),53x,6('<')/T8,32('>'),33('<')/)
```

```
6020  FORMAT(////T8,32('>'),33('<')/T8,6('>'),3x,'The maximum ',
     & 'allowed number of points to',11x,6('<')/T8,6('>'),3x,'def',
     & 'ine the Blow-Down Rate   is <20>.',14x,6('<')/T8,6('>'),53x,
     & 6('<')/T8,6('>'),3x,'In the input file <',A12,'>, NBP has a',
     & 7x,6('<')/T8,6('>'),3x,'a value of <',I3,'>.  Modify ',
     & 'the definition so that',2x,6('<')/T8,6('>'),3x,'this funct',
     & 'ion can be defined by only <20> points. ',6('<')/T8,6('>'),
     & 53x,6('<')/T8,6('>'),4x,44('!'),5x,6('<')/T8,6('>'),4x,10('!'),
     & '  Aborting EXECUTION  ',12('!'),5x,6('<')/T8,6('>'),4x,44('!'),
     & 5x,6('<')/T8,6('>'),53x,6('<')/T8,32('>'),33('<')/)
6016  FORMAT(////T8,32('>'),33('<')/T8,6('>'),3x,'The maximum ',
     & 'allowed number of points to',11x,6('<')/T8,6('>'),3x,'def',
     & 'ine the HX leak function is <20>.',14x,6('<')/T8,6('>'),53x,
     & 6('<')/T8,6('>'),3x,'In the input file <',A12,'>, NLP has a',
     & 7x,6('<')/T8,6('>'),3x,'a value of <',I3,'>.  Modify ',
     & 'the definition so that',2x,6('<')/T8,6('>'),3x,'this funct',
     & 'ion can be defined by only <20> points. ',6('<')/T8,6('>'),
     & 53x,6('<')/T8,6('>'),4x,44('!'),5x,6('<')/T8,6('>'),4x,10('!'),
     & '  Aborting EXECUTION  ',12('!'),5x,6('<')/T8,6('>'),4x,44('!'),
     & 5x,6('<')/T8,6('>'),53x,6('<')/T8,32('>'),33('<')/)
6017  FORMAT(////T8,32('>'),33('<')/T8,6('>'),3x,'The maximum allowe',
     & 'd number of nuclides in the',5x,6('<')/T8,6('>'),3x,'problem',
     & ' is <50>.',34x,6('<')/T8,6('>'),53x,6('<')/T8,6('>'),3x,'In ',
     & 'the input file <',A12,'>,  NR is read as',2x,6('<')/T8,6('>'),
     & 3x,'a value of <',I3,'>.    YOU HAVE TWO OPTIONS:',8x,6('<')/T8,
     & 6('>'),53x,6('<')/T8,6('>'),3x,'1. ENTER 1 to abort program,',
     & ' or',19x,6('<')/T8,6('>'),3x,'2. ENTER 2 to continue with pro',
     & 'gram with only   ',2x,6('<')/T8,6('>'),3x,'   the first 5',
     & '0 nuclides included in the problem',2x,6('<'),
     & /T8,6('>'),53x,6('<')/T8,
     & 32('>'),33('<')///T40,'ENTER OPTION ====> <1 or 2>  ')
6018  FORMAT(///T20,'YOU HAVE SELECTED OPTION 1',///T8,32('>'),33('<')/
     & T8,6('>'),53x,6('<')/T8,6('>'),4x,44('!'),5x,6('<')/T8,6('>'),
     & 4x,10('!'),'EXECUTION ABORTED  BYE',12('!'),5x,6('<')/T8,
     & 6('>'),4x,44('!'),5x,6('<')/T8,6('>'),53x,6('<')/T8,
     & 32('>'),33('<')/)
6019  FORMAT(/T8,'YOU HAVE SELECTED OPTION 2'//T8,'Only the data ',
     &  'for the first <50> nuclides will be read',/T8,'AND <',I3,
     &  '> Data points will be skipped/'//T8,
     & 'EXECUTION CONTINUES.......')
6008  FORMAT(A6)
6009  FORMAT(////1X,73('*')/1X,73('!')//5X,'The nuclide <',I6,'> was ',
     & 'not found in the data file <KCTA.D>. '/5x,'Check the nuclid',
     & 'e''s I.D. or modify the data file <KCTA.D> ',//20x,24('!')/20x,
     & '!!! ABORTING PROGRAM !!!',/20x,24('!'),//1X,73('!')/1x,73('*'))
C////////////////////////////////////////////////////////////////////
C////       The End of The Format Statements used in REED &       ///
C///#########################*******END REED*******#################////
C////////////////////////////////////////////////////////////////////
      RETURN
      END
```

B.3 The STEADY module

```
C        ////////////////////////////////////////////////////////
C       /                          SUBROUTINE STEADY             /
C      /                           ~~~~~~~~~~~~~~~~             /
C     / SUBROUTINE SUMMARY: Computes constants & coefficients  /
C    /                      that are isotope and steady-state /
C   /                       dependent, along with the intial /
C  /                        STEADY-STATE values of Control  /
C /                         Volumes Activity and Releases  /
C/                          to the Environment            /
C////////////////////////////////////////////////////////
      SUBROUTINE STEADY
      REAL*8 VX,VT,VB,VXT,VTB,VBX,Bd_0,E_0,R_0,Pw,Cw,sPw(50),DT,
     &       sCw(50),TLK(20),CLK(20),TMX,TPR,CPw(50),HLF(50),LAM1(50)
      REAL*8 fB_0,tr_X,tr_B,tr_T,tl_XT,tl_TB,tl_BX,TOTF,TOTS,
     &       LAMX(50),LAMT(50),LAMB(50),EP_BX(50),EP_XT(50),TPRINT,
     &       EP_TB(50),EPP(50),LMM(50),DD(50),R_E0(50),R_B0(50),
     &       TR_0(50),RE_0,RB_0,RT_0,CPw_0,CCw(50),CCw_0,T_in(50),
     &       T_in0,NT_0(50),NB_0(50),NX_0(50),INTER,TME,fR_0,fE_0,
     &       SLOPE,LKR,NT_t(50),NB_t(50),NX_t(50),NT_d(50),NB_d(50),
     &       NX_d(50),ER_t(50),ER_E(50),ER_B(50),c1,c2,c3,DTMX1,DTMX2,
     &       DTMX3,ZX(1000),ZT(1000),ZB(1000),DREQ,SLP2,SLP3,IXS2,IXS3,
     &       TEV(20),TBD(20),EVR(20),BDR(20),REV,RBD
      INTEGER*4 NR,NID(50),NLP,OPT,NEP,NBP,IFLGE,IFLGB
      INTEGER*4 NMD(50),I1,J1,IFLAG,I2,I3,
     &       NDUM,IX,IB,IT,RSIZE,JTN,JJ,IDT1,IDT2,IDT3
      LOGICAL EXT
      CHARACTER*12 INP,OUTP
      CHARACTER*6  NME(50),DUMA,SEC,DAY,YR
      COMMON /reed10/VX,VT,VB,VXT,VTB,VBX,Bd_0,E_0,R_0,Pw,Cw,DT,TMX,
     &               TPR,LAM1,NR,NID,sPw,sCw,NLP,TLK,CLK,OPT,HLF,
     &               SLP2,SLP3,IXS2,IXS3,TEV,TBD,EVR,
     &               BDR,REV,RBD,NEP,NBP,IFLGE,IFLGB
      COMMON /TRD/fR_0,fE_0,fB_0,tr_X,tr_B,tr_T,tl_XT,tl_TB,
     &       tl_BX,TOTF,TOTS,LAMX,LAMT,LAMB,EP_BX,EP_XT,TPRINT,
     &       EP_TB,EPP,LMM,DD,R_E0,R_B0,TR_0,RE_0,RB_0,RT_0,CPw,CPw_0,
     &       CCw,CCw_0,T_in,T_in0,NT_0,NB_0,NX_0,INTER,TME,SLOPE,
     &       LKR,NT_t,NB_t,NX_t,NT_d,NB_d,NX_d,ER_t,ER_E,ER_B,C1,C2,
     &       C3,DTMX1,DTMX2,DTMX3,ZX,ZT,ZB,DREQ,EXT
      COMMON /INTG/NMD,IFLAG,NDUM,RSIZE,JTN,JJ,IDT1,IDT2,IDT3
      COMMON /CHR/INP,OUTP,NME,DUMA,SEC,DAY,YR
C-------------------------------------------------------------------------
C----   Calculate the initial steady-state parameters, other
C----      coefficients, and isotope dependent constants.
C-------------------------------------------------------------------------
C
C          convert Pw and Cw from gp, to gallons per sec
C
       Pw = Pw/60
       Cw = Cw/60
C
C     Calculate total flow rate through the cooling tower [gpm] and
C           cooling tower flow fractions
C
      TOTF = BD_0 + E_0 + R_0
      TOTs = TOTF/60.0
      fR_0 =  R_0/TOTF
      fE_0 =  E_0/TOTF
      fB_0 = Bd_0/TOTF
C
```

```
C       Calculate the time constants (residence and loop times)
C
        tr_X = VX/TOTs
        tr_T = VT/TOTs
        tr_B = VB/TOTs
        tl_XT = VXT/TOTs + tr_X
        tl_TB = VTB/(fR_0*TOTs) + tr_T
        tl_BX = 60*VBX/(R_0 + Cw) + tr_B
C-------------------------------------------------------------------------
C----    Calculate the isotope and control volume dependent constants
C-------------------------------------------------------------------------
      DO 9009 i1= 1,NR
          EP_BX(i1) = EXP(-LAM1(i1)*tl_BX)/tr_B
          EP_XT(i1) = EXP(-LAM1(i1)*tl_XT)/tr_X
          EP_TB(i1) = EXP(-LAM1(i1)*tl_TB)/tr_T
           LAMX(i1) = LAM1(i1) + 1/tr_X
           LAMT(i1) = LAM1(i1) + 1/tr_T
           LAMB(i1) = LAM1(i1) + 1/tr_B
            LMM(i1) = LAMB(i1)*LAMT(i1)*LAMX(i1)
            EPP(i1) = EP_BX(i1)*EP_XT(i1)*EP_TB(i1)
             DD(i1) = LMM(i1) - (fR_0*EPP(i1))
C-------------------------------------------------------------------------
C----       Calculate the intitial steady-state ith radionuclide acitivity
C----       levels in the control volumes (HX's, CT, & 186-Basin). [Ci]
C-------------------------------------------------------------------------
         CPw(i1) = sPw(I1)*Pw
         CCw(i1) = sCw(I1)*Cw
        T_in(i1) = CCw(i1) + CPw(i1)
        NX_0(i1) = (LAMT(I1)/DD(I1))*(LAMB(I1)*CPw(i1) +
     &              EP_BX(I1)*CCw(I1))
        NT_0(i1) = (EP_XT(I1)/DD(I1))*(LAMB(I1)*CPw(I1) +
     &              EP_BX(I1)*CCw(I1))
        NB_0(i1) = (1/DD(I1))*(fR_0*EP_TB(I1)*EP_XT(I1)*CPw(I1) +
     &              LAMX(I1)*LAMT(I1)*CCw(I1))
C-------------------------------------------------------------------------
C----       Calculate the intitial steady-state rate of release (Ci/sec)
C----       of the ith radionuclide acitivity to the environment via
C----       evaporation, blow down, and total for I and all I combined.
C-------------------------------------------------------------------------
        R_E0(i1) = fe_0*NT_0(i1)/tr_T
        R_B0(i1) = fb_0*NT_0(i1)/tr_T
        TR_0(i1) = (1-fr_0)*NT_0(i1)/tr_T
        T_in0= T_in0 + T_in(i1)
        CPw_0= CPw_0 + CPw(i1)
        CCw_0= CCw_0 + CCw(i1)
        RE_0 = RE_0 + R_E0(i1)
        RB_0 = RB_0 + R_B0(i1)
        RT_0 = RT_0 + TR_0(i1)
9009    CONTINUE
C////////////////////////////////////////////////////////////////////////
C///#####################*******END STEADY*****####################///
C////////////////////////////////////////////////////////////////////////
        RETURN
        END
```

B.4 The RITE1 Module

```
C        ////////////////////////////////////////////////////////
C       /                          SUBROUTINE RITE1               /
C      /                           ~~~~~~~~~~~~~~~               /
C     / SUBROUTINE SUMMARY: Write the input and intial steady- /
C    /                      state values to the output file   /
C   /                       DEFINED BY outp on I/O unit 60.  /
C////////////////////////////////////////////////////////////////
      SUBROUTINE RITE1
      REAL*8 VX,VT,VB,VXT,VTB,VBX,Bd_0,E_0,R_0,Pw,Cw,sPw(50),DT,
     &       sCw(50),TLK(20),CLK(20),TMX,TPR,CPw(50),HLF(50),LAM1(50)
      REAL*8 fB_0,tr_X,tr_B,tr_T,tl_XT,tl_TB,tl_BX,TOTF,TOTS,
     &       LAMX(50),LAMT(50),LAMB(50),EP_BX(50),EP_XT(50),TPRINT,
     &       EP_TB(50),EPP(50),LMM(50),DD(50),R_E0(50),R_B0(50),
     &       TR_0(50),RE_0,RB_0,RT_0,CPw_0,CCw(50),CCw_0,T_in(50),
     &       T_in0,NT_0(50),NB_0(50),NX_0(50),INTER,TME,fR_0,fE_0,
     &       SLOPE,LKR,NT_t(50),NB_t(50),NX_t(50),NT_d(50),NB_d(50),
     &       NX_d(50),ER_t(50),ER_E(50),ER_B(50),c1,c2,c3,DTMX1,DTMX2,
     &       DTMX3,ZX(1000),ZT(1000),ZB(1000),DREQ,SLP2,SLP3,IXS2,IXS3,
     &       TEV(20),TBD(20),EVR(20),BDR(20),REV,RBD
      INTEGER*4 NR,NID(50),NLP,OPT,NEP,NBP,IFLGE,IFLGB
      INTEGER*4 NMD(50),I1,J1,IFLAG,I2,I3,
     &       NDUM,IX,IB,IT,RSIZE,JTN,JJ,IDT1,IDT2,IDT3
      LOGICAL EXT
      CHARACTER*12 INP,OUTP
      CHARACTER*6  NME(50),DUMA,SEC,DAY,YR
C      CHARACTER*80 TITLE
      COMMON /reed10/VX,VT,VB,VXT,VTB,VBX,Bd_0,E_0,R_0,Pw,Cw,DT,TMX,
     &               TPR,LAM1,NR,NID,sPw,sCw,NLP,TLK,CLK,OPT,HLF,
     &               SLP2,SLP3,IXS2,IXS3,TEV,TBD,EVR,
     &               BDR,REV,RBD,NEP,NBP,IFLGE,IFLGB
      COMMON /TRD/fR_0,fE_0,fB_0,tr_X,tr_B,tr_T,tl_XT,tl_TB,
     &       tl_BX,TOTF,TOTS,LAMX,LAMT,LAMB,EP_BX,EP_XT,TPRINT,
     &       EP_TB,EPP,LMM,DD,R_E0,R_B0,TR_0,RE_0,RB_0,RT_0,CPw,CPw_0,
     &       CCw,CCw_0,T_in,T_in0,NT_0,NB_0,NX_0,INTER,TME,SLOPE,
     &       LKR,NT_t,NB_t,NX_t,NT_d,NB_d,NX_d,ER_t,ER_E,ER_B,C1,C2,
     &       C3,DTMX1,DTMX2,DTMX3,ZX,ZT,ZB,DREQ,EXT
      COMMON /INTG/NMD,IFLAG,NDUM,RSIZE,JTN,JJ,IDT1,IDT2,IDT3
      COMMON /CHR/INP,OUTP,NME,DUMA,SEC,DAY,YR
C      COMMON /TIT/TITLE
C-------------------------------------------------------------------------
C----      Write all input data along with initial steady state calculated
C----      parameters to the output file defined by the variable OUTP.
C-------------------------------------------------------------------------
C       WRITE(20,6080) TITLE
       WRITE(20,6000) INP
       WRITE(20,6001) VX,VXT,VT,VTB,VB,VBX
C-------------------------------------------------------------------------
C----      Write relevant time constants
C-------------------------------------------------------------------------
       WRITE(20,6007) tr_x,tl_xt,tr_t,tl_tB,tr_b,tl_bx
       WRITE(20,6002) Cw*60.0,Pw*60.0
       WRITE(20,6003) BD_0,E_0,R_0,TOTF
C-------------------------------------------------------------------------
C----      Write the function describing the Process water In-Leakage
C----      to the HX's at time > 0
C-------------------------------------------------------------------------
       WRITE(20,6004) nlp
       do 9010 i1=1,nlp
9010   WRITE(20,6005) TLK(i1),CLK(i1)*60,CLK(i1)
```

```
C-----------------------------------------------------------------------
C----      Write the function describing the Process water In-Leakage
C----      to the HX's at time > 0
C-----------------------------------------------------------------------
      WRITE(20,6014) nbp
      do 9009 i1=1,nbp
9009  WRITE(20,6005) TBD(i1),BDR(i1)*60,BDR(i1)
C-----------------------------------------------------------------------
C----      Write the function describing the Process water In-Leakage
C----      to the HX's at time > 0
C-----------------------------------------------------------------------
      WRITE(20,6024) nep
      do 9008 i1=1,nep
9008  WRITE(20,6005) TEV(i1),EVR(i1)*60,EVR(i1)
      WRITE(20,6013)
C-----------------------------------------------------------------------
C----      Write initial i nuclide and all i nuclides release rates to
C----      envirnoment via all pathways in Ci/second, Ci/day, and Ci/year.
C-----------------------------------------------------------------------
C
C       Releases in Ci/sec
C
      WRITE(20,6011) SEC
      DO 9011 I1=1,NR
9011  Write(20,6006) NID(I1),NME(i1),T_in(i1),R_E0(i1),
     &               R_B0(i1),TR_0(i1)
      WRITE(20,6012) T_in0,RE_0,RB_0,RT_0
C
C       Releases in Ci/day
C
      WRITE(20,6011) DAY
      DO 9012 I1=1,NR
9012  Write(20,6006) NID(I1),NME(i1),c1*T_in(i1),c1*R_E0(i1),
     &       c1*R_B0(i1),c1*TR_0(i1)
      WRITE(20,6012) c1*T_in0,c1*RE_0,c1*RB_0,c1*RT_0
C
C       Releases in Ci/day
C
      WRITE(20,6011) YR
      DO 9013 I1=1,NR
9013  Write(20,6006) NID(I1),NME(i1),c2*T_in(i1),c2*R_E0(i1),
     &       c2*R_B0(i1),c2*TR_0(i1)
      WRITE(20,6012) c2*T_in0,c2*RE_0,c2*RB_0,c2*RT_0
C////////////////////////////////////////////////////////////////
C///         Format Statements used for I/O in RITE1          ///
C////////////////////////////////////////////////////////////////
6000  FORMAT(//T3,'The following data are obtained from the ',
     &  'input file <',A12,'>'/T3,67('='))
6001  FORMAT(//1x,73('-')/t8,19('>'),' VOLUMES (gallons) ',19('<')/1x,
     & 73('-')/3x,'Control Volume',28x,'Connecting Loop Volume'/
     & 1x,73('-')/1x,'Heat Exchangers = <',E9.4,'>',13x,'HX''s-to-CT',
     & 5x,'= <',E9.4,'>'/' Cooling Tower   = <',E9.4,'>',13x,
     & 'CT-to-186-Basin= <',E9.4,'>'/' 186-Basin       = <',E9.4,
     & '>',13x,'Basin-to-HX''s  = <'E9.4,'>'/1x,73('-')///)
6002  FORMAT(//T10,'Make-up Water Flow Rate',7x,'= <',E9.4,'> GPM',
     & /T10,'Process Water In-Leakage Rate = <',E9.4,'> GPM'/)
6003  FORMAT(/
     &    T10,'Cooling Tower Blow-down Rate     = <',E9.4,'> GPM'/
     &    T10,'Cooling Tower evaporation Rate   = <',E9.4,'> GPM'/
     &    T10,'Cooling Tower Recirculation Rate = <',E9.4,'> GPM'/
     &    T10,'Total Cooling Water Flow Rate    = <',E9.4,'> GPM'/)
6004  FORMAT(//' The following are the data used in defining the proc',
```

```
     &  'ess water'/' in-leakage to the heat exchangers at t > 0.'//
     &  '  NOTE: ONLY <',i2,'> points are used in defining the Process ',
     &  'Water Leak'/8x,'Rate Function, as follows:'//
     &  T10,'Time (sec)',T30,'Gallons/min',T50,'Gallons/sec'/T10,
     &  10('='),T30,11('='),T50,11('='))
6014  FORMAT(/////' The following are the data used in defining',
     &  ' the blow-down rate function'/'  at t > 0.'//
     &  '  NOTE: ONLY <',i2,'> points are used in defining this Functio',
     &  'n, as follows:'//
     &  T10,'Time (sec)',T30,'Gallons/min',T50,'Gallons/sec'/T10,
     &  10('='),T30,11('='),T50,11('='))
6024  FORMAT(/////' The following are the data used in defining ',
     &  'the evaporation rate function'/'  at t > 0.'//
     &  '  NOTE: ONLY <',i2,'> points are used in defining this Functio',
     &  'n, as follows:'//
     &  T10,'Time (sec)',T30,'Gallons/min',T50,'Gallons/sec'/T10,
     &  10('='),T30,11('='),T50,11('='))
6005  FORMAT(T10,E9.4,T31,E9.4,T51,E9.4)
6006  FORMAT(1x,I6,4x,A6,4x,E9.4,4x,E9.4,6x,E9.4,5x,E9.4)
6007  FORMAT(/1x,73('-')/t10,19('>'),' TIME CONSTANTS ',19('>')/
     & 1x,73('-')/3x,'Residence Time (sec)',22x,'Loop Delay',
     &  ' Time (sec)'/1x,73('-')/1x,'Heat Exchangers = <',E9.4,'>',13x,
     &  'HX''s-to-CT',5x,'= <',E9.4,'>'/' Cooling Tower   = <',E9.4,
     &  '>',13x,'CT-to-186-Basin= <',E9.4,'>'/' 186-Basin       = <',
     &  E9.4,'>',13x,'Basin-to-HX''s  = <'E9.4,'>'/1x,73('-'))
6013  FORMAT(/////////////)
6011  FORMAT(//1x,73('-')/10x,14('>'),' Initial Steady-St',
     &  'ate Release ',13('<'),/10x,14('>'),' of Radionuclides <Ci/',
     &   A6,'> ',13('<')/1x,73('-')/20x,'INTAKE BY',17x,
     &    'RELEASE PATHWAY'/5x,'ISOTOPE',9x,'Cw(0) &',6x,
     &   'Atmosphere',8x,'River',5x,'TOTAL TO THE'/
     &   3x,'ID',7x,'Name',6x,'Pw(0)',6x,'(Evaporation)',
     &   3x,'(Blow-Down)',3x,'ENVIRONMENT'/1x,73('-'))
6012  FORMAT(1x,73('-')/1x,'All Nuclides'/9x,'<TOTAL>',5x,
     &    E9.4,4x,E9.4,6x,E9.4,5x,E9.4/73('-'))
6080   FORMAT(2X,A80/2X,80('=')//////)
C////////////////////////////////////////////////////////////////////
C////       The End of The Format Statements used in RITE1 &      ///
C///#####################********END RITE1******#####################///
C////////////////////////////////////////////////////////////////////
      RETURN
      END
```

B.5 The ERRCHK Module

```
C        ////////////////////////////////////////////////////////
C       /                          SUBROUTINE ERRCHK             /
C      /                           ~~~~~~~~~~~~~~~~             /
C     / SUBROUTINE SUMMARY: Checks for Errors in the input      /
C    /                      and informs the user of these     /
C   /                       errors.  In some instances, the  /
C  /                        user is given an option of a    /
C /                         recommended correction or      /
C/                          ABORT the PROGRAM             /
C////////////////////////////////////////////////////////
      SUBROUTINE ERRCHK
      REAL*8 VX,VT,VB,VXT,VTB,VBX,Bd_0,E_0,R_0,Pw,Cw,sPw(50),DT,
     &       sCw(50),TLK(20),CLK(20),TMX,TPR,CPw(50),HLF(50),LAM1(50)
      REAL*8 fB_0,tr_X,tr_B,tr_T,tl_XT,tl_TB,tl_BX,TOTF,TOTS,
     &       LAMX(50),LAMT(50),LAMB(50),EP_BX(50),EP_XT(50),TPRINT,
     &       EP_TB(50),EPP(50),LMM(50),DD(50),R_E0(50),R_B0(50),
     &       TR_0(50),RE_0,RB_0,RT_0,CPw_0,CCw(50),CCw_0,T_in(50),
     &       T_in0,NT_0(50),NB_0(50),NX_0(50),INTER,TME,fR_0,fE_0,
     &       SLOPE,LKR,NT_t(50),NB_t(50),NX_t(50),NT_d(50),NB_d(50),
     &       NX_d(50),ER_t(50),ER_E(50),ER_B(50),c1,c2,c3,DTMX1,DTMX2,
     &       DTMX3,ZX(1000),ZT(1000),ZB(1000),DREQ,SLP2,SLP3,IXS2,IXS3,
     &       TEV(20),TBD(20),EVR(20),BDR(20),REV,RBD
      INTEGER*4 NR,NID(50),NLP,OPT,NEP,NBP,IFLGE,IFLGB
      INTEGER*4 NMD(50),I1,J1,IFLAG,I2,I3,
     &       NDUM,IX,IB,IT,RSIZE,JTN,JJ,IDT1,IDT2,IDT3
      LOGICAL EXT
      CHARACTER*12 INP,OUTP
      CHARACTER*6  NME(50),DUMA,SEC,DAY,YR
      COMMON /reed10/VX,VT,VB,VXT,VTB,VBX,Bd_0,E_0,R_0,Pw,Cw,DT,TMX,
     &               TPR,LAM1,NR,NID,sPw,sCw,NLP,TLK,CLK,OPT,HLF,
     &               SLP2,SLP3,IXS2,IXS3,TEV,TBD,EVR,
     &               BDR,REV,RBD,NEP,NBP,IFLGE,IFLGB
      COMMON /TRD/fR_0,fE_0,fB_0,tr_X,tr_B,tr_T,tl_XT,tl_TB,
     &       tl_BX,TOTF,TOTS,LAMX,LAMT,LAMB,EP_BX,EP_XT,TPRINT,
     &       EP_TB,EPP,LMM,DD,R_E0,R_B0,TR_0,RE_0,RB_0,RT_0,CPw,CPw_0,
     &       CCw,CCw_0,T_in,T_in0,NT_0,NB_0,NX_0,INTER,TME,SLOPE,
     &       LKR,NT_t,NB_t,NX_t,NT_d,NB_d,NX_d,ER_t,ER_E,ER_B,C1,C2,
     &       C3,DTMX1,DTMX2,DTMX3,ZX,ZT,ZB,DREQ,EXT
      COMMON /INTG/NMD,IFLAG,NDUM,RSIZE,JTN,JJ,IDT1,IDT2,IDT3
      COMMON /CHR/INP,OUTP,NME,DUMA,SEC,DAY,YR
C-------------------------------------------------------------------
C----    Check if the ZB, ZT, and ZX array sizes are sufficient
C----    for Storing data as defined by dt and the maximum of
C----    tl_XT, tl_TB, and tl_BX, as follows:
C-------------------------------------------------------------------
9001  RSIZE = DMAX1(tl_XT,tl_TB,tl_BX)/dt  + 1
      DREQ  = RSIZE*DT/1000
      IF (RSIZE .GT. 1000) THEN
           WRITE(6,6021) RSIZE,DREQ,RSIZE
           WRITE(20,6021) RSIZE,DREQ,RSIZE
           STOP
      ENDIF
C-------------------------------------------------------------------
C----    Check if the requested time step is within the recommended
C----    value by performing the following tests:
C-------------------------------------------------------------------

C
C   #1 Find the minimum time increment between two adjacent points in
```

```
C       all defined functions:
C
C       If the minimum time increment is less than dt, set the flag
C       IDT1 to 999, and inform the user if the step size is to be
C       decreased to DTMX1
C
        DO 9050 i1 = 1,NLP-1
9050    DTMX1 = DMIN1(TLK(i1+1)-TLK(i1),DTMX1)
        DO 9051 i1 = 1,NBP-1
9051    DTMX1 = DMIN1(TBD(i1+1)-TBD(i1),DTMX1)
        DO 9052 i1 = 1,NEP-1
9052    DTMX1 = DMIN1(TEV(i1+1)-TEV(i1),DTMX1)
        IF(DTMX1 .LT. dt) THEN
            IDT1 = 999
9002        WRITE(6,6022) DTMX1,DTMX1/2.0,dt
            READ(5,*) OPT
            IF(OPT .EQ. 1) THEN
                WRITE(6,6023)
                WRITE(20,6023)
            ELSE
                IF(OPT .EQ. 2) THEN
                    dt = DTMX1/2.0
                    GOTO 9001
            ELSE
                IF(OPT .NE. 3) GOTO 9002
            ENDIF
            ENDIF
        ENDIF
C
C   #2 Find the least of all time constants, i.e, the least value
C       of all loop connection and all CV's residence time.
C
C       If these values are less than dt, set the flag IDT2 to 99.
C
        DTMX2 = DMIN1(tl_XT,tl_TB,tl_BX,tr_T,tr_X,tr_B)
        IF(DTMX2 .LT. dt) then
            IDT1 = 99
9004        WRITE(6,6024) DTMX2,DTMX2/2.0,dt
            READ(5,*) OPT
            IF(OPT .EQ. 1) THEN
                WRITE(6,6023)
                WRITE(20,6023)
            ELSE
                IF(OPT .EQ. 2) THEN
                    dt = DTMX2/2.0
                    GOTO 9001
            ELSE
                IF(OPT .NE. 3) GOTO 9004
              ENDIF
            ENDIF
        ENDIF
C////////////////////////////////////////////////////////////////////
C///          Format Statements used for I/O in ERRCHK            ///
C////////////////////////////////////////////////////////////////////
6021  FORMAT(///3x,58('*')/3x,5('*'),48('!'),5('*')/3x,5('*'),'!!',
     & 11x,'<<<<<ERROR>>>>>',18x,'!!',5('*')/3x,5('*'),48('!'),
     &  5('*')/3x,5('*'),'!!',44x,'!!',5('*')/3x,5('*'),'!!',2x,
     & 'Required Array sizes for ZX, ZB, and ZT   !!*****'/3x,
     & '*****!!  is <',I5,'>.  This exceeds the set value   !!',
     &  '*****'/3x,'*****!!',
     & '  of <1000>.',32x,'!!*****'/3x,5('*'),'!!',44x,'!!',5('*')/3x
     & 5('*'),'!!',2x,'Either increase the time step size to a   !!',
```

```
     & 5('*')/3x,'******!!  minimum of <',E9.4,' sec> or increase    !',
     & '!******'/3x,'******!!  the size of the arrays to <',i5,'>.',8x,
     & '!!******'/3x,'******!!',44x,'!!******'/3x,58('!')/3x,'!!!!!**',
     & 44x,'**!!!!!'/3x,'!!!!!**',11x,'ABORTING EXECUTION',15x,
     & '**!!!!!'/3x,'!!!!!**',44x,'**!!!!!'/3x,58('!')/////)
6022  FORMAT(///3X,63('%')/3X,63('%')/3X,7('%'),2X,14('!'),1X,5('<'),
     &   'ERROR',5('>'),1X,14('!'),2X,7('%')/3X,63('%')/3X,7('%'),
     &   49X,7('%')/3X,7('%'),2X,'One of the pre-defined functions',
     &   ' in the    ',5X,7('%')/3X,7('%'),2X,'input file uses poi',
     &   'nts                ',5X,7('%')/3X,7('%'),2X,'That are',
     &   ' incremented by <',E9.4,' sec>.',7x,7('%')/3X,7('%'),2X,
     &   'This is less than the  Size of the time step!  ',7('%')/3X,
     &    7('%'),49x,7('%')/3X,7('%'),49X,7('%')/3X,7('%'),X,15x,'IF ',
     &    'YOU WISH TO ABORT ENTER <1>',3x,7('%')/3X,7('%'),49x,7('%')/
     &    3X,7('%'),2X,'IF YOU WISH TO ACCEPT THE MODIFIED',13x,7('%')/
     &    3X,7('%'),2X,'TIME STEP VALUE OF <',E9.4,'sec> ENTER <2>',4x,
     &    7('%')/3X,7('%'),49X,7('%')/3X,7('%'),2X,'IF YOU WISH TO PR',
     &    'OCEED WITH THE',16x,7('%')/3X,7('%'),3X,'CALCULATION WITH <',
     &    'dt=',E9.4,'sec>  ENTER<3>  '7('%')/3X,63('%')/3X,
     &    32('%')/3X,32('%'),'ENTER OPTION <1, 2, or 3> ====>')
6023  FORMAT(///T20,'YOU HAVE SELECTED OPTION 1',///T8,32('>'),33('<')/
     & T8,6('>'),53x,6('<')/T8,6('>'),4x,44('!'),5x,6('<')/T8,6('>'),
     & 4x,10('!'),'EXECUTION ABORTED  BYE',12('!'),5x,6('<')/T8,
     & 6('>'),4x,44('!'),5x,6('<')/T8,6('>'),53x,6('<')/T8,
     & 32('>'),33('<')/)
6024  FORMAT(///3X,63('%')/3X,63('%')/3X,7('%'),2X,14('!'),1X,5('<'),
     &   'ERROR',5('>'),1X,14('!'),2X,7('%')/3X,63('%')/3X,7('%'),
     &   49X,7('%')/3X,7('%'),2X,'The time constants associated wi',
     &   'ith the   ',5X,7('%')/3X,7('%'),2X,'COOLING TOWER WATER',
     &   ' SYSTEM CONTROL VOLUMES',5X,7('%')/3X,7('%'),2X,'have a m',
     &   'inimum time of < ',E9.4,' sec>.',7x,7('%')/3X,7('%'),2X,
     &   'This is smaller than the Size of the time step!',7('%')/3X,
     &    7('%'),49x,7('%')/3X,7('%'),49X,7('%')/3X,7('%'),X,15x,'IF ',
     &    'YOU WISH TO ABORT ENTER <1>',3x,7('%')/3X,7('%'),49x,7('%')/
     &    3X,7('%'),2X,'IF YOU WISH TO ACCEPT THE MODIFIED',13x,7('%')/
     &    3X,7('%'),2X,'TIME STEP VALUE OF <',E9.4,'sec> ENTER <2>',4x,
     &    7('%')/3X,7('%'),49X,7('%')/3X,7('%'),2X,'IF YOU WISH TO PR',
     &    'OCEED WITH THE',16x,7('%')/3X,7('%'),3X,'CALCULATION WITH <',
     &    'dt=',E9.4,'sec>  ENTER<3>  '7('%')/3X,63('%')/3X,
     &    32('%')/3X,32('%'),'ENTER OPTION <1, 2, or 3> ====>')
C////////////////////////////////////////////////////////////////
C////       The End of The Format Statements used in ERRCHK &    ///
C///#########################*****END ERRCHK*****#########################///
C////////////////////////////////////////////////////////////////
      RETURN
      END
```

B.6 The TRANS Module

```
C        ////////////////////////////////////////////////////////
C       /                          SUBROUTINE TRANS              /
C      /                           ~~~~~~~~~~~~~~~              /
C     / SUBROUTINE SUMMARY: Calculates the time-dependent      /
C    /                      levels in CTW components, and     /
C   /                       Radionuclide release rates and   /
C  /                        total releases to the           /
C /                         environment.                    /
C////////////////////////////////////////////////////////
      SUBROUTINE TRANS
      REAL*8 VX,VT,VB,VXT,VTB,VBX,Bd_0,E_0,R_0,Pw,Cw,sPw(50),DT,
     &       sCw(50),TLK(20),CLK(20),TMX,TPR,CPw(50),HLF(50),LAM1(50)
      REAL*8 fB_0,tr_X,tr_B,tr_T,tl_XT,tl_TB,tl_BX,TOTF,TOTS,
     &       LAMX(50),LAMT(50),LAMB(50),EP_BX(50),EP_XT(50),TPRINT,
     &       EP_TB(50),EPP(50),LMM(50),DD(50),R_E0(50),R_B0(50),
     &       TR_0(50),RE_0,RB_0,RT_0,CPw_0,CCw(50),CCw_0,T_in(50),
     &       T_in0,NT_0(50),NB_0(50),NX_0(50),INTER,TME,fR_0,fE_0,
     &       SLOPE,LKR,NT_t(50),NB_t(50),NX_t(50),NT_d(50),NB_d(50),
     &       NX_d(50),ER_t(50),ER_E(50),ER_B(50),c1,c2,c3,DTMX1,DTMX2,
     &       DTMX3,ZX(1000),ZT(1000),ZB(1000),DREQ,SLP2,SLP3,IXS2,IXS3,
     &       TEV(20),TBD(20),EVR(20),BDR(20),REV,RBD,
     &       IR_t(50),IR_E(50),IR_B(50)
      INTEGER*4 NR,NID(50),NLP,OPT,NEP,NBP,IFLGE,IFLGB
      INTEGER*4 NMD(50),I1,J1,IFLAG,I2,I3,
     &       NDUM,IX,IB,IT,RSIZE,JTN,JJ,IDT1,IDT2,IDT3
      LOGICAL EXT
      CHARACTER*12 INP,OUTP
      CHARACTER*6  NME(50),DUMA,SEC,DAY,YR
      COMMON /reed10/VX,VT,VB,VXT,VTB,VBX,Bd_0,E_0,R_0,Pw,Cw,DT,TMX,
     &               TPR,LAM1,NR,NID,sPw,sCw,NLP,TLK,CLK,OPT,HLF,
     &               SLP2,SLP3,IXS2,IXS3,TEV,TBD,EVR,
     &               BDR,REV,RBD,NEP,NBP,IFLGE,IFLGB
      COMMON /TRD/fR_0,fE_0,fB_0,tr_X,tr_B,tr_T,tl_XT,tl_TB,
     &       tl_BX,TOTF,TOTS,LAMX,LAMT,LAMB,EP_BX,EP_XT,TPRINT,
     &       EP_TB,EPP,LMM,DD,R_E0,R_B0,TR_0,RE_0,RB_0,RT_0,CPw,CPw_0,
     &       CCw,CCw_0,T_in,T_in0,NT_0,NB_0,NX_0,INTER,TME,SLOPE,
     &       LKR,NT_t,NB_t,NX_t,NT_d,NB_d,NX_d,ER_t,ER_E,ER_B,C1,C2,
     &       C3,DTMX1,DTMX2,DTMX3,ZX,ZT,ZB,DREQ,EXT
      COMMON /INTG/NMD,IFLAG,NDUM,RSIZE,JTN,JJ,IDT1,IDT2,IDT3
      COMMON /CHR/INP,OUTP,NME,DUMA,SEC,DAY,YR
C-----------------------------------------------------------------------
C----      Initialize the ith level in All CVs
C-----------------------------------------------------------------------
      DO 9014 i1=1,NR
      NT_t(i1) = NT_0(i1)
      NB_t(i1) = NB_0(i1)
      NX_t(i1) = NX_0(i1)
C-----------------------------------------------------------------------
C----      Write the ith nuclide information and initiate transient
C-----------------------------------------------------------------------
      WRITE(20,6020) I1,NME(I1),NID(I1)
C-----------------------------------------------------------------------
C----      Reset the time to zero along with the counters for each isotope
C----      and step into time by dt for each ith nuclide.
C-----------------------------------------------------------------------
      TME = 0.0
      JJ  = 0
      JTN = 0
      IR_t(i1) = 0.0
```

```
      IR_E(i1) = 0.0
      IR_B(i1) = 0.0

C
C     Calculate release rates in Ci/sec of i via total,
C     evaporation, and blowdown at time=0.0 sec
C
      ER_T(I1) = (1-FR_0)*NT_T(I1)/TR_T
      ER_E(I1) = FE_0*NT_T(I1)/TR_T
      ER_B(I1) = FB_0*NT_T(I1)/TR_T
      WRITE(20,6051) tme,NB_t(i1)/(3.785*VB),
     &                   NX_t(i1)/(3.785*VX),NT_t(i1)/(3.785*VT),
     &                   Er_E(i1),Er_B(i1),Er_T(i1),
     &                   Ir_E(i1),Ir_B(i1),Ir_T(i1)

9020  TME = TME + DT
      TPRINT = TPRINT + DT
       IF(JJ .EQ. 1000) JJ = 0
        JJ = JJ + 1
       jtn = jtn + 1
C -----------------------------------------------------------------------
C----      Use the definition of the function defining the leak
C----         Rate during the transient to obtain the leak rate
C----         at time t (LKR:gallons per sec).
C-----------------------------------------------------------------------
      IFLAG = 1010
      DO 9025 I3=1,NLP
      IF(TME .GT. TLK(NLP)) THEN
            LKR = CLK(NLP)
            GOTO 9025
       ENDIF
       IF (IFLAG .EQ. -999) GOTO 9025
       IF(TME .LT. TLK(I3)) THEN
       IFLAG = -999
           SLOPE = (CLK(i3) - CLK(i3-1))/(TLK(i3) - TLK(i3-1))
           INTER = CLK(i3) - SLOPE*TLK(i3)
           LKR   = SLOPE*TME + INTER
       ENDIF
9025     CONTINUE
C-----------------------------------------------------------------------
C----      Use the definition of the function defining the blow-down
C----         Rate during the transient to obtain the blow-down rate
C----         at time t (RBD:gallons per sec).
C-----------------------------------------------------------------------
      IFLAG = 1010
      DO 9044 I3=1,NBP
      IF(TME .GT. TBD(NBP)) THEN
            RBD = BDR(NBP)
            GOTO 9044
       ENDIF
       IF (IFLAG .EQ. -999) GOTO 9044
       IF(TME .LT. TBD(I3)) THEN
       IFLAG = -999
           SLOPE = (BDR(i3) - BDR(i3-1))/(TBD(i3) - TBD(i3-1))
           INTER = BDR(i3) - SLOPE*TBD(i3)
           RBD   = SLOPE*TME + INTER
       ENDIF
9044     CONTINUE
C-----------------------------------------------------------------------
C----      Use the definition of the function defining the evaporation
C----         Rate during the transient to obtain the evaporation
C----         rate at time t (RBD:gallons per sec).
```

```
C-----------------------------------------------------------------------
      IFLAG = 1010
      DO 9045 I3=1,NEP
      IF(TME .GT. TEV(NEP)) THEN
            REV = EVR(NEP)
            GOTO 9045
       ENDIF
       IF (IFLAG .EQ. -999) GOTO 9045
       IF(TME .LT. TEV(I3)) THEN
       IFLAG = -999
           SLOPE = (EVR(i3) - EVR(i3-1))/(TEV(i3) - TEV(i3-1))
           INTER = EVR(i3) - SLOPE*TEV(i3)
           REV   = SLOPE*TME + INTER
       ENDIF
9045     CONTINUE
C
C    Calculate i nuclide introduction rate into the HX's [Ci/sec]
C
9023    DO 9022 i3=1,NR
9022    CPw(i3) = sPw(I3)*LKR
C
C    Calculate the ith level in Ci in all CV's at tme
C
C
C    The next statements are used to obtain values at previous time
C    steps as a result of the lag time associated with transporting
C    nuclides between the control volumes.
C
      IX = jtn - tl_XT/dt
      IT = jtn - tl_TB/dt
      IB = jtn - tl_BX/dt
C
C     Find value of NX_t at tme - tl_XT, i.e., NX_D at tme
C
      IF((TME - tl_XT) .LE. 0.0) THEN
           NX_D(I1) = NX_0(I1)
      ELSE
9033       IF(IX .GT. 1000) THEN
                IX = IX - 1000
                GOTO 9033
           ELSE
                NX_D(I1) = ZX(IX)
           ENDIF
      ENDIF
C
C     Find value of NT_t at tme - tl_TB, i.e., NT_D at tme
C
      IF((TME - tl_TB) .LE. 0.0) THEN
           NT_D(I1) = NT_0(I1)
      ELSE
9031       IF(IT .GT. 1000) THEN
                IT = IT - 1000
                GOTO 9031
           ELSE
                NT_D(I1) = ZT(IT)
           ENDIF
      ENDIF
C
C     Find value of NB_t at tme - tl_BX, i.e., NB_D at tme
C
      IF((TME - tl_BX) .LE. 0.0) THEN
           NB_D(I1) = NB_0(I1)
```

```
      ELSE
9032       IF(IB .GT. 1000) THEN
                IB = IB - 1000
                GOTO 9032
           ELSE
                NB_D(I1) = ZB(IB)
           ENDIF
      ENDIF
C
C     Calculate FLOW RATE FRACTIONS
C
      fE_0  = 60.0*REV/TOTF
      fB_0  = 60.0*RBD/TOTF
      fR_0  = 1.0 - fE_0 - fB_0

C
C     Obtain the activity levels in all CV's at tme for
C       the ith nuclide.
C
      NX_T(I1)=(1 - DT*LAMX(I1))*NX_T(I1) + DT*CPW(I1) +
     &          DT*EP_BX(I1)*NB_D(I1)
       NT_T(I1)=(1 - DT*LAMT(I1))*NT_T(I1) + DT*EP_XT(I1)*NX_D(I1)
       NB_T(I1)=(1 - DT*LAMB(I1))*NB_T(I1) + DT*CCW(I1) +
     &          DT*FR_0*EP_TB(I1)*NT_D(I1)
C
C     Calculate release rates in Ci/sec of i via total,
C     evaporation, and blowdown.
C
      ER_T(I1) = (1-FR_0)*NT_T(I1)/TR_T
      ER_E(I1) = FE_0*NT_T(I1)/TR_T
      ER_B(I1) = FB_0*NT_T(I1)/TR_T
C
C     Calculate total released of i in Ci from tme=0.0 upto tme
C     via total, evaporation, and blowdown.
C
      IR_T(I1) = IR_T(I1) + ER_T(i1)*dt
      IR_E(I1) = IR_E(I1) + ER_E(i1)*dt
      IR_B(I1) = IR_B(I1) + ER_B(i1)*dt

C
C     Check if the print increment is satisfied, if so print the
C       activity levels in all CV's and release rates to the
C       environment via blowdown, evaporation and total at
C       time tme.
C
      IF(TPRINT .GE. TPR .OR. TME .GE. TMX) THEN

      WRITE(20,6051) tme,NB_t(i1)/(3.785*VB),
     &                   NX_t(i1)/(3.785*VX),NT_t(i1)/(3.785*VT),
     &                   Er_E(i1),Er_B(i1),Er_T(i1),
     &                   Ir_E(i1),Ir_B(i1),Ir_T(i1)

C
C       This section is used to inform the user at what time is
C       the simulation
C
        WRITE(6,6060)  tme,tme/60,tme/3600
          TPRINT = 0.0
       ENDIF
C
C     Store the current activity levesl in the ZX, ZT, and ZB
C         arrays for later use.
```

```
C
                ZX(jj) = NX_t(i1)
                ZT(jj) = NT_t(i1)
                ZB(jj) = NB_t(i1)

C
C     Check if the transient time is at maximum examination time
C
      IF(TME .LT. TMX) GOTO 9020
9014  CONTINUE
C////////////////////////////////////////////////////////////////////
C///          Format Statements used for I/O in TRANS                ///
C////////////////////////////////////////////////////////////////////
6060   format(3x,'SIMULATION TIME = ',e8.3,'<sec> ,',e8.3,'<min> ',
     &  ,e8.3,'<hrs>')
6020  FORMAT('1'///T4,'The following data relate to the ',I4,'th ',
     &    'nuclide, i.e., ====> ',A6/41x,'with the nuclide ID =>',I6///
     &  1x,109('-')/3x,'TIME',9x,'Activity Levels (Ci/L)',8x,'Relea',
     &  'se Rate of ith (Ci/sec)',7x,'Total Released (Ci)'/2x,'(sec)',
     &  6x,'186Basin  Heat-Ex.   K-Tower',5x,'Evapor.',5x,'River',
     &  6x,'Total',5x,'Evapor.',5x,'River',5x,'Total'/1x,109('-'))
6051  Format(1X,E9.4,2x,3(E9.4,2X),3(E9.4,2X),3(E9.4,2X))
C////////////////////////////////////////////////////////////////////
C////        The End of The Format Statements used in TRANS &      ///
C///#########################*******END TRANS******#################///
C////////////////////////////////////////////////////////////////////
       RETURN
       END
```

END

DATE
FILMED
7/12/93