Software Requirements for a Point Kinetics Neutronics Code for Simulating TREAT Reactor Transients

Nuclear Science & Engineering Division

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Executive Summary

This document provides the software requirements for a computer code to perform point kinetics-based simulations of nuclear reactor transients. These requirements address all aspects of code development and use, including input and output parameters and structure, software capabilities, and supporting documentation. This software is intended to replace the existing point kinetics code TREKIN, which is currently used for the analysis of the Transient Reactor Test Facility (TREAT).

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1 Introduction

The software requirements for a computer code to provide point kinetics-based simulations of nuclear reactor transients are presented. These requirements address all aspects of code development and use, including input and output parameters and structure, software features, and supporting documentation.

1.1 Purpose

This software is intended to replace the existing point kinetics code TREKIN [1], which is currently used for the analysis of the Transient Reactor Test Facility (TREAT). TREKIN operates in a Microsoft Excel environment on desktop computers with a Windows operating system, and its use requires the additional plugin acslX. The acslX plugin was obtained from an external commercial supplier, Aegis Technologies, and its installation requires an IP- and user-specific license. Effective November 24th, 2015, acslX is no longer supported or distributed by the supplier. Therefore, the use of TREKIN is limited to the set of existing IP- and user-specific licenses (i.e., the set of computers already possessing a license). Additionally, supplier technical support is no longer available if any issues with acslX arise. Therefore, it is necessary to develop a new point-kinetics code that will match or exceed the TREKIN capabilities.

1.2 Scope

The software will perform point kinetics transient calculations, solving the six delayed neutron group kinetics equations and will maintain the full suite of calculation capabilities of the existing TREKIN code, including the use of the same structure of data input tables as TREKIN. The software shall be able to simulate the wide variety of transients which the TREAT reactor is capable of performing.

The software shall simulate and output the time-dependent neutronic behavior of the core. It will additionally output two temperature values of the user's choosing as a function of time, but will obtain these values via interpolation of user-provided data tables, rather than via the solution of the thermal hydraulic equations.

1.3 Key References

The primary necessary features and functions of the software are outlined in the user manual of the existing TREKIN code [1]. The particular intended application of the new software is analysis of TREAT, and the software therefore shall be capable of analyzing the full set of possible TREAT transients. A physical description of the TREAT reactor is provided in [2]. Additional information on early analysis of the reactor kinetics of TREAT has been documented in ANL-6458 [3]. The study "Reactor Models and Neutronic Data Used for TREAT Upgrade Kinetics Analysis" [4] concluded that the point kinetics model is a good approximation of space-time kinetics for TREAT. Therefore, the use of PK_TREAT has been accepted for solving the kinetics equations for TREAT analyses.

2 Overall Description of the Software

The software shall provide transient analysis capabilities, and shall replace the existing code TREKIN. The software shall be developed at Argonne National Laboratory, with the particular properties outlined below.

2.1 Software Capability

The software shall match the capability of TREKIN [1] to simulate typical TREAT transients with the following simulation modes:

1. **Temperature-limited Transient:** A step reactivity insertion, in which the software evaluates the power burst which results from the withdrawal of the transient control rod bank at the maximum speed, producing a rapid power rise that is quickly constrained by temperature reactivity feedback
2. **Period-driven Transient:** A temperature-limited transient driven by a specific reactor period value; this mode requires at least two period-driven segments, with the code switching between periods based upon a specified power level criteria, with the intent of simulating the warming up period to a desired power level before switching to a new period
3. **Rod-driven Transient:** A mode in which the transient behavior of the core is dictated by a user-provided table of transient control rod bank positions as a function of time, which calculates the core power and energy corresponding to the given rod motion
4. **Power-driven Transient:** A mode in which the transient behavior of the core is dictated by a user-provided table of core power as a function of time, which calculates the reactivity insertion and corresponding transient control rod bank motion needed to achieve a given desired power-time history
5. **Reactivity-driven Transient:** A mode in which the transient behavior of the core is dictated by a user-provided table of reactivity insertion as a function of time, which calculates the core power and energy corresponding to the given insertion-time history

Additionally, the software shall support the combination of multiple different modes in a sequential fashion, such as two period-driven stages followed by a rod- or power-driven stage.

The software shall utilize user-specified datasets which provide information on the characteristics of a particular core loading, as outlined in the input data description below. Currently the scram of the reactor is simulated in the existing TREKIN code by the rapid insertion of the transient control rod bank only. It is not required for this to change in the new software, and therefore there is no requirement to introduce the functionality of more than one rod worth table.

The software shall have the functionality to evaluate and confirm that all necessary data for a given simulation is present, and should trigger an appropriate error message if this is not the case.

2.2 Operating Environment

The software shall operate on desktop computers which have Microsoft Excel installed. The software shall operate in the Microsoft Excel Visual Basic environment, and shall be compatible with current and

updated versions of Microsoft Office. The software shall be maintained in an svn repository, and new users shall obtain the software from this location.

2.3 Design and Implementation Constraints

The software shall support user interface via Excel worksheets. Both input and output data shall be contained in Excel worksheets within the same workbook. The software shall be self-contained and shall not rely on external libraries or codes, and therefore shall not require support from an outside contractor.

2.4 Assumptions and Dependencies

The following assumptions are made regarding use of the software:

- Users of the software shall have access to a desktop computer with the Microsoft Excel software installed.
- Users of the software shall have previous experience using Microsoft Excel.
- The computer running the software shall be connected to the internet in order to have access to the svn repository containing the software.

The software depends upon the specification of a set of reactor core-specific properties required for simulations, and it is assumed that these properties will be produced via a method external to the software (e.g., a neutronics code like MCNP). In particular, this data may be calculated using a separate computer code, or may be measured core data.

3 External Interface

The detailed input and output parameters the software shall support are outlined below. In addition to input and output data the software is required to support, additional parameters which the software should ultimately support are also described.

There are two data types required by the software to perform transient simulations:

- a. **Source data:** the core loading- and experiment-specific core characteristic parameters, which are required to perform any transient simulation
- b. **Input data:** the user-specific parameters that indicate the details of a specific transient, the solution method-related variables, and the collection of output data

The two different types of data are discussed below.

3.1 Source Data

The software shall utilize a set of user-provided core property data. These core properties shall be evaluated external to the software, either through the use of a separate computer code or through in-core measurements. The presence of this data is necessary in order to perform transient simulations, and therefore the software shall require that the input specifications for every simulation include the full set of core properties. The necessary core property data is as follows:

1. Prompt neutron generation lifetime
2. Six delayed neutron groups with the associated group fractions and decay constants
3. A tabulated dataset of the temperature reactivity feedback as a function of total core energy
4. Two* tabulated datasets of temperature as a function of total core energy
5. A tabulated dataset of the transient control rod bank worth as a function of rod bank position

* In TREKIN the two tabulated temperature datasets were explicitly defined as being the peak and average core temperatures as a function of core energy; under the current requirement these can be any two temperature sets

In addition to the set of parameters above, which shall be supported by the code, there are additional core property input datasets which should optionally be supported. They are as follows:

1. A tabulated dataset of prompt neutron generation lifetime as a function of total core energy

The input worksheet for the core property datasets shall also include a comment field where the user can provide a description of the particular core which the datasets correspond to.

3.2 Input Data

The software shall support a series of input parameters which describe the behavior of the core for a given transient. These include both tabulated datasets and individual input variables. The specification of the parameters described in this section is not required for all simulations, and shall be treated by the software as such.

The software shall support the input of the following parameters in tabulated form as a function of time:

1. Transient control rod bank position
2. Core Power
3. Inserted Reactivity

The software shall support the following solution-specific properties, which specify parameters related to the type of simulation:

1. Time step size (i.e. frequency) for calling the point kinetics equation solver
2. Frequency for printing the solution data to the output worksheet (i.e. number of calculation time steps between printing results)
3. Maximum number of simulation time steps before termination (to prevent an infinite loop in a scenario with incorrect input data)
4. Convergence criterion for the point kinetics solution
5. Stage time duration
6. Initial power level
7. Reactor period for every stage
8. Initial rod insertion
9. Interpolation or extrapolation functions

10. Delay time, which specifies an additional duration to continue a stage after a stage-ending criteria is met

The software should also support the following additional transient-specific variable(s):

11. Step reactivity insertion value

The software shall perform checks of the following parameters (trip criteria) which determine the termination of a stage or of an entire simulation.

1. Core power
2. Total core energy
3. Peak value of the second user defined temperature
4. Transient control rod bank reactivity
5. Reactor period
6. Stage time duration

The specific input parameters that the software is required to support in each category are described in the following sections. In addition to the described input parameters, the software shall also provide comment space in the input worksheet, where a user can document additional notes on the details of a given simulation.

3.3 Output Data

The software shall provide simulation output data, which shall be printed in the same Excel workbook which contains the input data.

For each individual transient simulation, the software shall provide as output tabulated values of the following parameters as a function of time:

- a. Core power
- b. Total core energy
- c. Reactor period
- d. Reactivity insertion
- e. Two user defined temperatures
- f. Temperature reactivity feedback

The software output should also document the following parameter as a function of time, if their specification as a function of energy is incorporated into the supported input parameter set:

- a. Prompt neutron generation lifetime

In addition to the simulation results, the output shall document the following additional key information:

- a. The date and time of the simulation
- b. The core property datasets that were utilized in the simulation

- c. The simulation-specific input parameters (transient characteristics and solution method controls)
- d. Warning and error messages prompted by the software solver

The following error and warning messages shall be provided by the software:

- a. An error message followed by termination of the simulation if the simulation requires extrapolation beyond the range of the values provided a current core property data table

Additionally, the following error and warning messages optionally should be provided:

- a. An error message when a necessary input parameter (e.g., a core property data table) was not provided by the user
- b. An error message when an incompatible combination of input parameters is specified

4 Requirements for Software Capabilities

The software shall provide the full set of capabilities needed to support TREAT analysis, as outlined in the following sections.

4.1 Capabilities to Support Required Operational Modes

The software shall support several different transient operational modes, as outlined in Section 2.1. The required modes are based upon the experience obtained using TREKIN as well as anticipated transient simulation needs. In particular, the software shall accommodate the following:

- a. A single rod step, resulting in a temperature-limited transient
- b. A single rod step to bring the core power smoothly up from very low power into the MW power range, followed by initiation of a second segment of the transient
- c. A constant power segment (power “flattop”) at a specified power level
- d. A gradual power rise from a moderate power level
- e. A power burst (generated by a step transient control rod bank motion) from a moderate power level
- f. A power “roll-over” at the end of a power rise, resulting from the transient control rod bank being held motionless which allows the power to peak and subsequently fall as determined only by increasing negative reactivity feedback due to core heating
- g. A scram, caused by the sudden insertion of the available rod worth at a maximum rate
- h. A power “tail”, caused by suddenly but incompletely inserting the transient rods with enough positive reactivity remaining in the core to produce an extended low power tail on a transient

Regardless of transient mode type, the software shall consistently evaluate and report the full set of time-dependent transient parameter results (power, energy, etc.), as outlined in the previously-discussed software output requirements.

4.2 Functional User-controlled Capabilities

Additional user-control of the transient shall be provided, in order to support the various simulation modes outlined above. In particular, the software shall support the following capabilities.

- a. The termination of a transient (via scram) or stage of a transient (prompting a transition to the next stage of the transient) based on the occurrence of a particular criteria, as consistent with the “flag” input variables described above:
 - Core power
 - Total core energy
 - Value of the second user defined temperature
 - Transient control rod bank reactivity
 - Reactor period
 - Duration of the stage

Optionally, the software should also support the following additional functions:

- a. The ability to modify the refinement of the calculation and reporting time steps for only a particular segment of the transient where more detail is needed, such as the timeframe surrounding a power pulse peak; without appropriate refinement near a power peak, the software may not correctly report the “actual” peak power, while on the other hand applying unnecessary refinement to the full timeframe of the transient could needlessly increase both simulation time and output data size

5 Additional Nonfunctional Requirements

In addition to the particular analysis-driven requirements outlined above, further requirements related to development and implementation of the software are described here.

5.1 Performance Requirements

For the simulation of a given transient, the software shall be capable of producing the solution in a similar timeframe to the time needed for the simulation of the same transient with the existing TREKIN code.

5.2 Documentation Requirements

It is required that a user’s manual be developed to support the software. The manual shall include documentation describing the key items in each of the following categories:

- a. Input data, including structure of the input tables
- b. Software output
 - a. Simulation result data
 - b. Common error or warning messages
 - c. Additional output, including additional information related to warning/error messages when appropriate
- c. Solution method implemented in the software

- d. Installation and verification procedure
- e. Functions of the software
- f. Practical instructions for use of the software

In addition to the user's manual, a separate brief document shall be developed which addresses the required procedure for utilizing the software in adherence with the quality assurance program. In particular, this document shall encourage the use of separate simulation workbooks to evaluate individual transients.

5.3 Example Problem Requirements

A set of example input cases (including corresponding core property datasets) shall be distributed with the software. The software distribution shall also contain record of the correct output for each of these cases, to allow the user to verify their personal installation. The example set shall contain a diverse group of transient cases which demonstrate the different simulation modes of the software (temperature-limited transients, power-driven transients, etc.).

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