Software Test Report: SNAP/RADTRAD 5.0.4

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1. Introduction

Generation of the SNAP/RADTRAD Independent Verification Report was recently automated in order to reduce the significant amount of manual effort that had been required in prior releases of this report. RADTRAD 5.0.4 was updated in order to fix issues that users had encountered and provide a segue into adopting changes made in regulatory guide 1.183, revision 1 (see section 3.4.5 for more details).

The purpose of this document is to report the testing performed on RADTRAD 5.0.4. The test suite is run and results are provided in this report. The individual test cases are described in Chapter 2. The testing methodology is described in Chapter 3. Test results are shown in Chapter 4, with regression test results presented in Section 4.1, external time stepper results presented in Section 4.2, and run time results presented in Section 4.3.

The following computational environment was used to test RADTRAD. The table below notes the environment in which the testing is performed.

Table 1.1.: Testing Environment

Processor	Intel(R) Core(TM) i7-10750H CPU @ 2.60 GHz 2.59 GHz
Operating System	Windows 10
Java Platform	Version 1.8.0-311

2. Description of Tests

The RADTRAD test suite includes various test cases that test different features of RADTRAD. The tests included in the suite are listed, with descriptions, in Table 2.1. A test identifier is listed in the table that is used to identify the test in later results tables.

Table 2.1.: Test Case Descriptions

Case	Name / Description
1	**Test1** This case consists of a compartment representing a PWR containment volume and a second compartment representing the environment. Dose is computed at the EAB and LPZ using TID DCFs. Only ^{131}I based on the TID source term is considered. No radionuclide decay is included in this case.
1.1	**Test1a** This case is quite similar to case 1 with the major addition of a control room dose location. Doses to the EAB and LPZ are not calculated.
1.2	**Test1bLimits** The limit on number of components was eliminated in RADTRAD 5.0.0. This test verifies that a model, with more components than the previous limit, runs correctly. It is based off case 1 and includes 11 copies of the case 1 model.
1.3	**Test1cID** This test includes 11 copies of the case 1 model components that are not numbered sequentially. Prior to RADTRAD 5.0.0, non-sequential numbering of components cause the simulation to fail or produce incorrect results. RADTRAD 5.0.0 or later is expected to run correctly with nonsequential component numbers.
2	**Test2** This case is the same as case 1, but all TID nuclides are considered.
2.1	**Test2a** This case is the same as case 2, but with the radionuclide decay option activated (without daughter production).
2.2	**Test2b** This case is the same as case 2, but with the radionuclide decay option activated (with daughter production).

Table 2.1.: Test Case Descriptions (Continued)

Case	Name / Description
3	**Test3** This case is similar to case 2 with the major addition of a control room dose location compartment and atmospheric dispersion tables.
4	**Test4** This case consists of a compartment representing a PWR containment volume and a second compartment representing the environment. Dose is computed at the EAB, LPZ, and in a control room using TID DCFs. The control room is filtered and has a filtered recirculation loop. An instantaneous TID-14844 release into the containment is modeled in this case. All TID nuclides are considered. No radionuclide decay is included. Additionally, a containment leak to the environment is modeled in this case. In-containment aerosol and elemental iodine removal via natural deposition with user-defined removal rates are also modeled in this case.
5	**Test5** This case is the same as case 4, but the Henry model is used for aerosol deposition, elemental deposition is set to zero, and the filters are changed.
6	**Test6** This case is the same as case 1, but only ^{131}I based on the NUREG-1465 [1] source term is considered
7	**Test7** This case is the same as case 6, but all NUREG-1465 nuclides [1] are considered.
7.1	**Test7a** This case is the same as case 7, but with the radionuclide decay option activated (without daughter production).
7.1a	**Test7aAdaptive** This case is the same as case 7.1, but with the RADTRAD adaptive time-stepping option enabled.
7.2	**Test7b** This case is the same as case 7, but with a BWR containment volume.
7.3	**Test7c** This case is the same as case 7, but with a BWR containment volume and the radionuclide decay option activated (without daughter production).

Table 2.1.: Test Case Descriptions (Continued)

Case	Name / Description
7.4	**Test7d** This case is the same as case 7, but with the radionuclide decay option activated and release assumed 10 hours after shutdown.
7.5	**Test7e** This case is the same as case 7, but with the radionuclide decay option activated (with daughter production) and release assumed 10 hours after shutdown.
8	**Test8** This case consists of a compartment representing a PWR containment and a second compartment representing the environment. A control room with a filtered inlet and recirculation loop is included in the case. All NUREG-1465 nuclides [1] are included. No radioactive decay is included in this case. Doses are computed at the EAB, LPZ, and in the control room.
8.1	**Test8All** This case is the same as case 8, but with all ICRP-38 nuclides included.
8.2	**Test8AllDecay** This case is the same as case 8, but with all ICRP-38 nuclides included and the radionuclide decay option activated (without daughter production).
8.2a	**Test8AllDecayAdaptive** This case is the same as case 8.2, but with the RADTRAD adaptive time-stepping option enabled.
9	**Test9** This case consists of a compartment representing a PWR containment volume and a second compartment representing the environment. Release into the containment is based on the NUREG-1465 [1] PWR model. Dose is computed at the EAB, LPZ, and in a control room using the FGR-11 and FGR-12 DCFs. All NUREG-1465 nuclides are considered in this case. No radionuclide decay is included in this case. A filtered control room that has a filtered recirculation loop is included in this case. In containment aerosol removal via natural deposition with user defined removal rates is included in this case.
10	**Test10** This case is the same as case 9, but uses the Powers' deposition model rather than user-defined coefficients for aerosol removal.

Table 2.1.: Test Case Descriptions (Continued)

Case	Name / Description
10.1	**Test10a** This case is the same as case 10, but uses the Henry deposition model rather than the Powers' deposition model for aerosol removal.
10.2	**Test10_tc** This case is the same as case 10, but with more time points considered.
10.3	**Test10a_tc** This case is the same as case 10.1, but with more time points considered.
11	**Test11** This case consists of a compartment representing a BWR containment volume and a second compartment representing the environment. The leak path to the environment is from the condenser. Dose is computed at the EAB and LPZ. Only ^{131}I from the TID nuclide data is considered. No radionuclide decay is included in this case.
12	**Test12** This case was developed to verify that the addition of a control room would not change the environmental doses and to add the control room dose calculation. The use of the TID ^{131}I, isotope for a puff source made the calculation easier to analyze.
13	**Test13** This case is the same as case 12 with the addition of a filtered control room with no recirculation loop.
13.2	**Test13b** This case is the same as case 13 with a few changes made to the user-defined pathway tables and source iodine fractions.
14	**Test14** This case is the same as case 12, but uses the Brockmann-Bixler pipe model rather than user-defined coefficients for piping deposition. Additionally, changes were made to the control room exhaust pathway filter.
14.2	**Test14b** This case is the same as case 14 with a few changes made to the user-defined leakage table and source iodine fractions. Additionally, an additional breathing rate table entry is added and the NUREG-1465 nuclide data [1] is used.

Table 2.1.: Test Case Descriptions (Continued)

Case	Name / Description
15	**Test15** This case consists of a compartment representing a BWR containment volume, a compartment representing an auxiliary building and a third compartment representing the environment. Dose is computed at the EAB and LPZ. Exhaust from auxiliary building is filtered. Only ^{131}I based on NUREG-1465 [1] is considered. No radionuclide decay is included.
16	**Test16** This case consists of a compartment representing a BWR containment volume, a compartment representing an auxiliary building and a third compartment representing the environment. Exhaust from the auxiliary building is filtered. A filtered control room with no recirculation loop is also included in this model. Dose is computed at the EAB and LPZ. Only ^{131}I based on NUREG-1465 [1] is considered. No radionuclide decay is included.
19	**Test19** This case consists of a sprayed and unsprayed 2-compartment compartment with an annulus representing a PWR containment. Dose is computed at the EAB and LPZ. Only ^{131}I based on NUREG-1465 [1] is considered. No radionuclide decay is included. A piping model is applied in the flow path from the annulus to the environment. User specified removal coefficients for aerosols, elemental iodine, and organic iodine are used.
20	**Test20** This case is the same as case 19, but with changes made to the user-specified pipe model.
21	**Test21** This case is the same as case 20, but with the addition of a control room. The control room is filtered and has a filtered recirculation loop. Also, all NUREG-1465 nuclides [1] are considered.
22	**Test22** This case is the same as case 21, but with user-specified natural deposition coefficients for the sprayed and unsprayed compartments. Sprays not actuated in the spray compartment are used in this case.

Table 2.1.: Test Case Descriptions (Continued)

Case	Name / Description
23	**Test23** This case is similar to case 22 with the major addition of user-specified deposition for elemental iodine, and additional table entries for the environment to control room filter.
23.1	**Test23All** This case is the same as case 23, but with all ICRP-38 nuclides included.
23.2	**Test23AllDecay** This case is the same as case 8, but with all ICRP-38 nuclides included and the radionuclide decay option activated (without daughter production).
23.2a	**Test23AllDecayAdaptive** This case is the same as case 23.2, but with the RADTRAD adaptive time-stepping option enabled.
24	**Test24** This case is similar to case 23, but with the Powers' spray model used for spray deposition rather than user-specified coefficients. Additionally, fewer table entries in the annulus to environment pathway and the environment to control room filter are present.
25	**Test25** This case consists of five compartments connected to the environment. An unfiltered control room is included in the problem. All NUREG-1465 nuclides [1] are included. No radioactive decay is included in the problem. Doses are computed at the EAB, LPZ, and in the control room.
25.1	**Test25Decay** This case is the same as case 25 but, with the radionuclide decay option activated (without daughter production).

Table 2.1.: Test Case Descriptions (Continued)

Case	Name / Description
26.1	**Test26a** This case consists of a compartment representing a PWR containment and a second compartment representing the environment. A control room with a filtered inlet and recirculation loop is included in the case. A fuel handling accident is analyzed using the NUREG-1465 nuclides [1] and the Regulatory Guide 1.183 release fractions. A decay time of 8 hours is included in this case through the source scenario interface. A spent fuel pool DF of 200 for iodine radionuclides is included. Release is assumed to be over a two-hour interval. A radial peaking factor of 1.65 is assumed and a total of 0.1 percent of the fuel is damaged. Doses are computed at the EAB, LPZ, and in the control room. Radionuclide decay is included in this case (without daughter production).
26.2	**Test26b** This case is the same as case 26.1, but with the onset of the gap release set to 8 hours rather than zero.
26.3	**Test26c** This case is the same as case 26.1, but with the accident start and the gap release set to 8 hours rather than zero.
26.4	**Test26d** This case is the same as case 26.1, but with the accident start and the gap release set to 8 hours rather than zero, and the duration of the accident set to 728 hours rather than 720. Additionally, all user-defined tables are set 8 hours late.
26.5	**Test26e** Unexpected behavior has been observed in cases 26.1 – 26.4 due to high leak rate settings. For this and the following three cases, leak rates are reduced from 1.0E09 to 1.0E04 percent per day in order to illustrate this problem. This case is identical to case 26.1, but with a reduced containment to environment leak rate.
26.6	**Test26f** This case is identical to case 26.2, but with a reduced containment to environment leak rate.
26.7	**Test26g** This case is identical to case 26.3, but with a reduced containment to environment leak rate.

Table 2.1.: Test Case Descriptions (Continued)

Case	Name / Description
26.8	**Test26h** This case is identical to case 26.4, but with a reduced containment to environment leak rate.
27.1	**Test27aPre** This case is a model of a SGTR accident. The model consists of a reactor vessel, an unaffected steam generator (SG) and ruptured SG connected by flow paths. Dose is computed at the EAB, LPZ, and in a control room. The control room is filtered and also has a filtered recirculation loop. The source is reactor coolant with RCS activity concentration assuming a pre-incident spike.
27.2	**Test27bCo** This case is the same as case 27.1, but a co-incident iodine spike is assumed.
27.3	**Test27cH3** This case is the same as case 27.1, but assuming a source term of reactor coolant with a tritium source.
28.1	**Test28a_FHA25** This case (based upon case 8) consists of a compartment representing a PWR containment and a second compartment representing the environment. A control room with a filtered inlet and recirculation loop is included in the case. An FHA source term is modeled using RG 1.25 gap fractions [2]. The containment leak rate is set to 100% per day for the duration of the accident. A one-hour delay in the release is modeled in the SNAP//RADTRAD interface and radioactive decay is included in this case. Doses are computed at the EAB, LPZ, and in the control room.
28.2	**Test28b_FHA183** This case is the same as case 28.1, but with RG 1.183 gap fractions [3] assumed.
28.3	**Test28c_FHA** This case is the same as case 28.1, but with Cesium isotopes included.
28.4	**Test28d_FHA** This case is the same as case 28.2, but with Cesium isotopes removed.

Table 2.1.: Test Case Descriptions (Continued)

Case	Name / Description
29.1	**Test29a_Gap25** This case is the same as case 28.1, but with different gap release durations and inventory amounts.
29.2	**Test29b_Gap183** This case is the same as case 29.1, but with RG 1.183 gap fractions [3] assumed.
30	**Test30_REA_CRDA** This case is the same as case 28.1, but models a control rod drop accident with a slower leak rate.
31	**Test31** This case is the same as case 8, but all iodine is assumed to be elemental, radioactive decay is assumed, and the spray removal data is changed.
31.1	**Test31TS** This case is the same as case 8, but with reduced time steps.
32	**Test32** The purpose of this problem is to check that bromine and iodine are analyzed chemically in the same manner in RADTRAD. The NUREG-1465 [1] chemical forms are used. Other inputs and modeling is from case 8.
33	**Test33** The purpose of this case is to check that bromine and iodine are analyzed chemically in the same manner in RADTRAD. The NUREG-1465 [1] chemical forms are used. Other inputs and modeling is from case 8. The radionuclide option turned on (without daughter production), a time delay of 10 hours, and all NUREG-1465 nuclides are included.
34	**Test34** This case consists of two compartments representing the sprayed and unsprayed compartment of a PWR containment and a third compartment representing the environment. A control room with a filtered inlet and recirculation loop is included in the case. All NUREG-1465 [1] nuclides are included. Radioactive decay without daughter production is included in this case. Doses are computed at the EAB, LPZ, and in the control room.

Table 2.1.: Test Case Descriptions (Continued)

Case	Name / Description
35	**Test35** This case is a duplicate of case 23 except that three additional dose points located at the EAB, LPZ and the control room are added. The same atmospheric dispersion tables, breathing rates and occupancy factors are used.
36	**Test36** This case is a duplicate of case 34 except daughtering is turned on and a minimum timestep of 0.01 hours for the first 24 hours, 0.5hour for the next 48, then 1.0 hours for the remaining time.

3. Test Methodology

Regression testing against the RADTRAD test suite shown in Table 2.1 is the primary verification method for this release. A separate verification test report is available that compares test cases run with a prior version of RADTRAD against independent implementations of the tests developed in Mathcad. This other report provides a basis for the regression testing reported herein.

Regression testing is used to confirm that recent code changes have not impacted existing features in unexpected ways. For regression testing, the RADTRAD test suite cases are run using the new version of the code and the previous release of the code. The test cases are run with the `--rgtest` option specified in order to disable plot variables and output text that produce irrelevant differences. Four methods are used to compare each test case:

1. **Binary comparison**: Firstly, the binary plot file results are compared to check for differences in numerical results. If no differences exist in the plot files (the plot files are identical) the test is determined to pass.

   The test cases are run using the default time stepping algorithm, and again using the adaptive time stepping algorithm. If changes are made to the time stepping logic, differences are expected.

2. **Difference magnitude**: If differences occur, a magnitude of the difference is computed using the root mean square algorithm described in Section 3.1. This provides a measure of how different the solutions are. When difference occur, these will be explained in the test report.

3. **CPU time**: The CPU times for each version are compared in order to check for significant differences. Large increases in CPU time can indicate that an undesirable change has been made to the code.

4. **External Time Stepper**: In order to perform adaptive time stepping, RADTRAD implements a save and restore feature that allows the calculation state to be cached at each time step and then restored when it is necessary to redo a time step. In order to confirm that this save and restore process covers the RADTRAD state, a method was added for writing the time step sizes used during adaptive time stepping to a time step output file, and loading the time steps for use in a simulation that does not use adaptive time stepping. Results can then be compared to verify that the adaptive time stepping algorithm correctly restores the state. Additional details are included in Section 3.3.

3.1. Difference Calculation Methodology

If $P_1(t)$ and $P_2(t)$ represent the same plot variable from two simulations of a test case run with different versions of RADTRAD, the difference between the two instances of the plot variable is calculated as the magnitude of the difference $\|P_2(t) - P_1(t)\|$ compared to the average magnitude of the two plot variables $(\|P_1(t)\| + \|P_2(t)\|)/2$ as shown below:

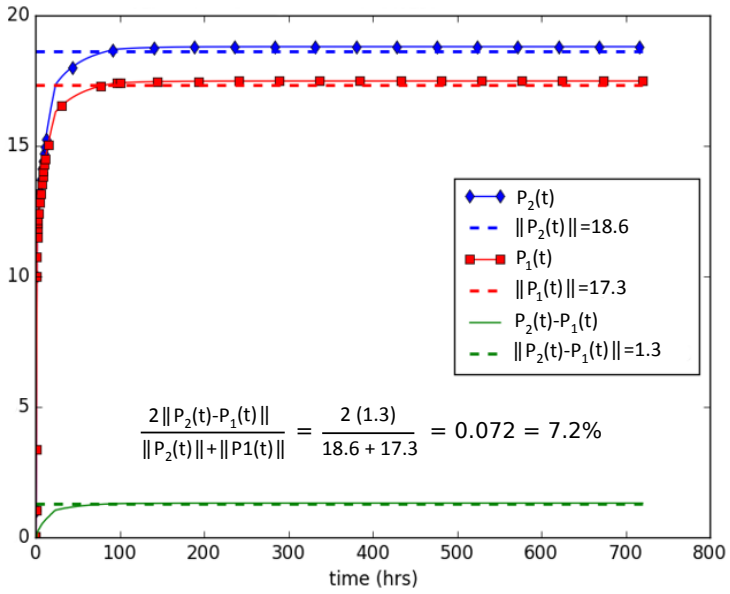

Figure 3.1.: The column vectors of a 2x2 matrix

$$\text{difference fraction} = \frac{2\|P_2(t) - P_1(t)\|}{\|P_1(t)\| + \|P_2(t)\|} \tag{3.1.1}$$

The magnitude formula (or norm) used in conjunction with Equation (3.1.1) is the root mean square (RMS) equation:

$$\|f(t)\| = \left(\frac{1}{t_2 - t_1}\int_{t_1}^{t_2}[f(t)]^2 dt\right)^{1/2} \tag{3.1.2}$$

This difference fraction may be multiplied by 100 to report a difference percentage. To provide a visual example, Figure 3.1 shows a sample plot with a difference of 7.2%. This can be interpreted as the magnitude of the difference between P_1 and P_2 (i.e., $\|P_2 - P_1\|$ or the dashed green line) being 7.2% of the average of magnitudes of P_1 and P_2 (i.e., $[\|P_2\| + \|P_1\|]/2$ or the average of the red and blue dashed lines). The percentage provides a reasonable measure of how similar the plots look on visual inspection.

3.2. Adaptive Time Step Methodology

An adaptive time stepping algorithm was added to RADTRAD 4.5.0. The purpose of the adaptive time stepping algorithm is to automatically select the time step size such that the solution's estimated error is below a threshold value, with the intent that a converged solution is obtained,

where a converged solution is a solution that does not change significantly as the time step size is decreased. Error is estimated by solving a time step twice. One solution uses a full time step, and the other uses two half time steps. The change in dose over the time step is compared for the single two time step solutions to obtain an error estimate to determine if the time step size should be decreased or increased. The adaptive time stepping algorithm can be enabled explicitly in the model via the 'Time Step Algorithm' setting in SNAP that is available under 'Model Options'. However, the test cases are run both with and without adaptive time stepping enabled, so the test suite enables adaptive time stepping via the `-a` command line option as needed.

An error that is small does not necessarily imply that the error in individual nuclide dose contributions will be small since this depends upon the method for calculating error as well as on the stability of the error (i.e., how the error changes as the time step size is decreased). Two methods are used to compute error when the adaptive time stepping option is active:

1. The default option is to use an $L2$ norm which computes an aggregate error that incorporates all of the doses for each nuclide and compartment. In this case, nuclides that do not contribute significantly to the overall dose will have a smaller impact on the error measure, and thus may have relatively large error.

2. An alternative option is an L_∞ (L infinite) norm that computes error for each nuclide dose individually and uses the maximum dose as the dose factor. Thus, this is more sensitive to local error. The L infinite error option is activated with the `-M` command line option.

It may seem like the L_∞ norm would tend to be more accurate. However, this is not guaranteed to be the case. There are some disadvantages to the L_∞ norm. It can be sensitive to the behavior of nuclides with negligible concentration, which can make the solution less stable. There is a limit at which reducing the time step does not improve the calculated error, and it is possible for RADTRAD to have trouble spots where a proper time step size is difficult to determine, causing the instability. Instabilities in the error may force the time stepper to use larger step sizes to get past the region of instability. The $L2$ norm can also experience problems finding a stable time step size, but it is not expected to be as sensitive as the L_∞ norm in estimating error.

3.3. External Time Stepper Methodology

As noted above, the adaptive time stepping algorithm repeats a time step in order to calculate an error estimate. An error in the adaptive time stepping logic was identified and discussed in the SNAP/RADTRAD 5.0.0 test report. The error involved an incomplete restoration of simulation state when repeating the time step for error estimation. This error was fixed in SNAP/RADTRAD 5.0.1.

This error suggested the need to have a method to verify that the adaptive time step algorithm produces results identical to a case run without adaptive time stepping, but with the same time steps. An identical solution provides verification that the solution state is properly saved and restored during adaptive time stepping. In order to make this possible, a new `-t` command line option was added to SNAP/RADTRAD 5.0.1 that causes the time step sizes, used in a simulation, to be saved to a binary output file. The binary time step file has the same base name as the

SNAP/RADTRAD input file with "_ts.bin" appended to the name.

In order to use this file, a `-f` command line option was added that causes RADTRAD to look for a file with the same base name as the RADTRAD input file ending with "_ts.bin". Time steps are then taken from this file rather than using the default time step size logic. After running the non-adaptive time step simulation with time steps from the adaptive time step solution, the results of the two simulations are compared to verify that the dose calculation results are identical. See Section 4.2 for results.

3.4. Description of the Issue Prompting Release of SNAP/RADTRAD

Users reported a couple of errors and requested additional information be printed to the output for use in other software packages. Each of these user reports are discussed in the following subsections.

3.4.1. Changes to Daughter Production

The first issue users reported was that different nuclides were being tracked when comparing RADTRAD 5.0.3 to other radiation dose calculations. The error was found to be in the daughter production in RADTRAD 5.0.3. RADTRAD 5.0.3 handles the decay of parent nuclides and adding activity to daughter nuclides when daughtering is turned on, but only if the daughter nuclides were included in the initial inventory. It was found that a work around to this was adding in every daughter manually into the initial inventory with a starting activity of zero. RADTRAD 5.0.4 fixed this issue by automatically adding daughters to the inventory when daughtering is turned on. The daughters that are added to the inventory are reported in the log file and if any of the automatically added daughter nuclides do not have a specified dose conversion factor, the default values from Federal Guidance Reports 11 and 12 are used. Information on the daughters that used a default dose conversion factor is printed to the output. Even though the daughters are being included automatically, the user still has the ability to define a user-defined dose conversion factor.

Testing proved that limits were needed when including additional daughters in the inventory. The first limit that was included was how many of the daughters of the parent nuclide should be added. Only the next daughter(s) in the decay chain of the parent nuclide is added. For example, Ru-106 is included in the default inventories for PWRs and BWRs. If the default inventory was used and daughtering was turned on, then only Rh-106 would be added to the inventory, not the entire decay chain of Ru-106. Also, if the parent nuclide includes multiple daughters on the first step in the decay chain, then each of those daughter nuclides are included in the inventory. The probability of the parent nuclide being decayed into each of these multiple daughters are taken into consideration during the decay calculations. If a daughter lower down on a chain is wanted by the user, then the work around of adding that nuclide into the initial inventory with an activity of zero still works. The second limit on the daughtering production was that any daughters automatically added to the inventory would not affect the time step sizes. The shortest half-life of the nuclides in the inventory affects the minimum time step if no minimum time step is defined by the user. In the case with Ru-106, Rh-106 is added to the inventory as a daughter, but Rh-106 has a half-life of 30 seconds. If the Rh-106 half-life were used to determine the time step, the time step sizes would

become significantly smaller creating much larger plot file and output file sizes with no significant change in ending doses. Also, because Rh-106 is automatically added into the inventory, the drastic change in time step sizes could lead to confusion. Additionally, another column was added to the default time stepping table that includes a minimum time step size to give users more control over the time step sizes.

3.4.2. Worst 2-Hour Dose

When RADTRAD 5.0.3 was compared to a user's LocaDose calculations, the results seemed to align well with RADTRAD 5.0.3 except the max two-hour was reported as happening much earlier in the simulation. A closer look at the results from RADTRAD 5.0.3 showed that the max two-hour dose should have been at the same time as the LocaDose simulation. The logic in the code to determine the max two-hour dose seemed to have an unintentional limit at 24 hours. This logic was corrected in RADTRAD 5.0.4 to remove that unintentional limit and provide the correct max two-hour dose when that dose occurs later than 24 hours in the simulation.

3.4.3. Null Pointer Exception

During the testing of the changes in RADTRAD 5.0.4, it was also found that certain instances would cause the simulation to fail with a null pointer exception. After examining the code changes, it was found that the null pointer exception was only happening when the stripped down version of Java used in the installation of SNAP is used to run the simulation with an issue in the heap allocation. When running a case that added several daughter nuclides at once (i.e., test 34 with daughtering on), the amount of free space would be used up and cause some memory issues. SNAP requires Java 8 or later and relies on the environment variable JAVA_HOME to set the location of Java on the user's system. However, if JAVA_HOME is pointed to Java in SNAP or if JAVA_HOME is no longer included as an environment variable, the Java in SNAP is used. Most cases will still run without a problem using the version of Java in SNAP, but to help avoid this issue the ability to use Java command line options to adjust the heap of whichever Java is being used was included in the RADTRAD job stream.

3.4.4. Mass and Gamma Information

Users have requested that gamma spectra information and the mass of each nuclide be reported in the output file. A new mass column in the description of each compartment inventory was added to the output. The work for adding in gamma spectra to the output is still ongoing, but the ability to specify a gamma with its energy has been included in the .nix file as shown below.

```
<NuclideData name="Kr-85m" mass="84.91253" halfLife="1.6128E4">
        <daughter name="Kr-85" fraction="0.211" />
        <gammDecay name="gamma 1" energy="1.51E-1" frequency="7.55E-1" />
        <gammDecay name="gamma 2" energy="3.05E-1" frequency="1.40E-1" />
</NuclideData>
```

Where the energy is in MeV and the frequency is in 1/bq-s. These values are currently up to

the user to add. However, this capability might be removed and added to a separate utility that provides gamma information in excel sheets. Discussions on how or if this separate utility tool will be implemented are still ongoing.

3.4.5. Future Changes for Regulatory Guidance 1.183 Revision 1

With the new revision of the regulatory guidance 1.183, RADTRAD developers have looked into what changes will need to be made and how these changes will be tested. RADTRAD 5.0.4 has some of the changes from 1.183 revision 0 to revision 1 incorporated into the code (primarily in MHA table values), but there are several changes that need to be included before RADTRAD is up to date with revision 1.

4. Test Results

This section reports the results to the test cases and criteria laid out in Chapter 2.

4.1. Regression Tests

For all time stepping algorithms (default, L2, and L_∞), all plots are the same except for the cases that had daughtering turned on. These tests included test cases 2.2 and 7.5. These tests had daughter products automatically added in them for the updates incorporated into RADTRAD 5.0.4 as shown in the sections that follow. The following sections include tables that compare the results for cases 2.2 and 7.5 using RADTRAD 5.0.3 and RADTRAD 5.0.4. The cases were run using the three time stepping algorithms (default, L2, and L_∞) and differences that are greater than one percent are marked in red.

4.1.1. Default Time Step Dose and Nuclide Results

Table 4.1.: Dose/Nuclide Differences for Default

	RADTRAD 5.0.3			RADTRAD 5.0.4		
Case 2.2	Whole Body	Thyroid	TEDE	Whole Body	Thyroid	TEDE
LowPopulationZone	**3.2923**	1614.8624	**53.0232**	**3.0684**	1614.8594	**52.7504**
ExclusionAreaBoundary	**6.4352**	640.6575	**26.9018**	**5.8997**	640.6499	**26.2414**
Nuclides in Inventory	14			18		
Case 7.5	Whole Body	Thyroid	TEDE	Whole Body	Thyroid	TEDE
LowPopulationZone	**3.3862**	2514.2437	**154.4469**	**3.373**	2514.2435	**154.4311**
ExclusionAreaBoundary	**1.0627**	449.0593	**20.384**	**1.0496**	449.0591	**20.3678**
Nuclides in Inventory	60			85		

The results of this table is discussed in the following section.

4.1.2. Adaptive Time Step Dose and Nuclide Results

Table 4.2.: Dose/Nuclide Differences for L2

	RADTRAD 5.0.3			RADTRAD 5.0.4		
Case 2.2	Whole Body	Thyroid	TEDE	Whole Body	Thyroid	TEDE
LowPopulationZone	**3.2632**	1614.3422	**52.974**	**3.0552**	1614.3673	**52.7207**
ExclusionAreaBoundary	**6.3716**	640.371	**26.8212**	**5.8707**	640.4515	**26.2041**
Nuclides in Inventory	14			18		
Case 7.5	Whole Body	Thyroid	TEDE	Whole Body	Thyroid	TEDE
LowPopulationZone	**3.3795**	2513.3593	**154.4115**	**3.3668**	2513.3598	**154.3963**
ExclusionAreaBoundary	**1.061**	448.9786	**20.3793**	**1.0483**	448.9784	**20.3637**
Nuclides in Inventory	60			85		

Table 4.3.: Dose/Nuclide Differences for L_∞

	RADTRAD 5.0.3			RADTRAD 5.0.4		
Case 2.2	Whole Body	Thyroid	TEDE	Whole Body	Thyroid	TEDE
LowPopulationZone	**3.2623**	1614.3335	**52.9726**	**3.0514**	1614.328	**52.7155**
ExclusionAreaBoundary	**6.3678**	640.3537	**26.8164**	**5.8566**	640.3551	**26.1859**
Nuclides in Inventory	14			18		
Case 7.5	Whole Body	Thyroid	TEDE	Whole Body	Thyroid	TEDE
LowPopulationZone	**3.3795**	2513.7598	**154.4242**	**3.3672**	2513.7651	**154.4097**
ExclusionAreaBoundary	**1.0601**	448.9368	**20.3769**	**1.0477**	448.9376	**20.3616**
Nuclides in Inventory	60			85		

From the tables, the addition of the 4 and 15 nuclides in cases 2.2 and 7.5, respectively, tends to lower the doses. The nuclides flowing out of a compartment are fractions of the total nuclide inventory in the compartment. Because there are now several additional daughters included in the inventory, the total compartment inventory is increased, but the outflow is being diluted by the less active daughters causing the combined outflow of the more active parent nuclides to be less. The diluted outflow from the upstream compartment tends to make the worst 2-hour dose to be later in the simulation and tends to decrease the final doses.

Test 36 has been included in the regression tests for RADTRAD 5.0.4 but incorporates the new feature of being able to set a minimum time step value for default time steps. The purpose of this

test was to prove that the new time stepping ability is working correctly and that it does not clash with previous features regarding time. The minimum time step feature changes the .psx input file and older versions of RADTRAD do not include the ability to read these changes and will fail. because of this, an option for the user to choose the version of RADTRAD is included in SNAP. The results of Test 36 were manually reviewed and left out of the auto-generated results. This test will be included in the regression results moving forward. All input files created for RADTRAD version 5.0.3 and older will still be able to be used with RADTRAD 5.0.4.

On top of checking that the minimum time step was correct, test 36 was also checked manually to ensure that all the appropriate daughters with the given restrictions mentioned previously were included. The automation of the regression testing does not currently include these checks, but there are plans to advance the regression testing to be more vigorous to include checks like these.

4.2. External Time Stepper Results

This section presents results to the external time stepper testing method described in Section 3.2.

During the process of adding in the changes to RADTRAD 5.0.4, there were differences noticed when comparing the cases run with adaptive time stepping (L2 and L_∞) vs. the cases run with the external time stepping file. The time step should be exactly the same using the external time stepping file and differences are not expected. These differences had to do with additional error information being recorded in the plot file for adaptive time steps compared to the plots not using the adaptive time step. Moving forward, when the argument –rgtest is used, this additional error information will not be included in the plot files by default. The error information can still be included in the plot files when using –rgtest if the argument -c or –calculate_error is also included.

4.3. Simulation Run Time Results

In general, the test case run time is expected to remain similar in different releases of RADTRAD, particularly for the default time stepping algorithm. All cases that run significantly slower than prior versions of RADTRAD warrant a review of code changes. For this release, test cases 2.2 and 7.5 had an expected increase in runtime due to the changes to the daughter production. Test case 2.2 showed only a slight increase in run time, but 7.5 saw a more significant increase in time. Test 2.2 had an additional 4 nuclides with the changes to RADTRAD 5.0.4 while test 7.5 had an additional 25 nuclides added. Because of the large number of additions to 7.5, it was expected to take a much longer to finish the simulation. All other cases did not see a significant change in runtime.

4.3.1. Default Time Step Run Time Results

The RADTRAD 5.0.4 runtime results appear to be about what is expected. Table 4.4 shows the CPU time for each case run with RADTRAD 5.0.4 and RADTRAD 5.0.3, and the ratio of RADTRAD 5.0.3 CPU time to the RADTRAD 5.0.4 CPU time. It is noted that many things can

affect the CPU time for running each case. Computer processes that start and stop during the run through the test cases will affect the amount of time each case takes. Since all the RADTRAD 5.0.4 cases are run before the RADTRAD 5.0.3 cases, it is anticipated that the CPU times may vary as a result of variations in the processor loads during the runs. Some cases are faster with RADTRAD 5.0.4 than with RADTRAD 5.0.3, and others are a little slower. Evaluating the current results against a test report from a previous version of RADTRAD can also provide clues to code changes that significantly increase the runtime.

The results shown in Table 4.4 are considered to be within reason.

Table 4.4.: Test case run time results

Case	5.0.4 Time (s)	5.0.3 Time (s)	Time Ratio (5.0.3 / 5.0.4)
1	0.257000	0.343000	1.33
1.1	0.340000	0.437000	1.29
1.2	3.063000	3.584000	1.17
1.3	3.140000	3.636000	1.16
2	0.351000	0.383000	1.09
2.1	0.348000	0.369000	1.06
2.2	1.298000	1.485000	1.14
3	0.431000	0.521000	1.21
4	0.391000	0.513000	1.31
5	0.409000	0.473000	1.16
6	0.565000	0.590000	1.04
7	0.619000	0.692000	1.12
7.1	0.711000	0.748000	1.05
7.2	0.683000	0.665000	0.97
7.3	0.603000	0.731000	1.21
7.4	0.655000	0.711000	1.09
7.5	5.231000	2.845000	0.54
8	0.832000	0.953000	1.15
8.1	10.126000	7.794000	0.77
8.2	8.528000	11.046000	1.30
9	0.831000	0.942000	1.13

Table 4.4.: Test case run time results (continued)

Case	5.0.4 Time (s)	5.0.3 Time (s)	Time Ratio (5.0.3 / 5.0.4)
10	0.957000	1.067000	1.11
10.1	0.891000	0.957000	1.07
10.2	10.486000	10.294000	0.98
11	0.372000	0.404000	1.09
12	0.508000	0.473000	0.93
13	0.472000	0.519000	1.10
13.2	0.893000	0.839000	0.94
14	0.509000	0.521000	1.02
14.2	0.877000	0.877000	1.00
15	0.687000	0.674000	0.98
16	0.929000	0.916000	0.99
19	0.888000	0.794000	0.89
20	0.992000	1.019000	1.03
21	1.260000	1.330000	1.06
22	1.324000	1.253000	0.95
23	1.236000	1.579000	1.28
23.1	13.852000	12.036000	0.87
23.2	11.362000	12.750000	1.12
24	1.294000	1.330000	1.03
25	1.105000	1.139000	1.03
25.1	1.192000	1.259000	1.06
26.1	0.886000	0.935000	1.06
26.2	0.862000	0.919000	1.07
26.3	0.790000	0.902000	1.14
26.4	0.932000	1.000000	1.07
26.5	0.879000	0.904000	1.03
26.6	0.857000	0.882000	1.03

Table 4.4.: Test case run time results (continued)

Case	5.0.4 Time (s)	5.0.3 Time (s)	Time Ratio (5.0.3 / 5.0.4)
26.7	0.937000	0.991000	1.06
26.8	1.012000	0.971000	0.96
27.1	0.785000	0.928000	1.18
27.2	0.771000	0.973000	1.26
27.3	0.378000	0.404000	1.07
28.1	0.512000	0.558000	1.09
28.2	0.519000	0.527000	1.02
29.1	0.564000	0.548000	0.97
29.2	0.549000	0.545000	0.99
30	0.521000	0.560000	1.07
31	1.058000	0.986000	0.93
31.1	6.608000	6.652000	1.01
32	0.409000	0.422000	1.03
33	0.970000	1.174000	1.21
34	1.079000	1.087000	1.01
35	1.796000	1.664000	0.93

4.3.2. Adaptive Time Step Runtime Results

The RADTRAD 5.0.4 runtime results in Table 4.5 appear to be about what is expected. RADTRAD 5.0.4 runs slightly slower due to the additional output. Test 2.2 takes significantly longer due to the additional nuclides added from the daughtering changes, however, 7.5 runs a bit faster despite the additional information. Since the regression results were ran on a single computer, fluctions with As was described in Section 4.3.1, the differences are considered to be within reason.

Table 4.5.: Test case run time results

Case	5.0.4 Time (s)	5.0.3 Time (s)	Time Ratio (5.0.3 / 5.0.4)
1	0.735000	0.599000	0.81
1.1	1.068000	0.796000	0.75

Table 4.5.: Test case run time results (continued)

Case	5.0.4 Time (s)	5.0.3 Time (s)	Time Ratio (5.0.3 / 5.0.4)
1.2	7.418000	5.717000	0.77
1.3	7.271000	6.161000	0.85
2	0.767000	0.684000	0.89
2.1	4.528000	4.057000	0.90
2.2	6.889000	2.856000	0.41
3	1.156000	0.944000	0.82
4	1.355000	0.991000	0.73
5	1.203000	0.924000	0.77
6	1.343000	1.051000	0.78
7	1.557000	1.316000	0.85
7.1	10.987000	7.825000	0.71
7.2	1.466000	1.232000	0.84
7.3	10.241000	8.685000	0.85
7.4	6.361000	5.281000	0.83
7.5	11.782000	13.095000	1.11
8	2.144000	2.006000	0.94
8.1	24.296000	19.287000	0.79
8.2	121.615000	122.269000	1.01
9	2.159000	1.835000	0.85
10	2.287000	2.171000	0.95
10.1	2.211000	1.928000	0.87
10.2	13.457000	11.317000	0.84
11	0.881000	0.767000	0.87
12	1.266000	0.992000	0.78
13	1.588000	1.170000	0.74
13.2	2.209000	2.328000	1.05
14	1.332000	1.074000	0.81

Table 4.5.: Test case run time results (continued)

Case	5.0.4 Time (s)	5.0.3 Time (s)	Time Ratio (5.0.3 / 5.0.4)
14.2	2.278000	1.863000	0.82
15	1.407000	1.297000	0.92
16	1.955000	2.007000	1.03
19	2.396000	1.633000	0.68
20	2.054000	2.254000	1.10
21	3.479000	2.510000	0.72
22	3.922000	3.550000	0.91
23	4.021000	4.213000	1.05
23.1	30.171000	24.469000	0.81
23.2	144.856000	133.518000	0.92
24	4.878000	3.719000	0.76
25	2.894000	2.756000	0.95
25.1	16.216000	17.151000	1.06
26.1	3.444000	2.966000	0.86
26.2	3.537000	2.905000	0.82
26.3	3.203000	2.904000	0.91
26.4	3.449000	2.985000	0.87
26.5	3.254000	2.724000	0.84
26.6	3.040000	2.515000	0.83
26.7	2.662000	2.603000	0.98
26.8	3.064000	2.917000	0.95
27.1	13.774000	10.232000	0.74
27.2	12.595000	10.300000	0.82
27.3	0.835000	0.665000	0.80
28.1	5.418000	4.873000	0.90
28.2	4.739000	3.644000	0.77
29.1	5.043000	3.799000	0.75

Table 4.5.: Test case run time results (continued)

Case	5.0.4 Time (s)	5.0.3 Time (s)	Time Ratio (5.0.3 / 5.0.4)
29.2	3.753000	3.242000	0.86
30	5.920000	4.011000	0.68
31	12.872000	10.939000	0.85
31.1	15.129000	13.361000	0.88
32	0.863000	0.802000	0.93
33	9.078000	8.657000	0.95
34	14.251000	9.803000	0.69
35	4.090000	3.203000	0.78

4.4. Summary

RADTRAD 5.0.4 has fixed a number of problems reported by the users and seen by the developer. These included fixes with correctly outputting the worst 2-hour time and doses, adding in daughter nuclides when the decay and daughtering option is turned on, and solving the differences in the plot files when comparing different time stepping options. RADTRAD 5.0.4 also provided more control over Java heap allocation that was causing a null pointer exception in specific cases. Two new features added to RADTRAD 5.0.4 include the ability for users to add gamma information to the .nix file to include in the output and the ability for the users to adjust the minimum default time step size. However, the gamma feature is still in progress and changes in future versions are expected. All of the results from the regression testing are as expected leaving RADTRAD 5.0.4 in good standing to make additional changes based on the the new release of Regulatory Guidance 1.183 Revision 1.

5. Conclusion

As stated in Section 4.4, RADTRAD 5.0.4 is in a good standing to release to the users and build upon for future releases.

A. Informational Data for Convergence Analysis

This section provides the results of a difference magnitude comparison between the RADTRAD 5.0.4 default time step algorithm and the adaptive time stepping algorithm. Generally, a smaller precent difference provides confidence that the analytical code is nearer to a true solution for both algorithms, while a larger percent difference suggests that the default time stepping algorithm is not fully converged. The purpose of this appendix is to provide a basic sense of how much difference in results might be expected due to use of the adaptive time stepping algorithm.

Differences are reported for the TEDE, Thyroid, and Cloudshine dose for the EAB (Exclusion Area Boundary), LPZ (Low Population Zone), and CR (Control Room) compartments included in the test case. Some test cases do not include all of these compartments. When the compartment is not present, N/A is reported in place of the percent difference value.

In table below, percent difference greater than 1% is listed in red.

Table A.1.: Adaptive Vs. Default Time Stepping Results

Case	Location	Percent Difference			
		TEDE	**Thyroid**	**Cloudshine**	**Max Nuclide (any location)**
1	EAB	5.336e-11	5.336e-11	5.336e-11	5.336e-11
	LPZ	1.634e-12	1.639e-12	1.107e-12	for: ExclusionAreaBoundary.inhalation.I131
	CR	N/A	N/A	N/A	and 9 others
1.1	EAB	0	0	0	1.010e-05
	LPZ	0	0	0	for: ControlRoom.skin.I131
	CR	1.010e-05	1.010e-05	1.010e-05	and 9 others
1.2	EAB	5.336e-11	5.336e-11	5.336e-11	1.215e-07
	LPZ	9.100e-08	9.073e-08	1.215e-07	for: LPZ10.cloudshine.I131
	CR	N/A	N/A	N/A	and 43 others
1.3	EAB	5.336e-11	5.336e-11	5.336e-11	1.215e-07
	LPZ	9.100e-08	9.073e-08	1.215e-07	for: LPZ10.cloudshine.I131
	CR	N/A	N/A	N/A	and 43 others
2	EAB	5.336e-11	5.336e-11	5.336e-11	5.336e-11
	LPZ	1.448e-12	1.639e-12	1.108e-12	for: ExclusionAreaBoundary.cloudshine.I133
	CR	N/A	N/A	N/A	and 56 others
2.1	EAB	3.513e-01	7.741e-02	**1.21**	**9.88**

Table A.1.: Adaptive Vs. Default Time Stepping Results (continued)

Case	Location	Percent Difference			
		TEDE	**Thyroid**	**Cloudshine**	**Max Nuclide (any location)**
	LPZ	9.036e-01	7.730e-01	**2.53**	for: LowPopulationZone.skin.Xe135m
	CR	N/A	N/A	N/A	and 5 others
2.2	EAB	3.002e-01	4.473e-02	9.932e-01	**8.18**
	LPZ	1.120e-01	4.223e-02	9.164e-01	for: LowPopulationZone.skin.Xe135m
	CR	N/A	N/A	N/A	and 2 others
3	EAB	1.559e-07	1.559e-07	1.559e-07	5.603e-01
	LPZ	9.631e-06	9.595e-06	9.693e-06	for: ControlRoom.inhalation.I134
	CR	5.599e-01	5.603e-01	5.567e-01	and 56 others
4	EAB	1.354e-04	1.457e-04	1.022e-04	5.563e-01
	LPZ	4.810e-03	7.645e-03	2.561e-03	for: ControlRoom.cloudshine.Xe135m
	CR	5.546e-01	5.545e-01	5.561e-01	and 56 others
5	EAB	3.836e-06	4.090e-06	2.987e-06	5.606e-01
	LPZ	3.333e-04	3.635e-04	2.657e-04	for: ControlRoom.thyroid.I132
	CR	5.604e-01	5.606e-01	5.569e-01	and 56 others
6	EAB	1.738e-09	1.738e-09	1.738e-09	1.738e-09
	LPZ	2.600e-11	2.607e-11	1.752e-11	for: ExclusionAreaBoundary.cloudshine.I131
	CR	N/A	N/A	N/A	and 9 others
7	EAB	1.493e-09	1.696e-09	1.432e-09	2.231e-09
	LPZ	2.056e-11	2.536e-11	1.411e-11	for: ExclusionAreaBoundary.tede.Cs134
	CR	N/A	N/A	N/A	and 19 others
7.1	EAB	1.930e-01	7.374e-02	**1.34**	**4.34**
	LPZ	5.359e-01	7.777e-01	**2.26**	for: LowPopulationZone.cloudshine.Te127
	CR	N/A	N/A	N/A	and 10 others
7.2	EAB	1.952e-09	2.360e-09	1.866e-09	2.818e-09
	LPZ	2.505e-11	3.352e-11	1.704e-11	for: ExclusionAreaBoundary.thyroid.Cs136
	CR	N/A	N/A	N/A	and 19 others
7.3	EAB	1.834e-01	7.327e-02	**1.32**	**4.39**

Table A.1.: Adaptive Vs. Default Time Stepping Results (continued)

Case	Location	Percent Difference			
		TEDE	**Thyroid**	**Cloudshine**	**Max Nuclide (any location)**
	LPZ	4.556e-01	7.782e-01	**2.19**	for: LowPopulationZone.skin.Te127
	CR	N/A	N/A	N/A	and 10 others
7.4	EAB	2.175e-02	2.241e-02	1.614e-01	**4.12**
	LPZ	4.449e-01	7.007e-01	**1.48**	for: LowPopulationZone.skin.Te127
	CR	N/A	N/A	N/A	and 8 others
7.5	EAB	2.308e-02	1.799e-02	1.663e-01	**3.86**
	LPZ	3.196e-02	4.406e-02	2.329e-01	for: ExclusionAreaBoundary.inhalation.Rb88
	CR	N/A	N/A	N/A	and 4 others
8	EAB	1.247e-03	1.244e-03	1.249e-03	6.320e-01
	LPZ	2.189e-05	2.302e-05	1.836e-05	for: ControlRoom.inhalation.Mo99
	CR	6.039e-01	6.121e-01	5.710e-01	and 242 others
8.1	EAB	4.382e-03	3.457e-03	3.630e-03	6.324e-01
	LPZ	5.906e-05	5.273e-05	3.701e-05	for: ControlRoom.thyroid.Ca45
	CR	6.313e-01	6.121e-01	5.711e-01	and 3408 others
8.2	EAB	4.463e-03	1.542e-02	**1.58**	**21.36**
	LPZ	4.013e-03	1.332e-01	**1.28**	for: ControlRoom.thyroid.Sm141
	CR	6.409e-01	8.046e-01	**2.50**	and 4 others
9	EAB	1.300e-03	1.298e-03	1.286e-03	5.289e-01
	LPZ	6.405e-03	8.554e-03	2.561e-03	for: ControlRoom.cloudshine.Xe133
	CR	5.276e-01	5.269e-01	5.289e-01	and 47 others
10	EAB	1.108e-02	1.226e-02	8.724e-03	4.446e-01
	LPZ	5.499e-03	7.681e-03	2.071e-03	for: ControlRoom.skin.Kr85m
	CR	4.419e-01	4.404e-01	4.446e-01	and 46 others
10.1	EAB	3.610e-02	3.983e-02	2.764e-02	5.703e-01
	LPZ	1.009e-01	1.388e-01	3.460e-02	for: ControlRoom.cloudshine.Xe133
	CR	5.480e-01	5.355e-01	5.702e-01	and 19 others
10.2	EAB	1.108e-02	1.226e-02	8.724e-03	1.436e-01

Table A.1.: Adaptive Vs. Default Time Stepping Results (continued)

Case	Location	Percent Difference			
		TEDE	**Thyroid**	**Cloudshine**	**Max Nuclide (any location)**
	LPZ	4.163e-03	6.218e-03	1.299e-03	for: ControlRoom.skin.Cs136
	CR	9.850e-02	1.045e-01	9.051e-02	and 19 others
11	EAB	1.159e-14	2.273e-14	1.546e-14	5.154e-14
	LPZ	9.676e-15	1.986e-14	4.097e-14	for: LowPopulationZone.thyroid.I131
	CR	N/A	N/A	N/A	
12	EAB	1.159e-14	2.273e-14	1.546e-14	5.950e-01
	LPZ	8.842e-04	8.842e-04	8.823e-04	for: ControlRoom.skin
	CR	5.950e-01	5.950e-01	5.950e-01	and 9 others
13	EAB	5.549e-04	5.549e-04	5.549e-04	3.614e-01
	LPZ	1.262e-03	1.262e-03	1.262e-03	for: ControlRoom.tede.I131
	CR	3.614e-01	3.614e-01	3.614e-01	and 9 others
13.2	EAB	3.964e-04	3.964e-04	3.964e-04	6.219e-02
	LPZ	7.528e-04	7.528e-04	7.524e-04	for: ControlRoom.skin.I131
	CR	6.219e-02	6.219e-02	6.219e-02	and 9 others
14	EAB	5.549e-04	5.549e-04	5.549e-04	5.957e-01
	LPZ	1.775e-03	1.775e-03	1.774e-03	for: ControlRoom.thyroid
	CR	5.957e-01	5.957e-01	5.957e-01	and 9 others
14.2	EAB	6.114e-05	6.114e-05	6.114e-05	5.854e-01
	LPZ	7.802e-04	7.802e-04	7.784e-04	for: ControlRoom.thyroid.I131
	CR	5.854e-01	5.854e-01	5.854e-01	and 9 others
15	EAB	5.659e-10	5.659e-10	5.659e-10	5.659e-10
	LPZ	1.641e-12	1.645e-12	1.087e-12	for: ExclusionAreaBoundary.tede.I131
	CR	N/A	N/A	N/A	and 9 others
16	EAB	5.659e-10	5.659e-10	5.659e-10	**1.56**
	LPZ	3.242e-05	3.242e-05	3.203e-05	for: ControlRoom.tede
	CR	**1.56**	**1.56**	**1.56**	and 9 others
19	EAB	2.272e-03	2.272e-03	2.272e-03	2.272e-03

Table A.1.: Adaptive Vs. Default Time Stepping Results (continued)

Case	Location	Percent Difference			
		TEDE	**Thyroid**	**Cloudshine**	**Max Nuclide (any location)**
	LPZ	4.069e-05	4.081e-05	2.726e-05	for: ExclusionAreaBoundary.tede
	CR	N/A	N/A	N/A	and 9 others
20	EAB	2.333e-03	2.283e-03	2.318e-03	2.838e-03
	LPZ	3.109e-05	4.120e-05	1.194e-05	for: ExclusionAreaBoundary.thyroid.Nd147
	CR	N/A	N/A	N/A	and 222 others
21	EAB	2.307e-03	2.256e-03	2.306e-03	7.388e-01
	LPZ	2.555e-03	1.610e-03	4.322e-03	for: ControlRoom.tede.Pr143
	CR	5.350e-01	6.103e-01	4.719e-01	and 242 others
22	EAB	2.325e-03	2.272e-03	2.317e-03	8.610e-01
	LPZ	3.455e-03	3.365e-03	4.614e-03	for: ControlRoom.inhalation.I132
	CR	7.319e-01	8.605e-01	6.817e-01	and 26 others
23	EAB	2.102e-03	3.390e-03	1.535e-03	7.933e-01
	LPZ	5.087e-03	3.128e-03	5.145e-03	for: ControlRoom.skin.I132
	CR	6.977e-01	7.916e-01	6.967e-01	and 25 others
23.1	EAB	5.741e-03	3.510e-03	2.109e-03	4.718e-01
	LPZ	3.995e-03	3.217e-03	5.207e-03	for: ControlRoom.cloudshine.Xe125
	CR	4.487e-01	4.688e-01	4.718e-01	and 213 others
23.2	EAB	1.243e-02	1.519e-02	**1.74**	**20.99**
	LPZ	2.759e-01	1.054e-01	**2.32**	for: ControlRoom.thyroid.Sm141
	CR	9.234e-01	8.870e-01	**3.29**	and 4 others
24	EAB	3.720e-01	5.041e-01	1.028e-01	**7.57**
	LPZ	4.788e-02	**1.49**	7.678e-03	for: LowPopulationZone.cloudshine.Ba140
	CR	5.190e-01	**1.05**	5.094e-01	and 87 others
25	EAB	6.589e-14	1.793e-13	5.114e-14	2.301e-13
	LPZ	6.653e-14	1.274e-13	7.435e-14	for: LowPopulationZone.inhalation.I133
	CR	9.186e-14	1.489e-13	6.230e-14	and 2 others
25.1	EAB	1.861e-01	6.340e-01	2.497e-01	**47.49**

Table A.1.: Adaptive Vs. Default Time Stepping Results (continued)

Case	Location	Percent Difference			
		TEDE	**Thyroid**	**Cloudshine**	**Max Nuclide (any location)**
	LPZ	1.861e-01	6.340e-01	2.497e-01	for: ControlRoom.skin.I132
	CR	1.918e-01	6.422e-01	2.564e-01	and 4 others
26.1	EAB	7.272e-03	1.387e-02	2.512e-01	**3.39**
	LPZ	7.272e-03	1.387e-02	2.512e-01	for: ExclusionAreaBoundary.thyroid.I134
	CR	3.698e-01	3.161e-01	7.397e-01	and 9 others
26.2	EAB	1.311e-02	1.387e-02	2.512e-01	**3.39**
	LPZ	1.311e-02	1.387e-02	2.512e-01	for: ExclusionAreaBoundary.cloudshine.I134
	CR	3.596e-01	3.064e-01	7.381e-01	and 9 others
26.3	EAB	1.311e-02	1.387e-02	2.512e-01	**3.39**
	LPZ	1.311e-02	1.387e-02	2.512e-01	for: LowPopulationZone.cloudshine.I134
	CR	3.698e-01	3.161e-01	7.397e-01	and 9 others
26.4	EAB	7.272e-03	1.387e-02	2.512e-01	**3.39**
	LPZ	7.272e-03	1.387e-02	2.512e-01	for: ExclusionAreaBoundary.thyroid.I134
	CR	3.698e-01	3.161e-01	7.397e-01	and 9 others
26.5	EAB	7.745e-03	1.435e-02	2.476e-01	**3.57**
	LPZ	7.745e-03	1.435e-02	2.476e-01	for: LowPopulationZone.skin.I134
	CR	1.844e-01	1.435e-01	7.797e-01	and 14 others
26.6	EAB	1.304e-02	1.421e-02	2.455e-01	**3.55**
	LPZ	1.304e-02	1.421e-02	2.455e-01	for: LowPopulationZone.cloudshine.I134
	CR	2.048e-02	5.037e-02	7.149e-01	and 9 others
26.7	EAB	1.303e-02	1.421e-02	2.456e-01	**3.55**
	LPZ	1.303e-02	1.421e-02	2.456e-01	for: ExclusionAreaBoundary.skin.I134
	CR	2.284e-02	5.280e-02	7.127e-01	and 9 others
26.8	EAB	7.745e-03	1.435e-02	2.476e-01	**3.57**
	LPZ	7.745e-03	1.435e-02	2.476e-01	for: ExclusionAreaBoundary.skin.I134
	CR	1.844e-01	1.435e-01	7.797e-01	and 14 others
27.1	EAB	**1.13**	2.560e-01	**2.08**	**12.57**

Table A.1.: Adaptive Vs. Default Time Stepping Results (continued)

Case	Location	Percent Difference			
		TEDE	**Thyroid**	**Cloudshine**	**Max Nuclide (any location)**
	LPZ	**1.13**	2.565e-01	**2.08**	for: ControlRoom.cloudshine.Xe138
	CR	2.996e-01	6.737e-02	**2.15**	and 2 others
27.2	EAB	**1.87**	4.042e-01	**2.47**	**11.82**
	LPZ	**1.88**	4.054e-01	**2.47**	for: ControlRoom.skin.Xe138
	CR	5.813e-01	1.979e-01	**2.15**	and 2 others
27.3	EAB	2.859e-03	2.859e-03	0	1.055e-02
	LPZ	3.059e-03	3.059e-03	0	for: ControlRoom.inhalation.H3
	CR	1.055e-02	1.055e-02	0	and 5 others
28.1	EAB	9.066e-01	6.501e-02	**1.20**	**3.92**
	LPZ	**1.29**	4.434e-01	**1.96**	for: ControlRoom.thyroid.I134
	CR	**2.11**	**1.39**	**2.23**	and 4 others
28.2	EAB	3.345e-02	1.753e-02	7.589e-01	**3.92**
	LPZ	3.096e-02	1.117e-01	6.593e-01	for: ControlRoom.inhalation.I134
	CR	**1.03**	**1.08**	**2.20**	and 4 others
29.1	EAB	2.329e-01	6.646e-02	**1.48**	**3.46**
	LPZ	5.235e-01	4.164e-01	**1.97**	for: LowPopulationZone.cloudshine.I134
	CR	**1.26**	**1.22**	**1.84**	and 9 others
29.2	EAB	1.499e-01	5.585e-02	**1.39**	**3.46**
	LPZ	3.426e-01	3.679e-01	**1.65**	for: LowPopulationZone.cloudshine.I134
	CR	**1.14**	**1.17**	**1.84**	and 9 others
30	EAB	2.059e-01	7.279e-02	**1.44**	**4.00**
	LPZ	5.830e-01	7.218e-01	**2.10**	for: ControlRoom.skin.Xe135
	CR	**1.50**	**1.63**	**2.38**	and 2 others
31	EAB	2.049e-01	7.723e-02	**1.40**	**4.82**
	LPZ	1.024e-01	6.260e-02	**1.74**	for: ControlRoom.cloudshine.Xe135
	CR	9.504e-01	6.770e-01	**2.85**	and 2 others
31.1	EAB	1.826e-01	6.871e-02	**1.25**	**3.61**

Table A.1.: Adaptive Vs. Default Time Stepping Results (continued)

Case	Location	Percent Difference			
		TEDE	**Thyroid**	**Cloudshine**	**Max Nuclide (any location)**
	LPZ	1.140e-01	6.806e-02	7.540e-01	for: ControlRoom.skin.I134
	CR	2.835e-01	1.545e-01	8.043e-01	and 4 others
32	EAB	1.738e-09	1.738e-09	1.738e-09	6.064e-01
	LPZ	1.598e-05	1.597e-05	1.605e-05	for: ControlRoom.tede.I133
	CR	6.064e-01	6.064e-01	6.064e-01	and 44 others
33	EAB	4.020e-01	7.374e-01	**1.17**	**5.58**
	LPZ	4.423e-01	6.959e-01	**1.49**	for: ExclusionAreaBoundary.skin.Te127
	CR	**1.37**	**1.72**	**2.17**	and 6 others
34	EAB	4.179e-01	7.814e-01	**1.21**	**8.96**
	LPZ	4.955e-01	8.091e-01	**1.69**	for: ExclusionAreaBoundary.cloudshine.Kr85m
	CR	**1.31**	**1.71**	**2.54**	and 2 others
35	EAB	2.102e-03	3.390e-03	1.535e-03	7.933e-01
	LPZ	5.087e-03	3.128e-03	5.145e-03	for: CR-2.skin.I132
	CR	6.977e-01	7.916e-01	6.967e-01	and 51 others

B. References

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[2] Regulatory Guide 1.25, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Fuel Handling Accident in the Fuel Handling and Storage Facility for Boiling and Pressurized Water Reactors." USNRC, 1972. Web. nrc.gov/docs/ML0833/ML083300022.pdf.

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