SIMBRASS and Neutron Overpower Analysis

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SYNOPSIS

CANDU reactors are equipped with two independent Shutdown Systems (SDSs) which may be initiated through a variety of measures. One of the principal means is the Neutron Overpower Protective System (NOP)[1] which provides a direct measurement of the neutron flux throughout the reactor core. SIMBRASS is the Nuclear Safety Analysis code which has been used to establish the NOP trip setpoints implemented at Ontario Hydro, Ontario Power Generation (OPG) and Bruce Power nuclear stations for over 20 years.

This paper describes the SIMBRASS code, its applications, and some of the capabilities of the newly developed code version, SIMBRASS 5.0.

1.0 Introduction

SIMBRASS is a Monte Carlo code which statistically determines the NOP Trip Setpoint (TSP) which is required to meet a specific safety criterion. The ultimate safety criterion is to preclude the release of radioactive material by preventing damage to the fuel. The analysis criterion has been conservatively taken to be the much more restrictive prevention of the onset of Fuel Sheath Dryout, with a high reliability. OPG and Bruce Power have adopted the criterion that there should be a 98% probability that each Shutdown System (SDS) will be activated, prior to Fuel Sheath Dryout in any fuel channel, in the event of a slow Loss of Regulation (LOR) transient. This assumes that the first of the three NOP logic channels to trip is permanently unavailable (3/3 trip). The required NOP trip setpoint is equal to the limiting, or lowest, required trip setpoint, as computed by SIMBRASS, for a large number of perturbed flux shapes. This set of shapes should reasonably span the set of configurations which might be expected to occur during normal operation. It also includes shapes arising from abnormalities due to the regulating system, unusual reactivity device configurations, xenon effects, shim operation and so forth.

SIMBRASS has been completely re-written as part of the general code qualification initiative at OPG. The current version, 5.0, is discussed in this paper.

2.0 The SIMBRASS Code

SIMBRASS 5.0 was released in October, 2002 for preliminary user testing. User and Theory Manuals (References 1 and 2) are available, as are numerous design, testing, and validation documents.

2.1 Functionalities Addressed in SIMBRASS

1 Determine the required NOP TSPs for a large number of perturbed flux shapes in the event of a slow LOR accident. Assume that each NOP detector in a SDS must have an identical TSP. The system reliability (probability of tripping before dryout), statistical accuracy and numerical precision are specified by the user. This is the prime functionality.

[1] Neutron Overpower is sometimes referred to as Regional Overpower, or ROP, in the literature.

2 Determine the decrement to the Required Trip Setpoint (RTSP) which occurs when one or more NOP detectors have become impaired (read low) or fail;

3 Determine the degree to which a specified number of detectors, randomly chosen from a selected subset of detectors, would have to have been reading low in order for the NOP system to have been impaired. Here system impairment is defined as the inability to meet the required safety criteria. This is true over all specified reactor core configurations and is referred to as the Impairment Limit;

4 Determining the Required Trip Setpoints (RTSPs) of the remaining NOP detectors when one or more NOP detectors have specific TSPs assigned to them prior to the analysis. This enables analysis of non-uniform trip setpoint systems;

5 Ascertaining the deterministic NOP Required TSPs for each flux shape.

2.2 SIMBRASS Features

SIMBRASS 5.0 includes the following features, some of which are new to this version of the code or supersede related abilities of earlier versions.

- Produces report-ready Tables and Figures (in Post Script) as well as text, summary and log files;
- Accumulates useful statistics. The user may specify which are to be reported;
- User-friendly; Easy to use and understand:
- Flexible input structure and uncertainty specifications;
  - intelligent defaults and adjustable Reference Data Set specifications exist;
  - specifications may be entered at the command line;
  - a complete paper trail of data file usage, including symbolic links, is automatically produced for QA records;
- Extensive detector impairment and failure features including:
  - Automatic production of detector failure and impairment matrices – tables of TSP decrements for all combinations of up to 3 impaired/failed detectors (per NOP logic channel or SDS);
  - Automatic generation of Detector Assembly failure and impairment tables (or user-specified detector combinations);
  - Perform *a posteriori* impairment limit analysis – determination of the maximum detector impairment levels which avoid system impairment. The user may also produce tables of system impairment as a function of detector impairment;
  - Specifications of random detector, assembly or logic channel failures;
  - Specific detector and assembly impairment and failure combinations may be examined for many flux shapes by changing a few input lines;
- Different fuelling ripple distribution sets may be applied to different flux shapes as required. Internal generation of specialised ripple sets (useful for shim and related analysis);
- Non-uniform TSP systems may be analysed;
- Diagnostics:
  - Input auditing. Most input data are examined against tables of ranges and values. Messages are issued at the time of input for suspect or flagged values. The user may tailor these to appropriate specifications;
  - A central error-tracking module which issues Informational, Warning, Error and Fatal messages from an external database. The user may suppress some messages by selecting a quiet mode.
- Efficient. It typically requires far less than an hour to analyse a thousand core distributions;
- Optional pruning mechanisms exist, for detector impairment/failure tabulations, in order to safely restrict the effort expended on highly non-limiting flux distributions;
- User may specify a required precision and confidence level. The code iterates until this is satisfied, case by case, possibly with different numbers of iterations for each flux shape;
- 2/3, 3/3 or 2/2 NOP channel trips at any level of system reliability (probability of initiation an NOP reactor trip prior to the onset of fuel sheath dryout) may be analysed;

- The Monte Carlo approach is readily extensible to model effects that are not easily incorporated by other techniques.

2.3 The Monte Carlo Approach

There are numerous uncertainties involved when the required trip setpoint is computed for a given power distribution. These include electronic drift, fuelling effects, simulation errors, modelling errors *etc*. These uncertainties are tabulated from station measurements and associated errors, code validation and testing. From these, a number of uncertainty distributions are established relating to the important parameters input to the SIMBRASS code. SIMBRASS is a purely mathematical simulation code that uses a Monte Carlo technique to sample the expected uncertainties, of various physical and modelled parameters, in order to statistically determine the Neutron Overpower Protection (NOP) Required Trip Setpoint (RTSP).

In the Monte Carlo approach, many solutions of a problem are calculated with variations in the boundary conditions, randomly determined according to the frequency at which they are expected to occur. The set of results thus obtained may be taken as constituting a statistical ensemble, and is thus amenable to analysis. This is a standard approach to solving complex, realistic problems whose solution might be difficult or impossible to obtain analytically. In a typical analysis, the user specifies the precision to which the NOP setpoint is required, the desired accuracy (statistical confidence) of the solution, and the safety criterion (generally a 98% probability of trip preceding dryout for a 3/3 trip). SIMBRASS 5.0 will sample the uncertainty distributions, generating solutions until the requirements are satisfied for all of the cases being examined. The code then reports, both in tabular form and graphically, the results of the statistical analysis for all cases, beginning with the most limiting.

3.0 Methodology

3.1 Deterministic Required Trip Setpoint

When a slow Loss of Regulation event occurs, the power is assumed to increase uniformly. The reactor power increases with relatively little spatial distortion in the relative bundle power distribution. It is desired to find the NOP TSP that trips the reactor just as the onset of dryout is occurring in the limiting fuel channel. When the NOP detectors are well placed to measure the flux peaks, the margin to trip will be small relative to the margin to dryout and the reactor will be tripped long before the Critical Channel Power (CCP), at which dryout occurs, is reached. The NOP TSP that is required to protect the fuel is high for such a perturbed flux shape. For a different flux distribution, the peak flux may be registered less effectively and a lower, more restrictive NOP TSP will be required to provide the same level of protection. If there is a degree of variation or uncertainty in the channel power distribution, the power at which dryout occurs (CCP), the model etc., then this must also be accounted for, reducing the required TSP. The Margin to Dryout (MD) at 100% FP for the entire core for flux shape J in fuelling ripple k is (Reference 2):

$$MD^{J;k} = \min_i \left(\frac{CCP_i^J}{OP_i^J \times Ripple_i^k \times CP_i^{Ref}} \right) \qquad \textbf{Equation 3.1}$$

where i is the fuel channel. CP^{Ref} is a Reference NOP Channel Power distribution (normalized to 100% FP). OP^J, the channel overpower for flux shape J, is the ratio of channel powers of flux shape J to the nominal, steady-state, time-averaged channel power distribution.

The detector readings may be described in terms of DR^J, the Detector Ratios (relative to this nominal, steady-state configuration) for a specific flux shape J. The tripping, or limiting, detector of the system has a Detector Ratio denoted by DR_{lim}^J.

The deterministic (no uncertainties) Required Trip Setpoint (DRTSP) is given by:

$$DRTSP^{J,k} = DR_{lim}{}^{J} \times MD^{J,k} \times CPPF^{k}$$ **Equation 3.2**

Where the CPPF is defined to be the largest channel ripple in the central, high power region of the core. This region varies from plant to plant and is generally referred to as the "CPPF Region":

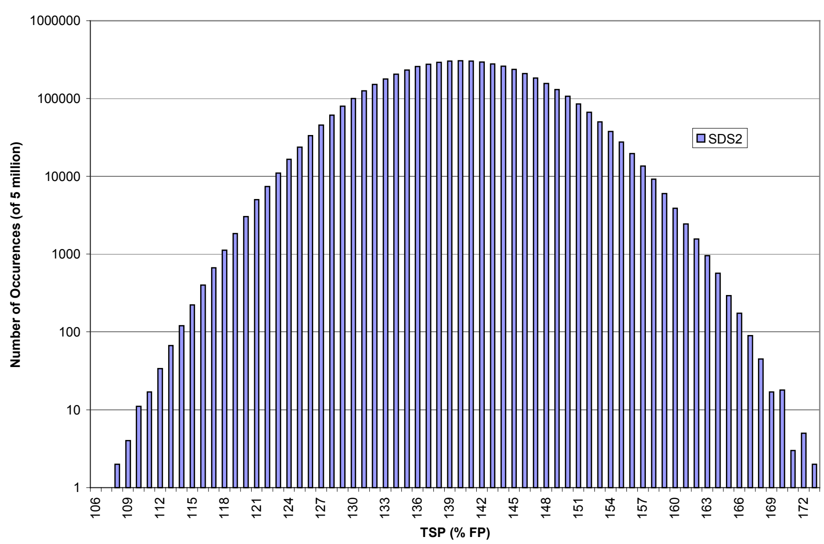
$$CPPF^{k} = \max\{Ripple_{i}^{k}\},\ i \in \text{CPPF Region}$$ **Equation 3.3**

3.2 Errored Trip Setpoint

In order to ensure a high probability of trip before dryout, the NOP system detector setpoints must be set lower by some safety margin to allow for parameter uncertainties. Each contributory term in Equations 3.1 and 3.2 has uncertainties associated with it. These may be divided into four broad categories: Detector-Random, Detector-Common, Channel-Random and Channel-Common. The "common" uncertainties affect all fuel channels or NOP detectors in a common fashion; if one is slightly increased then they all are. The "random" uncertainties affect all channels or NOP detectors independently and to a different extent. In addition, there is a finite probability of failure of one or more NOP detectors. Variations in fuelling may be added, via inclusion of sufficient station ripple data, to be representative of the fuelling schemes over a fuelling cycle.

SIMBRASS examines the convolution of all of the above effects by randomly sampling the frequency distributions of all of the uncertainties contributing to the DRTSP. A fuelling state is randomly selected and the corresponding ripples applied. SIMBRASS samples all of the uncertainty distributions many times, creating a statistical ensemble of RTSP values. Each of these RTSPs corresponds to the DRTSP of Equation 3.2, in which all of the contributing terms have specific values. These are sometimes referred to as "Errored" DRTSPs, or EDRTSPs. The individual frequency densities (*i.e.* the uncertainty distributions) determine the probability that each of these contributing values was selected. If the statistical ensemble is large enough, then a fair representation of the overall probability density function may be obtained. The Monte Carlo approach is well understood and well documented. Figure 3-1 is an example of this distribution:

Figure 3.2-1: SDS2 EDRTSP Frequency



3.3 The SIMBRASS 5.0 Algorithm

The algorithm of SIMBRASS 5.0 involves binning the EDRTSP samples, as in the histogram of Figure 3-1, and doing no further sorting, interpolation etc. The reasoning is that, for a given level of statistical accuracy, there is no purpose in stating the TSPs to a greater level of significance than is available. The user will be asked to supply the precision required (number of significant figures, given by the bin width). The user must also specify either the number of simulations to be performed or the statistical "accuracy". The accuracy is best expressed as the confidence that the "*true"* RTSP is at least as great as the reported RTSP for the indicated system reliability. Here "true" may be defined as "the result of an infinite number of simulations".

For **N** Monte Carlo EDRTSP samples, the RTSP is the $(1\text{-R})\times\mathbf{N}^{th}$ smallest EDRTSP in the above distribution, where R is the reliability (normally 0.98, the probability of trip before dryout for a 3/3 trip). In other words, in the example in Figure 3.1 where R = 0.98 and $\mathbf{N} = 5\times10^6$, the code would find the bin in which 10^5 counts were in lower bins. The lower end of the bin would conservatively be reported as the RTSP. Invoking the Central Limit Theorem, and using properties of the Binomial distribution, it is possible to obtain the statistical confidence of this TSP. The user should request no more precision than is required for the problem. The default bin value for the code is 0.1% FP. This avoids reporting non-significant digits, as was often done in earlier versions of the code. If a particular statistical accuracy is requested, the code continues to sample the distributions until "convergence" has been achieved.

4.0 Sample Results

4.1 Production Runs

The most common type of SIMBRASS run involves the calculation of the required TSPs for one or more perturbed flux distributions as part of a particular study. The primary results are tables of case numbers, descriptions and TSPs, one per SDS, sorted by increasing TSP. Each entry lists the number of simulation trials which were required to meet the user's reliability, precision and accuracy specifications. If combinations of failed or impaired detectors were specified, then this too is listed.

Since the user is often primarily interested in the most limiting shape (that with the lowest RTSP), additional information is included for this shape. Figure 4.1-1 has been imported from the Postscript report output file. It indicates the bin that the EDRTSP of interest falls in as well as the nearby bins. The corresponding reliabilities are given as well as the confidence values that the true RTSP greater than the given value (one-sided confidence). The two-side confidence interval indicating the probability that the true RTSP is in the indicated bin is also shown (as the midpoint of the bin plus or minus half the bin width). A similar figure appears in the output text file.

This is followed by a histogram of the EDRTSP distribution frequency as a function of TSP as shown in Figure 4.1-2 and the cumulative probability distribution as in Figure 4.1-3. The RTSP value is indicated by a vertical line labelled "Limit TSP". A plot of the statistical confidence, as a function of TSP, follows with the requested confidence level (accuracy) indicated by a vertical line (Figure 4.1-4).

Figure 4.1-1

Confidence and Reliability Summary

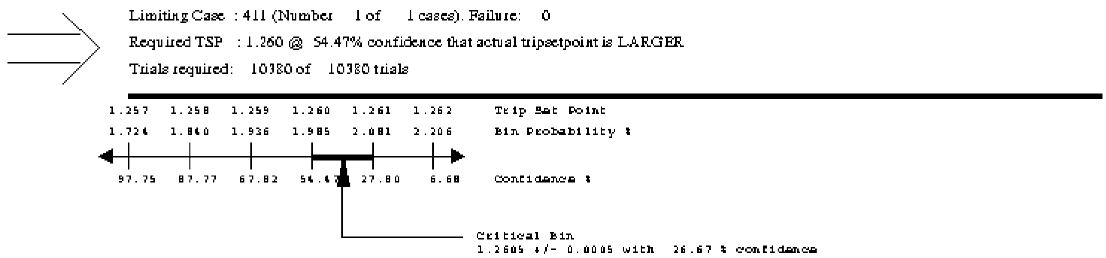


Figure 4.1-2

EDRTSP Frequency

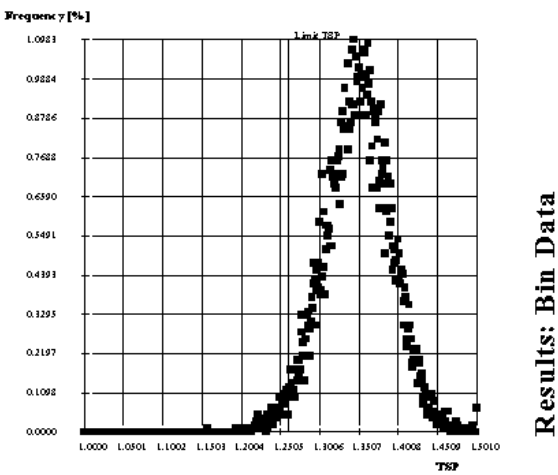


Figure 4.1-3

EDRTSP Cumulative Probability

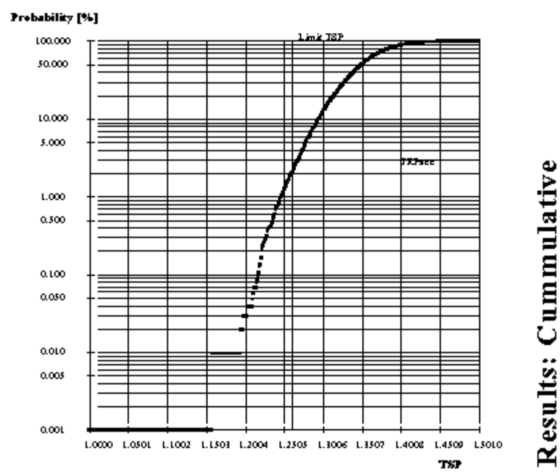
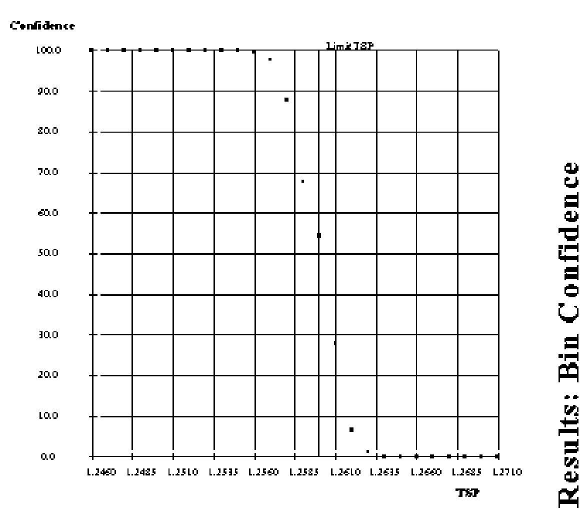


Figure 4.1-4

Confidence as a Function of TSP



4.2 Detector Failure Matrices

4.2.1 The Detector Failure Matrix

SIMBRASS 5.0 has many convenient features relating to the examination of failed or impaired detectors. One of the more useful abilities is to automatically generate concise tables showing the effects of multiple failures on an SDS. The user may specify that all combinations of up to three detectors should be failed in a logic channel or SDS. The code will examine each failure over a specified set of flux distributions, for instance the design set, and report the flux shape which is limiting for each failure combination. The user may specify that a decrement is quoted with respect to a specified target TSP value (the decrement is quoted as zero if the limiting TSP is still greater than the target TSP). The default for the target value is the lower of the limiting TSP for SDS1 and SDS2 with no detectors failed (which SIMBRASS will automatically calculate). Since the number of failure combinations may be large, the code also quotes the overall lowest TSP and the corresponding flux shape and failure combination. This table may be used at the station to apply a penalty when one, two or three specific detectors fail.

The user may also specify that the failures not be total; i.e. that the detectors merely read low. Another useful feature is the ability to cluster the detectors into groups and examine successive failures of these particular groups of detectors. This is most often applied to assemblies of detectors, and the assembly structure is part of the Reference Data Set.

Table 4.2-1: Sample DFM

Detector Table Information SDS 1 Reference TSP = 1.220

Fail	ID	Impaired Detectors		Min TSP	Penalty	Case
0	0	NONE		1.300	0.000	457
1	1	VA02-1D		1.290	0.000	457
2	2	VA02-6D		1.300	0.000	468
3	3	VA03-3D		1.300	0.000	451
•	•	•				
17	17	VA26-3D		1.300	0.000	451
18	18	VA27-4D		1.300	0.000	451
19	19	VA02-1D	VA02-6D	1.215	0.005	457
20	20	VA02-1D	VA03-3D	1.290	0.000	468
21	21	VA02-1D	VA03-5D	1.290	0.000	457
•	•	•				
169	169	VA25-3D	VA26-3D	1.205	0.015	451
170	170	VA25-3D	VA27-4D	1.300	0.000	451
171	171	VA26-3D	VA27-4D	1.300	0.000	451

Minimum TSP occurs 1 time(s) for TSP = 1.200

IN SDS 1

Limiting Case: 465 (Number 16 of 20 cases). Failure: 84
Required TSP: 1.200 @ 99.08% confidence that actual trip setpoint is LARGER
Trials required: 10380 of 10380 trials

Table 4.2-1 illustrates part of a Detector Failure Matrix (DFM) for a system of 20 flux shapes (in this case numbers 450 to 469 in a particular set) for combinations of 0, 1 and 2 detectors completely failed in channel D.

The Failure Combinations are also given in a separate table. This run specified a precision of 0.5% FP. The limiting TSP of 120.0 % FP was found to be greater than or equal to the true RTSP with a statistical confidence of 99% (after 10,380 passes).

4.2.2 Pruning

In order to reduce the number of calculations, the user can specify that very non-limiting flux shapes be eliminated prior to achieving the normal level of accuracy. This is referred to as “pruning” the unimportant shapes. The user specifies the level of confidence that no limiting shapes will be removed prematurely. Additionally, a minimum number of un-pruned shapes may be specified, as may the minimum TSP (in percent FP) that a shape must be above the limiting TSP before that shape is eliminated.

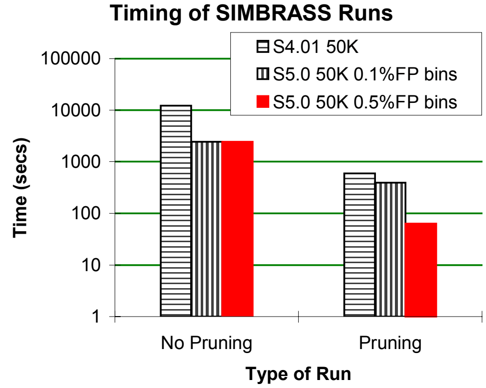
In the example of Table 4.2-2, the user has selected the pruning interval to be every 1000 passes. Note that it is possible to re-instate a previously pruned shape if the random sampling indicates that this is required. This is referred to as being “un-pruned. In the example, shape number 99 is pruned and un-pruned several times.

Table 4.2-2: Sample Pruning Results (95% Pruning Confidence)

```
Starting TSP calculation Loop ...                        SDS1   SDS2
 Case 85   was PRUNED at trial    1000 Limiting TSPs =  1.411, 1.119
 Case 86   was PRUNED at trial    1000 Limiting TSPs =  1.411, 1.119
 Case 96   was PRUNED at trial    1000 Limiting TSPs =  1.411, 1.119
 Case 88   was PRUNED at trial    2000 Limiting TSPs =  1.407, 1.121
 Case 94   was PRUNED at trial    2000 Limiting TSPs =  1.407, 1.121
 Case 98   was PRUNED at trial    2000 Limiting TSPs =  1.407, 1.121
 Case 100  was PRUNED at trial    2000 Limiting TSPs =  1.407, 1.121
 Case 104  was PRUNED at trial    2000 Limiting TSPs =  1.407, 1.121
 Case 95   was PRUNED at trial    3000 Limiting TSPs =  1.409, 1.121
 Case 100  was UN-PRUNED at trial    3000 Limiting TSPs =  1.407, 1.121
 Case 101  was PRUNED at trial    3000 Limiting TSPs =  1.409, 1.121
 •  •  •
 Completed trial      11000
 Case 99   was PRUNED at trial   12000 Limiting TSPs =  1.408, 1.121
 Completed trial      13000
 Completed trial      14000
 Completed trial      15000
 Completed trial      16000
 Case 99   was UN-PRUNED at trial   17000 Limiting TSPs =  1.408, 1.120
 Completed trial      18000
 Completed trial      19000
 Case 99   was PRUNED at trial   20000 Limiting TSPs =  1.409, 1.120
 Completed trial      21000
        •  •  •
 Completed trial      35000
 Case 99   was UN-PRUNED at trial   36000 Limiting TSPs =  1.409, 1.121
 Completed trial      37000
 Completed trial      38000
 Completed trial      39000
 Completed trial      40000
 Case 99   was PRUNED at trial   41000 Limiting TSPs =  1.409, 1.121
 Completed trial      42000
 Case 99   was UN-PRUNED at trial   43000 Limiting TSPs =  1.409, 1.121
 Completed trial      44000
 Completed trial      45000
 Completed trial      46000
 Completed trial      47000
 Case 99   was PRUNED at trial   48000 Limiting TSPs =  1.410, 1.121
 Completed trial      49000
Main loop completed after    50000 Trials
```

Figure 4.2-1 compares the run time of a fifty thousand pass run for SIMBRASS 4, SIMBRASS 5 with a requested precision of 0.5% FP and SIMBRASS 5 with a requested precision of 0.1% FP.

Figure 4.2-1
Timing of SIMBRASS Runs



4.3 Impairment Limit Analysis

Impairment Limit Analysis was originally performed using the computer programs CALIBER and IMPAIR, and was incorporated as part of SIMBRASS as of version 3.0. In version 5.0 this technique was replaced by a more direct, intuitively appealing Monte Carlo approach.

When an NOP detector has been discovered to have failed, or is reading low (unsafe direction), then prompt action will be taken to ensure that the NOP system as a whole remains unimpaired. Consider the discovery that detectors have been reading low over a period of time. Was the system impaired during this period? The answer to this question is important from the perspective of overall system reliability, which may be determined statistically from such data. If the same detector continually drifts low then the appropriate analysis would involve the failure of that particular detector. If this appears to randomly happen to all detectors with equal probability, then another approach may be called for. Such an approach is discussed here.

Since reliability must be simultaneously demonstrated for all flux distributions in the test set, it is posited that requiring full normal reliability for each combination of detectors reading low at all times violates the statistical flavour of the approach. Instead, ensure that the required statistical reliability be maintained if each detector which may *potentially* read low, weighted by the probability of that detector reading low, is accounted for. In the simplest case, where every detector is taken to have identical characteristics, the analysis would be equally weighted for each detector reading low from the entire ensemble of detectors (SDS or logic channel). In this simplest case (the only one that we will consider), if multiple detectors read low then each will read low by the same degree.

In adopting the above approach, the precise identity of the detector reading low becomes unimportant, even though this will be known in most realistic scenarios. The problem may be stated as follows:

Determine to what degree a random detector (or detectors) may drift low before the NOP system becomes impaired (unable to prevent dryout prior to NOP trip to the desired level of reliability).

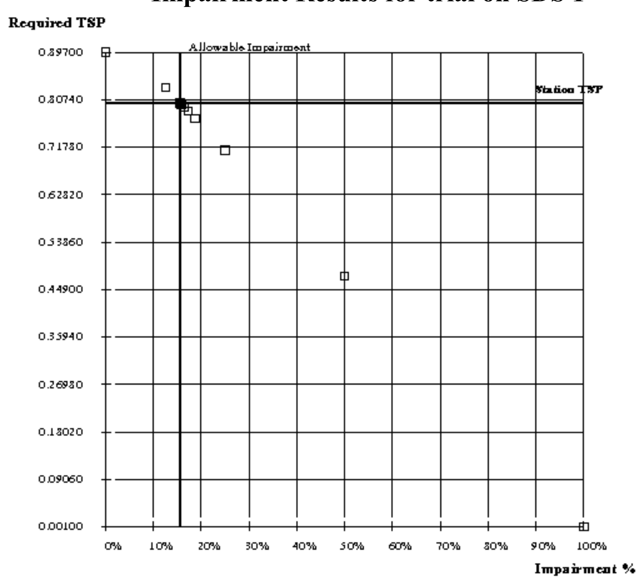
Since the affected detector identities are presumed to be unknown, an analysis is performed in which all combinations of n detectors (n = 1, 2 or 3) are "randomly" considered and the statistics accumulated in aggregate. This is done separately for each flux shape. From this, the uniform detector decrement (factor by which the detectors read low) which results in RTSP becoming equal to a reference TSP, with a given reliability and confidence, is determined. The reference TSP is usually the implemented station TSP before any penalties imposed from unrelated sources are considered.

Note that there are three possible situations:

1 The <u>system</u> may be "impaired" even when the detectors do not drift low (no detector impairment). The NOP detector system does not supply adequate coverage to attain the requested TSP.
2 The <u>system</u> may never be impaired – even when each combination of detectors fails completely (detectors 100% impaired). This is the situation for the majority of flux shapes.
3 The <u>system</u> becomes impaired for some finite degree of detector impairment.

The user may request that SIMBRASS determines the maximum impairment level (decrement) which leaves the system unimpaired to a specified degree of accuracy. This is done for each flux shape. The smallest such decrement gives the maximum permissible detector impairment limit over all shapes. SIMBRASS 5.0 uses a Newton's Method search for the impairment level, although the user may specify that a binary search be used instead. The user may also request that SIMBRASS produces a table of RTSP values as a function of decrement value. Figure 4.3-1 shows that graphical output from a Newton's Method search where the final impairment limit is 15.8%. This example examined all combinations of two detectors in SDS1. If each pair of detectors has an equal probability of reading low, then each detector may read low by 15.8% before the RTSP becomes equal to the implemented TSP (the target).

Figure 4.3-1
Impairment Results for trial on SDS 1



This run is for an artificial system whose unimpaired RTSP is 89.7% FP. SIMBRASS has been requested to find the detector impairment level (any two SDS1 detectors at a time) resulting in a RTSP of 80% FP. The squares indicated the various estimates, homing in on the final impairment level of 15.8%.

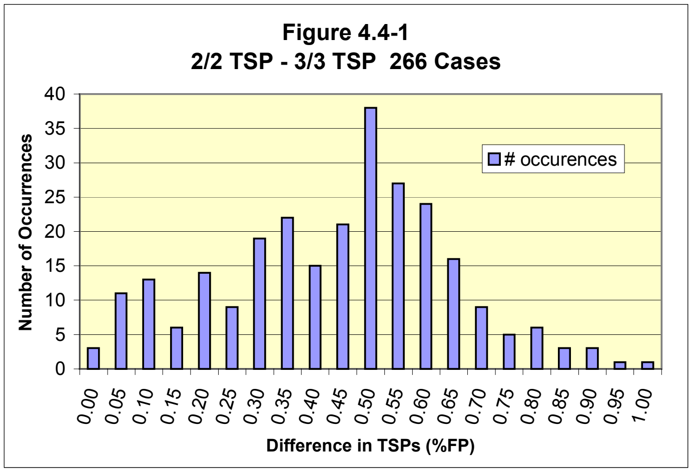
4.4 2/2 vs. 3/3 Trip Logic

The user may specify whether 2/3, 2/2 or 3/3 trip logic will be used in the simulation. The trip logic of the NOP systems is 2/3. Both 2/2 and 3/3 logic assume that one logic channel has failed.

<u>3/3 Trip Logic:</u> For each pass through the Monte Carlo, the tripping detector reading, in each of the three NOP logic channels, is determined after all uncertainties have been sampled and incorporated. The best channel, *i.e.* the one that trips first of the three, is then failed. The result is that the detector reading associated with the worst of the three channels is used to determine the EDRTSP for that pass.

<u>2/2 Trip Logic:</u> For each pass through the Monte Carlo the tripping detector reading is determined as above but with the same channel failed each time. The *overall* best channel, over *all* passes, is assumed to fail. The only certain method of determining which channel is best overall is to run three simulations, with each of the channels failed in turn. The result with the worst RTSP, for a given flux shape, is taken the to be the 2/2 RTSP.

Note that 3/3 trip logic is more conservative than 2/2 logic. With 3/3 logic the worst Detector Ratio (DR) of the three channels is always used whereas, on occasion, a less limiting DR is used when 2/2 logic is employed. Only when the most limiting channel is the same for every pass of the Monte Carlo will the two results be equal. A comparison of 2/2 and 3/3 setpoints over 266 flux shapes appears in Figure 4.4-1. In every case the 2/2 RTSP was equal to or greater than the 3/3 RTSP, confirming that 3/3 analysis is more conservative. In only three cases were the 2/2 and 3/3 RTSPs in the same TSP bin (at a precision of 0.05% FP). The average difference over all shapes was 0.5% FP.



4.5 Multiple Trip Setpoints

Ontario Power Generation and Bruce Power reactors currently employ common trip setpoints for every NOP detector during normal operation. There are two basic situations involving non-uniform TSP which may be easily examined in SIMBRASS 5.0:

1. The NOP detector TSPs are fixed with respect to each other in given ratios.
2. A subset of the NOP detectors are assigned specified TSP values.

In the former case, the task is to find the RTSPs while maintaining the TSPs in a certain ratio. This facility was available in prior versions of the code. In the latter case, the objective is to find the RTSPs of the subset of detectors whose TSPs have not been pre-specified. This new facility is the subject of discussion in this section. SIMBRASS is required to determine the equal setpoints for the remaining detectors, such that dryout is precluded prior to trip with the specified reliability and accuracy (statistical confidence).

Code Validation tests involved a system which was simple enough to analytically determine how the required trip setpoints (RTSPs) of the "unrestricted" NOP detectors will vary with the prescribed TSPs of the selected detectors. Note that these prescribed TSPs need not be uniform.

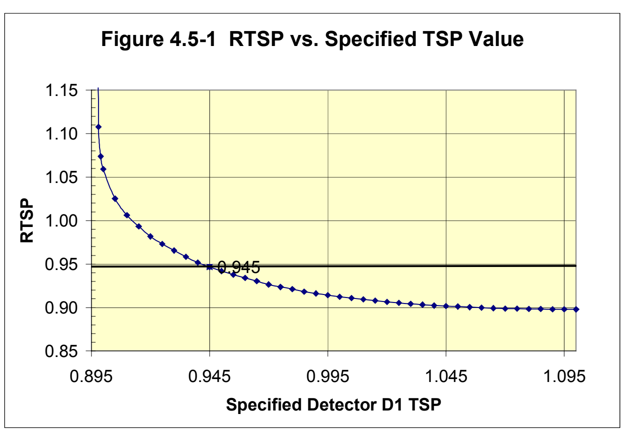


Figure 4.5-1 demonstrates how the RTSP of the remaining detectors varies with the pre-specified TSP of a detector for a simplified NOP system whose RTSP with no pre-specified detector is 0.945.

In general, let T^n_α, be the TSP for NOP detector α, during Monte Carlo pass *n*, which trips this detector precisely as dryout occurs. If detector α has a specified TSP of T_α^*, then it will trip prior to dryout if $T^n_\alpha \geq T_\alpha^*$ and will trip after dryout if $T^n_\alpha < T_\alpha^*$. As far as determining the RTSP for the non-specified detectors,

$T_\alpha^* \leq T^n_\alpha$ the NOP channel containing detector α has tripped

$T_\alpha^* > T^n_\alpha$ the NOP detector α has effectively failed

Consider another special system of four detectors with no detector errors, but only channel errors. Here the TSP is specified for the detector D2 in a system whose Detector Ratios are given by:

D: 1.26 1.51 E: 1.38 F: 1.38

With no specification, the RTSP is 1.1 (110% FP). The detector D2 has greatest detector signal of the entire SDS. D1, the other detector in channel D has the smallest detector reading of the SDS. A 3/3 trip is assumed with a required system reliability of 98%.

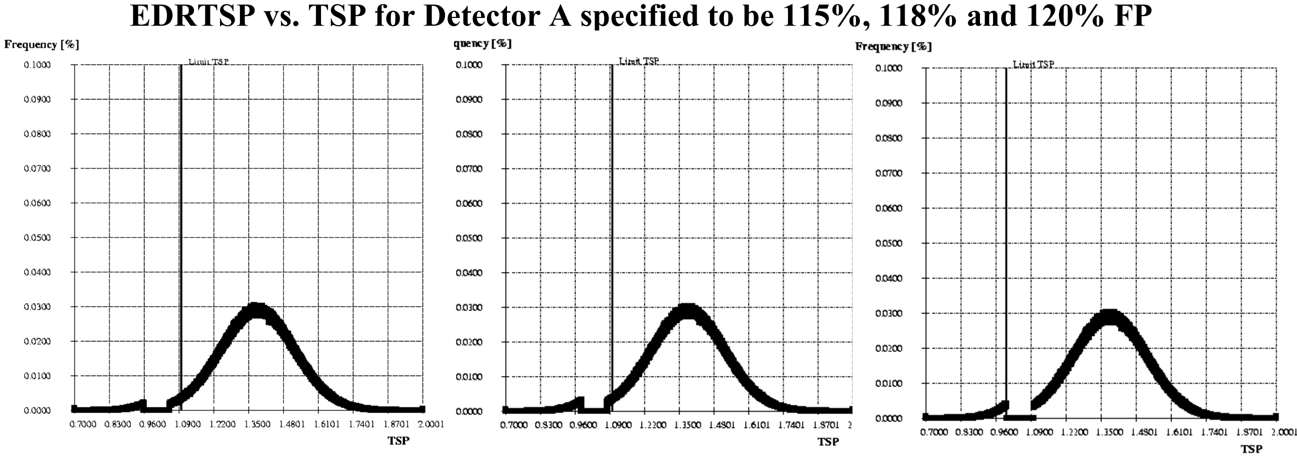
For this system, consider the effect of forcing detector D2 to trip at a specified TSP value, T^*_{D2}. If T^*_{D2} is small then, D2 will always trip and the uniform RTSP for the remaining detectors will be unchanged at 1.1. As T^*_{D2} is increased, however, some small fraction of the passes will have a particularly small Margin to Dryout, in accordance with the uncertainty distribution, and D2 will trip after dryout. For the small proportion of passes where this occurs, the detector system will appear to be

D: 1.26 0.0 E: 1.38 F: 1.38

and the DR_{lim} will decrease from 1.38, to 1.26, *i.e.* by 10%. The corresponding SIMBRASS 5 EDRTSP entry will jump to a TSP bin that is 10% FP lower. This may be visualised as a 10% reduction in all of the EDRTSP values in the lower tail of the EDRTSP distribution up to and including the value which makes $T^*_{D2} = T^n_{D2}$ true. A plot of EDRTSP frequency vs. TSP will show a 10% FP gap in the distribution. This gap migrates to higher TSPs as T^*_{D2} increases.

Figure 4.5-2 displays EDRTSP histograms from a SIMBRASS output (analogous to Figure 4.1-2) for such a system for T^*_{D2} values of 115%, 118% and 120% FP. The greater the specified TSP of detector D2, the more of the tail of the original distribution will "jump the gap" downwards. At a specified TSP of 120% FP, fully the lowest 2% of the EDRTSP distribution has "jumped the gap". This point determines the RTSP for a reliability of 98%. Consequently, the common RTSP of the remaining detectors in the system is 110% FP if the specified TSP of D2 (T^*_{D2}) is less than 120% FP, and discontinuously changes to 100% FP when the specified TSP of D2 is greater than or equal to 120% FP. The SIMBRASS outputs match the analytic results exactly.

Figure 4.5-2
EDRTSP vs. TSP for Detector A specified to be 115%, 118% and 120% FP



5.0 Summary

SIMBRASS is a Monte Carlo code designed to analyse NOP Trip Setpoints. A new version has been created, extensively tested and validated, with improved algorithms and features.

References

1 Blake, L., SIMBRASS User's Manual Version 5, File: N - 06631.07 SIMBRASS Users Manual T-10, August 20, 2002.

2 Levine, M., "SIMBRASS 5.0 Software Theory Manual", Document Number: V&VP-ST-MAN-SIM-01, File: N-ST-MAN-SIM-06631.07-10001 P, November 15, 2001.