

# ***What Have We Done Lately?***

## **The Current Status of the SAPHIRE Risk Analysis Software**

Authors :

S. Ted Wood, James K. Knudsen, and Kellie J. Kvarfordt

[www.inl.gov](http://www.inl.gov)



## ***SAPHIRE – What is it?***

### **SAPHIRE - Systems Analysis Programs for Hands-on Integrated Reliability Evaluations**

SAPHIRE is an integrated PRA software tool that gives a user the ability to create and analyze fault trees and event trees using a personal computer using Windows operating system developed by Idaho National Laboratory (INL) for US Nuclear Regulatory Commission (NRC).

INL has been a principal developer of Probabilistic Risk Analysis (PRA) tools for over 45 years, supporting risk activities at government agencies that include the U.S. Nuclear Regulatory Commission (NRC), National Aeronautics and Space Administration (NASA), and Department of Energy (DOE).

## ***SAPHIRE - History***

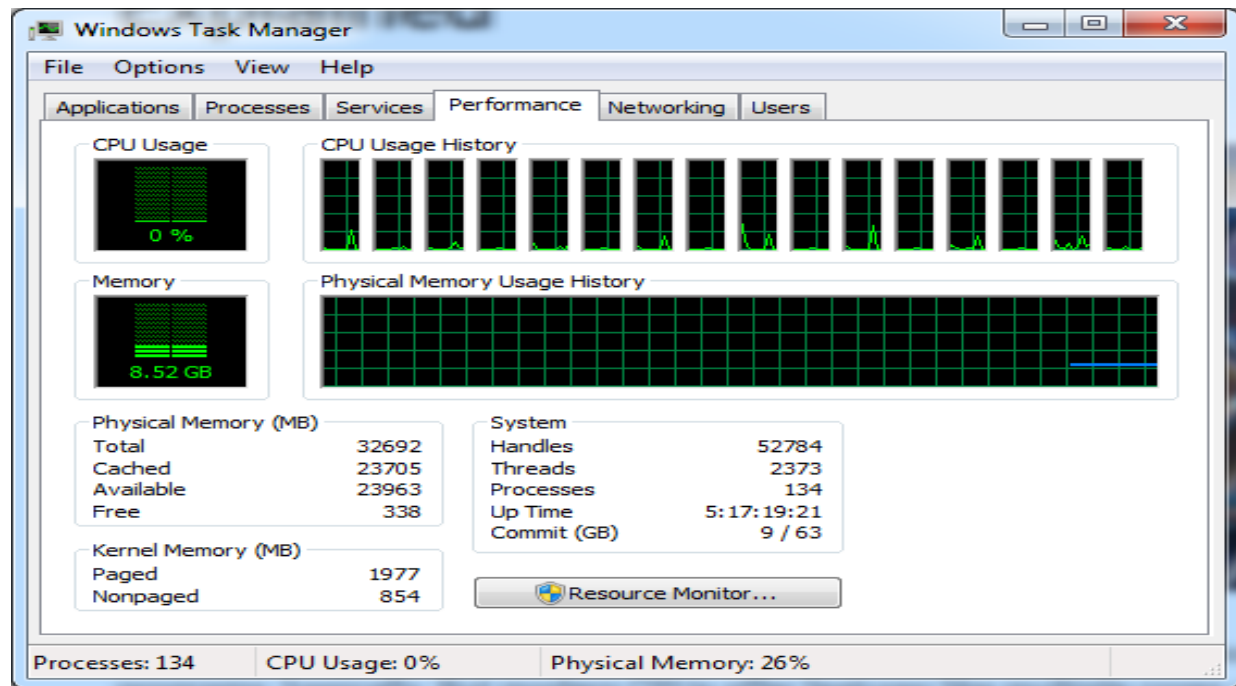
- 1987 – Integrated Reliability and Risk Analysis System (IRRAS) 1.0
- 1989 – IRRAS 2.0
- 1990 – IRRAS 4.0
- 1992 – IRRAS 5.0 (32-Bit) resulted in an order of magnitude decrease in analysis time.
- 1997 – SAPHIRE for Windows version 6.0.
- 1999 – SAPHIRE for Windows version 7.0
- 2010 – SAPHIRE for Windows version 8.0
- 2018 – SAPHIRE for Windows version 8.1.8 (Current Release)

## ***SAPHIRE – Fundamental Capabilities***

- Cut set generation and quantification
- PC-based fault tree and event tree graphical editors
- Importance measures and uncertainty modules
- Relational database with cross-referencing features
- External events analysis (e.g., seismic)
- Rule-based recovery and end-state analysis
- Common Cause Failure (CCF) basic event capabilities

## SAPHIRE – Make it faster!!

How to use more of our desktop power?

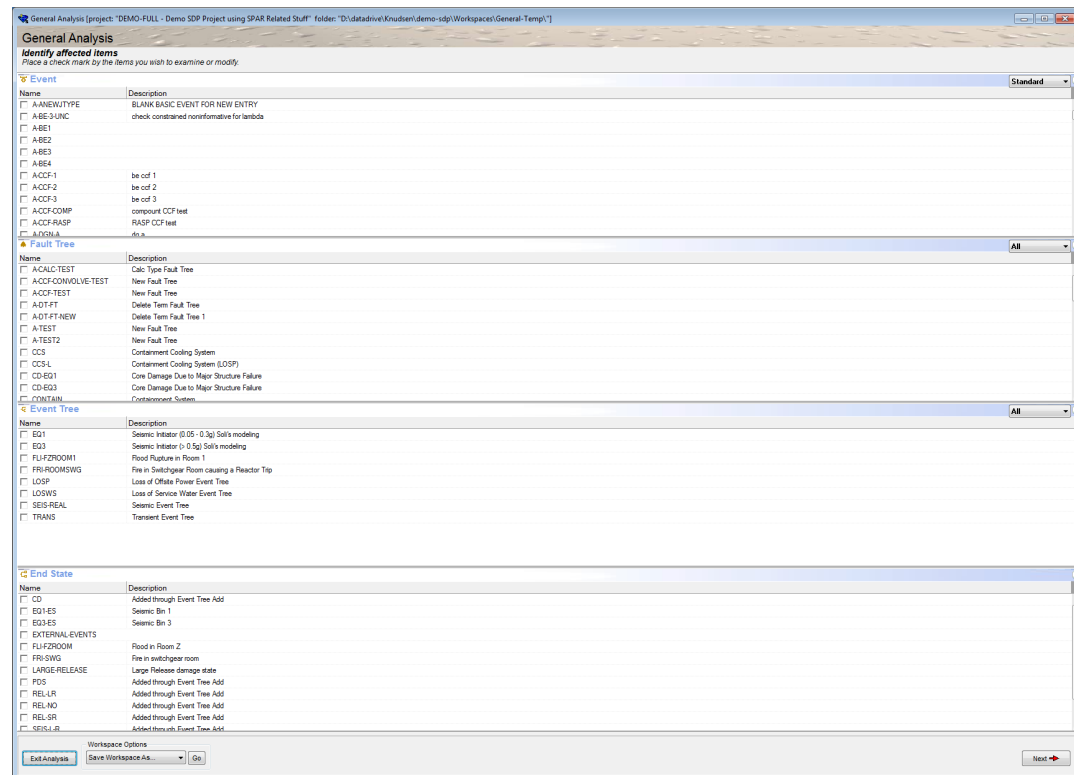


## ***SAPHIRE – Workspace Concept***

- Workspace
  - A snapshot or copy of the original model
    - Can be modified and analyzed to determine the impact of possible changes
    - Doesn't change original model
    - Can be saved and examined in more detail

# SAPHIRE - Workspace Examples

- General Analysis
- Events and Conditions Analysis (ECA)
- Significance Determination Process (SDP)



## ***SAPHIRE – Sandbox Concept***

- **Sandbox almost = Workspace**
- Differences –
  - Not saved for future analysis
  - Specific answers from sandbox are used to get values for reports in the parent project
  - Each sandbox has its own SAPHIRE executable driven by a SAPHIRE instruction set or macro

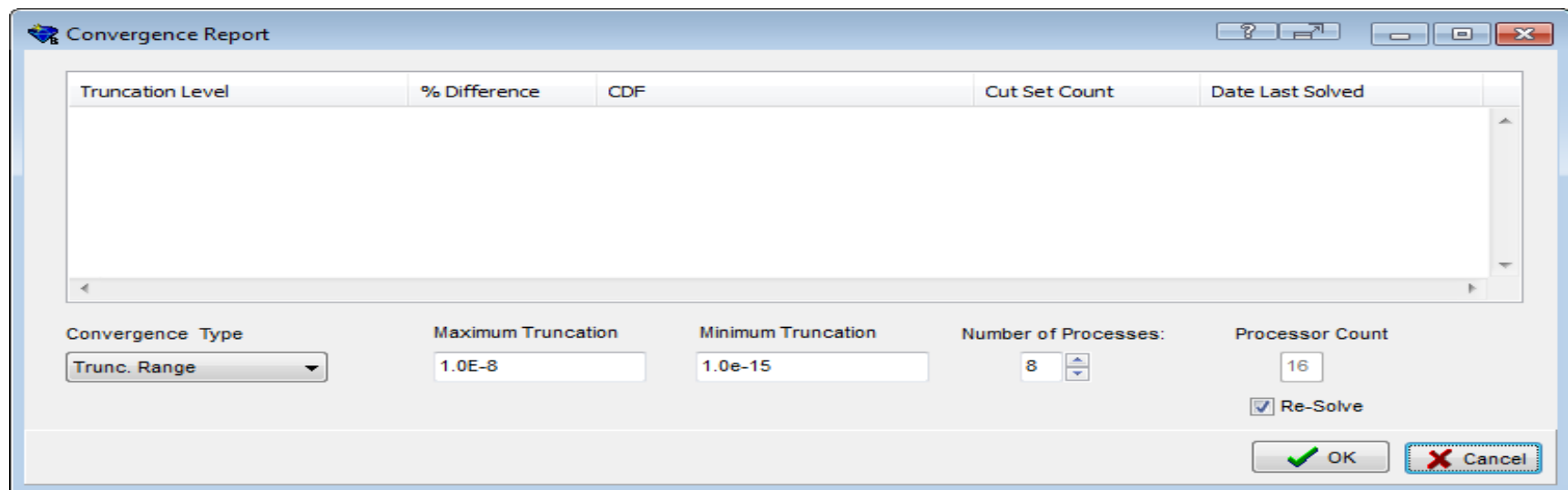


## ***SAPHIRE – Sandbox Examples***

- **Two examples of Sandboxes**
  - **Convergence Report** – Calculate and display the Core Damage Frequency (CDF) at various truncation levels.
  - **Plant Information e-Book (PRIB) Report** – Calculate and display System and Component Level Importance.

## SAPHIRE – Convergence Report

- Convergence Form

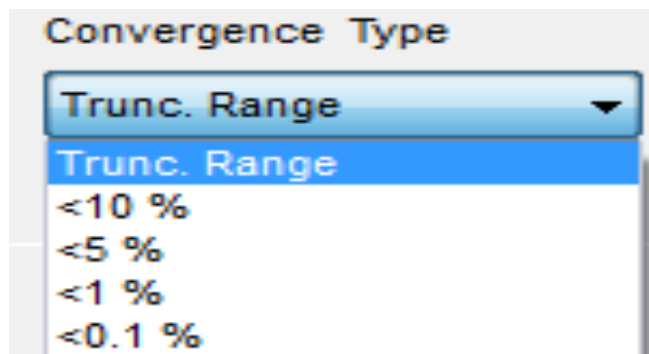


The screenshot shows a software dialog box titled "Convergence Report". It features a table with five columns: "Truncation Level", "% Difference", "CDF", "Cut Set Count", and "Date Last Solved". The table is currently empty. Below the table, there are several configuration options:

- Convergence Type:** A dropdown menu set to "Trunc. Range".
- Maximum Truncation:** A text input field containing "1.0E-8".
- Minimum Truncation:** A text input field containing "1.0e-15".
- Number of Processes:** A spin box set to "8".
- Processor Count:** A text input field containing "16".
- Re-Solve:** A checked checkbox.

At the bottom right, there are "OK" and "Cancel" buttons.

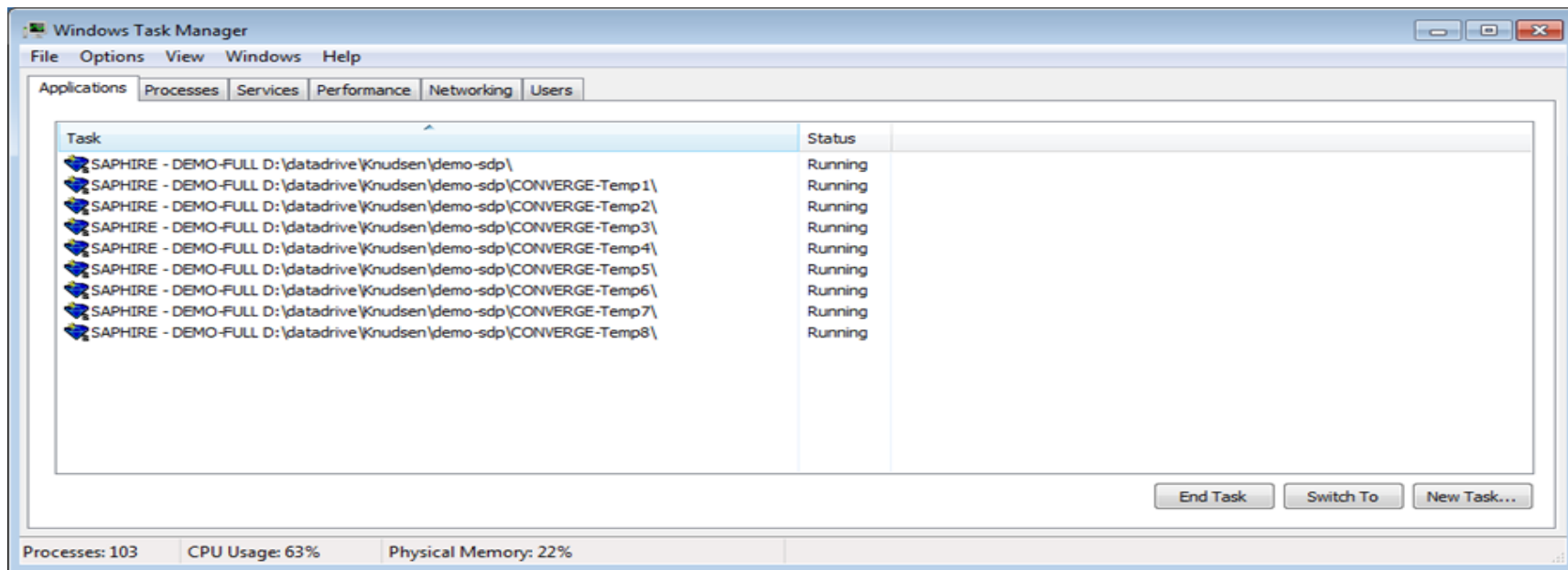
## SAPHIRE – Convergence Options



- The default option is “Trunc. Range”, or truncation range, which allows the user to select the maximum and minimum truncation values.
- Other options – Stop the convergence when levels of % Difference floors are achieved
  - <10 %
  - < 5%
  - < 1%
  - < 0.1%
- % Difference =  $(CDF_n / CDF_{n-1}) * 100.0$ 
  - where
    - $CDF_n$  is the overall CDF for the current truncation level and
    - $CDF_{n-1}$  is the overall CDF for the previous truncation level.

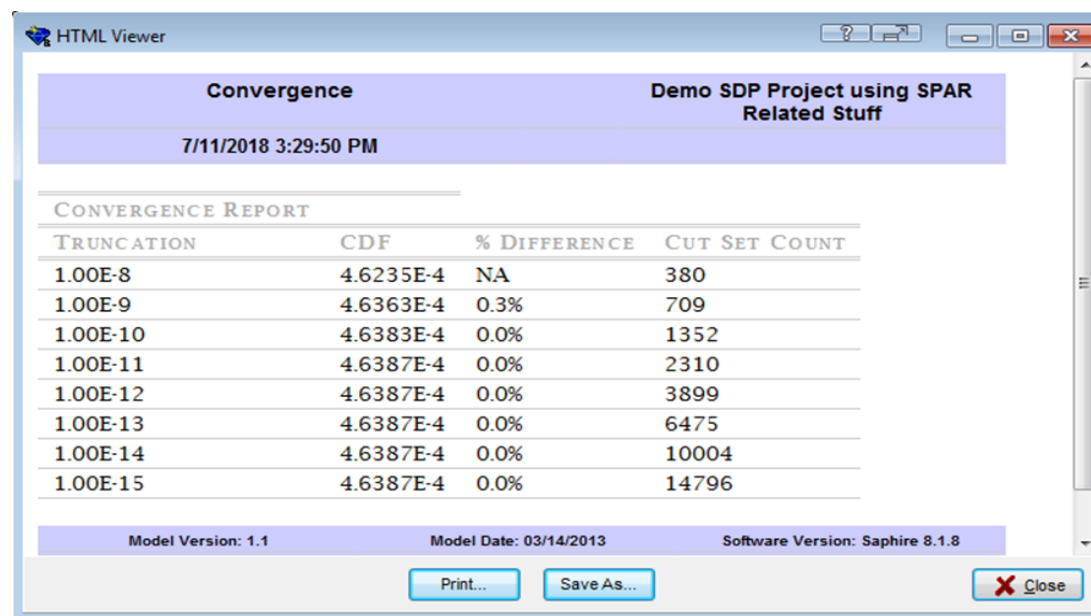
## SAPHIRE – Convergence Process

- Each SAPHIRE sandbox sub-instances is started with an assigned project sub-directory
- Each SAPHIRE sandbox sub-instance is running a macro (SAPHIRE defined command language)



## SAPHIRE – Convergence Report

- Convergence Report for maximum of 1.0E-8 to minimum of 1.0E-15 truncation



The screenshot shows an HTML Viewer window titled "HTML Viewer" with a standard Windows-style title bar. The main content area displays a convergence report for a "Demo SDP Project using SPAR Related Stuff". The report includes a table with columns for Truncation, CDF, % Difference, and Cut Set Count. The data shows that as the truncation level decreases from 1.0E-8 to 1.0E-15, the number of cut sets increases significantly, and the percentage difference reaches 0.0% for all truncation levels from 1.0E-10 onwards. The CDF value remains constant at 4.6387E-4 for all truncation levels from 1.0E-10 to 1.0E-15. At the bottom of the window, there are buttons for "Print...", "Save As...", and "Close", along with model and software version information.

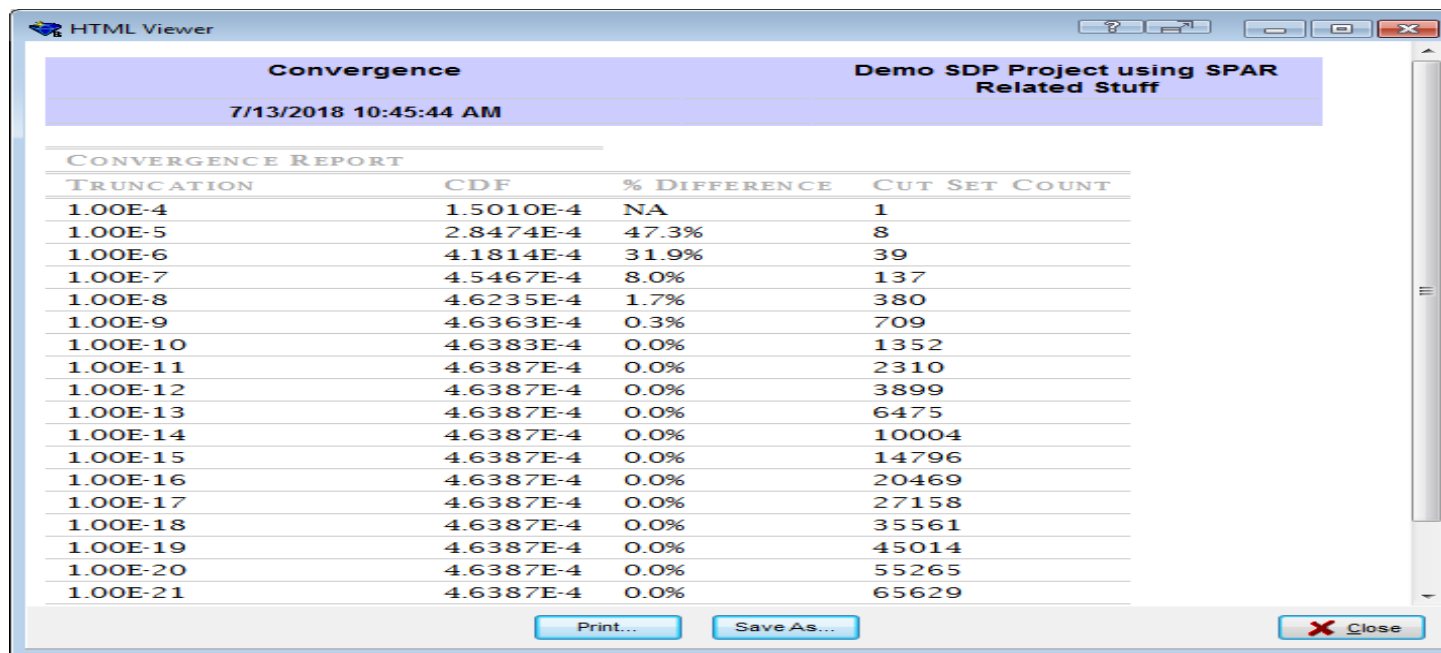
Convergence		Demo SDP Project using SPAR Related Stuff	
7/11/2018 3:29:50 PM			
CONVERGENCE REPORT			
TRUNCATION	CDF	% DIFFERENCE	CUT SET COUNT
1.00E-8	4.6235E-4	NA	380
1.00E-9	4.6363E-4	0.3%	709
1.00E-10	4.6383E-4	0.0%	1352
1.00E-11	4.6387E-4	0.0%	2310
1.00E-12	4.6387E-4	0.0%	3899
1.00E-13	4.6387E-4	0.0%	6475
1.00E-14	4.6387E-4	0.0%	10004
1.00E-15	4.6387E-4	0.0%	14796

Model Version: 1.1      Model Date: 03/14/2013      Software Version: Saphire 8.1.8

Print...      Save As...      Close

## SAPHIRE – Another Convergence Report

- Convergence Report for maximum of 1.0E-4 to minimum of 1.0E-21 truncation



Convergence		Demo SDP Project using SPAR Related Stuff	
7/13/2018 10:45:44 AM			
CONVERGENCE REPORT			
TRUNCATION	CDF	% DIFFERENCE	CUT SET COUNT
1.00E-4	1.5010E-4	NA	1
1.00E-5	2.8474E-4	47.3%	8
1.00E-6	4.1814E-4	31.9%	39
1.00E-7	4.5467E-4	8.0%	137
1.00E-8	4.6235E-4	1.7%	380
1.00E-9	4.6363E-4	0.3%	709
1.00E-10	4.6383E-4	0.0%	1352
1.00E-11	4.6387E-4	0.0%	2310
1.00E-12	4.6387E-4	0.0%	3899
1.00E-13	4.6387E-4	0.0%	6475
1.00E-14	4.6387E-4	0.0%	10004
1.00E-15	4.6387E-4	0.0%	14796
1.00E-16	4.6387E-4	0.0%	20469
1.00E-17	4.6387E-4	0.0%	27158
1.00E-18	4.6387E-4	0.0%	35561
1.00E-19	4.6387E-4	0.0%	45014
1.00E-20	4.6387E-4	0.0%	55265
1.00E-21	4.6387E-4	0.0%	65629

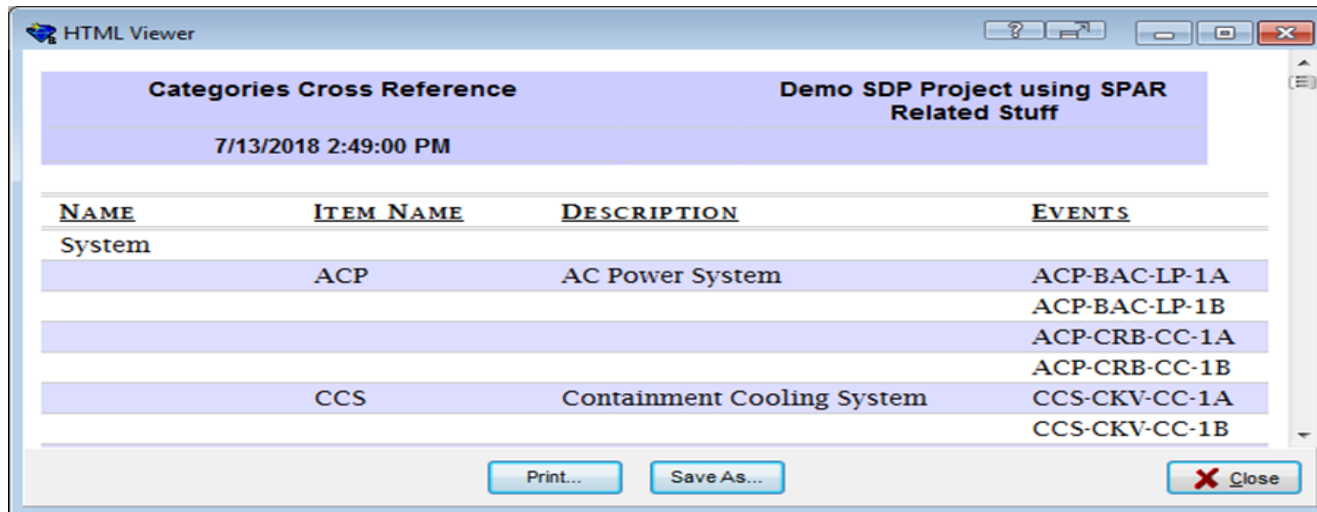
## SAPHIRE – Convergence Report Timing Results

Sandbox Count	Setup Time (mm:ss)	Total Time (mm:ss)
<b>1</b>	<b>0:03</b>	<b>4:01</b>
<b>2</b>	<b>0:05</b>	<b>1:25</b>
<b>3</b>	<b>0:08</b>	<b>1:09</b>
<b>4</b>	<b>0:10</b>	<b>1:30</b>
<b>5</b>	<b>0:12</b>	<b>0:50</b>
<b>6</b>	<b>0:15</b>	<b>1:03</b>
<b>7</b>	<b>0:17</b>	<b>0:51</b>
<b>8</b>	<b>0:20</b>	<b>0:54</b>
<b>12</b>	<b>0:30</b>	<b>1:05</b>
<b>16</b>	<b>0:39</b>	<b>1:20</b>

- Convergence Report - Hand timed calculation times for various numbers of sandboxes

## SAPHIRE – PRIB Example

- **Plant Information e-Book (PRIB) Report**
  - Performed on Standardized Plant Analysis Risk (SPAR) models
  - Works like Convergence Report with multiple sandboxes of SAPHIRE
  - Calculates system and component type importance measures



<u>NAME</u>	<u>ITEM NAME</u>	<u>DESCRIPTION</u>	<u>EVENTS</u>
System	ACP	AC Power System	ACP-BAC-LP-1A ACP-BAC-LP-1B ACP-CRB-CC-1A ACP-CRB-CC-1B
	CCS	Containment Cooling System	CCS-CKV-CC-1A CCS-CKV-CC-1B



# SAPHIRE – PRIB Report Setup Form

Systems With Reportable Components

**Checking box will force a recalculation of system and components.**

Description	ID	Date Last Solved	F(X)	Increase F(1)	F(0)
<input checked="" type="checkbox"/> Systems and Components					
<input checked="" type="checkbox"/> Systems (Only)					
<input checked="" type="checkbox"/> AC Power System	ACP	7/11/2018 4:21:50 PM		3.7411E-01	
<input checked="" type="checkbox"/> Containment Cooling System	CCS	7/11/2018 4:21:52 PM		2.0774E-04	
<input checked="" type="checkbox"/> Emergency Cooling System	ECS	7/11/2018 4:21:53 PM		8.3035E-01	
<input checked="" type="checkbox"/> Electrical Power System	EPS	7/11/2018 4:21:54 PM		5.7879E-02	
<input checked="" type="checkbox"/> Offsite Emergency Power	OEP	7/11/2018 4:21:55 PM		4.2151E-04	
<input checked="" type="checkbox"/> Safety Injection System	SIS	7/11/2018 4:21:56 PM		8.3013E-01	
<input checked="" type="checkbox"/> Service Water System	SWS	7/11/2018 4:21:57 PM		8.3898E-01	
<input checked="" type="checkbox"/> Components by System					
<input checked="" type="checkbox"/> AC Power System	ACP				
<input checked="" type="checkbox"/> Division 1A ac power	ACP-BAC-1A	7/11/2018 4:22:08 PM	2.5562E-04	9.5690E-03	4.6354E-04

This report performs multiple calculations to create importance measures for every component of a system. Depending on the model and the number of components, this report could take some time to complete. Press OK to continue with report generation, or Cancel to abort reporting.

Nominal CDF:

PRIB Solve Truncation:

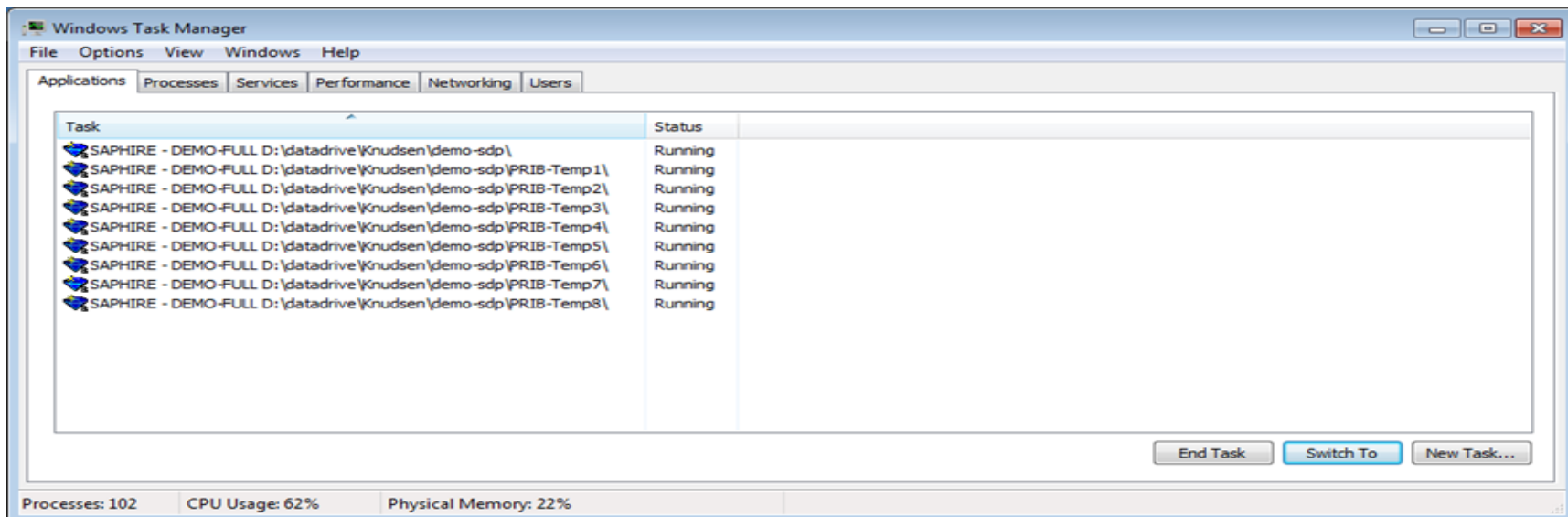
Refresh Documents

Split Calculations over multiple processes

Number of Processes:

## SAPHIRE – PRIB Process

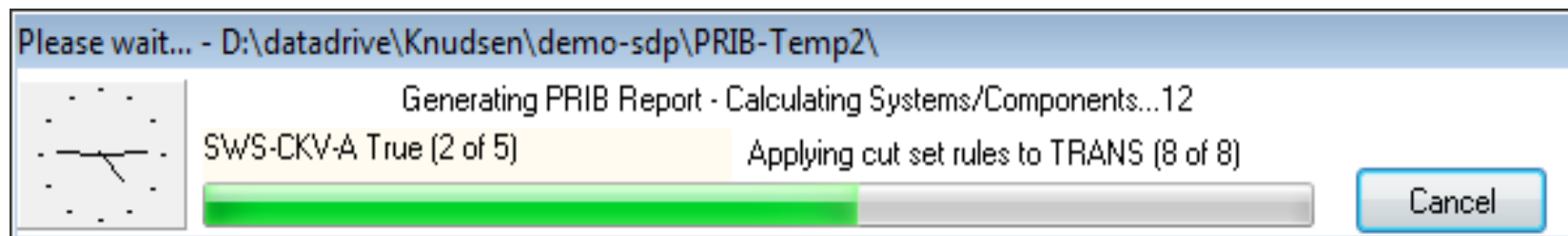
- Each SAPHIRE sandbox sub-instances is started with an assigned project sub-directory
- Each SAPHIRE sandbox sub-instance is running a macro (SAPHIRE defined command language)



## SAPHIRE – PRIB Process (Continued)

### Each instance of SAPHIRE displays a status dialog.

- The caption displays the sandbox directory.
- Text just beneath the caption indicates the overall solve process and how many times this sandbox has been used.
- Text to the right of the clock shows the system/component type pair being processed along with the counter of which component it is of the total components for the system.
- Text to the right of the system/component pair name shows the state of the solve process.



# SAPHIRE – PRIB Report Results

Systems With Reportable Components

**Checking box will force a recalculation of system and components.**

Description	ID	Date Last Solved	F(X)	Increase F(1)	F(0)
<input checked="" type="checkbox"/> Systems and Components <ul style="list-style-type: none"> <li><input checked="" type="checkbox"/> Systems (Only)               <ul style="list-style-type: none"> <li><input checked="" type="checkbox"/> AC Power System</li> <li><input checked="" type="checkbox"/> Containment Cooling System</li> <li><input checked="" type="checkbox"/> Emergency Cooling System</li> <li><input checked="" type="checkbox"/> Electrical Power System</li> <li><input checked="" type="checkbox"/> Offsite Emergency Power</li> <li><input checked="" type="checkbox"/> Safety Injection System</li> <li><input checked="" type="checkbox"/> Service Water System</li> </ul> </li> <li><input checked="" type="checkbox"/> Components by System               <ul style="list-style-type: none"> <li><input checked="" type="checkbox"/> AC Power System                   <ul style="list-style-type: none"> <li><input checked="" type="checkbox"/> Division 1A ac power</li> </ul> </li> </ul> </li> </ul>	ACP	7/11/2018 4:21:50 PM		3.7411E-01	
	CCS	7/11/2018 4:21:52 PM		2.0774E-04	
	ECS	7/11/2018 4:21:53 PM		8.3035E-01	
	EPS	7/11/2018 4:21:54 PM		5.7879E-02	
	OEP	7/11/2018 4:21:55 PM		4.2151E-04	
	SIS	7/11/2018 4:21:56 PM		8.3013E-01	
	SWS	7/11/2018 4:21:57 PM		8.3898E-01	
	ACP				
	ACP-BAC-1A	7/11/2018 4:22:08 PM	2.5562E-04	9.5690E-03	4.6354E-04

This report performs multiple calculations to create importance measures for every component of a system. Depending on the model and the number of components, this report could take some time to complete. Press OK to continue with report generation, or Cancel to abort reporting.

Nominal CDF:

PRIB Solve Truncation:

Refresh Documents

Split Calculations over multiple processes

Number of Processes:

## SAPHIRE - PRIB Report Timing Results

Sandbox Count	Setup Time (mm:ss)	Total Time (mm:ss)
1	0:02	14:00
2	0:08	7:20
3	0:11	4:50
4	0:14	3:30
5	0:18	3:02
6	0:21	2:51
7	0:24	2:53
8	0:29	3:13
12	0:43	3:42
16	1:00	4:10

- PRIB Report - Hand timed calculation times for various numbers of sandboxes

## ***SAPHIRE – Conclusion and Future Work***

Possible sandbox uses in the future:

- Sensitivity studies where each sandbox is assigned a change set
- Dividing a solve process for multiple event trees/sequences
- Performing uncertainty analysis for multiple event trees/sequences

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## ***SAPHIRE – Credits***

### Core INL development team

- James Knudsen (project manager)
- Curtis Smith (technical advisor)
- Ted Wood (lead developer)
- Kellie Kvarfordt (developer)
- Steve Prescott (developer)

### NRC

Jeffery Wood (current technical manager), Walter Leschek (current project manager), Erasmia Lois, Richard Robinson, Jr., Dale Rasmuson, Harold Vanderمولen, Patrick O'Reilly, Dan O'Neal.

## ***SAPHIRE – Credits (Continued)***

INL

Kenneth D. Russell, Martin Sattison, John Schroeder, William Galyean, Scott Beck, Robert Buell, John Biersdorf, Michael Calley, Dana Kelly, Doug Zeek, Dan Jensen, Rae Nims, Dan Kurkowski, Charity Follett, Howard Stewart, Douglas Brownson, Dick Fowler, Tami Thatcher, Leon Wolfram, Kevin Quick, Dale Snider, Kurt Wagner, Robin Van Horn, Scott Matthews, Cory Atwood, Carol English, Nancy Skinner, Melinda Cebull, Wendell Richardson, and K.A. Branham-Haar.





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