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Development of a Graphical Animation Interactive Feature to Assess MAAP-CANDU Simulation Results

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Abstract

MAAP-CANDU is an integrated severe accident analysis code for CANDU plant simulations that necessitates the assessment and post-processing of extensive amounts of information obtained from code run results. The MAAP-CANDU GRaphical Animation Package Extension (GRAPE) is a flexible, efficient, interactive and integrated visualization tool for analyzing plant behaviour during postulated accidents including accident management actions for single and multi-unit CANDU plants. GRAPE was developed by FAI in consultation with CNL (AECL) and CNSC from the FAI MAAP-GRAAPH code used in MAAP (LWR version). CNSC plans to use MAAP-CANDU and GRAPE as one of the tools in their Emergency Operations Centre.

Keywords: Severe Accident Management, Code Development, Emergency Operations

1. Introduction

Postulated severe accidents in nuclear reactors have lower probabilities but higher consequences to the reactor and the public, than do design-basis accidents. During a severe accident, radioactive fission products could be released to the environment, posing a risk to public health, the environment and the economy. Several severe accidents such as Three-Mile Island (1979, USA), Chernobyl (1986, USSR, Ukraine) and Fukushima (2011, Japan) demonstrated that the consequences of severe accidents could be very significant.

In order to minimize the consequences of severe accidents, a good understanding of severe accident phenomena and accident progression as well as efficient means for accident simulation and analysis results interpretation are required. This information and capability are necessary to determine measures to prevent such accidents or to implement appropriate Severe Accident Management (SAM) measures to mitigate fission product releases to the environment.

The MAAP-CANDU code [1] was developed by the Canadian nuclear industry and international partners to assess the progression and consequences of a severe accident in CANDU plants. The code is currently being used in the analysis of postulated events to assess any possible fission product releases to the environment. The Canadian Nuclear Safety Commission (CNSC) uses MAAP-CANDU to assess licensing applications submitted for both current reactors and new designs. The code can be used to develop and assess severe accident management techniques and evaluate the effects of mitigating actions.

While performing a CANDU plant severe core damage analysis using MAAP-CANDU, the code user is involved in the evaluation and post-processing of a large amount of simulation data. The current version of the MAAP-CANDU code only comes with a two-dimensional plotting package (no graphical animation feature is available). This makes real-time assessment and decision making difficult because there is a large amount of information that is not presented in an easy-to-digest manner. Effective and timely implementation of SAM actions requires visualization tools to assist in determining which actions should be taken at which specific time given the wide range of plant condition information output (in a disperse fashion) by the code. This requirement and the current deficiencies in the code's graphical capabilities led to the development of a graphical animation tool for MAAP-CANDU.

Canadian Nuclear Laboratories (CNL, formerly AECL), in partnership with the CNSC, is currently working with MAAP-CANDU code developer Fauske and Associates Inc. (FAI) to develop an interactive "Graphical Animation Package Extension" (GRAPE) for the MAAP-CANDU code, to assist in understanding MAAP-CANDU output and in the review of severe accident management guidelines (SAMGs) developed by industry. This paper describes the GRAPE software which provides a flexible, efficient, interactive and integrated visualization tool for analysing the in-plant effects of a wide range of postulated accidents and possible accident management actions for CANDU single-unit and multi-unit plants.

2. Background

The current MAAP-CANDU code predicts the progression of a severe core damage accident starting from initial conditions (usually normal operating conditions), employing a set of nuclear plant system faults and initiating events that could lead to severe core damage. The code calculates the overall plant response, including the heat-up and damage progression in the reactor core and surrounding structures, as well as fission product (FP) release, transport, and deposition in various plant components, and FP releases to the environment.

While performing a CANDU plant severe core damage analysis using MAAP-CANDU, the code user must assess and post-process extensive amounts of simulation data.

This large volume of information results from several factors:

1. Many of the nuclear plant systems/components data are processed in parallel in severe accident analysis scenarios;
2. The numerous systems/components in the plant are each represented by several elements. For example, in a CANDU 6 plant model in MAAP-CANDU, the containment is represented by thirteen compartment nodes and thirty junctions linking these nodes; the reactor building walls/floors are represented by ~100 heat sink structures; the reactor core is represented by 36 characteristic fuel channels, each of which has 12 axial nodes (bundles); each fuel bundle is represented by nine concentric rings; etc.
3. Many parameters are calculated/tracked by MAAP-CANDU in various plant systems, including:
   i) Pressure;
   ii) Temperature;
   iii) Gas concentrations;
   iv) Masses and energies of several materials components, such as: UO_2, Zr, ZrO_2, etc.;

v) Fission product chemical groups (e.g., nobles, CsI, BaO) and phases (gas, aerosol, deposited); and
vi) Fluid flows and water levels (single and two-phase).

The extensive plant condition data generated is used to determine the progression of the accident and the state of the reactor at a given time, allowing the user to assess the consequences and possible mitigating actions. Therefore, dynamic access to the transient plant conditions (provided by graphical animation software) during a severe core damage accident simulation would be useful, providing an overview of the progression of the plant response and the current conditions.

Interventions can be written into the MAAP-CANDU input file to perform user-defined operations like opening valves or adding make-up water. These interventions can be based upon calculated internal conditions (e.g., pressure, temperature, events) or user-defined external parameters (e.g., after 24 hours of elapsed time, restore power). Writing, debugging and running the simulation, followed by plotting and interpreting the results of the interventions, is a slow and iterative process. These input file interventions must be pre-planned before initiating the simulation run and cannot be inserted while the simulation is running. Thus the capability to dynamically change plant operations (e.g., valves, pumps, water additions and status of power sources) through a graphical interface software would be useful and provide the ability to implement SAM actions or external events (e.g., power loss).

3. MAAP-CANDU Code Brief Description

MAAP-CANDU is the primary code used for integrated severe accident analysis of CANDU reactor designs. It was developed from the original MAAP (Modular Accident Analysis Program) code for light water reactors (LWRs) with special modules added to simulate the horizontal fuel channel and calandria vessel geometry of CANDU. MAAP is a best-estimate integral nuclear plant analysis code for modelling severe core damage accidents and was developed by FAI for pressurized water reactors (PWRs) and boiling water reactors (BWRs). MAAP is owned by the Electric Power Research Institute (EPRI) [2] and is currently in use by more than 50 international PWR/BWR utilities.

The MAAP codes incorporate both mechanistic and parametric models to simulate severe accident transients and progression in a reactor. The code has been refined over several years with more detailed models and extensive benchmarking with experiments. MAAP continues to provide a fast-running, best-estimate representation of integrated plant response to all types of plant accident conditions. The MAAP codes are specific to particular reactor designs (e.g., PWR, BWR, and CANDU, etc.), due to their reliance on hard-coded nodalization of the reactor cooling systems. The codes are flexible with respect to geometric dimensions, numbers of loops, etc., but the basic reactor design is fixed in each code (e.g., the PWR and CANDU codes have steam generator and pressurizer models; the CANDU code has a core model with separate horizontal fuel channels in an unpressurized horizontal calandria tank, rather than vertical fuel in a pressure vessel). Many reactor coolant system subroutines are shared amongst the code versions, due to a commonality of purpose (e.g., pressurizer and steam generator models). All the MAAP codes utilize the same general containment model, although there are some modifications (e.g., only MAAP-CANDU has a vacuum building model).

MAAP-CANDU models the major phenomena and processes in severe accidents including:

- Thermalhydraulics (in the PHTS, calandria, reactor vault/shield tank, end shield and containment)
- Core heat-up, melting, and disassembly
- Oxidation reactions (both Zr and steel) and associated hydrogen generation
- Material creep and failure (pressure tube or calandria tube rupture, calandria vessel or shield tank wall creep failure)
- Ignition of combustible gases (CO and H_2)
- Energetic corium-coolant interactions
- Molten corium-concrete interactions
- Fission product release, transport and deposition
- Operator actions for the management of severe accidents

MAAP-CANDU is used in the Canadian nuclear industry by reactor operators (e.g., Bruce, OPG, NB Power), consulting firms (e.g., AMEC Foster Wheeler, Candu Energy Inc., etc.), the national nuclear research laboratory (CNL) and the national regulator (CNSC). The code is regularly employed in severe accident analysis for assessing licensing applications.

4. GRAPE Description

The inclusion of a graphical animation package is a standard option for most major integral severe accident codes (MELCOR, MAAP-PWR/BWR, and ASTEC) and provides increased functionality for analysis and interpretation of the copious amounts of data generated by a severe accident code.

The graphical animation package extension (GRAPE) for the MAAP-CANDU code is expected to significantly enhance the usability of MAAP-CANDU when performing analyses of CANDU plants undergoing postulated severe core damage accidents. Additionally, the visualization and interactive control capabilities of GRAPE will be effective in the planned use of the code by the CNSC in assessing CANDU licensing and compliance applications and in their Emergency Operations Centre.

GRAPE provides two specific modes:

- Animation of the simulation results ("post-processing mode"). In this mode, GRAPE allows easy access to the transient conditions (e.g., pressures, temperatures, concentrations, etc.) in various plant components (e.g., PHTS components, pressurizer, fuel channels, fuel bundles, containment compartments, etc.);
- Intervention in the accident sequence during the simulation ("interactive mode"). In this mode, GRAPE allows the MAAP-CANDU user to change the status of the plant components during the simulation, such as to open/close valves, start/stop pumps, etc. This mode also displays the transient conditions in real-time helping to inform the user on plant status and progression of the accident sequence.

The modifications to incorporate GRAPE were implemented in the MAAP4-CANDU code but these code changes are transferrable to the future code versions currently in development, such as MAAP5-CANDU.

The development of GRAPE is a joint CNL-CNSC project, with FAI preparing the GRAPE code to meet the requirements of CNL and CNSC. The problem definition and software requirement specifications produced by CNL (formerly AECL), in consultation with CNSC, were answered with a proposal from FAI in early 2013. This resulted in an initial beta version of GRAPE released in 2013 October. This was developed into the initial full release of GRAPE (v1) in 2014 March. This version of GRAPE was further refined through extensive consultations and assessments by CNL and CNSC to produce the current full release version, GRAPE v2, which was released for testing by CNL in 2014 September and provided to the CNSC in 2014 November.

GRAPE is a flexible, efficient, interactive, and integrated visualization tool for analyzing the in-plant effects of a wide range of postulated accidents and possible accident management actions, for CANDU single-unit and multi-unit plants. This software is a powerful tool for understanding and visualizing severe accident progression throughout the plant, providing a platform for severe accident management evaluations. GRAPE allows the user to process extensive information produced by the MAAP-CANDU code, through dynamic access to transient plant conditions in a timely and transparent fashion, providing an overview of plant response. Several dedicated data screens allow the user to monitor plant behaviour over multiple elements and systems (Fuel Channels, Core, Calandria, Containment, and Primary Heat Transport System), as discussed in Section 4.1. GRAPE is currently configured for the CANDU 6 and Darlington type plants but there are plans to develop the code further to include other CANDU designs (e.g., Pickering, Bruce).

4.1 CANDU View Screens

The GRAPE software produces several data screens to output the information generated by the MAAP-CANDU run in real-time and for later analysis in playback mode. The screens are reactor-design specific with different depictions for CANDU 6 and Darlington plant designs. The CANDU view screens (Figure 1 to Figure 8) and the main GRAPE window (Figure 9) are presented with a brief description of the information provided in each screen.

4.1.1 Fuel Channel Screen

The fuel channel screen (Figure 1) presents:

- Fuel temperatures of all fuel rings (7), and the pressure tube and the calandria tube of the currently selected bundle. The user selects the loop, characteristic channel and bundle to view, from all modeled bundles.
- Information on the status of the selected characteristic channel, i.e., water cooled ("not dry") or "dry" based on the mass of water in channel compared to a user-specified minimum water mass.
- The mass flow rates of steam and H_2 (flow at the channel exit, in kg/s), for a dry characteristic channel.
- When an axial channel position (bundle) has disassembled to debris (i.e., the fuel and fuel channel at the specific bundle position has separated from the intact remnants of the channel due to the failure of the pressure tube and the calandria tube), the display shows a red semi-circle (open at the bottom).

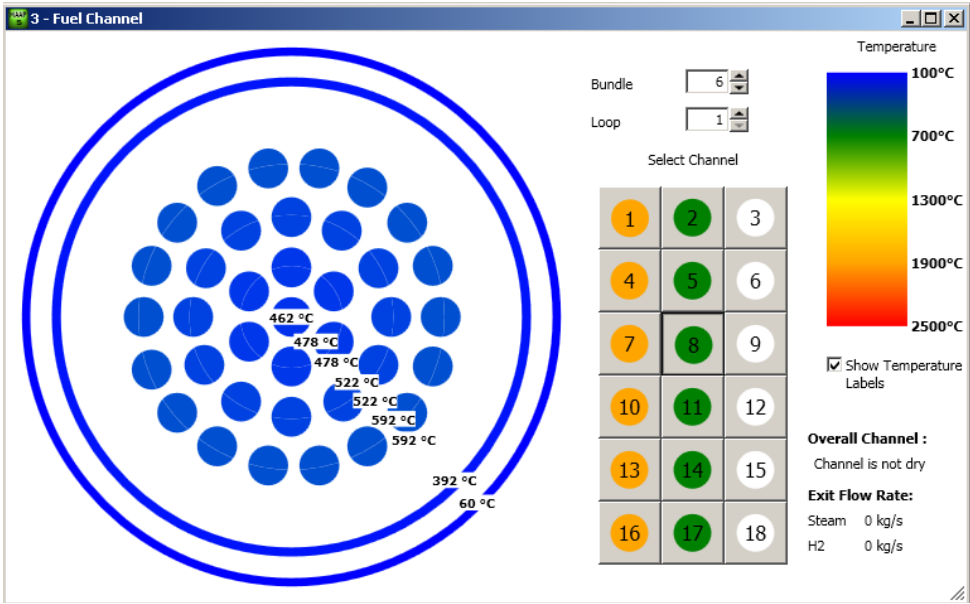

Figure 1 Fuel Channel Screen

4.1.2 Core Side View Screen

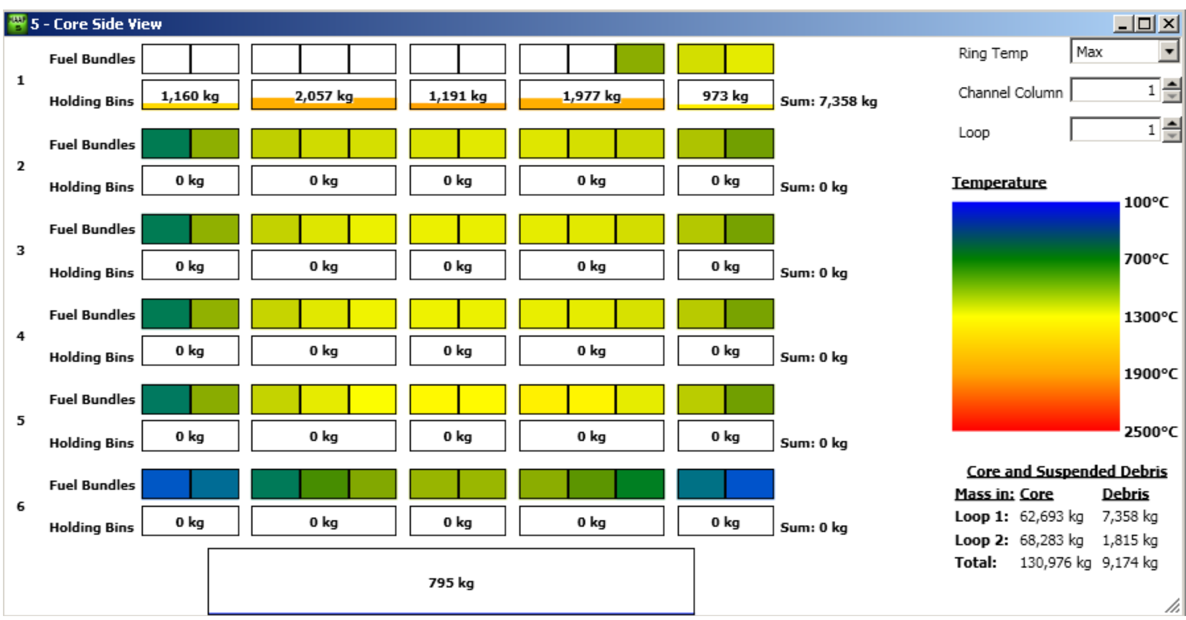

Figure 2 Core Side View Screen

The core side view screen (Figure 2) presents:

- Temperatures, for characteristic channels and suspended debris (user-selected ring temperature).
- A depiction of the characteristic channels and their status (i.e., intact/failed).
- A depiction of the suspended debris, its mass, temperature and location in the core (vertical and axial core node), along with the terminal debris bed at the bottom of the calandria vessel.

4.1.3 Core and Calandria Vessel Screen

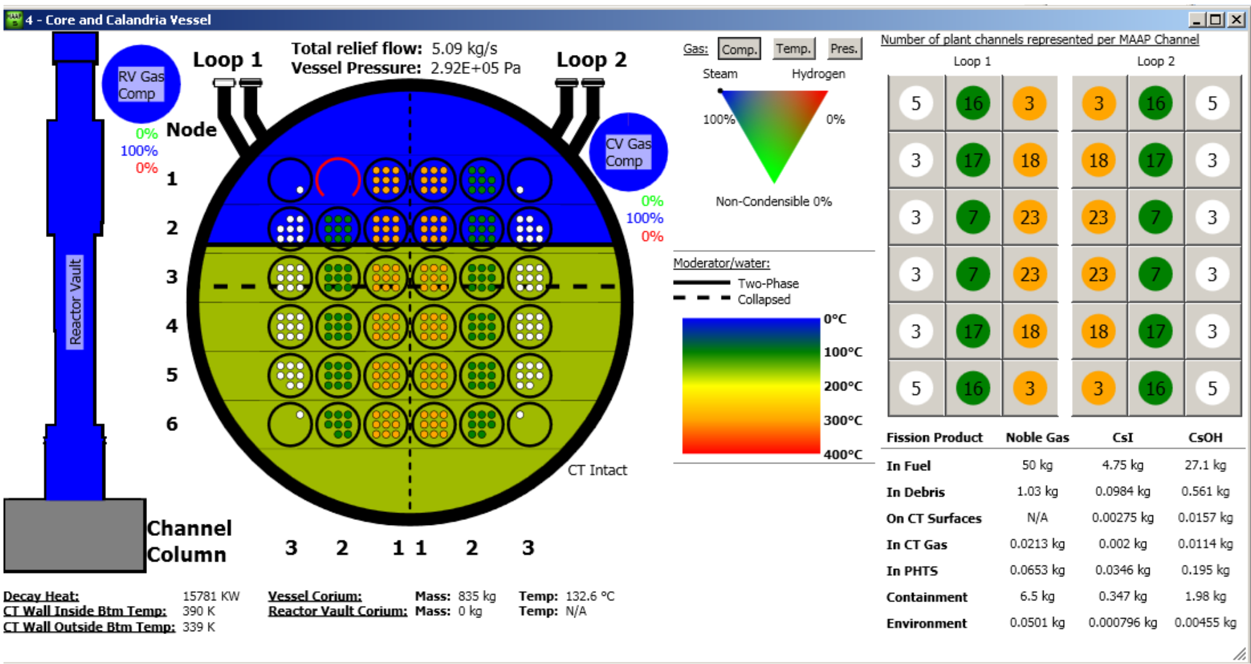

Figure 3 Core and Calandria Vessel Screen (CANDU 6)

The core and calandria vessel screen (Figure 3 and Figure 4) presents:

- Temperatures, levels and pressures for water and gas and the gas compositions in the calandria vessel and the reactor vault (CANDU 6) or shield tank (Darlington).
- A depiction of the channels and their status (intact = black circle or failed = red semicircle).
- Depictions of the status (closed or burst) of the calandria vessel rupture discs and the total relief flow (from the relief valve and calandria vessel relief ducts) out of the calandria vessel.
- Noble gas, CsI and CsOH fission product concentrations in various locations in the reactor core, containment and environment.
- Temperatures and presence of corium in the calandria and reactor vault/shield tank.
- The integrity and temperatures of the calandria. The integrity of the shield tank (Darlington only) and concrete ablation in the reactor vault (CANDU 6 only).

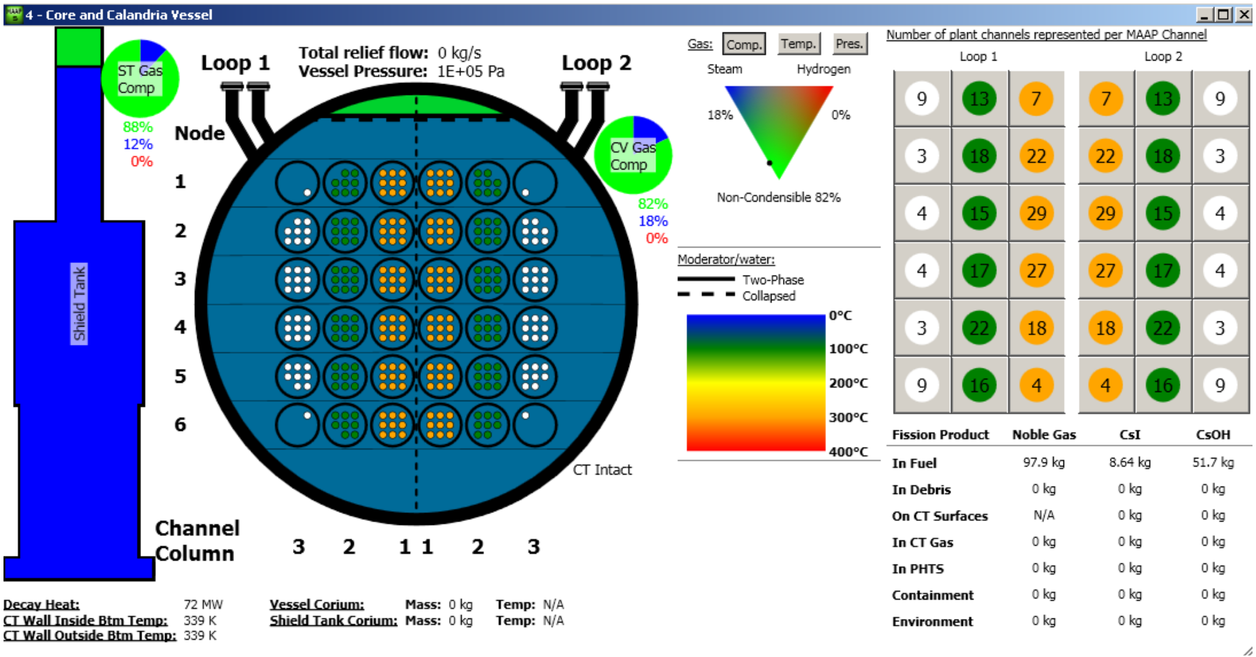

Figure 4 Core and Calandria Vessel Screen (Darlington)

4.1.4 Containment Screen

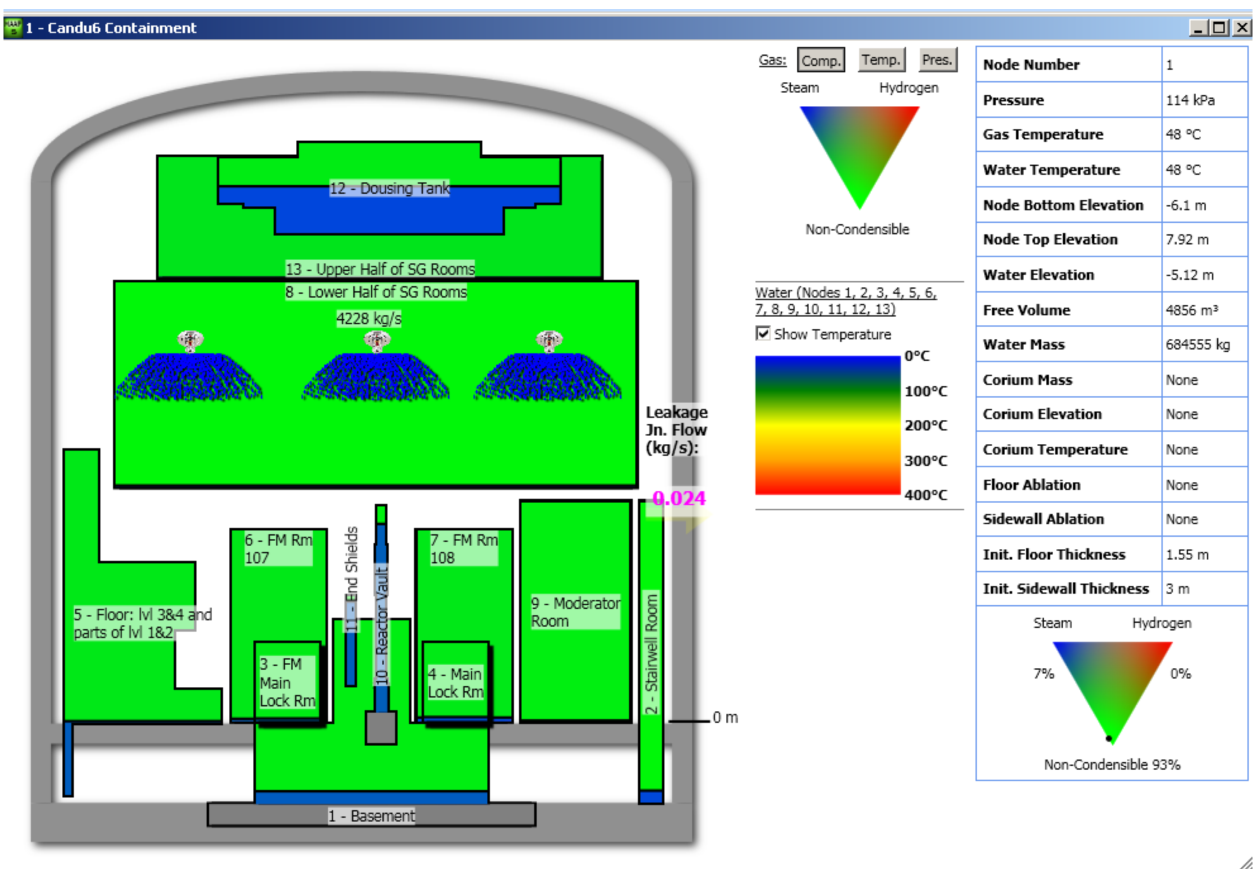

Figure 5 CANDU 6 Containment Screen

The containment screen (Figure 5 and Figure 6) presents:

- Reactor-specific containment configuration and geometry (volumes, elevations, etc.).
- Temperatures, levels and pressures for water and gas, and the gas compositions, in each containment node.
- Visual depictions of dousing spray systems, containment leakage/failure flows, and (in Darlington) the pressure relief flows to the vacuum building and the Emergency Filtered Air Discharge System (EFADS).
- Corium presence, mass, temperature and concrete ablation (including changes in node geometry due to ablation).
- The containment screen nodalization is static but changes to the node properties (e.g., volume, elevation, volume vs. height tables, etc.) are correctly reflected in the data window on the right of the screen and in the simulation behaviour.

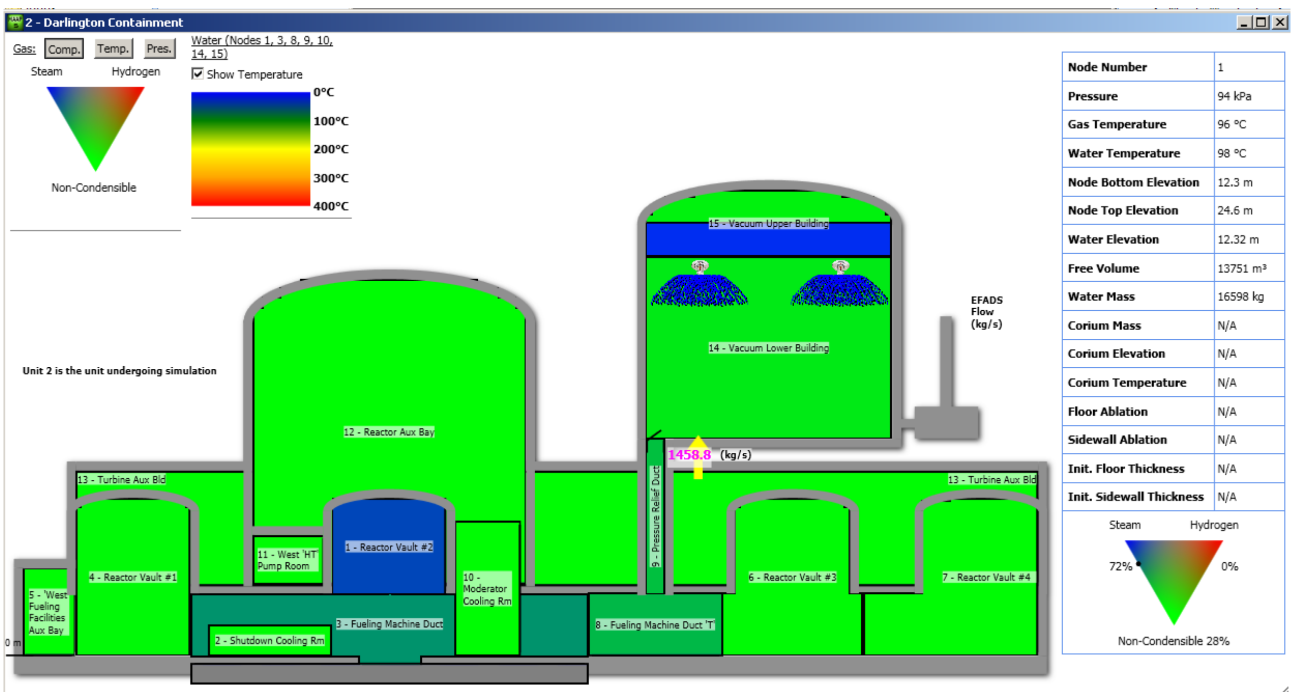

Figure 6 Darlington Containment Screen

4.1.5 Overview Screen

The overview screen (Figure 7 and Figure 8) presents:

- Reactor specific PHTS and emergency cooling (ECI/ECCS) configurations including pumps, valves, tanks and flows. Additionally, calandria vessel, shield tank/reactor vault and related containment configurations and geometry (volumes, elevations, etc.) are presented.
- Temperatures, levels and pressures for water and gas; gas compositions in the containment nodes, calandria and PHTS Loops (headers, pressurizer, steam generators, emergency coolant vessels, etc.).
- Visual depictions of dousing spray (CANDU 6) and fan coolers, containment leakage/failure flows, pressure relief flows to the vacuum building (Darlington).

The overview screen also provides interactive control of several reactor systems (AC/DC power trip, ECI/ECCS, moderator/shield cooling, valves, pumps, fan coolers, steam generator feedwater, emergency water makeup, etc.) and the ability to define breaks in the PHTS while GRAPE is in live/interactive mode. Interactive control is only available on this screen, though many different variable modifications can be entered using the "modify variable" option in the main GRAPE window.

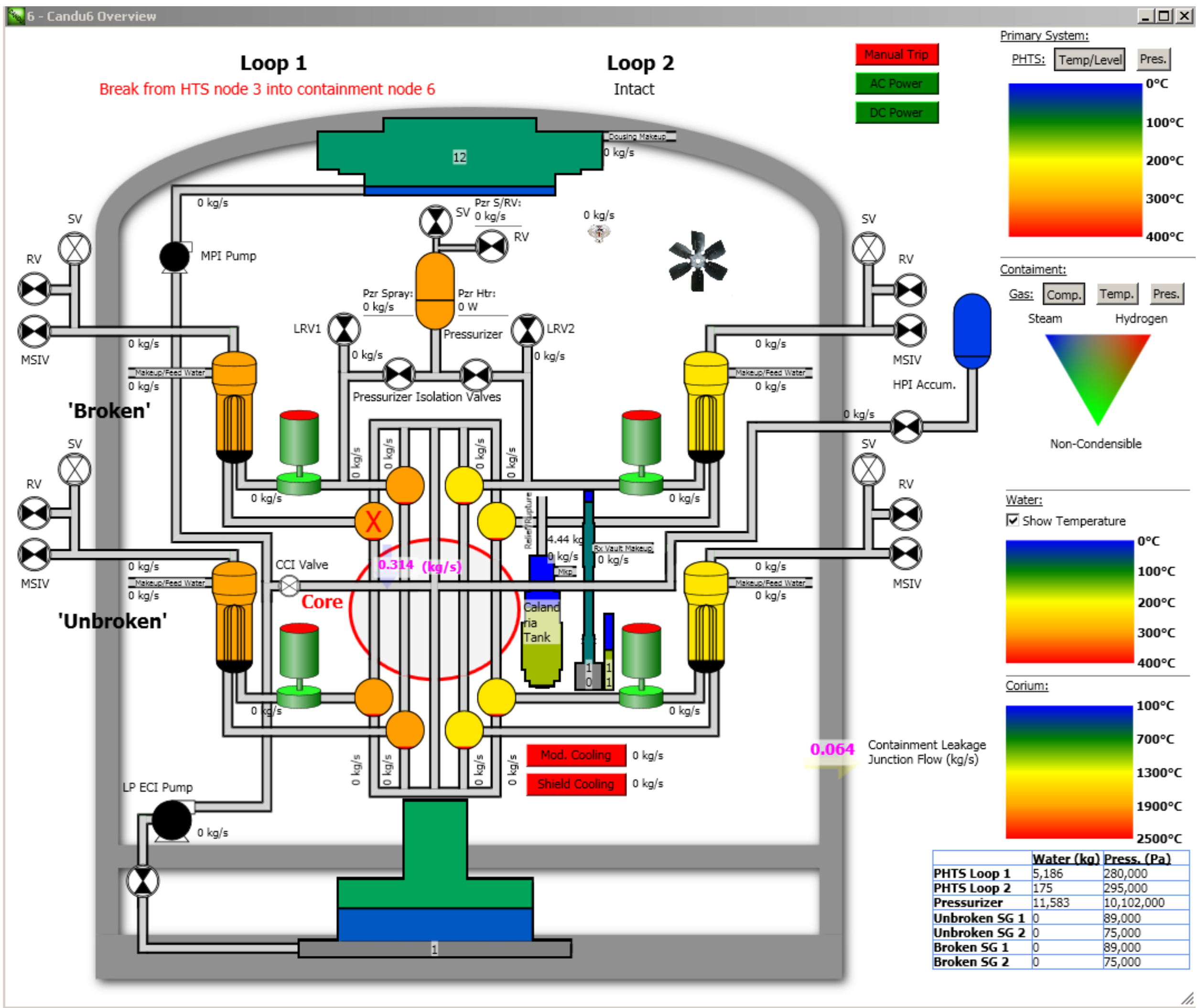

Figure 7 CANDU 6 Overview Screen

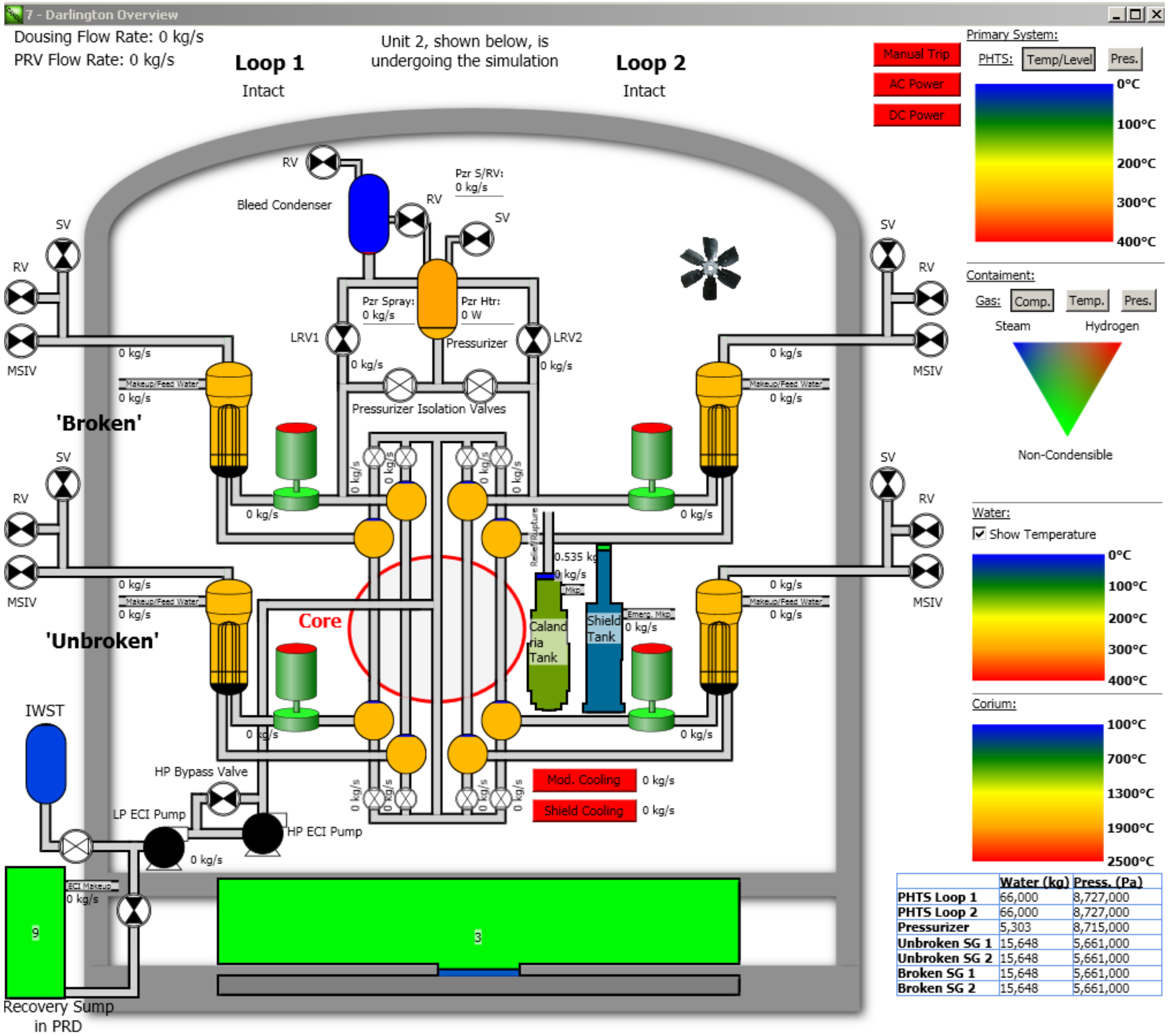

Figure 8 Darlington Overview Screen

4.1.6 Main GRAPE Window

The main GRAPE environment window (Figure 9) appears when GRAPE is opened and provides the following:

- Controls to navigate the simulation (play, pause, stop, forward, back, etc.) along with a simulation time display, track bar and simulation progress indicator.
- Menus to select features of the code, such as opening different display screens (CANDU View), modifying MAAP-CANDU variables during the simulation (Modify Variable), generating restart files (File) and tuning the playback and refresh rates (Options).
- An event recording window to track user-initiated event flags or variable change requests in GRAPE and their communication to the MAAP-CANDU run including the success or failure of the change (failed changes are highlighted in red)

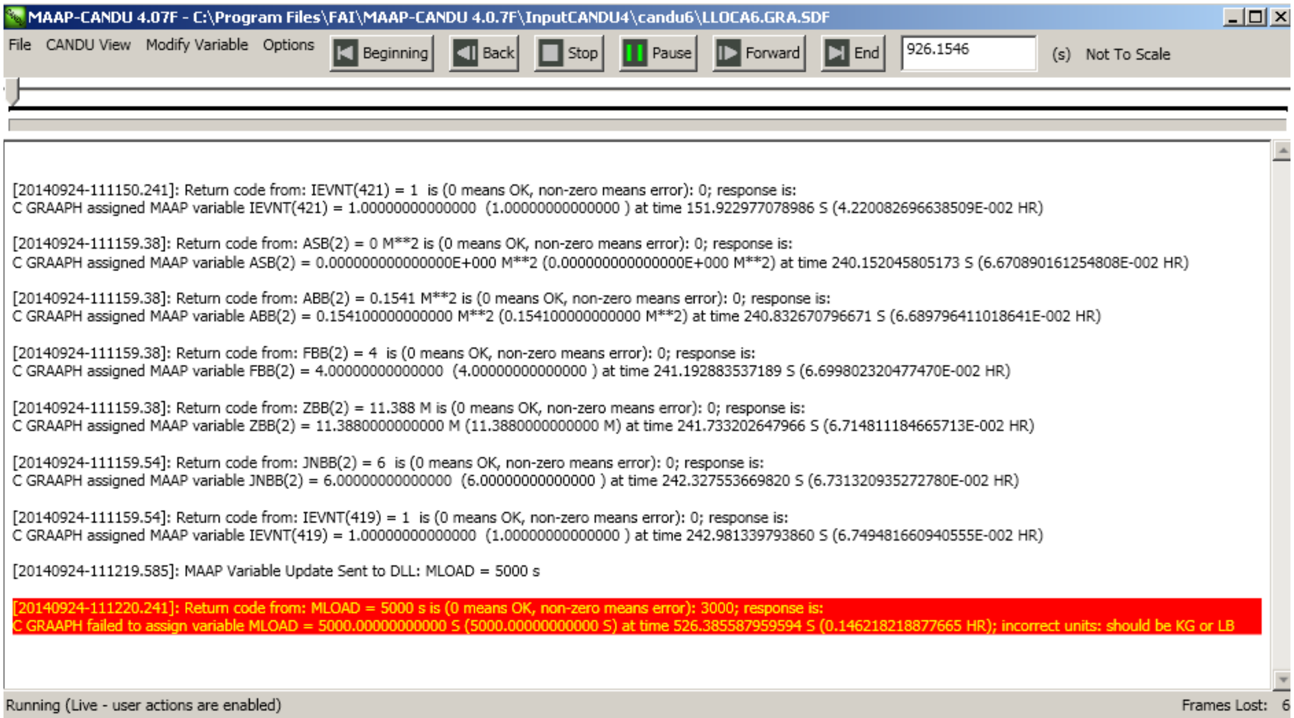

Figure 9 Main GRAPE Environment Window

As seen in Figure 9, the following user actions are recorded in the event window:

- Manipulation of flag IEVNT(421), opening a relief valve on the steam generator in the Loop 2 "broken" core pass (Figure 7).
- Insertion of a break in PHTS node 4 (reactor inlet header) of Loop 2, FBB(2) including:
  - The associated PHTS break area, ABB and break height, ZBB;
  - The containment node which the PHTS break discharges to, JNBB;
  - The area of SG break, ASB (there is no SG break so ASB = 0.0); and
  - Initiation of the PHTS break, flag IEVNT(419) is set = 1.
- Changes that are not accepted are displayed in yellow text on a red background accompanied by a reason for the failure (e.g., unrecognizable units). For example, mass MLOAD was set to 5000 s in Figure 9, rather than 5000 kg resulting in an error of incorrect units.

5. Important Engineered Safety Features and Controls

GRAPE provides interactive controls to the user which allows the implementation of severe accident management actions (e.g., manipulating valves, operating emergency cooling, controlling steam generator feedwater sources, etc.). These actions can be initiated as a simulation is running (using GRAPE in interactive mode while the MAAP-CANDU simulation is being executed), to model real operator actions that may be taken in a severe accident scenario. Typically the simulations run much faster than real time but they can be slowed or paused to permit operator intervention at a particular time. This intervention modelling capability allows for the comparison of different severe accident management actions to determine their capability for accident mitigation. The actions available are discussed below with special focus on steam generator make-up flows and emergency cooling systems.

The user can also implement changes in the input file to generate pre-planned interventions, as before, which can work with the changes implemented by the interactive controls in GRAPE. Additionally, the user can define more complex operator action sequences in the input file that are then triggered or slightly modified from GRAPE. Such input file interventions can be used to modify the behaviour of systems (e.g., apply additional conditions or trigger other actions) or even implement additional SAM capabilities that are not currently included in MAAP-CANDU, modelling them using input file coding.

The interactive controls within GRAPE include the following:

- Manipulation of valves (e.g., automatic operation, manually open, locked closed):
    - Safety (passive) and relief (powered) valves on the steam generators and the main steam isolation valves.
    - PHTS liquid relief valves and loop isolation valves.
    - Pressurizer and bleed condenser safety and relief valves.
- Manipulation of fan coolers and dousing sprays.
- Activation/deactivation of AC/DC power, moderator cooling and shield cooling. Loss of power will automatically prevent operation of pumps and powered valves.
- Control of the PHTS pumps.
- Insertion of breaks in the PHTS and in-core piping (feeders, fuel channels).
- Control of make-up water flows to the dousing tank, calandria vessel, pressure relief duct and reactor vault/shield tank.
- Control of feedwater to the steam generators (main, auxiliary, or from dousing, deaerator or external sources).
- Control of the emergency core cooling system (ECCS, CANDU 6) and emergency coolant injection system (ECI, Darlington).

5.1 Steam Generator Feedwater Make-up Flows

GRAPE provides interactive control of steam generator feedwater flows during an accident scenario. This control is an important mitigating action because the steam generators in a CANDU station are the primary heat sink for the reactor coolant and thus are very important during both normal operating conditions and during an accident. The feedwater systems provide cooling water to the secondary side of the steam generators. The primary side of the steam generator (i.e., the PHTS coolant flow) transfers heat to the secondary side water which boils and is converted to steam which is condensed in the balance of plant during normal operations. During an accident the SG inventory can also be discharged to the atmosphere to cool the PHTS. Thus a constant supply of feedwater is necessary to maintain the steam generators as the primary heat sink.

GRAPE allows the user to provide feedwater to the SGs from various sources including:

- Main feedwater pumps: main source of feedwater with independent controls for each SG; requires power for operation.
- Auxiliary feedwater pumps: secondary feedwater source with independent controls for each SG; requires power for operation, does not operate if main feedwater pump is running.
- Dousing tank make-up to feedwater: connection between dousing tank and SG secondary side, gravity driven flow based on pressure head, single control connecting to all SGs simultaneously.

- Deaerator tank make-up to feedwater: connection between deaerator tank and SG secondary side, gravity driven flow based on pressure head, independent controls for each SG.
- External make-up source for feedwater: this simulates the use of an external water source (e.g., a fire truck) to provide steam generator feedwater using a generic reserve water tank model in MAAP-CANDU, and has independent controls for each steam generator.

The feedwater flow is depicted in the GRAPE Overview Screens (Figure 7 and Figure 8) with a flow rate display (depicted beneath the feedwater input pipes into the steam generator) that provides the aggregate feedwater make-up flows from all enabled sources (main, auxiliary, dousing tank, deaerator tank, and external source). The effects of feedwater and dousing tank make-up are seen in the steam generator water levels and those of the dousing tank, as shown in the overview screens.

5.2 Emergency Coolant Injection/Emergency Core Cooling Systems

The GRAPE overview screen provides detailed depictions of the emergency core cooling system (ECCS) in CANDU 6 (Figure 7) and the emergency coolant injection (ECI) system in Darlington (Figure 8) along with the capabilities to control the activation of the various stages of these systems to provide cooling water to the PHTS system during an accident scenario. The ECCS/ECI systems are design specific and provide a simplified (but practical) representation of the real reactor system.

5.2.1 CANDU 6 ECCS

The CANDU 6 ECCS system is depicted in the GRAPE overview screen (Figure 7) and shows the three stages available: high pressure (driven by gas pressure, fed by ECC water tanks), medium pressure (pump driven, fed by the dousing tank) and low pressure (pump driven, fed by the reactor basement sump). All stages of ECCS inject into the reactor inlet and outlet headers of the PHTS through the core coolant injection (CCI) valves. GRAPE also provides controls for the CCI valves, the high pressure injection valve and the PHTS loop block valves through pop-up menus.

The high pressure ECC is a non-refillable system driven by gas pressure and fed from the dedicated ECC water tanks. The medium and low pressure ECC are both driven by the same set of pumps but source their water from different places; the systems cannot operate at the same time. The medium pressure ECC is fed by the dousing tank and has increased pressure due to the elevation head of the dousing tank located in the top of the containment building; the dousing tank can also be refilled using the make-up water controls in GRAPE simulating an external supplementary water supply. The low pressure ECC is fed by the reactor basement sump which is the collection point for water in the building including break flows, dousing sprays and condensate flows. The controls in GRAPE allow the user to manipulate the ECCS and provide flow to the PHTS during an accident scenario. Automatic operation of the ECCS can also be coded into the MAAP-CANDU input file.

5.2.2 Darlington ECI

The Darlington ECI system is depicted in the GRAPE overview screen (Figure 8) and shows the two stages available: high pressure and low pressure, both of which are pump driven and fed by either the internal water storage tank (IWST) or the sump located in the pressure relief duct between the reactor and the vacuum building. The high pressure and low pressure pumps operate in series with the water source feeding into the low pressure pump inlet and the low pressure pump outlet passing flow to: i) the high pressure pump (and on to the PHTS); or ii) through the high pressure bypass valve directly into the PHTS. High pressure ECI operates when the bypass is closed and is driven by both the low pressure and high pressure pumps. Low pressure ECI operates when the bypass valve is open and is driven by the low pressure pumps only. All ECI flows into the PHTS are regulated by the core coolant injection valves which are controllable in GRAPE.

The IWST tank provides the initial inventory of emergency cooling water and, once drained, the source for ECI is switched to the recovery sump in the pressure relief duct, which is the collection point for break flows and condensate flows (dousing sprays are contained within the vacuum building for Darlington). GRAPE includes the capability to refill the recovery sump simulating an external supplementary water supply. GRAPE allows the user to manipulate the ECI and provide flow to the PHTS during an accident scenario. Automatic ECI operation can also be coded into the MAAP-CANDU input file.

6. Implementation of GRAPE in the CNSC's Emergency Operations Centre and Future Development

The new version of MAAP-CANDU (v4.0.7F) which includes the GRAPE package has been provided to the CNSC for their evaluation and use. CNL has conducted a detailed training course (December 2014 and February 2015) on the new MAAP-CANDU version (v4.0.7F) with the included GRAPE code. This provided CNSC staff with information on the development, theory and operation of the new code version and the many features of GRAPE.

The CNSC intends to integrate MAAP-CANDU v4.0.7F with GRAPE into its emergency operations centre (EOC), to provide both on-demand analysis and real-time simulation of possible accident scenarios being tracked in the EOC.

Future development of GRAPE includes the extension of the software to simulate other multi-unit CANDU designs (e.g. Pickering, Bruce) and refinement of the code to enhance the user experience. Additionally, the GRAPE software is being assessed for upgrade to be compatible with future versions of the MAAP-CANDU code (e.g. MAAP5-CANDU). The path for GRAPE code development is currently under discussion between CNL, CNSC, and the code developer, FAI.

7. Summary

The Graphical Animation Package Extension (GRAPE) developed for MAAP-CANDU is an excellent tool that enhances the capabilities of the code to provide insight on the progression of a severe accident in a CANDU plant, and to evaluate the effects of severe accident management actions in the mitigation of accident consequences.

GRAPE provides two modes of operation:

- A post processing "Playback" mode which allows easy and detailed review of the plant behaviour and accident progression throughout a transient.
- The real-time "Interactive mode" which displays the transient conditions of the plant and allows the user to change the status of plant systems and components (e.g., open/close valves, start/stop pumps, etc.) as the simulation is running.

The GRAPE software provides multiple data screens (7 including the Darlington and CANDU 6 specific screens) that present the extensive information generated by MAAP-CANDU, increasing the capability of the user to process this large amount of information. GRAPE provides dynamic access to transient plant conditions in a timely and transparent fashion, producing a succinct overview of the plant state and its response during the progression of a severe accident. MAAP-CANDU v4.0.7F with GRAPE will be employed by the CNSC for both assessing licensing applications and as one of the tools used in the CNSC Emergency Operations Centre for real-time simulation and accident assessment.

8. Acknowledgements

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9. References

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10. Acronyms

AC	Alternating Current
AECL	Atomic Energy of Canada Limited
ASTEC	Accident Source Term Evaluation Code
BWR	Boiling Water Reactor
CANDU	CANada Deuterium Uranium reactor
CCI	Core Coolant Injection
CNL	Canadian Nuclear Laboratories, formerly AECL
CNSC	Canadian Nuclear Safety Commission
DC	Direct Current
ECC	Emergency Core Cooling
ECI	Emergency Coolant Injection
EFADS	Emergency Filtered Air Discharge System, Darlington only
EPRI	Electric Power Research Institute
FAI	Fauske and Associates, Inc. (Burr Ridge, IL, USA)
FP	Fission Product
GRAPE	GRaphical Animation Package Extension
LWR	Light Water Reactor, includes PWR and BWR designs
MAAP	Modular Accident Analysis Program
MAAP-CANDU	Modular Accident Analysis Program, CANDU version
MAAP-GRAAPH	Graphics Animation Package for MAAP-LWR
MELCOR	MELCOR is an integrated severe accident analysis code designed by SNL for the

	US Nuclear Regulatory Commission.
NRX	National Research Experimental, Chalk River, ON, Canada
PHTS	Primary Heat Transport System
PWR	Pressurized Water Reactor
SAM	Severe Accident Management
SAMG	Severe Accident Management Guidelines
SG	Steam Generator
SNL	Sandia National Laboratories, Albuquerque, NM, USA