ACR-1000 DESIGN PROVISIONS FOR SEVERE ACCIDENTS

N.K. Popov, P. Santamaura, H. Shapiro, V.G. Snell

Atomic Energy of Canada Ltd., 2251 Speakman Drive, Mississauga, Ontario, Canada, L5K 1B2, popovn@aecl.ca

Abstract – Atomic Energy of Canada Limited (AECL) developed the ACR-700™ (Advanced CANDU Reactor™-700) as an evolutionary advancement of the current CANDU 6® reactor. As a further advancement of the ACR design, AECL is currently developing the ACR-1000™ for the Canadian and international market. The ACR-1000 is aimed at producing electrical power for a capital cost and a unit-energy cost significantly less than that of the current generation of operating nuclear plants, while achieving enhanced safety features, shorter construction schedule, high plant capacity factor, improved operations and maintenance, and increased operating life. The reference ACR-1000 plant design is based on an integrated two-unit plant, using enriched fuel and light-water coolant, with each unit having a nominal gross output of about 1200 MWe. The ACR-1000 design meets Canadian regulatory requirements and follows established international practice with respect to severe accident prevention and mitigation.

This paper presents the ACR-1000 features that are designed to mitigate severe core damage states, including core retention within vessel, core damage termination, and containment integrity maintenance. While maintaining existing structures of CANDU reactors that provide inherent prevention and retention of core debris, the ACR-1000 design includes additional features for prevention and mitigation of severe accidents. Core retention within vessel in CANDU-type reactors includes both retention within fuel channels, and retention within the calandria vessel. The ACR-1000 calandria vessel design permits for passive rejection of decay heat from the moderator to the shield water. Debris retention in the calandria is minimized by reducing the number of penetrations at the bottom periphery and by accommodating thermal and weight loads of the core debris. The ACR-1000 containment is required to withstand external events such as earthquakes, tornados, floods and aircraft crash. Containment integrity is achieved through control of containment pressure, flammable gas control, and control/prevention of the core-concrete interaction.

1. INTRODUCTION

New reactor designs require the evaluation of design alternatives to reduce the radiological risk by adequate prevention of severe accidents or by limiting releases from the plant in the event of such accidents. The Advanced CANDU Reactor™-1000 (ACR-1000) design has provisions to prevent and mitigate severe accidents.

The ACR-1000 reactor design accounts for international practice with respect to the achievement of cost-effective Severe Accident Mitigation Design. The ACR-1000 Core Damage States (CDSs) include two categories of Beyond Design Basis events (BDBAs) [1]: fuel damage events that are CANDU-specific, and Severe Core Damage events (SCDs). The Severe Core Damage events include In-Calandria Core Damage states (ICCDs), which are also CANDU-specific.

In principle, the design of a nuclear power plant (NPP) should prevent the occurrence of any accident that could affect the safety of the public and plant personnel, and expose the environment to unacceptable levels of radiological risk. Although BDBAs are highly unlikely events, such accidents may occur. To provide defense-in-depth of a NPP, it is important to provide design features to both prevent and mitigate the consequences of those accidents.

The ACR-1000 design includes features and provisions to prevent and mitigate severe accidents. These design provisions are in line with the Canadian regulatory requirements, and are based on international practice and guidelines [2, 3]. Also, as part of the defense-in-depth strategy, the ACR-1000 design includes a variety of passive features.

Traditionally, the effort by the Canadian nuclear industry was aimed at the prevention of severe accidents by developing robust reactor designs and ensuring a high reliability of vital reactor systems. For new reactor designs, domestic and international regulatory bodies require an evaluation of design alternatives to reduce the radiological risk in the unlikely event of severe core damage. The purpose of this evaluation is to establish cost-effective Severe Accident Mitigation Design of the ACR-1000 design which is part of the ACR program.

2. ACR-1000 DESIGN FEATURES

The ACR-1000 design has evolved from AECL's internationally recognized line of CANDU pressure tube reactors, based on in-depth knowledge and experience with CANDU systems, components and materials, as well as from the experience and feedback received from owners and operators of CANDU plants. The ACR design is based on the use of modular, horizontal fuel channels surrounded by a heavy water moderator, the same feature as in all CANDU®[1] reactors. The major innovation in ACR is the use of low enriched uranium (LEU) fuel and light water as the coolant, which circulates through the fuel channls [4,7]. This results in a more compact reactor design and a reduction of heavy water inventory, both of which contribute to a significant decrease in cost compared to traditional CANDU reactors. Figure 1 shows a schematic of the ACR-1000 heat transport system.

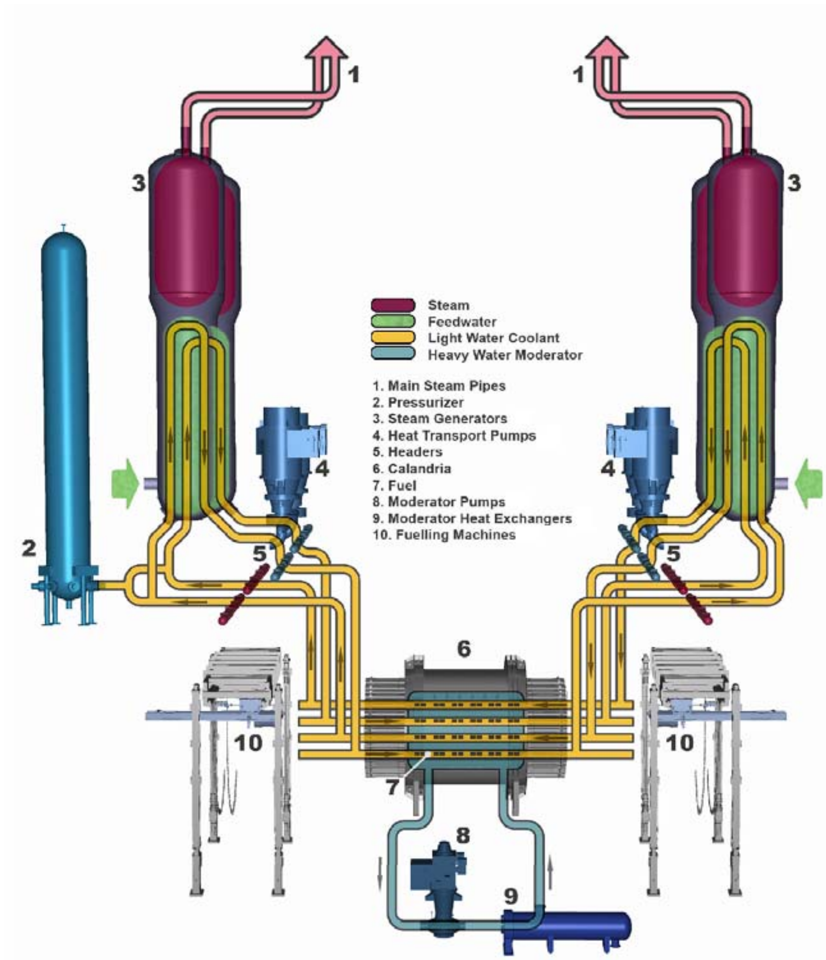

Figure 1: Schematic of ACR-1000 Reactor Heat Transport System

The safety systems provided in the ACR-1000 are based on the traditional CANDU safety philosophy. The ACR-1000 design features two fast-acting, fully capable, diverse, and separate shutdown systems, which are physically and functionally independent of each other and from the reactor regulating system.

The Emergency Core Cooling (ECC) System consists of the Emergency Coolant Injection (ECI) System and the Long-Term Cooling (LTC) System. The Containment System consists of a strong, steel-lined containment structure with low leakage design, containment isolation system, containment heat removal system, and hydrogen mitigation system.

Safety supporting services are provided by a number of safety related systems, including the Reserve Water System, Recirculated Cooling Water System, Raw Service Water System, Compressed Air System, Chilled Water System, and Secondary Control Area.

When required, the Reserve Water System (RWS) provides an emergency source of water by gravity to the steam generators, moderator system, shield cooling system, and Heat Transport System (HTS). Recirculated Cooling Water System circulates demineralized cooling water to different loads in the plant. Raw Service Water System disposes of the heat from the RCW to the ultimate heat sink. Compressed Air System provides instrument air and breathing air to different

[1] CANDU® (CANada Deuterium Uranium) is a registered trademark of Atomic Energy of Canada Limited (AECL).

systems in the plant. Chilled Water System supplies water to air conditioning and miscellaneous equipment. Secondary Control Area (SCA) contains monitoring and control capability to shut down the reactor and to maintain the plant in a safe shutdown condition following postulated events that render the Main Control Room (MCR) unavailable.

The following sections provide more details about the systems that play important role in severe accident mitigation.

2.1 Shutdown Systems

As in previous CANDU designs, the ACR-1000 incorporates two fast-acting, fully capable, diverse, and separate shutdown systems (SDS1 and SDS2), which are physically and functionally independent of each other. Both shutdown systems perform their function in the low-pressure moderator contained in the calandria.

SDS1 consists of mechanical shutoff rods, which drop into the core when a trip signal de-energizes the clutches that hold the shutoff rods out of the core. The design of the shutoff rods is based on proven CANDU 6 design. The in-core guides and rods have a plate design to fit in the reduced space available between the calandria tubes. The drive mechanisms for the shutoff rods are similar to those used in CANDU 6 reactors.

SDS2 injects a concentrated solution of gadolinium nitrate into the low-pressure moderator to quickly render the core subcritical. On a trip, fast-acting valves open, and stored, high-pressure helium pressurizes the gadolinium tanks, which are filled with gadolinium nitrate solution. Each gadolinium tank is connected to an injection nozzle that passes through the calandria. The gadolinium nitrate solution is directed from holes in the injection nozzles into the core so that the solution is dispersed uniformly, maximizing shutdown effectiveness.

2.2 Reserve Water System

The Reserve Water System (RWS) (Figure 2) is comprised of a seismically qualified Reserve Water Tank (RWT), containing a large volume of water used by other systems to mitigate accidents.

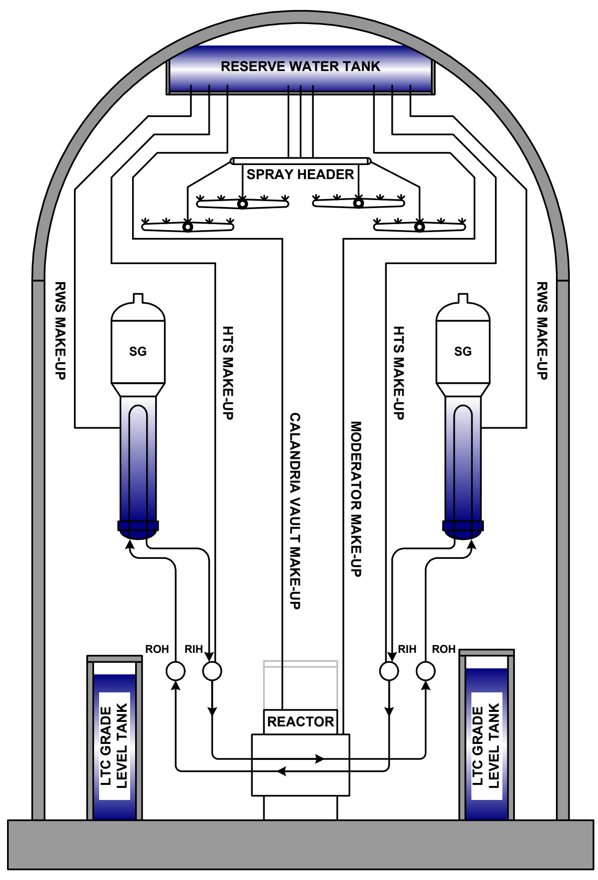

Figure 2: Reserve Water System

The RWT is located at a high elevation in the reactor building, and it provides a passive emergency source of water to the steam generators (back-up emergency feedwater), containment cooling system, moderator system, shield cooling system and heat transport system. Injection from the RWT to the Heat Transport System (HTS) by gravity helps mitigating accidents for which Emergency Core Cooling (ECC) system is postulated to be impaired.

A part of the RWS water inventory is allocated for the containment cooling spray system. Following actuation of the spray valves, post-accident containment pressure mitigation is achieved by injecting water from the RWT into the spray headers. In case when the main and emergency feedwater systems are impaired, the RWS provides feedwater supply to the steam generators (SGs).

Following a severe accident, heat transfer to the moderator and shield cooling systems' inventory is important as it maintains fuel cooling and helps arresting progression of the accident. In a severe accident the operator has a choice of manually connecting the RWT to the moderator system and/or the shield cooling system.

2.3 Emergency Coolant Injection System

The ACR-1000 Emergency Coolant Injection (ECI) system supplies light water coolant to the HTS and refills the fuel channels in the short term after a LOCA.

The ECI system consists of two RIH accumulators connected to the heat transport system reactor inlet headers of both loops on the corresponding reactor face, and four ROH accumulators (arranged in pairs) connected to the heat transport system reactor outlet headers of both loops on the corresponding reactor face. Accumulators are pressurized during normal reactor operation by compressed nitrogen gas. When the HTS depressurizes to below the pressure of the accumulators, check valves at the HTS/ECI pressure boundary open, and expansion of the compressed nitrogen gas forces cooling water flow from the accumulators into the HTS to refill the fuel channels in the core.

Core Make-up Tanks (CMTs) provide passive make-up to limit the extent and duration of HTS voiding for secondary side depressurization events in the intact HTS loop during a LOCA event. CMTs also provide large make-up flows to the broken HTS loop in the short-term following a LOCA, and facilitate thermosyphoning and operation of the Long Term Cooling (LTC) pumps. The CMTs are located above the top of the steam generator U-tube bundles and are maintained at approximately the same pressure and temperature as the reactor inlet headers. CMT injection starts when the HTS depressurizes to below the saturation pressure corresponding to the operating temperature of the CMTs (no signal or valve operation is required).

2.4 Long-Term Cooling System

The Long Term Cooling (LTC) System is a safety system incorporated into the ACR-1000 to circulate water through the reactor fuel channels to remove decay heat. The LTC system provides long-term decay heat removal following a reactor shutdown with Heat Transport System (HTS) pressure boundary intact (shutdown cooling mode), or following a Loss of Coolant Accident (LOCA) to the broken HTS loop (post-LOCA recovery mode).

The LTC is comprised of four independent divisions each having a single pump and a heat exchanger, with separate divisions of electrical power and service water supply. Use of a four-division design provides complete separation between divisions of the LTC system and increases reliability by minimizing common-mode failures.

Major components of the LTC system are the four shell and tube heat exchangers, four vertical motor-driven pumps, two Grade Level Tanks (GLTs), and four strainers located at the RB sump entrances. The pumps and heat exchangers are located outside the Reactor Building, each division in a separate enclosure. The process equipment of this system is designed to handle the designated heat loads for all specified modes of operation.

Following a LOCA, the LTC system recovers the water collected in the RB sumps and injects it into the HTS. On detection of a LOCA, the LTC pumps start automatically. Once the HTS is depressurized sufficiently such that the LTC pump head exceeds the RIH pressure, the LTC pumps start injecting coolant from the sumps into the reactor inlet headers of HTS via the LTC heat exchangers. The intact HTS loop is cooled through the steam generators.

Following a reactor shutdown with an intact HTS, the LTC system provides a long-term heat sink after initial cool-down of the HTS by the steam generators and the feedwater systems.

2.5 Containment Cooling System

The basic function of the containment system is to form a continuous, pressure-retaining envelope around the reactor core and the heat transport system. It limits releases to the external environment of radioactive material resulting from an accident. An accident that causes a release of radioactive material to containment may or may not be accompanied by a rise in containment pressure.

The containment system includes a steel-lined, prestressed concrete reactor building containment structure, access airlocks, sprays for pressure reduction, and a containment isolation system, consisting of valves in certain process lines and ventilation ducts that penetrate the containment structure. This containment design ensures a low leakage rate and, at the same time, provides a pressure-retaining boundary for LOCAs.

The containment system automatically closes all penetrations open to the reactor building atmosphere when an increase in containment pressure or radioactivity level is detected. Measurements of containment pressure and radioactivity are quadrupled and the system is actuated using two-out-of-four logic.

A safety-related containment cooling spray system, supplied from the Reserve Water System (RWS), is provided for steam condensation and post-accident pressure suppression (Figure 3). Back-up connections to the Long Term Cooling (LTC) system are provided for long-term post accident containment heat removal. The ACR-1000 design has been adapted to utilize passive components of the system for short-term mitigation of harsh environmental conditions inside containment following a postulated accident. The containment cooling spray is actuated automatically for any event resulting in pressures or temperatures that challenge the environmental conditions for equipment qualification or the integrity of the containment structure.

Following a postulated severe accident (e.g. a LOCA co-incident with a total loss of service water), the gravity-driven sprays, utilizing only the allocated RWT inventory, will ensure containment its leak tightness for at least 24 hours after the onset of core damage. After 24 hours, other intervention may be taken to establish a sustainable means of preventing containment failure.

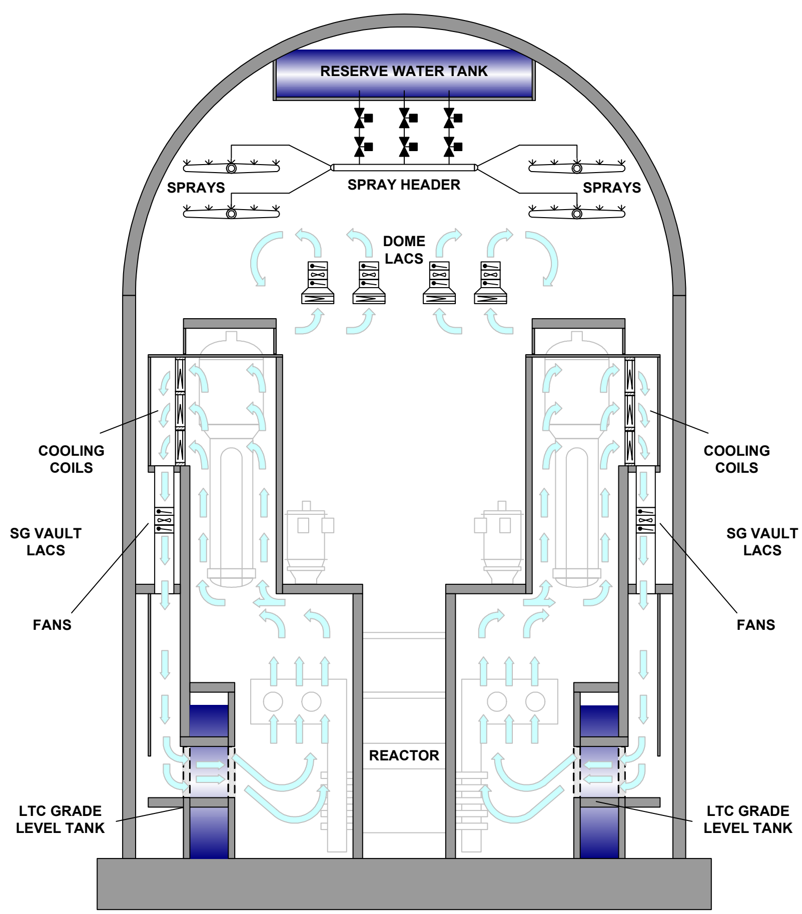

Figure 3: Containment Cooling System

2.6 Hydrogen Control System

The containment atmospheric hydrogen control is achieved by passive autocatalytic recombiners, and active igniters that limit the concentration of hydrogen in the RB atmosphere to below the threshold limit at which deflagration or detonation could occur.

In the event of severe accidents, active igniters placed at strategic locations in the containment supplement the action of the passive recombiners. If the hydrogen production rate released from the core surpasses the capacity of the passive recombiners, the igniters deliberately ignite accumulated hydrogen, hence considerably reducing the risk of uncontrolled deflagration or detonation.

The containment structure (Figure 3) is designed to provide a thorough mixing of the containment atmosphere, to minimize occurrence of flammable gas pockets. The containment layout also minimizes the possibility of any standing flame thermally interacting with the containment boundary.

3. ACR-1000 CORE DAMAGE STATES

The Core Damage States (CDSs) pertinent to Severe Accident Mitigation Design Alternatives (SAMDAs) are schematically illustrated in Figure 4. All these core damage states pertain to a shutdown reactor and they all involve a loss of multiple heat sinks and multiple barriers.

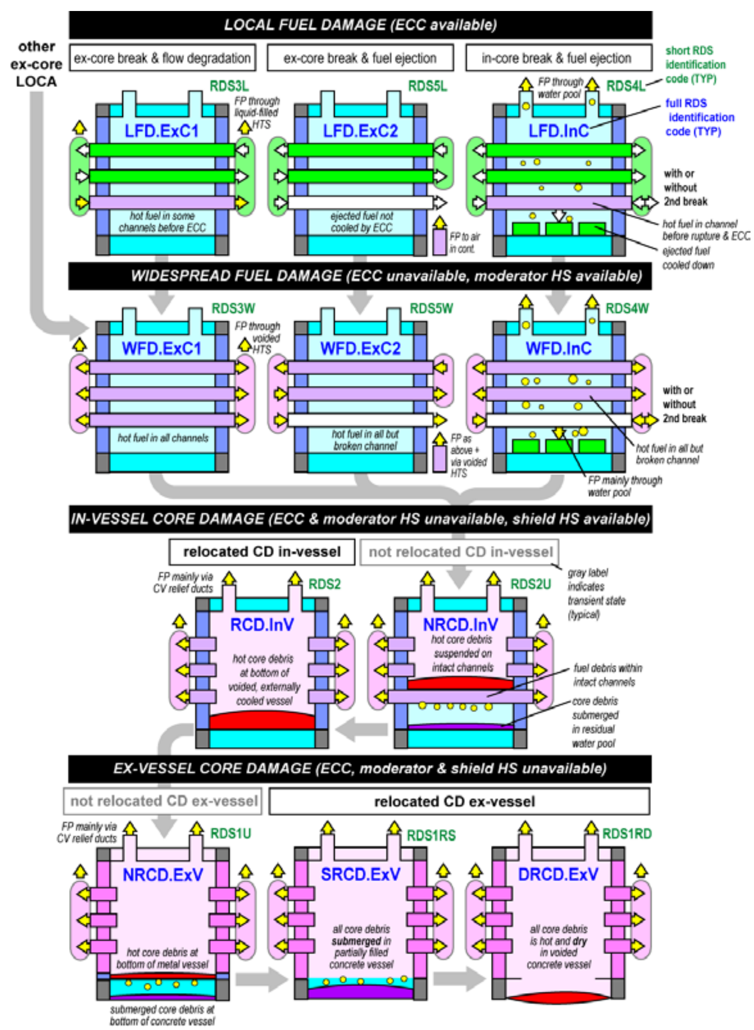

Figure 4: ACR Fuel and Core Damage States

The first category of core damage states is local and widespread fuel damage states that are specific to a channel type reactor. A common characteristic of this category is that the accident progression is arrested within multiple, distributed "pressure vessels" (i.e., within the fuel channels). The fuel channels may be cooled either externally by heavy water (moderator) surrounding the channels, or internally, by light water within the channels. The moderator heavy water serves as an alternate heat sink that provides an indefinite heat removal function, which is one of the characteristics of the CANDU reactor designs that is utilized in the ACR-1000 design, as illustrated in Figure 4.

Extensive experimental and analytical databases exist for the local and widespread fuel damage states. Fuel debris remains solid and is readily coolable (Figure 5). Fission products are released from the fuel, and hydrogen is produced in modest quantities compared to severe accident scenarios.

The second category in Figure 4, In-Calandria Core Damage (ICCD), is analogous to the in-vessel core damage state of the Advanced Light Water Reactors (ALWRs), and results in the same final configuration (i.e., hot core debris at the bottom of an externally cooled metal vessel). However, the transient ACR-1000 core relocation phenomena are considerably different from those in ALWRs, resulting in different severe accident phenomena. Notable differences are:

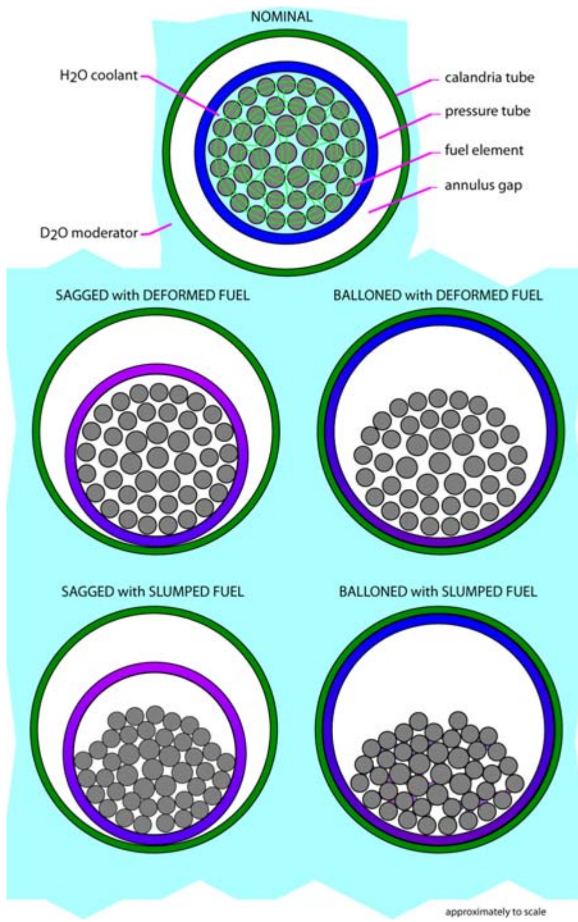

Figure 5: Conditions of Widespread Fuel Damage State

- Core break-up and relocation (Figure 6) is slow due to presence of residual water in the calandria and proceeds only at low system pressures in the ACR, and
- melting of core materials is typically avoided until after the debris has relocated to the bottom of the ACR-1000 calandria vessel.

In the event of an accident resulting in a sustained power-cooling mismatch in a pressurized Heat Transport System (HTS), the fuel channels act as 'pressure fuses'. When the HTS voids at high pressures, one or a few channels fail at modest temperatures (fuel at 1000°C or less) to depressurize the system. This would normally activate the ECC, preventing a significant fission product release from the fuel.

If the ECC were unavailable, the widespread fuel damage configuration as shown in Figure 4 would arise, which is stable as long as a liquid pool is available in the calandria vessel (i.e., a small amount of fuel is ejected into the vessel, with the bulk of fuel in the configuration illustrated on the right-hand side of Figure 4). The core break-up and relocation illustrated in Figure 6 only comes into play if fuel channels are voided on the inside and not submerged in liquid on the outside.

In severe accidents, depressurized channels deform and break up into coarse core debris, which is largely trapped on the rows of channels at lower elevations. The low-elevation channels would typically be located within a residual liquid pool inside the calandria vessel and are thus structurally stable. The weight load imposed by the accumulating core debris ('suspended debris' in Figure 6) eventually exceeds the load-bearing capacity of low-elevation channels, and the whole core collapses (relocates) into the residual water pool in the calandria vessel.

Experimental and analytical data support the "pressure-fuse" behaviour of the pressure tubes and aspect of the ICCD state. Core break-up and relocation aspects are determined by analyses, with some experimental demonstration of integral (multi-channel) core relocation kinetics. Uncertainty in terms of fission product and hydrogen release during the transient core relocation will be covered by deterministic ACR-1000 specific severe accident analysis. Generic best-estimate analysis has shown a "core-collapse" (relocation to the bottom of the vessel) while the fuel is solid; much of the Zircaloy is unoxidized, and the bulk of fission products retained in the fuel matrix. Therefore, severe accident phenomena such as core-coolant and core-structure interactions are qualitatively and quantitatively different from those in ALWRs. A pressurized melt ejection from the ACR-1000 core (calandria) is physically impossible.

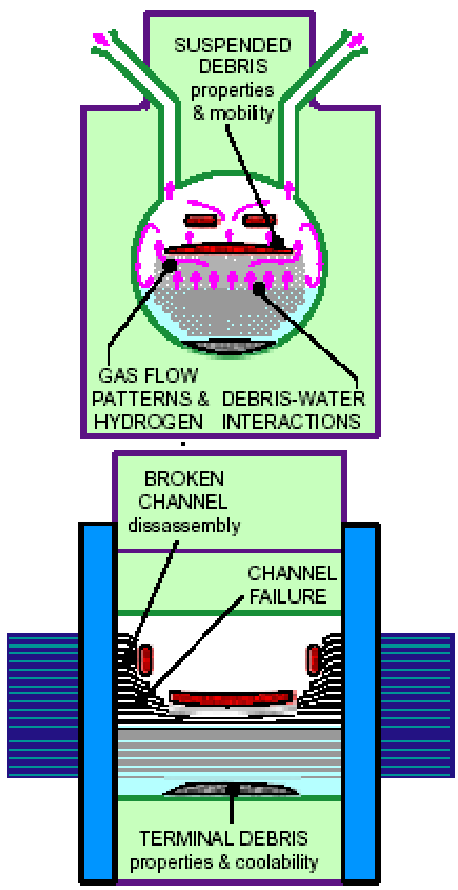

Figure 6: Severe Core Damage – Molten Debris on Reactor Floor

The relocated solid fuel debris eventually dries out, compacts, and partially liquefies. This "dry debris compaction" process is not amenable to the escape of residual fission products from debris. The calandria vessel geometry provides conditions well suited to in-vessel debris cooling by external water. The calandria vessel assembly is situated in the reactor vault that is filled with shield water (Figure 6). Also, both ends of the calandria vessel cylinder are surrounded by end-shield water.

The heat fluxes are low and the "terminal debris" bed is largely solid as long as a water pool is available on the outside. An extensive database is available internationally on debris coolability within metal vessels, which is applicable to the ACR-1000. The ICCD state can be maintained indefinitely by external vessel cooling. After the transient core relocation stage, there are no particularly strong challenges to containment integrity posed by severe accident phenomena if the external water pool is adequately cooled.

Uncovered and depressurized channels deform and break up into coarse core debris, which is largely trapped on the rows of channels at lower elevations. The low-elevation channels would typically be located within a residual liquid pool in the calandria vessel and are thus structurally stable.

The third category in Figure 4, Ex-Calandria Core Damage (ECCD), is generic to all reactor designs. This category needs to be avoided in order to avoid severe accident phenomena related to core-concrete interactions that invariably challenge the containment integrity. To address regulatory requirements with respect to this type of a severe accident, the ACR-1000 reactor design provides sufficient floor space for debris spread, and means to keep the debris on the floor submerged in water. Further details are provided in [5].

4. SEVERE ACCIDENT MITIGATION

Severe accident mitigation is defined internationally as [6]:

…those actions that are taken by the plant staff during the course of an accident to ***prevent core damage****,* ***terminate progress of core damage*** *and* ***retain the core within the vessel****,* ***maintain containment integrity****, and* ***minimize offsite releases****. Severe accident management also involves pre-planning and preparatory measures for SAM guidance and procedures, equipment modifications to facilitate procedure implementation, and severe accident training.*

This section discusses briefly the ACR-1000 capabilities for severe accident mitigation for a postulated severe accident sequences for ACR-1000. A limiting severe accident is the loss of all AC Power Supplies ("Station Blackout"). The sequence of events for this severe accident is based on preliminary analyses of CANDU 6 and ACR-700.

For this case, total loss of all AC power supplies is postulated. Power from the grid (off-site) and the turbine generator is lost (Class IV power), and the on-site Class III diesel generators are assumed to fail. In this scenario, the HTS pumps lose power and the reactor is promptly shut down by the two shutdown systems. There is no power available to the service water system, to the LTC system, to the emergency feedwater system, to the moderator cooling system, to the shield cooling system, and to the containment cooling system LACs.

The HTS remains full by the CMTs and circulation is maintained by thermosyphoning. The inventory in the SGs boils off providing heat removal. Initiation of gravity-fed make-up water to the SGs from the RWT extends heat removal. The remaining inventory in the SGs will boil off and the SGs will dry out when the RWT inventory is depleted (after several hours).

Under these conditions, one or two calandria tubes are postulated to fail resulting in a depressurization of the primary side. The CMTs and ECI are available to inject into the HTS. As the moderator heats up and boils off, water from the RWT is directed to the calandria and the reactor vault. This delays accident progression, allowing alternative (e.g. off-site) sources of make-up water to be provided to maintain containment integrity.

5. ACR-1000 HEAT SINK CAPABILITIES

Availability and sequencing of the ACR-1000 safety and safety related systems is important for fuel heat removal and containment cooling during postulated severe accidents. The viable heat sinks for fuel heat removal are predominantly dependent on whether or not the HTS is intact. Reference 7 summarizes the fuel heat removal capabilities of ACR-1000 for two key groups of events: LOCA events, in which the HTS is not intact, and non-LOCA events (e.g. station blackout or Main Steam Line Break), in which the primary pressure boundary is intact. The severe accident prevention and mitigation features of the ACR-1000 are shown in Table 1. These heat sinks will give the severe accident management more than 1 day (likely several days) of time to diagnose the accident and to establish the ultimate heat sinks.

For LOCA events, following reactor shutdown, crash cooldown (via opening of the main steam safety valves) is initiated automatically upon detection of the LOCA. This depressurizes the HTS and facilitates HTS refill by:

- Injection from the ECI accumulators, or
- Make-up by gravity from the RWT.

Crash cooldown also reduces the tendency of the secondary side to act as a heat source.

Fuel integrity may be affected if ECI is unavailable and RWT is relied upon for core refill, but the fuel and fuel channels will still be maintained in a configuration that allows long-term heat removal.

Table 1: Severe Accident Prevention and Mitigation Features

SCD Prevention (no loss of core coolability)	SCD Mitigation
Normal Heat Removal Systems	Passive thermal capacity of moderator
Emergency Feedwater System	Passive thermal capacity of reactor vault
Core Makeup Tanks	Passive makeup to calandria vessel from Reserve Water Tank
Emergency Core Cooling	Passive makeup to reactor vault from Reserve Water Tank
Backup moderator heat sink	Other Severe Accident Management features

Once the HTS is sufficiently depressurized, the LTC system begins to take water from the RB sumps and/or the grade level tanks and injects recirculated cooled water into the HTS.

In the event of a small LOCA, heat removal via the secondary side (using Main Feedwater or Emergency Feedwater as the heat sink) would be the method of choice.

In the event of a postulated failure of the LTC system, the fuel and fuel channels will heat up until the pressure tubes contact the calandria tubes, resulting in efficient heat transfer by direct conduction to the moderator. The moderator cooling system can then operate to remove decay heat. The above systems provide severe accident prevention.

If the moderator cooling system is also unavailable, heating, and eventually boiling, of the moderator and reactor vault inventories will occur. The calandria and shield tank rupture discs will burst, and decay heat is removed from the core by discharge of steam to the RB.

Further accident progression is delayed by initiation of make-up to the calandria and reactor vault from the RWS (depending on the time required for the operator to act, RWS make-up may be established either before or after bursting of the rupture discs occur).

6. SUMMARY AND CONCLUSIONS

The severe accident design provisions of the ACR-1000 provide both accident prevention and mitigation. The heat sinks for the fuel channels, the calandria vessel, the calandria end-shields, and the reactor vault are all capable of dissipating the severe accident heat loads. These heat sinks are designed to be operable under severe accident environmental conditions.

The active heat sinks for the various process vessels are 'backed up' by passive heat sinks (e.g., steaming plus water make-up from the RWS). For any postulated accident, there is at least one group of systems available to mitigate the event that is comprised solely of passive systems and features. The supply side of passive heat sinks is simple, rugged, and not vulnerable to failures of plant systems. The importance of the steam relief side is recognized, and the adequate relief capacity is provided. The passive heat sinks will give the severe accident management more than 1 day (likely several days) to diagnose the accident and to establish the heat sinks.

The ACR-1000 design has achieved safety improvements by building on the CANDU traditional design features, by implementing further design enhancements for prevention and mitigation of severe accidents, and by improving reliability in support of key safety functions and heat sinks.

NOMENCLATURE

ACR	Advanced CANDU Reactor
ALWR	Advanced Light Water Reactor
BDBA	Beyond design Basis Accident
CDS	Core Damage State
CMT	Core Makeup Tank
ECCD	Ex-Calandria Core Damage
ECC	Emergency Core Cooling
ECI	Emergency Coolant Injection
HTS	Heat Transport System
ICCD	In-Calandria Core Damage
LAC	Local Air Cooler (containment)
LTC	Long-Term Cooling
RCW	Recirculated Cooling Water
RWS	Reserve Water System
RWT	Reserve Water Tank
SAM	Severe Accident Management
SAMDA	Severe Accident Mitigation Design Alternative
SCD	Severe Core Damage
SG	Steam Generator

REFERENCES

1. M. Bonechi et al., *Safety Basis of the Advanced CANDU Reactor*, Proceedings of the 25th Annual Conference of the Canadian Nuclear Society, Toronto, Ontario, June 6-9 (2004).

2. *Severe Accident Issue Closure Guidelines*, Nuclear Energy Institute, Report NEI 91-04, Rev. 1 (1994).

3. Policy, Technical, and Licensing Issues Pertaining to Evolutionary and Advanced Light-*Water Reactor ALWR Designs*, US Nuclear Regulatory Commission SECY-93-087, April 2 (1993).

4. *An Evolution of CANDU - ACR-1000 Technical Summary*, Atomic Energy of Canada Limited, 115-01372-230-002, Rev 0, January 2006.

5. H. Shapiro et al., *Design Features of ACR in Severe Accident Mitigation*, Proceedings of OECD NEA Workshop on the Evaluation of Uncertainties in Relation to Severe Accidents and Level II Probabilistic Safety Analysis, Aix-en-Provence, France, November 7-9 (2005).

6. Senior Group of Experts on Severe Accident Management (SESAM), *Implementing Severe Accident Management in Nuclear Power Plants*, OECD (1996).

7. B. Lekakh et al., *ACR-1000 Passive Features*, Proceedings of ICONE 14: 14th International Conference on Nuclear Engineering, ICONE 14-89062, Miami, Florida, USA, July 17-20, (2006).