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Automatic DRAC LMFBR to Speed Licensing and Mitigate CO2

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Abstract: - A metallic sodium LMFBR (Liquid Metal Fast Breeder Reactor) can sustain a full power SCRAM shutdown using only natural convection after SCRAM. A venturi DRAC allows this mode change without any active fluid control elements. Venturi DRAC is Direct Reactor Auxiliary Cooling that uses venturi flow control elements. Each venturi DRAC low-pressure side port is connected to a DRAX (Direct Reactor Auxiliary eXchanger) outlet. Primary sodium flow path is from core exit to DRAX inlet, DRAX outlet to venturi side port, out the venturi and back to core. A separate Na or NaK secondary loop transfers heat from DRAX to an external heat sink. Venturi DRAC primary flow path is in parallel with reactor power-production primary sodium flow. Flow is always into the venturi side port. Venturi DRAC primary and secondary circuit flow rates are approximately the same at full power (Mode 1) they are during decay heat removal (Mode 3). DRAX flow is forced by eduction at power and maintained by natural conduction during decay heat removal. At power (Mode 1) DRAC venturi mixes DRAX cold discharge with core feed. A venturi DRAC that has both driver and blanket sodium going through its nozzle at power is referred to as a driver venturi DRAC. Driver venturi DRAC exploits reduced blanket plenum pressure for boundary layer control. Driver venturi DRAC nominal decay heat removal power is between 1% and 3% full core power. DRAC nominal power is the DRAC natural-convection heat transfer rate at full-power bulk temperatures. By definition, maximum core power depends inversely on DRAC nominal decay heat removal capability. A constant-temperature SCRAM requirement makes maximum core power depends on (Core Temperature Rise)^(1 + 1/n). Exponent n ranges from 1.75 to 2, depending on fuel pressure drop characteristics. Remaining DRAC parameters, including full-power pressure drop, influence core design power by exponent 1/n. Venturi DRAC rejects heat at a constant rate regardless of core power. Shutdown decay heat removal is done using only venturi DRAC and primary sodium. Not using secondary loop decay heat removal allows increasing core temperature rise at power. SCRAM thermal shock is mitigated by maintaining secondary loop temperatures. Steam cycle is controlled to mitigate SCRAM thermal shock. Core inlet temperature is optimized for maximum electricity production.
Driver venturi DRAC allows licensing without requiring IHX (Intermediate Heat Exchanger) integrity. Ease of licensing allows LMFBR deployment starting y-2035. Each LMFBR delays CO2 doubling one week, irrespective of uranium resource.

Key-Words: LMFBR, SCRAM, DRAC, Liquid Metal, Decay Heat, Reactor

1 Introduction

This is the fourth ICAPP paper in a series [01][02][03]. A 1.0 GWe metallic sodium LMFBR (Liquid Metal Fast Breeder Reactor) can sustain a full power SCRAM shutdown using only natural convection after SCRAM. A venturi DRAC allows this mode change without any active fluid control elements. Venturi DRAC is Direct Reactor Auxiliary Cooling that uses venturi flow control elements. There are two venturi DRAC types: driver venturi DRAC and blanket venturi DRAC.

Venturi DRAC is used as the LMFBR primary post-SCRAM decay heat removal system. DRAC primary sodium side is natural convection post-SCRAM. Secondary and tertiary backup decay heat removal systems designs are provided as DRAC backup. Primary, secondary, and tertiary decay heat removal systems are independent except guard vessel integrity. Heat transfer to the environment may be by natural convection at the expense of requiring equipment above grade and not generating backup power.

Decay heat removal rating applies to either forced or natural convection systems. Rating is per cent full core power while operating steady-state at full power bulk temperatures. Primary (DRAC) and secondary decay heat removal systems are rated 3 per cent.

Tertiary decay heat removal system operates at elevated temperature and removes roughly 1 per cent full power. Tertiary system operates at elevated temperatures and requires a transient calculation. It is used when primary and secondary systems are inoperable: an anticipated operational incident.

A venturi DRAC that has both driver and blanket sodium going through its nozzle at power is referred to as a driver venturi DRAC. Driver venturi DRAC exploits reduced blanket plenum pressure for boundary layer control.

The patented 1980 blanket venturi DRAC [04][05] is referred to as a blanket venturi DRAC. The patented design was a 1 per cent tertiary decay heat removal system. Only blanket feed goes through its DRAC nozzle at power. At power, driver feed bypasses the venturi to avoid increasing primary pump head. Post-SCRAM, blanket venturi DRAC side port flow divides. Blanket feed goes forward and driver feed goes backwards through the venturi nozzle.

Maximum core power depends inversely on driver venturi DRAC nominal decay heat removal capability. A nominal constant-temperature SCRAM requirement makes maximum core power depends on (Core Temperature Rise)^(1 + 1/n). Exponent n ranges from 1.75 to 2, depending on fuel pressure drop characteristics. Remaining DRAC parameters, including full-power pressure drop, influence core design power by exponent 1/n. It may be possible to design a blanket venturi DRAC that has similar characteristics.

Venturi DRAC can be designed to reject heat at a constant rate regardless of core power. Post-SCRAM decay heat removal is done using only venturi DRAC and primary sodium. Not using power equipment for decay heat removal allows increasing core temperature rise at power. Post-SCRAM thermal shock to power equipment is mitigated independent of decay heat removal.

Driver venturi DRAC allows licensing without requiring secondary loop or steam plant integrity. Ease of licensing allows LMFBR deployment starting y-2035. Each LMFBR delays CO2 doubling one week, irrespective of uranium resource [01]. Rapid LMFBR licensing is required to mitigate an exponentially deteriorating environment [02]. Otherwise, CO2 mitigation using seawater uranium in LWRs is more expensive [03].

Venturi DRAC licensing goal is to make full power SCRAM with Station BlackOut (SBO SCRAM) an unusual event. An unusual event nominally allows returning to full power without major repairs or major inspections.

2 Background

During Nureth11 meetings on October 6, 2002 [03], G. Vaidyanathan and Dr. Endo Hiroshi were discussing problems getting proper fluid flow through a pool-reactor DRAX (Direct Reactor Heat eXchanger). Post-SCRAM natural convection flow was through the DRAX and IHX (Intermediate Heat Exchanger) in series. The discussion included the belief that the DRHX could be located in parallel, instead of in series with, the IHX. Flow could be controlled by using a venturi to control flow through the DRAX as was done in U. S. Patent 4,367,194 [04]. Plumbing DRHX and IHX in parallel, versus series, shortens the reactor vessel and improves decay heat removal. U. S. Patent 4,367,194 [04] is for a blanket venturi DRAC applied to the Atomics International PLBR [06] design. The blanket venturi DRAC was a result of a DOE and NRC research to improve DRAC performance in a loop LMFBR (Liquid Metal Fast Breeder Reactor). Blanket venturi DRAC development stopped in 1980 [05].

3 Plant Configuration

Plant configuration is a modification of the 1977 Atomics International PLBR loop LMFBR design [06]. Major PLBR modifications included using multiple reheat steam cycle [03] and not using steam cycle or intermediate sodium for licensed decay heat removal. PLBR core power was reduced from PLBR 2600 MWt to 2400 MWt and power output was increased from PLBR 1.0 GWe gross [07] to 1.0 GWe net. PLBR primary loop check valves are deleted to compensate for venturi /\P. Reactor outlet temperature is 550 Centigrade, 50 Centigrade higher than PLBR and 15 Centigrade higher than CRBR (Clinch River Breeder Reactor) [08]. PLBR uses 20% CW 316 SS (18 Cr-8 Ni + 2Mo), with a 525 C core outlet limit [07]. Core inlet is 350 Centigrade, similar to PLBR.

3.1 Pressure-Barrier Pool Reactors

Most pool reactor designs have a cold primary sodium pump. Hot sodium goes from reactor to the hot pool, located at the primary liquid surface. Hot pool feeds the IHX inlet. IHX discharges into the cold pool. Primary pump takes suction from the cold pool and discharges into reactor driver and blanket plenums. Hot and cold pools are separated by a pressure barrier REDAN that resists IHX friction /\P.

Optional mechanical REDAN valves may be added to improve post-SCRAM natural convection cooling. Otherwise buoyancy forces may decrease if the IHX fills up with hot sodium.

3.2 Hot-Pump Loop Reactors

Loop reactor design uses a hot primary pump. Pump suction is from the hot pool at the top of the reactor vessel. Primary pump discharge goes to the IHX inlet. IHX discharge goes to the reactor driver and blanket plenums. Hot and cold pools are thermally insulated from each other by an optional REDAN [05]. Some loop designs do not use a REDAN [06]. A 1000 MWe loop reactor vessel is 14 m diameter with a 17 meter normal Na depth above the bottom of the reactor vessel [06].

3.3 Steam Plant Configuration

LMFBR has a secondary sodium loop and a multi-reheat steam cycle [03]. Steam cycle efficiency can be maximized, irrespective of decay heat removal requirements. High steam cycle efficiency increases safety margin by minimizing core to 2400 MWt in a 1000 MWe net power plant.

Net power plant efficiency is 80 per cent Carnot based on secondary sodium temperatures, 1.5 mmHg condenser, and LWR dual-reheat calculations [03]. Reactor thermal power available for power generation is 2330 MWt, leaving 70 MWt for DRAC continuous heat removal and neglecting pump power input.

Reactor inlet and outlet temperatures are 550 Centigrade and 350 Centigrade. IHX temperature drop is 25 Centigrade. Turbine exhaust is 5000 N/m^2 (1.5 inches Hg), giving 32.88 Centigrade condensation temperature:

Net Power = 2330 MWt REACTOR * 0.80
* [1.0 - (32.88 C + 273.15)
* ln ((550 C - 25 C IHX LOSS + 273.15)
/ (350 C - 25 C IHX LOSS + 273.15))
/ (550 C - 350 C)] = 1041 MWe . (01)

The 70 MWt DRAC Brayton Cycle generates another 12 MWe.

4 Venturi DRAC Operation

Figure 1 shows the driver venturi DRAC for a pool reactor. Figure 2 shows the driver venturi DRAC for a Loop Reactor. Figure 3 shows the two types of flow elements that can be used in the venturi DRAC system: 1) Driver Venturi DRAC and 2) Blanket Venturi DRAC. Power flow distributions are shown above centerlines and decay heat removal flow distributions are shown below centerlines. This gives 8 permutations of reactor types, flow element types, and operating modes. The venturi DRAC allows an LMFBR to go from full power mode to post-SCRAM decay heat removal mode using only passive flow control components. A separate DRAC secondary loop transfers heat from DRAX to an external heat sink.

DRAC primary sodium is plumbed parallel to the reactor. A venturi flow control element causes DRHX primary flow to be from reactor outlet to reactor inlet when the reactor is at power. Natural convection maintains the same flow direction when primary pumps are not running. DRAC flow is forced by eduction at power and maintained by natural conduction post SCRAM. Venturi DRAC primary and secondary flow rates remain approximately constant when going from full power (Mode 1) to SCRAM decay heat removal (Mode 3). The patented [04] blanket venturi DRAC flow control element only passes blanket feed. The blanket venturi DRAC is a 1% nominal decay heat removal system. The blanket venturi DRAC can only keep up with decay heat production by allowing a reactor fuel temperature increase post SCRAM. The fuel temperature increase normally regulates the blanket venturi DRAC to being a tertiary decay heat removal system.

The driver venturi DRAC flow control element passes all reactor feed. Its has separate discharges for driver and blanket feed. The larger flow passages enable the driver venturi DRAC to be a 3% nominal system. The driver venturi DRAC maintains constant reactor temperatures immediately post SCRAM. It is this feature that allows the driver venturi DRAC to be a primary decay heat removal system.

Maximum reactor core power depends directly on the ability to remove post-SCRAM decay heat by natural convection. This causes maximum core power to be roughly proportional to (Core Temperature Rise)^(1 + 1/n). For most systems: 7/4 < n <= 2. Core design power is roughly inverse to DRAC nominal power. All other natural convection DRAC parameters influence core design power by roughly the 1/n power.

4.1 Decay Heat Power

Decay heat power is based on 2400 MWt core power. Decay heat is:

Qdecay = 2400 MWt * (10/180)

* Exp(-1.3 * ((Tau - SCRAM)^0.25). (02)

The 2400 MWt * (10/180) at-SCRAM power is from [09][10]. Decay heat is a crude curve fit to published data [10] for more than 1 month at full power. Tau is GMT time in seconds. SCRAM is GMT at SCRAM in seconds.

The DRHX thermal center was chosen to be 4.5 m above core thermal center. Core pressure drop in N/m^2 is chosen to be 0.08 * (Driver kg/s)^n, with n= 7/4. Driver flow is assumed 80 per cent IHX flow. Core /\P is assumed 2/3 DRAC circuit /\P, a simplifying assumption. 3 per cent DRAC approximate results, using liquid Na properties [11], is:

Qpower = (1.2710 kJ/kg-K * (550 C - 350 C)
/(0.8 * 0.03)) * ((0.22473 kg/m^3-C)
* (550 C - 350 C) * 4.5 m * 9.80665 m/s^2
* (2/3)/0.08)^(4/7) = 10592 * 257.2
= 2.724E+06 kWt = Max core kWt. (03)

Equation (3) results is verified by calculating driver flow at power to be 2.724E+06 kWt * 0.8 driver fraction/(1.2710 kJ/kg-K * 200 K loop /\T), giving 8573 kg/s. DRAC flow is 0.03 * 8573 kg/s giving 257 kg/s. DRAC loop pressure drop is (3/2) * 0.08 * (257 kg/s)^(7/4) giving 1980 N/m^2 (0.23 psi /\P). Buoyancy drive around the DRAC loop is 9.80665 m/s^2 * 4.5 m /\h * 0.22473 kg/m^3-C * 200 C /\T giving 1983 N/m^2. Buoyancy drive around DRAC loop equals loop pressure drop. Design core power is limited to 2400 MWt because Outer Loop Decay Heat Removal (OLDHR) calculation assumes a 2400 MWt core. Driver Venturi DRAC can remove 3% full reactor power using natural convection.

Driver venturi DRAC /\P at power was not estimated. The venturi element, at power, is expected to have a /\P that is less than 1/10 primary loop /\P at power. A venturi element /\P increase at power increases primary pump head requirement by the same amount. Absent a complete power plant design, the venturi element /\P is the same magnitude as the uncertainty from estimating a primary loop /\P.

4.2 DRHC Configuration

All flows are in per cent IHX flow. Core feed exceeds 100 per cent IHX flow at power because the venturi educts DRHX (Direct Reactor Auxiliary Heat eXchanger) flow. DRHX is in parallel with the IHX. Some leakage flow may be educted from the cold pool, reducing primary pump size.

At SCRAM, drivers may experience brief temperature increase while DRHX discharge temperature is falling from 420 C to 350 C. Brayton Cycle may require multiple small machines so it can follow post SCRAM decay power decrease. SBO SCRAM with emergency diesel failure is mitigated by maintaining roughly 3% reactor power post SCRAM.

The Atomics International PLBR [06] used a DRAC system for tertiary decay heat removal. PLBR used the steam cycle for primary and secondary decay heat removal. The modified Atomics International PLBR in this paper uses DRAC as the primary decay heat removal system, Figure 1 or Figure 2. First backup (Secondary) is the CTDHR, Cold Trap Decay Heat Removal system, Figure 4. Second backup (tertiary) decay heat removal system is the RCDHR, Reactor Coil Decay Heat Removal system. RDCHR is piping coils between the reactor vessel and guard vessel, Figure 5.

Driver venturi DRAC analysis has DRHX thermal center at 4.5 meters above core thermal center, for both pool and loop reactors. This elevation difference gives 3 per cent full power heat transfer at 200 Centigrade /\T using natural convection. The blanket venturi DRAC analysis [05] used 4 meters and a more complex model.

Driver venturi DRAC loop flow at power is estimated 5 per cent IHX flow. 5 per cent flow is where the DRAC circuit pressure drop, excluding the reactor, equals buoyancy forces.

Driver venturi DRAC rejects 3 per cent reactor thermal power whenever the reactor is producing at least 3 per cent thermal power. Brayton cycle is shown instead of natural convection heat rejection. DRAC makes backup power. Brayton cycle allows all DRAC equipment to be hidden below grade. For SBO SCRAM, reactor could be kept at 3 per cent power post-SCRAM.

5 Venturi DRAC Hydraulics

Flows are per cent IHX primary flow at power. Reactor core is assumed to leak 2 per cent into cold pool. This leakage includes any cooling flow that normally ends up in the cold pool. Reactor leakage is assumed to be at the hot pool bulk temperature, 550 Centigrade. IHX exit temperature is 350 Centigrade. Pool reactors are assumed to leak 1 per cent from the hot pool to the cold pool. Loop reactors are assumed to leak 1 per cent from the cold pool to the hot pool.

At power, DRHX discharge is educted by the DRAC venturi. DRHX flow is estimated 5% IHX flow at power. DRAC circuit pressure drop must equal buoyancy forces at power, without the reactor providing flow resistance.

At power, DRAX discharge temperature is roughly 70 Centigrade higher than the IHX discharge temperature. The 70 Centigrade hotter DRAX discharge causes roughly 20 Centigrade upward temperature degradation to the blanket plenum feed.

The DRAX is designed to remove 3% full power, requiring the core to make 3% power, just to carry the DRHX. All flows are in per cent primary loop design flow. DRHX design flow is 3% during natural convection, with hot and cold pools at the corresponding primary loop normal hot and cold leg temperatures.

At power, DRHX flow increases to an estimated 5 per cent. At a fixed heat removal rate from the DRHX secondary side, a primary-side flow increase decreases the primary side temperature change. Buoyancy forces decrease and pressure drop increases. Equilibrium condition is estimated 5 per cent IHX full-power flow.

DRHX is designed to use buoyancy forces to push sodium from the hot pool to the venturi side port. During decay heat removal, the DRAC circuit must create enough extra pressure rise to push 3 per cent IHX flow through the core during decay heat removal.

At power, all venturi educted flow from the DRHX goes to the reactor low-pressure plenum. In the driver venturi DRAC design, blanket flow is scraped off by an annulus before the mixing region reaches the driver flow. In the blanket venturi DRAC design, only blanket flow goes through the venturi. At power, blanket plenum pressure is roughly 1/5 driver plenum pressure.

In the driver venturi DRAC at power (Mode 1), driver and blanket feed are accelerated in a single nozzle. DRAX discharge is educted into the venturi side port. DRAX flow is nominally 1% core flow at power. Blanket feed is scraped off the flow by an annulus. Blanket and driver sodium undergo pressure recovery separately. This boundary layer control is expected to improve driver sodium pressure recovery in the expansion region.

Driver venturi DRAC has a larger nozzle than does a blanket venturi DRAC. Driver venturi DRAC does not have flow reversal when going from power to decay heat removal as does blanket venturi DRAC. Driver venturi DRAC reverse flow is resistance greater than forward flow resistance. This feature is used to justify eliminating primary loop check valves. Driver Venturi DRAC operation during decay heat removal is similar to MONJU IRACS (Intermediate Reactor Auxiliary cooling System) [12].

Post-SCRAM, after coast down, buoyancy forces circulation around the DRAC circuit. Decay heat conditions for 3 per cent reactor power are shown in Figure 1 (Pool) and Figure 2 (Loop). DRAX discharge temperature falls roughly 70 Centigrade to the IHX at-power discharge temperature.

The 5 per cent DRHX flow at power causes the blanket feed temperature to be roughly 20 Centigrade higher than the IHX discharge temperature. The resulting 400 Centigrade is educted into the blanket feed. All venturi DRAC side port feed is scraped off the jet before the mixing region reaches the driver feed.

At power, 1 per cent IHX flow from the cold pool is used to cool the hot pool wall so that the outside of the entire reactor vessel is at the cold pool temperature. Pool reactors bleed primary pump discharge and loop reactors educt from the cold pool.

A post-SCRAM flow path is made available through the REDAN. This path connects the bottom of the hot pool to the top of the cold pool. This internal flow path has two benefits: 1) It improves transient response and 2) it improves cooling through the reactor vessel wall.

5.1 Pressure-Barrier Pool Reactor Venturi DRAC

Pool reactor conditions are shown in Figure 2. Figure 2 shows two conditions: full power and post-SCRAM, for a driver venturi DRAC. Blanket venturi DRAC configuration would be similar, except post-SCRAM temperatures might be higher.

Primary pump has a suction venturi that allows pump suction to be open to the bottom of the cold pool. Suction venturi picks up pressure barrier leakage from the hot pool ceiling and pulls the hot pool leakage into the pump suction. Entire cold pool is kept at same temperature.

Figure 2 shows the driver venturi DRAC configuration for a pool reactor. The patented blanket venturi DRAC could be used with a slight piping change. In this configuration, venturi DRAX side port must be isolated from the cold pool.

A SCRAM bypass valve is opened post-SCRAM to allow maximum use of elevation differences for natural-convection decay heat removal. The SCRAM bypass helps natural circulation if the IHX lower tube sheet is below the REDAN.

5.2 Hot-Pump Loop Reactor Venturi DRAC

Figure 3 is a hot-pump loop reactor with a driver venturi DRAC. Figure 3 shows two conditions: full power and post-SCRAM, for a driver venturi DRAC. Blanket venturi DRAC configuration would be similar, except post-SCRAM temperatures might be higher.

DRHX discharge venturi allows reactor plenums to be open to the bottom of the cold pool. At power, DRHX discharge venturi picks up reactor leakage and mixes it with DRHX discharge. Combined DRHX and leakage flow goes to DRAC venturi side port.

Figure 3 shows the driver venturi DRAC configuration for a Loop reactor. Venturi DRAX side port is connected to the cold pool via the DRHX discharge venturi.

At power, a primary pump bleed and venturi is used to control upper reactor vessel wall cooling. This feature eliminates the need for mechanical SCRAM valves through the REDAN.

The Loop Reactor DRHX is connected between hot and cold pools. A Cold Pool Trim Eductor (CPTE) is in the DRAX discharge line between the DRAX and the blanket venturi DRAC. The CPTE allows natural circulation post SCRAM between hot pool, cold pool and core. The CPTE prevents DRAX discharge from entering the cold pool when DRHX buoyancy forces exceed cold pool buoyancy forces.

6 Diverse Decay Heat Removal

Licensing requires multiple, independent, and diverse decay-heat removal systems. Normally a LMFBR uses the secondary sodium loop and steam cycle to achieve diversity and independence [06]. Both systems use a secondary sodium loop and a Brayton Cycle. Brayton Cycles are used instead of natural convection so that everything can be below grade.

The diverse and independent methods used in this concept are: 1) Cold Trap Decay Heat Removal (CTDHR), 3 per cent nominal. 2) Reactor Coil Decay Heat Removal (RCDHR), 3/4 per decay heat removal capability.

6.1 Cold Trap Decay Heat Removal (CTDHR)

(FBR-77-1-02011977, Unknown Source: Sodium O2 limit: < 1 ppm O2.) Primary reactor cold trap decay heat removal (CTDHR) system has a stand-by Brayton cycle. CTDHR is shown in Figure 04. 200 kg/s (3600 gpm) primary sodium circulates through the cold trap at all times. 200 kg/s at 1 ppm represents 17 kg/d impurity removal rate.

Atomics International LMEC (Liquid Metal Engineering Center) hockey-stick steam generator experience demonstrated unpleasant results of inadequate cold trap capability. Initial cleanup can take weeks. SBO during initial cleanup can cause irreversible impurity relocation, followed by holes through piping.

Cold trap sodium circulation paths and flows do not change when this system goes from power to decay heat removal. At power and for normal cold trapping, A secondary sodium circuit acts as a cold trap economizer. A mesh less cold trap is shown, requiring sodium temperature to be brought down close to freezing. In normal use, at 200 kg/s, CTDHR removes 5 MWt from the primary system.

Starting the Brayton cycle causes the cold trap system to remove 70 MWt from the circuit. An optional freeze plug is melted to switch cold trap return from the hot pool to the cold pool, to mitigate thermal shock. The system also produces 3.5 MWe backup power. The 3.5 MWe can drive independent parallel EM pumps to ensure flow should SBO occur. Brayton cycle is built using aircraft certified parts and an aircraft starter system. QA for aircraft parts already exists, along with proven performance during acceleration events. Brayton Cycle auto-starts if hot pool temperature criterion is exceeded. CTDHR safety concept falls between PLBR normal operation and PLBR anticipated operational incident [06].

6.2 Outer Loop Decay Heat Removal (OLDHR)

The Figure 5, Outer Loop Decay Heat Removal (OLDHR) system runs all the time. Results are in Figure 5 and Table 1. Secondary sodium circulate through coils that are inside the annulus formed by the reactor vessel and guard vessel. Under normal operating conditions OLDHR rejects 1.5 MWt heat and generates 80 kWe electric power. System has 3/4 per cent decay heat removal capability, 18 MWt, at 800 Centigrade (1472 F) primary sodium temperature. Because of temperature increase, OLDHR is not a "nominal" system. OLDHR is the third fuel protection system. Using OLDHR is a PLBR anticipated operational incident [06]. ODLHR is based on radiant heat transfer from the reactor vessel to the coils.

7 Conclusion

A nominal 3% driver venturi DRAC using natural convection and no active control element is achievable. LMFBR DRAC gets promoted from tertiary decay heat removal to primary decay heat removal. This allows designing diverse secondary and tertiary decay heat removal systems that use metallic sodium. Result is LMFBR decay heat removal that does not use secondary sodium or steam cycle components.

All liquid-metal decay heat removal minimizes licensing issues involving Na-H2O reactions. Not using secondary sodium or steam cycle components for decay heat removal allows maximizing thermodynamic efficiency. This minimizes core thermal power, fission product inventory, and first-core plutonium inventory. All of these factors speed breeder reactor deployment and mitigates atmospheric CO2. Each GWe atomic power delays CO2 doubling 1 week [01].

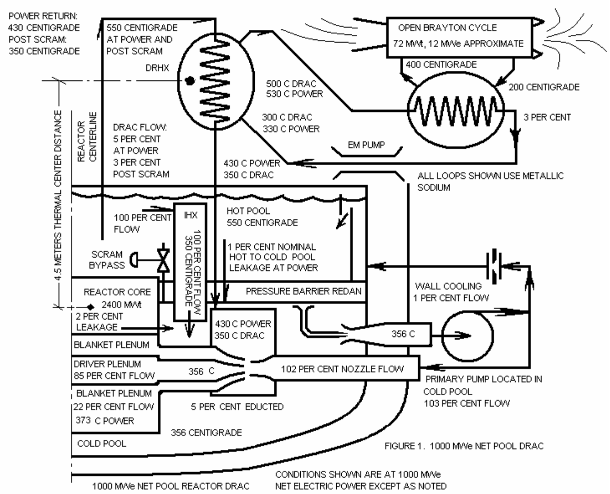

Figure 1. 1000 MWe Net Pool Reactor DRAC.

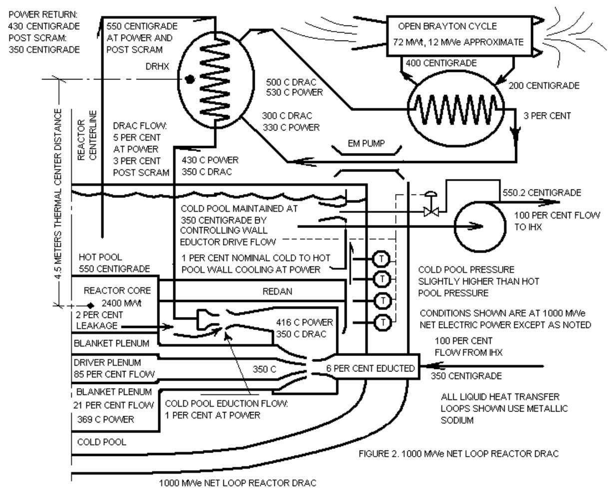

Figure 2. 1000 MWe Net Loop Reactor DRAC.

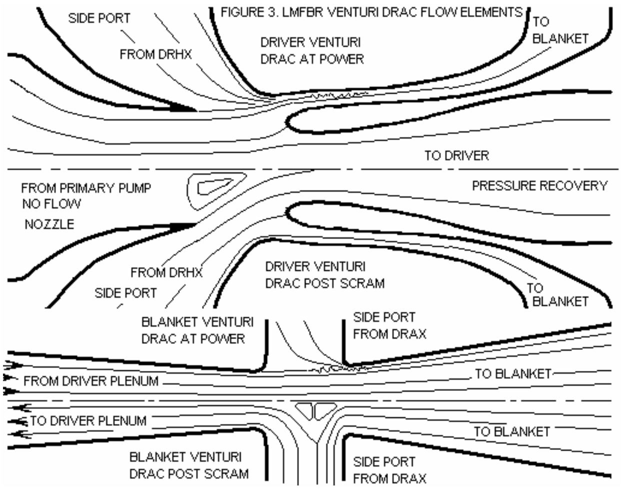

Figure 3. LMFBR Venturi DRAC Flow Elements.

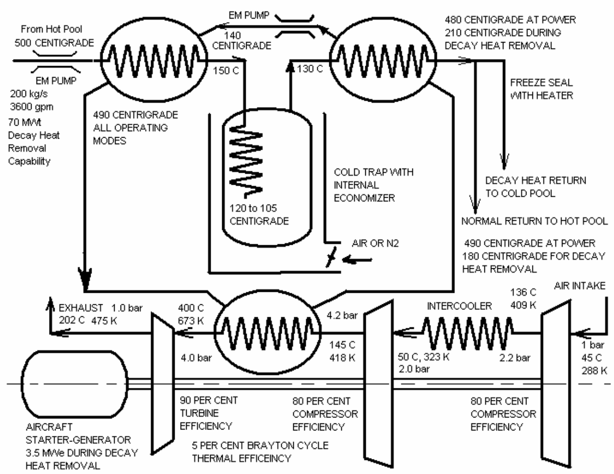

FIGURE 4. LMFBR COLD TRAP DECAY HEAT REMOVAL (CTDHR).

Figure 4.
LMFBR Cold Trap Decay Heat Removal (CTDHR).

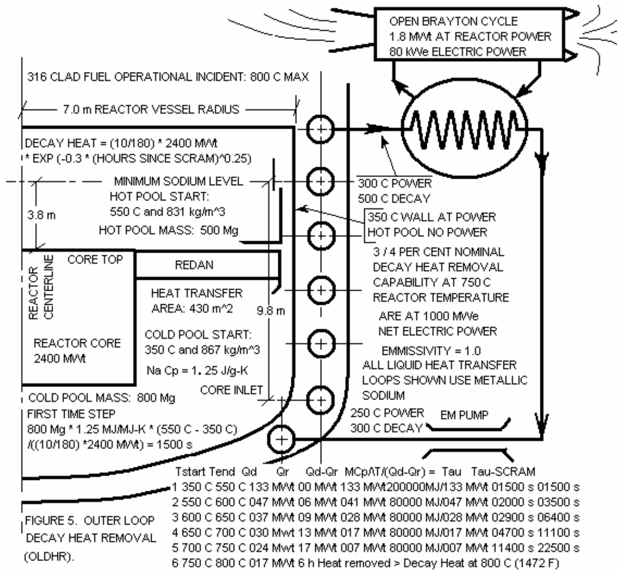

FIGURE 5. OUTER LOOP
DECAY HEAT REMOVAL
(OLDHR).

Figure 5.
Outer Loop Decay Heat Removal (OLDHR).

Sp	Start	End	Decay Heat	Radiation	Seconds - SCRAM
01	350 C	550 C	133 MWt	00 MWt	01500
02	550 C	600 C	047 MWt	06 MWt	03500
03	600 C	650 C	037 MWt	09 MWt	06400
04	650 C	700 C	030 MWt	13 MWt	11100
05	700 C	750 C	024 MWt	17 MWt	22500
06	750 C	800 C	017 MWt	----	---

Table 1.
Outer Loop Decay Heat Removal Transient Results.

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