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Fast Neutron Reactors (FNRs) for Mitigation of Climate Change (Part 2, Hardware Issues)

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ORAL PRESENTATION:
Hello!

Today we can safely assert that future electricity grids will have two power sources. Intermittent renewable power from wind, solar and hydroelectric generation and firm power from nuclear generation. The statistics of renewable power indicate that it is uneconomic at supplying more than 20% to 25% of the total grid energy requirement. The remaining 75% to 80% of the grid energy requirement must be met with sustainable and dependable nuclear generation.

It is shown in Part 1 of this two part presentation that depletion of the U-235 resource will force nuclear reactors to be fueled with U-238 instead of U-235. This fuel conversion to U-238 implies widespread deployment of fuel sustainable Fast Neutron Reactors (FNRs). Rapid fuel conversion requires use of additional Intense Neutron Generators (INGs).

Get used to the reality that there is no viable alternative to FNRs.

Stopping further CO2 accumulation in the atmosphere will require a world fuel sustainable FNR capacity of about;
15,000 X 300 MWe
That is about one new 300 MWe FNR per day every day for the next 45

years. This industrial effort is comparable to the combined aircraft production of Boeing and Airbus. About 300 of these FNRs must be sited in Canada.

The FNRs will need startup TRU. TRU are atoms with atomic numbers greater than 92 that form when U-238 is exposed to a thermal neutron flux. In a FNR TRU enables fuel sustainable operation.

Of particular importance in rapid conversion from today's thermal neutron reactors to FNRs are Intense Neutron Generators (INGs) with sub-critical neutron multipliers to rapidly increase the initial TRU inventory.

It is critical for present young people to grasp that if they fail to promptly deploy sufficient FNR capacity they and their descendants will become victims of CO_2 induced climate change. The ING hardware requirements are set out in ING Status Report July 1967 AECL-2750.

The immediate risk is uncontrolled human migration away from the tropics driven by the rising wet bulb temperature. Uncontrolled human migration is already a significant problem.

In this respect young people should ignore the false and deceptive claims made by governments, utilities and fossil fuel companies and independently study the relevant data..

FNR Primary Coolant:

Many of the FNR physical characteristics are set by the choice of FNR pool coolant. The coolant must meet a number of physical parameters including low melting point, low vapor pressure at its working temperature, low viscosity, high atomic weight, suitable energy dependent neutron absorption cross section, fuel tube compatibility, structural metal compatibility, toxicity and acceptable cost.

Review of the various coolant options indicates that at this time the only practical FNR coolant is sodium.

At some future time availability of economic mono-isotopic molybdenum fuel tube material might change that conclusion, but at this time **Na is the only viable FNR coolant for fuel sustainable fast neutron power reactors.**

However, Na has a number of awkward chemical properties that must be accommodated. Na burns in air and reacts explosively with water. The requirement for Na fire prevention and fire suppression in extreme situations determines many aspects of practical FNR Nuclear Power Plant (NPP) design.

1)**The elevation of the sodium pool must be high enough that the sodium pool will never flood.**

2) Extinguishing a sodium pool fire under worst case circumstances implies the existence of a reliable means of dumping about 16% of the reactor's full load power capacity, **which is about 160 MWt, via steam release.** This requirement sets limits on the height of adjacent buildings.

3) Points #1 and #2 above in combination with foundation requirements constrain the siting of FNR NPPs.

4) An issue of great economic importance in terms of energy conservation is urban siting of FNRs so that the low-grade heat rejected by thermal electricity generation can be used for district heating.

5) Locating FNRs in cities means that for public safety they must operate at a low pressure and must be passively walk away safe.

6) Direct sodium to high pressure water heat exchange is generally a bad idea. Sooner or later even a small heat exchange tube failure will quickly become a big service problem. Such service problems cause prolonged equipment shutdowns that are unacceptable in a power reactor. The sodium and water heat transport loops must to be separated by more chemically compatible heat transport media.

7) The product of the Na heat capacity and density is about (1 / 4) that of water. Hence, other things being equal Na heat transport pipe diameters must to be twice as large as equivalent water pipe diameters

8) Na melts at 98 degrees C and is slightly less dense than water. If Na contacts water, hydrogen gas and NaOH are instantly formed.

9) Generally there should be no piped water in a NPP's nuclear island.

10) Hot Na vapor is potentially very dangerous. Any manual work in the proximity of hot Na requires both extensive personnel protection and an oxygen free atmosphere. Generally argon is used.

11) Neutron irradiated pure Na is radiation safe after about one week after fission shutdown due to the 15 hour half life of Na-24. However, workers should be aware that the Na might contain impurities, especially if there is a fuel tube failure. Do not presume that just because the reactor has been off for a week that the sodium radiation level is safe.

12) Due to its below room temperature melting point and good electrical conductivity it is convenient to use induction pumped NaK in the secondary heat transport circuit.

13) If potassium (mostly K-39) from the secondary coolant leaks into the primary sodium pool over time it will form K-40 which has a 1.4 X 10^9 year half life. Thus over time the sodium pool may gradually become more radioactive. Ideally. a constantly running filter technology should be used to remove K and higher molecular weight species from the sodium pool.

14) All personnel involved must be taught Na and NaK properties and safety issues.

Other Essential FNR Features:

- Governmental investment and regulatory cooperation to achieve workable fuel production automation and safety compliance without serious delays or excessive costs;
- A practical FNR consists of concentric core, blanket, cooling and heat exchange assemblies immersed in a sodium pool;
- FNR enclosure must safely withstand extreme tornadoes, hurricanes, air borne debris, and earthquakes;
- FNRs must safely manage low angle aircraft impacts and RPG attacks;
- FNR enclosure outer and inner walls must both be gas tight;

- FNR enclosure must be equipped for sodium fire suppression and emergency roof repair;
- Flex radial pipe sections to accommodate thermal expansion;
- Modular turbo-steam-electric power plant with at least 15% spare capacity;
- Polar gantry crane;
- Argon cover gas in sodium pool space;
- Argon storage bladder to accommodate argon thermal expansion/contraction;
- Airlocks for fuel bundles, heat exchange bundles and humans;
- Isolated interior service space heat rejection;
- Passive temperature control;
- Two independent cold shutdown systems;
- Multiple independent heat transport systems each with fluid drain down;
- Grid independent backup power sufficient for rejection of both fission product decay heat and sodium pool enthalpy;
- Small NPP footprint for urban installation;
- No external exclusion zone outside the NPP boundary;
- Shared remote fuel reprocessing facility;
- Transportable hot fuel bundles;
- A fuel bundle must not go critical if its transportation container is immersed in water.
- 20% of fuel bundles to be swapped out at 6 year intervals.

In 1965 Atomic Energy of Canada Ltd. (AECL) had the capacity to make INGs. From 1965 to 1990 Canada made large CANDU reactors and supporting heavy water separation systems. From 1964 to 1994 the USA demonstrated the capacity to make and operate sodium cooled Fast Neutron Reactors.

Various incompetent and corrupt politicians destroyed the organizations that harbored these skill sets.
Today, technical expertise in nuclear energy matters is not sufficiently

respected by the persons who populate our government and civil service.

If young people want to survive, they are going to have to re-acquire these skill sets, which today mostly reside in persons who are more than 75 years of age.

Detailed engineering, prototype development and deployment planning for FNRs cannot be financed by either provinces or private industry until the federal government provides for efficient sourcing and reprocessing of FNR fuel;

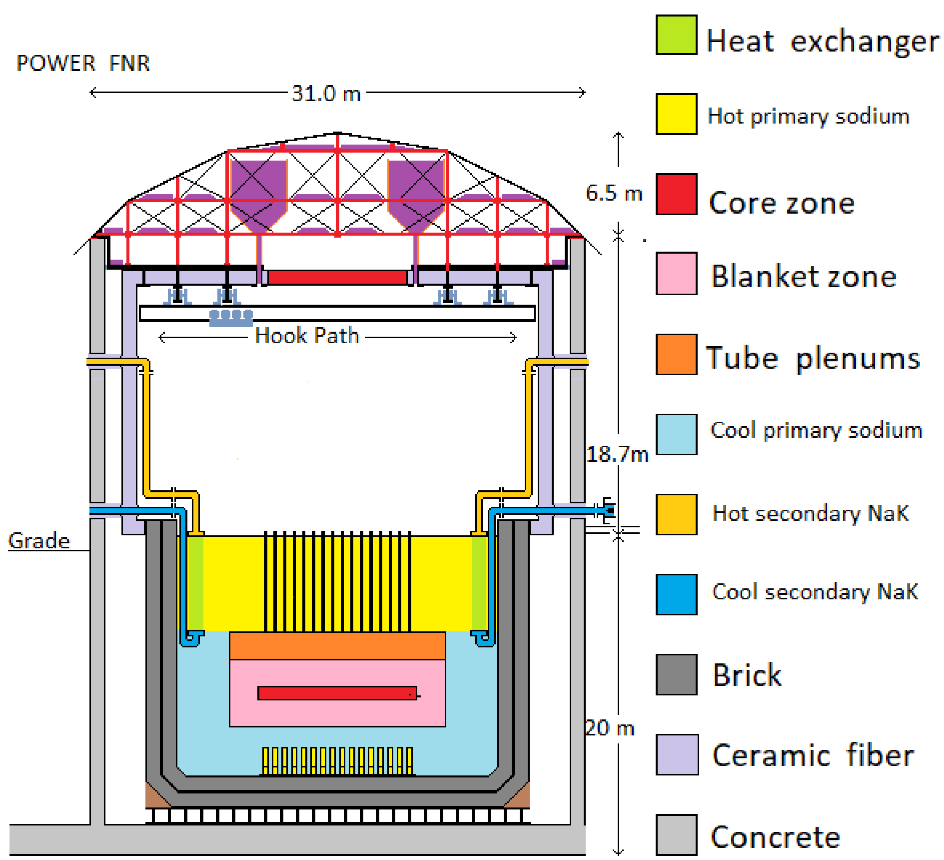

Figure 1

From a structural strength perspective, for safety compliance a FNR enclosure should be comparable to a water tight highway overpass. Forget about artists conceptions to the contrary.

In order to economically build and service FNRs in cities the FNR component modules must be truck transportable and airlocks must provide for safe installation and removal of fuel bundles and intermediate heat exchange bundles.

FNR Description

A basic fuel sustainable FNR consists of the following components:
a) An insulated triple wall sodium pool which confines the liquid sodium and is designed to last for centuries (black and dark gray);
b) A central core region where fast fission takes place (red);
c) A blanket region surrounding the core where depleted U-238 atoms slow and then absorb neutrons which escape from the central core (pink);
d) A cooling region surrounding the blanket region where there is minimal neutron flux. Used core fuel bundles are stored in the cooling region for several years before being removed from the sodium pool (pink);
e) A plenum region above the core and blanket where inert gas fission products are stored (orange);
f)A neutron absorption region surrounding the cooling region where liquid sodium absorption reduces the neutron flux to zero (light blue, yellow);
g) An intermediate heat exchange bundle region, above the neutron absorption region, where heat is extracted from the sodium pool using internal pumped NaK (light green);
h) Gasketed NaK pipe flanges to enable heat exchange bundle replacement;
i) Radial NaK pipes with flex sections to accommodate differential thermal expansion (gold and blue);
j) An overhead space filled with argon gas that allows polar gantry crane manipulation of both fuel bundles and intermediate heat exchange bundles;
k) An overhead polar gantry crane (white);
l) Indicator tubes to convey local reactor conditions to overhead

instrumentation.

The FNR core, blanket and cooling regions contain components fabricated from chrome-steel that are subject to fast neutron damage and are intended to be periodically replaced.

FNR Other Feature Summary:
No high pressure in the nuclear island.
Passive high temperature shutdown;
Two independent cold shutdown safety mechanisms.
Ability to load follow from 10% to 100% of reactor full load rating;
Fuel high temperature disassembly
Gravity safety default
Interior argon bladder
8 X Redundant heat transport
Sodium fire suppression

FNR Fuel:
The FNR core fuel is a metallic alloy initially consisting of 20% Pu, 70% U and 10% Zr. The role of the Zr is to prevent the Pu combining with the adjacent fuel tube material to form a low melting point Pu-Fe eutectic. Metallic fuel is preferred because it is easy to reprocess and it allows use of sodium bonding within the fuel tubes to provide both good thermal contact between the fuel rods and fuel tube and to absorb corrosive fission products. This bonding sodium also plays an important role in suppressing undesired prompt neutron criticality and in mechanical fuel rod sorting.

Summary:
If mankind is to survive as a species FNR technology must be adopted to provide sustainable and dependable clean power.

At this time the only practical FNR coolant choice is sodium. Chloride salts are a future possibility but there are major extra costs for fuel tubes, isotope separations and elaborate reactor chemistry.

Sodium has associated with it significant fire risks which must be faced, especially for urban sited FNRs. For safety compliance a sodium cooled FNR requires very robust nested enclosures with sodium fire suppression capability.

Distributed FNR's require ongoing fuel bundle reprocessing at a central location.

The fuel bundle transportation containers must be designed to ensure that the contents will not go critical if the transportation container is immersed in water.