

Xylene Power Ltd. Is identifying the nuclear reactor related technologies required for mitigation of climate change. The present thinking is summarized below:

- 1) Excess carbon dioxide (CO₂) formed by combustion of fossil fuels is accumulating in the atmosphere and oceans.
- 2) The time frame for natural processes to cause the carbon contained in this excess CO₂ to revert into a fossil fuel is many millions of years.
- 3) Excess fossil CO₂ in the atmosphere is causing global warming.
- 4) Global warming is melting near polar permafrost, which is releasing large quantities of the green house gas methane, causing further global warming.
- 5) Global warming is reducing the average annual circumpolar snow and ice cover which is reducing the fraction of incident solar radiation reflected back into space (planetary albedo).
- 6) The consequent increased absorption of solar energy is causing further warming which is melting the near polar glaciers, causing an ongoing increase in sea level.
- 7) Excess CO₂ dissolved in the ocean is reducing the ocean pH, causing destruction of the marine food chain.
- 8) The best that we can do to mitigate these problems is to completely stop burning fossil fuels.
- 9) Our descendants will have to live with the excess CO₂ that has already been produced plus whatever excess fossil CO₂ is produced until there are sufficient non-fossil energy sources to fully displace fossil fuels.
- 10) Even if we stop burning fossil fuels today global warming will continue to increase due to progressive near polar snow and ice melting which is further reducing the planetary albedo.
- 11) It is essential to recognize that fossil fuels presently supply about 85% of world energy requirements.
- 12) In order to fully displace fossil fuels we need to continuously obtain an at least equal amount of non-fossil energy from new non-fossil energy sources.
- 13) The only sufficient non-fossil power sources are nuclear reactors with sustainable fuel cycles.
- 14) In order to displace present fossil fuel consumption we require about 20,000 GW of new non-fossil thermal power, about 50X the present total world wide nuclear electric power supply capacity.
- 15) This new reactor power capacity requirement can be reduced by about 50% if the new reactors are sited in major urban areas, so that heat can be delivered directly to thermal loads by piped hot water and steam instead of by electricity.
- 16) There is complete failure by western politicians and their lackeys to face the extent of this required nuclear new build, the rate at which these new reactors must be built to combat climate change, the reactor fuel requirements and the related energy transmission infrastructure requirements.
- 17) The opportunities for carbon capture and long term storage are orders of magnitude too small to significantly mitigate the excess fossil CO₂ accumulation.

- 18) To be effective at climate change mitigation the technologies for supplying and distributing the new non-fossil power must be suitable for world wide deployment.
- 19) The nuclear reactor technology must be relatively simple and must not rely on scarce resources or require large numbers of highly educated personnel for deployment and future support.
- 20) The major raw materials used must be abundant, low in cost and readily available world wide.
- 21) Nuclear reactors must be fabricated from materials and material combinations that are well understood and characterized from chemical, physical and nuclear engineering perspectives.
- 22) Fabrication of major reactor components must not require large capital equipment that is only available in a few countries.
- 23) For public safety reasons urban nuclear reactors should have low pressure primary reactor coolants.
- 24) Liquid sodium cooled reactors and molten salt cooled reactors both feature low pressure primary reactor coolants.
- 25) Liquid sodium cooled reactors and molten salt cooled reactors both offer fuel sustainability.
- 26) Liquid sodium cooled nuclear reactors are favored over molten salt cooled nuclear reactors in part due to much greater technology maturity and in part due to much lower educational requirements for field personnel.
- 27) The corrosion control and radio chemistry issues of molten salt reactors that can support sustainable fuel cycles are simply too complex for most field personnel to master.
- 28) Due to lack of suitable geography for seasonal energy storage renewable energy can supply less than 30% of the required non-fossil energy. The balance of the future energy requirement must be met with nuclear reactors operating with sustainable fuel cycles.
- 29) Sustainable fuel cycles will require a mix of U-238 - Pu-239 and Th-232 - U-233 reactors.
- 30) The excess neutrons from the U-238 - Pu-239 fuel breeding technology are required to enable the Th-232 - U-233 fuel breeding technology.
- 31) A sustainable nuclear fuel cycle that maximizes energy recovery from the available nuclear fuel inherently minimizes the long term nuclear waste disposal issues.
- 32) There must be isolated dry storage of nuclear fuel fission products for three centuries to allow safe natural radio isotope decay.
- 33) There must be a comparatively small amount of isolated long term dry storage for disposal of long lived low atomic weight radio isotopes.
- 34) Any non-fossil energy system with sufficient capacity to ensure meeting the annual peak electricity load has surplus electricity generation and delivery capacity at most other times.
- 35) In order for the surplus intermittently available non-fossil electrical energy to be sold for fossil fuel displacement there must be peak demand based retail electricity pricing. The marginal cost of a kWh of surplus electrical energy, when it is available, must be lower than the marginal cost of a kWh of fossil fuel supplied heat.
- 36) Surplus non-fossil electricity will remain economically unavailable to consumers for fossil fuel displacement until provincial and US state politicians approve appropriate restructure of local retail electricity rates. The Canadian federal government should create a tax or like measure that has the practical effect of forcing each province to restructure its retail electricity rates.
- 37) In urban areas the most economic non-fossil heat source will be nuclear heat produced by

distributed small modular reactors (SMRs) and delivered to consumers via a district heating system.

- 38) To achieve economy the SMR nuclear power plant modules should be of common design and performance with standardized lifting points and external connections.
- 39) For public safety the reactor primary coolant must operate at a low pressure.
- 40) For public safety liquid sodium cooled reactors with metallic fuel are favored over other reactor types due to the protection from prompt neutron criticality damage provided by core fuel disassembly within the sealed metal fuel tubes.
- 41) Provincial regulators must enable district heating municipal utilities. These district heating utilities may also supply electricity for heat pumps and rooftop fan coil heat rejection units.
- 42) Municipal planners and building code regulators must do all necessary to enable retrofitting of district heating systems, including provision of energy supply corridors, pipe easements and space for terminal heat exchangers and related pumps.
- 43) Municipal planners must face the issue that the choice of potential distributed reactor locations is constrained by both the reactor elevation requirement and by the district heating system's network and elevation requirements.
- 44) Nuclear power plant modules must be truck transportable along existing city streets and must comply with existing truck load height, weight and length constraints.
- 45) With suitable module replacements urban nuclear power plants should have an almost unlimited operating life.
- 46) Siting nuclear reactors in cities requires a different perspective on public safety than is currently the norm for power reactors.
- 47) The urban nuclear power plants must be safe with no requirement for a perimeter exclusion zone.
- 48) The nuclear reactors should be capable of safe autonomous operation.
- 49) Anything that can go wrong sooner or later will go wrong. When a technical problem occurs a reactor or the affected heat transport systems must automatically shut down and there must be no credible threat to public safety.
- 50) Every reactor must be walk-away safe.
- 51) In order to realize a sustainable fuel cycle the reactors must be physically large enough to capture the entire radial neutron flux. Hence the reactor primary coolant enclosure, which when fully assembled is too large for truck transport, must be assembled on site.
- 52) To enable safe future removal of the primary sodium pool structure and safe intermediate heat exchange bundle replacement these components must not be neutron activated.
- 53) Normal reactor operation should not neutron activate anything other than the reactor fuel and the primary reactor coolant. This constraint effectively increases both the diameter and height of the reactor enclosure.
- 54) To enable large scale world wide deployment the reactors must be inherently simple.
- 55) The reactors and accompanying power plant components should be easy to maintain with a minimum number of moving parts.
- 56) To minimize fuel reprocessing costs the fuel cycle time for each fuel bundle should be 20 to 30 years.

- 57) To minimize fuel reprocessing costs used fuel bundles should be truck and railway transported to a shared remote fuel reprocessing facility.
- 58) The fuel bundle must remain sub-critical when its transport container is accidentally immersed in water.
- 59) The fuel bundle transportation container must remain intact and the contained fuel sub-critical after it is involved in a high speed transportation crash.
- 60) All radioactive fuel should be contained in sealed metal fuel tubes.
- 61) The reactor must be able to safely withstand a horizontal earthquake induced acceleration of 0.5 g without damage and must tolerate a 3 g horizontal earthquake induced acceleration without causing a hazard to the public.
- 62) A major advantage of liquid sodium cooled reactors with metallic fuel is that they can be made with two different temperature ratings.

Medium > 330 C to 480 C at the load, Fe-Cr fuel tubes, stainless steel primary sodium pool enclosure, U-Pu-Zr Na bonded fuel

High > 600 C to 750 C at the load, Mo fuel tubes depleted in Mo-25, 617 alloy primary sodium pool enclosure, U-Pu Na bonded fuel

OPINION:

- 1) We are concerned about the exaggeration and falsehoods presently being circulated by promoters of molten salt cooled reactors. The simple reality is that there is little practical experience with molten salt reactors, and even with an unlimited budget it will likely take over 20 years of R & D before a credible molten salt power reactor design can be considered. The major problems include corrosion control, isotope separations of Li-7 and Cl-37, Mo-95 isotope depletion and moderator durability. There are also many practical plumbing and mechanical issues related to the high melting points of the salts and maintenance of salt purity.
- 2) The on-line radio chemistry required for autonomous operation of a molten salt reactor running a sustainable Th-232 – U-233 fuel cycle has never been demonstrated. Making molten salt reactors operate with a sustainable Th-232 – U-233 fuel cycle will likely require many more billions of R & D dollars and decades of effort before molten salt reactor technology is in a position to significantly mitigate climate change. There are many difficult material issues and there is an unwillingness of electricity utilities to invest in the protracted R & D necessary to address these issues.
- 3) Hence, if we are serious about mitigation of climate change we should be deploying liquid sodium cooled reactors now.
- 4) Liquid sodium cooled reactors are not without their own challenges, but large liquid sodium cooled power reactors have been built and are safely operating today. The material issues are well understood.
- 5) The sodium related safety issues must take precedence over almost all other considerations. This requirement is particularly important with respect to locating the reactor primary sodium pool above the maximum elevation of the local water table.

6) Converting existing North American cities to district heating is a massive task requiring 50 to 100 year future municipal planning. The present political regime of planning only to the next election has to change. A major issue is easements and right-of-way for future energy transmission and public transit corridors. A related issue is site expropriation for nuclear power plants in existing cities. There will have to be major changes in utility related legislation.

7) Another related issue is modification of building and other codes to enable connection to district heating systems. There will have to be major changes in condominium related legislation.

8) Our concern is that both politicians and green energy proponents have put little or no thought into these practical matters. Worse yet, there is political reluctance to learn from parties that do have relevant practical experience. The Russians have lots of real life experience with both large sodium cooled reactors and district heating systems.

9) Why has OPG failed to send a delegation to Russia to learn about these matters? In Toronto there has been a representative of European district heating equipment suppliers for over 35 years. However, that knowledge base has not been utilized by either the City of Toronto or the government of Ontario. There is a "not invented here" mentality.
