Closely Meeting Gen IV Goals

By Victoria Ashley, Roger Ashworth, John Earp, Colin Fuller and Andrew Leigh,Aker Solutions.

1. *What percentage of design of Aker Solutions' ADTR™ Reactor is complete?*

A concept design for the ADTR™ has been developed to date. This comprised performing a technical and economic optimisation of the selected concept to achieve the best for purpose technology, price and delivery programme. It involved identifying a project execution plan and establishing a capital cost budget and programme which was then compared to potential product income levels to build a business case. The concept study is a substantial piece of work with integrity.

2. *During the design phase are you taking advantage of system simulation and other computational tools to analyze safety and licensing issues? Is this effort being undertaken in-house or it is subcontracted to another organization?*

The majority of work done to date has been with in-house expertise. As we develop the design further, written codes will need to be validated to meet the requirements of regulators. Three key simulation packages were utilised:

a) Aker Solutions benefited from Professor Carlo Rubbia's demonstrated capability in reactor core simulation modelling. Energy Amplifier Monte-Carlo (EA-MC) code develops time-evolving calculations for the core and provides isotopic composition of core materials throughout the fuel cycle. This code has been further developed by our own scientist working closely with Carlo Rubbia and is key to understanding the development of waste products within the fuel, neutron damage sustained by the core structure and the resulting evolution of raw reactivity of the core.

b) The review of heat exchangers involved investigating the most appropriate method of transferring heat energy from the lead coolant to the water/steam cycle to generate the electrical power in the turbines, in addition to the heat energy in the various water streams. Heat Transfer Research Institute (HRTI) code was used to determine options for the overall height and diameter of the unit and to provide options to accommodate the mechanical constraints of the vessel.

c) Computational Fluid Dynamics (CFD) modelling examined the coolant flow in the outer shell, core and inner barrel.

3. *Provide a spotlight on the digital instruments and controls of ADTR™. Has Aker Solutions chosen a vendor to supply the digital controls and instrumentation for ADTR™?*

At this stage in the design Aker Solutions has not selected qualified vendors to supply digital controls and instrumentation for the ADTR™. They will be selected at a later date. We are at an early stage where we have considered aspects of reactor control, in particular we have invented a method to measure

Responses to questions by Newal Agnihotri, Editor of Nuclear Plant Journal.

Victoria Ashley

Victoria Ashley is a chartered chemical engineer, with more than 15 years' experience in the nuclear industry. Her experience includes process simulation, modelling, and several project management roles. She has previous experience in process modelling within BNFL and spent 2 years on the Hanford nuclear project leading the design flow-sheeting. She has 5 years' experience in the management of a large team of modellers, providing technology service to nuclear plants. She also has experience of project managing research and facilities activities for nuclear sites, including NDA research portfolios at Sellafield and improvement projects at various sites. Victoria is currently Aker Solutions' Project Manager for the ADTR™ power station development project.

Roger Ashworth

Roger Ashworth has worked as a consultant engineer at Aker Solutions for more than 10 years and is currently Senior Physicist for the ADTR™ project. Graduating from the University of London Kings College as a physicist he has since specialised in simulation software. Using Monte Carlo and Discrete Event software techniques he has modelled systems as diverse as water treatment plants to nuclear processes. Roger also has experience working on remote handling and robot control software for both the offshore oil and gas and the nuclear industries.

the neutron multiplication coefficient, keffective. A keff value of 0.995 has been used as the basis for the study. This allows the use of a smaller and more reliable accelerator thus reducing capital cost and power consumption during operation. This work is fundamental to commercial viability of the ADTR™. Without a method for assessing the reactivity of the system at any chosen moment then safe and effective control of the system cannot be guaranteed. Furthermore, without such a method, it would be imprudent to proceed with design of a system based on such a high keff. The method could be a key enabling technology to control other fast breeder reactors.

4. *Who is manufacturing the key components, such as reactor vessel, turbine, fabricated modules, steam generator (if applicable), diesel generators, piping, large valves, and large motors for ADTR™?*

At this early stage in the design we have not selected qualified manufacturers for key components of the ADTR™. However unlike conventional PWR's and BWR's where the reactor vessel is a major supply issue, the ADTR™ vessel operates at atmospheric conditions and hence is not affected by issues found in manufacturing a pressurized vessel. Hence although the vessel will need to be manufactured to the highest quality standards it is less likely to be limited by supply chain capacity.

5. *Who will be supplying the fuel for ADTR™? Has Aker Solutions, or one of its contractors done a fuel analysis to ensure the optimal efficiency and optimum safety?*

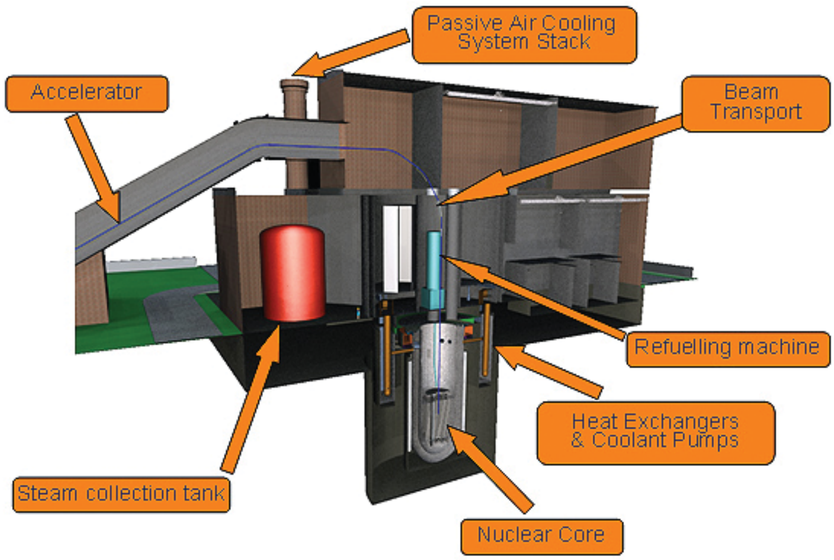
Aker Solutions has not selected the ultimate fuel supply vendor for the ADTR™ at this early stage in the concept design. Aker Solutions has not undertaken analysis of the fuel however the Institute for Energy Technology (IFE) has offered to use their Halden reactor for future fuel testing.

6. *What thermal hydraulic testing and analysis has been done on ADTR™ to ensure reactor safety and efficiency?*

CFD analysis has been undertaken as described in question 2 above. No physical testing has been done at this early stage in development.

7. *Please summarize the results of serious accident analysis, including loss of coolant accident (LOCA) and Non-LOCA analysis that has been done on ADTR™ to ensure safety and reliability?*

A rapid loss of coolant accident is not considered to be credible as the main coolant is not under pressure. The vessel design has no connections or welds below the level designed for the natural circulation circuit required for decay heat removal. The regular maintenance and inspection periods will give advanced warning of vessel wall reduction due to corrosion or crack propagation.



As a result of safety reviews carried out, the maximum credible accident envisaged is guillotine break of the pipe connecting the main vessel to the heat exchanger. This would result in immediate loss of the main heat sink and would initiate shutdown of the reactor (this sequence is led by accelerator switch-off which instantaneously reduces core reactivity). Coolant would continue to circulate within the reactor vessel and remove heat from the core. Decay heat is removed by heat transfer to a series of pipes containing air. Using natural convection these pipes reject heat to atmosphere. This does not result in a degenerated core or radioactive release to the environment.

8. *What are the different applications such as desalination, hydrogen generation, and other industrial applications which may utilize ADTR™?*

Main features of the ADTR™ are its ability to both burn waste actinides and produce power. Other potential applications for future consideration are Process/District Heating and Desalination.

A simplified ADTR™ could heat water/steam for district/process heating. Accelerator sub-critical operation opens the possibility of automatic unmanned operations giving operational savings. The lack of a pressure vessel vastly improves ease of design, aides online refuelling, online servicing together with huge safety improvements and large capital cost reductions. The simplified design potentially reduces the capital expenditure for construction significantly from around £2 billion to £250m.

According to the World Nuclear Association, small and medium sized nuclear reactors are suitable for desalination, often with cogeneration of electricity using low-pressure steam from the turbine and hot sea water feed from the final cooling system. This fits well with the scope of the ADTR™ design.

9. *How will the sale of reactors in small countries such as Vietnam, Indonesia, Thailand, Angola, and others be supported financially?*

World wide funding for nuclear programmes in developing countries has not been part of our ADTR™ study to date. However the global need to reduce carbon emissions and to promote living standards in order to meet aspirations of many developing countries is likely to lead to innovative ways of funding for major infrastructure projects internationally.

10. *How did you determine the material suitability for the reactor vessel and other components taking into account the corrosion, cracking, and other material degradation issues which have occurred in current light water reactors in the last 30 years?*

Selection of structural materials for the ADTR™ requires consideration of reactions between these materials and the liquid lead coolant. This is further complicated when these structural materials are subject to sustained neutron flux. Russian Institutes have investigated this over several decades achieving notable success. Recent work (such as that carried out by Myrrha) continues to improve knowledge in this key area. Therefore, whilst noting this is a complex area, there is confidence that suitable known and understood materials can be used.

11. *What are the design features which makes ADTR™ a better reactor to withstand terrorism attack?*

Using thorium fuel in a breeding cycle generates fission products, plus U232 decays to Thallium208, high energy beta/gamma emitters requiring significant shielding. Hence in the event that a terrorist organisation attempted to acquire spent fuel with the intent to construct a weapon, the irradiated fuel offers a high degree of self protection.

The ADTR™ is based on an extended fuel cycle of 8-10 years. Therefore once the reactor is fuelled, IAEA safeguard seals can be applied at appropriate points on the reactor, prohibiting access to fuel for many years. Fewer fuel movements improve control and independent monitoring of the system and implies less fuel transport when it would be at risk of terrorism.

A further benefit in terms of terrorist resistance is the construction below ground meaning the reactor is highly resistant to damage from external attack such as aircraft impact.

The ADTR™ also has features to give better proliferation resistance compared to other reactor systems, specifically related to no requirement for enrichment. Most modern reactors need to enrich natural uranium to 235U using sophisticated centrifuge technology. The equipment required is identical to that needed to enable uranium to be enriched for use in a weapon. Since thorium does not require enrichment technology proliferation risks are reduced.

12. *Why you believe your reactor may be constructed on time and under budget, without any cost and time overruns?*

For the ADTR™ to be viable as a business opportunity it needs to be among leading Generation IV reactors hence a time line has been constructed which shows it coming to market as an operational power station by 2030. To do this the concept design has been developed where ever possible applying existing technology.

The ability to manage and execute large capital projects professionally is the basis for Aker Solutions' global business. In order to successfully execute complicated projects in a systematic manner according to plans and satisfy client expectations, Aker Solutions has developed its own Project Execution Model™ (PEM), a flexible model that can be adapted to different businesses and projects. Effective implementation of the risk reduction process increases certainty of success so the opportunity associated with further project development can be pursued with greater confidence.

John Earp

John Earp is a chartered mechanical engineer and a Fellow of both the Institutions of Mechanical and Nuclear Engineers. He has more than 44 years' experience in the electricity supply industry, with more than 35 years of this related to the nuclear industry. His career has included nuclear design, engineering, plant operation and maintenance on both AGR and Magnox reactors. Working in the USA on PWR's and BWR's, he evaluated business and management performance related to safe and reliable nuclear operation in a business environment. Latterly, his career has focused on development of strategy and has assisted in the setting up of the UK's Nuclear Decommissioning Authority. He is currently Aker Solutions' nuclear strategy director, the immediate past president of the British Nuclear Energy Society (now the Nuclear Institute), and a member of both the NIA board and the NTEC External Advisory Board.

Colin Fuller

Colin Fuller is a Chartered Mechanical Engineer and a Fellow of both the Nuclear Institute and the Institute of Mechanical Engineers. A graduate of Strathclyde University in Mechanical Engineering, he also holds a Business Masters from Henley Management College and a Science Masters from Lancaster University. A long term Aker Solutions employee he has in excess of 20 years nuclear engineering experience which has covered the complete range of nuclear plant engineering activities from concept design studies through detail engineering and design, installation, commissioning and active plant operation to decommissioning. Colin has carried out consultancy work for both UK and US nuclear clients. Colin is currently the Engineering Manager for the ADTR™ project. He is a member of the Nuclear Institute, board member of the Council of the Institution of Nuclear Engineers and a member of the editorial review panel for "The Nuclear Engineer."

13. *How will ADTR™ minimize its per megawatt cost by making the thermal hydraulics and fuel more efficient?*

The preliminary design is a conventional cylindrical heat exchanger, with the minimum amount of steel adjacent to the core and maximise space efficiency. The steam cycle generated by these heat exchangers is a relatively standard power generating design.

The reactor control system allows easy adjustment of reactor power via adjustment of accelerator beam current. The coolant system will be required to react to changes in reactor power output to maintain the design operating temperatures and steam cycle. The coolant pumps are therefore required to be variable speed to allow control of the coolant operating temperatures and achieve the required heat transmission.

14. *What computational tools have been used to optimize the usage of fuel by providing assistance in design and in operation?*

The computational techniques used so far have been described above. As the project progresses further, computational work will be done to optimise fuel use, for the benefit of both design and operations. Clearly the design already benefits operations in that no fuel movement is required outside of the 10 year fuel cycle.

15. *Who are current Aker Solutions' global partners?*

Aker Solutions is a global engineering and construction business delivering products, services and solutions to the oil and gas, refining and chemicals, mining and metals, power generation, onshore LNG, biofuels, carbon capture, nuclear and water treatment industries. Aker Solutions' vision is to be the preferred partner for solutions in the energy and process industries. We commonly partner for project delivery and have a number of alliances and joint venture partners established in different fields. We are currently pursuing interested parties to become involved in taking the ADTR™ to the next stage.

16. *You may share any domestic or international utilities who have expressed interest in ADTR™?*

We would rather not declare specific organisations however we have received positive responses from utilities, research institutes and industry.

17. *Provide a brief description of ADTR™ providing additional information which is not covered above.*

Aker Solutions has developed the concept design for a commercial 600MW(e) power station based on an accelerator driven, thorium fuelled, lead cooled, fast reactor, derived from original work by Professor Carlo Rubbia.

The ADTR™ has many features to meet the Generation IV goals of sustainability, economics, safety and reliability, proliferation resistance and physical protection. Minor actinides generated from reactors fuelled with natural uranium are the most problematic wastes in irradiated fuel to handle. Thorium fuelled reactors do not create actinides since 238U is not present. In fact the ADTR™ can be configured to burn actinides whilst producing power, further reducing the long term waste burden. Several unique features of the reactor mean it can be deployed in countries with aspirations to gain benefit from nuclear power and its size fits the gap for less mature grid systems.

For the ADTR™ to be a viable business opportunity it needs to be among the leading Generation IV reactors to market hence the first ADTR™ is planned to be an operational power station by 2030 To do this the design has been developed wherever possible applying existing technology. Cost analysis demonstrates the ADTR™ could be built at costs per MW output equivalent to conventional nuclear power systems. Also, since refuelling intervals are long, operational costs are reduced.

The next stage, requiring significant investment, will underpin the technology with development programmes and progression of engineering. It is essential that physical testing commences to provide empirical data and prove physical aspects of the design. Current activities are focussed on securing the necessary investment to take the project forward. The project team is publicising Aker Solutions' market lead in this technology, engaging with potential partners. Aker Solutions have a passionate belief that the ADTR™ technology has real potential to be part of the nuclear renaissance to solve many future energy issues.

Andrew Leigh

Andy Leigh is a chartered chemical engineer with more than 25 years experience in the nuclear industry. Andy leads Aker Solutions' interests in the global nuclear market. Based in the UK, he is a member of Magnox North's Trawsfynydd Strategic Integrated Framework (TSIF) steering group and a board member of ACKtiv, the joint venture between Atkins, Carillion and Aker Solutions. He has managed several major nuclear and non-nuclear projects and has extensive nuclear design, commissioning and decommissioning experience. Andy was the Project Manager for the Legacy Ponds Projects at Sellafield undertaken in an integrated team with the client. He is familiar with business case preparation, design, safety of nuclear waste management projects and the management and co-ordination of all required engineering, project services and site inputs.

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