Current Status and Prospects for Small Modular Reactors

Tony Irwin, Chair, Nuclear Engineering Panel, Engineers Australia

1 pm Thurs 1 May 2014
AINSE Theatre, New Illawarra Rd, Lucas Heights, NSW.

Abstract
Small Modular Reactors (SMRs) have the potential to provide low emissions baseload power to remote areas and small grid systems. SMRs have high levels of "natural" safety and the reactor containment can be installed underground providing protection against external hazards and unauthorized access. Construction has started in Argentina on the world's first new design SMR and one USA vendor will be submitting their formal Design Certification Application to the NRC this year.

This presentation will examine the current licensing status and deployment plans of water cooled SMRs and also review progress with some of the more advanced designs.

About Tony Irwin
Tony Irwin graduated in electrical engineering and worked for British Energy (formerly the Central Electricity Generating Board) in the UK for more than thirty years commissioning and operating 8 nuclear power plants.

In 1999 he moved permanently to Australia and joined ANSTO’s Department of Government and Public Affairs where he managed fuel strategies, including two spent fuel shipments to France, and provided advice on nuclear energy. In 2004 he was appointed as Reactor Manager for the commissioning and early operation of the new OPAL research reactor.

Since retiring in late 2009, Tony is Chairman of Engineers Australia Sydney Division Nuclear Engineering Panel and visiting lecturer for the Master of Nuclear Science Course at the Australian National University and the Nuclear Engineering course at the University of New South Wales. Tony is the Technical Director of SMR Nuclear Technology Pty Ltd, an Australian company established in 2012 to provide Australia with the option of SMRs for electricity generation.
Small Modular Reactors (SMRs)

- Reactors with a power output < 300 MWe (IAEA), more usually < 200 MWe
- Factory built reactor module

Three technologies:
- Light water reactors (coolant and moderator)
- Fast neutron reactors
- High temperature gas reactors
Small Modular Reactors (SMRs)

- Provide baseload, low emissions power in remote locations or for small grid systems
- High level of passive or inherent safety
- Reactor vessel can be installed below ground
- Compact, factory built, transportable module – reduced on-site construction time
- Modules can be added as demand increases
- Simpler to operate and maintain
- Long time between refuelling
## Light Water Reactors

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US Department of Energy Initiatives

SMR Licensing Technical Support Program

*To promote the accelerated development of SMRs by supporting certification and licensing requirements through co-operative agreements with industry*

- March 2012 – First Funding Opportunity Announcement
  - Five year $452m cost share program for two designs
  - November 2012 - first award to B&W mPower - $79m
  - DOE funding of $101m to March 2014

- 2013 – Second Funding Opportunity Announcement
  - Up to $226m
  - December 2013 – second award to NuScale Power
  - Funding agreement expected this month
Primary cooling circuit
Pressure 14 MPa
Inlet 322°C, outlet 348°C
8 primary coolant pumps
Flow 3.1 m/s

Secondary steam circuit
Pressure 5.7MPa
SG Inlet 227°C, turbine 304°C
31°C superheat
Balance of Plant

- Plant designed to produce a nominal 160 MWe
- Conventional steam cycle equipment (small, easy to maintain and replace)
- BOP operation not credited for design basis accidents
The B&W mPower Standard Nuclear Plant

1. 2 x 180 MWe* units
2. Compact <0.16 km² (40-acre) site footprint* 
3. Separated Nuclear and Turbine Islands 
4. All safety-related systems underground 
5. One-to-one reactor to T/G alignment 
6. Optimized for minimum staff and O&M 
7. Water- or air-cooled condenser option 
8. Conventional steam cycle components 
9. “Island Mode” and load following operation 
10. Small Emergency Planning Zone (EPZ) radius 

*with water-cooled condenser
mPower Integrated Systems Test Facility (IST) Lynchburg, Virginia

- Licensing support
- Design evaluation
- Develop operating procedures
- Training
- Full operating conditions from July 2012

Full height, full operating pressure and temperature, separate reactor and steam generator, electric heating, 15/20 staff, 24 hour real time operation
Power, area and volume (~1/400) scaled, 19 tube steam generator

Test scope: normal operation; reactor coolant system performance; steam generator performance; transient operation; natural circulation; LOCA/ECCS performance; steam generator tube rupture; protection and control; loss of offsite power and station blackout
mPower Control Room Simulator

Reactor protection and post-trip monitoring

Unit 1

Unit 2

Common plant systems
First Deployment

- Tennessee Valley Authority (TVA) signed letter of intent May 2011
- Clinch River site, Roane County, Tennessee, adjacent to large DOE site (ORNL)
- Site characterisation completed: core boring, groundwater wells, metrology tower operating for 2 years, botany, wetlands,
- Site analysis in progress: groundwater analysis, flood analysis, environmental baseline
- Pre-application interactions with NRC for Construction Permit Application (10 CFR 50)
**NuScale 45 MWe Module**

- **Reactor vessel**
  - 2.7m OD x 19.8m high

- **Complete module**
  - 4.6m dia x 24m high

- **Natural circulation**
  - 8.72 MPa, core outlet 329°C
  - Two helical once through steam generators

- **Module sits in a large pool**

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*Convection – energy from the nuclear reaction heats the primary reactor coolant causing it rise by convection and natural buoyancy through the riser, much like a chimney effect.*

*Conduction – heat is transferred through the walls of the tubes in the steam generator, heating the water (secondary coolant) inside them to turn it to steam. Primary water cools.*

*Gravity – colder (denser) primary coolant “falls” to bottom of reactor pressure vessel, cycle continues.*

Source: NuScale Power
Our testing supports reactor safety code development and validation, reactor design, and technology maturation to reduce FOAK risk.
3 clusters of 4 modules each
One operator/cluster

7 screens for each module
9 screens for common plant

Source: NuScale Power
What is Project WIN?

- Western Initiative for Nuclear (WIN) is a multi-western state collaboration to investigate the demonstration and deployment of an innovative SMR design developed by NuScale Power, sited in ID.
- Involved Project WIN participants: NuScale, UAMPS, Energy Northwest, ID, UT, OR, WA, WY, AZ, NM?, MT?

Source: NuScale Power
Other USA Vendors

• Westinghouse 225 MWe
  – Westinghouse priority now completion of AP-1000 projects

• Holtec SMR-160
  – Natural circulation
  – Supported by URS, PSEG Power and SCE&G
  – Design Certification Application expected late 2016
US Licensing Challenges

• Multi-module facilities
• Control room staffing
• Security requirements
• Emergency planning requirements
• Licence fees
• Insurance and liability
• Decommissioning funding

• How to take benefit from the safety advantages of SMRs
PREPARING THE SITE

RÍO PARANÁ DE LAS PALMAS

PREDIO CAREM-25

ATUCHA I y II

CAREM PROJECT
REACTOR AND BOP BUILDINGS

CAREM PROJECT

CAREM25
CAREM-25 first concrete – 8 February 2014

Cold testing scheduled for 2016, initial fuel load 2017
KLT-40S  OKBM, Russia
150 MWTh / 35 MWe

Pressuriser 2nd reactor
Pressuriser
CRDM
PCP
Reactors
Hx
Steam generator
ECCS accumulator
steam to turbine
FLOATING POWER UNIT AT BUILDING BERTH
BALTIYSKY ZAVOD, JUNE 2010

Barge 140m long x 30m width, 21,000 t displacement
Akademik Lomonosov Floating Power Unit
2 x 35MWe KLT-40S PWRs on 21,000 tonne barge
Initial deployment near the port of Sevek, Chukotka, East Siberian Sea

2007 keel laid
2010 hull launched
2011 turbines installed
2011 shipbuilding company bankrupt
2012 new contract
Sept 2013 reactors installed
Delivery scheduled for September 2016
ACP 100 (China)
Developed by NPIC/CNNC
310 MWTh, 100 MWe

Primary circuit forced circulation 15 MPa, 4 canned reactor coolant pumps
Secondary circuit steam 4.5 MPa, 287°C

57 fuel assemblies, 17x17
24 months refuelling
2.2 Main technical characteristics of ACP100

- Integrated layout of primary system and equipment. So the large LOCA accident is eliminated. And the dimension and the amount of the penetration in RPV can be also reduced.
- Large primary coolant inventory. The thermal inertia is increased.
- Small radioactivity storage quantity.
Nuclear Power Technology Development

CNNC: ACP100 - Multi-Purpose Small Modular Reactor

- Adapting the passive safety system and integrated layout
  - NSSS designed as module, with SG installed inside RPV

- Combined production of power, heat, steam and fresh water

![Diagram of nuclear power plant with multiple output pathways: Electricity, City heating, Industrial steam, Desalination]
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<td>DCA 2017</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CPA ?</td>
</tr>
<tr>
<td>USA</td>
<td>NuScale</td>
<td>45 MWe</td>
<td>DCA late 2016</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>COLA early 2017</td>
</tr>
<tr>
<td>USA</td>
<td>Westinghouse</td>
<td>225 MWe</td>
<td>DCA?</td>
</tr>
<tr>
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<td>Holtec SMR-160</td>
<td>160 MWe</td>
<td>DCA 2015</td>
</tr>
<tr>
<td>South Korea</td>
<td>KAERI SMART</td>
<td>100 MWe</td>
<td>Design approved 2012</td>
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<td></td>
<td></td>
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<td>Construction 2015?</td>
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<tr>
<td>Argentina</td>
<td>CNEA/INVAP CAREM</td>
<td>27 MWe</td>
<td>Construction started February 2014</td>
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<td></td>
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<td>Fuel load 2017</td>
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<td>Russia</td>
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<td>Delivery due Sept 2016</td>
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<td>Deployment 2014/5</td>
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</table>
Gen 4 Energy

Fast neutron reactor
70 MWTh / 25 MWe
Lead Bismuth Eutetic cooled
Outlet temperature 500°C
Reactor 2.5m x 1.5m
Weight < 35 tonnes

Uranium nitride fuel
19.75% enrichment
10 years core life – return to factory
Shandong Shidaowan Plant
Construction commenced December 2012
Scheduled operating 2017

**HTR-PM Designs Parameters**

<table>
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<tr>
<th>Parameter</th>
<th>Value</th>
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<tbody>
<tr>
<td>Plant electrical power, MWe</td>
<td>211</td>
</tr>
<tr>
<td>Core thermal power, MW</td>
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<tr>
<td>Number of NSSS Modules</td>
<td>2</td>
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<tr>
<td>Core diameter, m</td>
<td>3</td>
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<tr>
<td>Core height, m</td>
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<tr>
<td>Primary helium pressure, MPa</td>
<td>7</td>
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<tr>
<td>Core outlet temperature, °C</td>
<td>750</td>
</tr>
<tr>
<td>Core inlet temperature, °C</td>
<td>250</td>
</tr>
<tr>
<td>Fuel enrichment, %</td>
<td>8.9</td>
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<tr>
<td>Steam pressure, MPa</td>
<td>13.25</td>
</tr>
<tr>
<td>Steam temperature, °C</td>
<td>567</td>
</tr>
</tbody>
</table>
Conclusions

• Funding issues are slowing progress in the USA

• Construction started on the world’s first new design SMR in 2014 (CNEA CAREM)

• The KAERI SMART SMR was the first in the world to achieve Design Approval (2012) and construction of a demonstration unit is likely to commence soon

• Construction of a demonstration ACP 100 SMR is likely to commence soon in China
Offering Australians the option of developing the safest nuclear power generation based on Small Modular reactors

www.SMRnuclear.com.au