The AVR as Small Modular Thorium Very High Temperature Reactor: Experiences—Design—Safety—Fuel Cycle

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Abstract: As a young engineer in the power plant department of Brown Boveri, Dr. Schulten had the idea to design nuclear power stations without major risk. The following requirements must be accomplished:

- A negative temperature coefficient had to avoid an MCA (Maximum Credible Accident);
- Ceramic materials for core construction and fuel elements;
- A homogenous mixture of nuclear fuel and graphite had to be able to use uranium and thorium as breeding material;
- The produced high temperature heat shall be the basis for production of electricity, drinking water, hydrogen, etc.;
- A relatively simple plant, which could be operated in developing countries, to cogenerate electricity and heat;
- Helium used as cooling gas.

Key words: High temperature technology, nuclear, reactor.

The AVR GmbH (Atom Versuchsreaktor GmbH) was established in 1959 and ordered in 1960 to construct the new experimental power station (Fig. 1) by BBC/Krupp GmbH, which was founded by Brown Boveri and Krupp, mainly through the initiative of Dr. Berthold Beitz, to develop Schultens ideas [1-3].

Start of the design began in 1960, first criticality reached in 1966, and start of power production in 1967. The AVR was in operation for 22 years and had to be shut down in 1988 by order of the Government [4]. No safety incidents occurred during that timer.

The main design features are:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermal power</td>
<td>46 MW</td>
</tr>
<tr>
<td>Electric power</td>
<td>15 MW</td>
</tr>
<tr>
<td>Steam conditions</td>
<td>505 °C, 172 bar</td>
</tr>
<tr>
<td>He-Cooling gas temperature</td>
<td>950 °C/10.8 bar</td>
</tr>
<tr>
<td>Fuel</td>
<td>Triso coated pebbles</td>
</tr>
<tr>
<td>Power production</td>
<td>$1.6 \times 10^{10}$ kWh</td>
</tr>
<tr>
<td>Availability</td>
<td>67.2% average up to 92%</td>
</tr>
</tbody>
</table>

The high availability shows the quality of design of the complete power station with all components including: the new graphite construction, the steam-generator, the blowers, the fuel recycle system and all major components. The combined installation of the pebble bed core and the heat exchanger in one pressure vessel was very important for safety reasons.

The most important experience gained only in the AVR and THTR300 (Thorium Hochtemperaturreaktor 300 MWel) was first fueling and operation using Pebbles with Triso coated particles, the German development, containing uranium, thorium as breeding material and plutonium. They proved from the beginning as extremely safe and reliable nuclear fuel (Fig. 2). The operation with Triso coated Pebble-Fuel-Elements by continuous charging and measuring of each single pebble makes it possible to keep the NPT (Non Proliferation Treaty) [4-6].

The design of SMTVHTR (Small Modular Thorium Very High Temperature Reactor) Power plants will be nearly the same as the AVR design in a capacity range...
Fig. 1  The AVR 46 MWth/15 MWel experimental HTR power plant.

Fig. 2  Composition of a TRISO-pebble.

from 20 MWth up to 100 MWth with the following improvements and modifications (Fig. 3):

- Only one instead of two steel pressure vessels;
- Helium gas pipe work without surrounding pipes for He-barrier gas;
- He/primary-He/secondary heat exchanger instead of steam generator in the pressure vessel;
- He cooling gas temperature up to 1-100 °C/10 to 70 bar;
- He-barrier-gas system is not necessary;
- He/sec./water-steam-generator up to 200 bar; 525/525 °C;

All the experiences gained from the complete plant, as well as 23 years of successful operation of the AVR
will be the basis for the design of the SMTVHTR. It will be designed to produce heat and electricity for all kinds of secondary plants mainly those consuming very high heat, such as coal gasification, drinking water and hydrogen production and natural gas fracking [7, 8].

This compact of Small Modul Reactor Concept can also be installed in large ships to drive them with nuclear power and on platforms to produce electricity in polar regions and for oil drilling platforms.

The safety of this design was proven during the first worldwide first MCA simulation tests [2, 4, 5]. The thermal behavior of the AVR core in those difficult situations is shown in Fig. 4. These tests proved the total safety of the AVR design under all circumstances [2, 4, 9].

The improved AVR is by far the best developed and operational completely tested SMR (Small Modular Reactor).

Further and more detail design explanations are published in atw special print and atw 3 (2018) [2, 4, 6, 10].

Larger THTR up to 4.000 MWth are designed with a PCPV (prestressed concrete pressure vessel) for safety reasons [2, 4] (Fig. 5).
Fig. 4  Results of loss of coolant LOCA/MCA accident of AVR.

Fig. 5  Pre-stressed concrete pressure vessel and THRT-300 core.
References