2nd International Technical Meeting on Small Reactors
Ottawa, Ontario, Canada, 2012 November 7-9

Molten Salt Small Modular Reactors (MSSMRs): From DMSR to SmAHTR

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ABSTRACT – Molten salt reactors were developed extensively from the 1950s to 1970s as a thermal breeder alternative on the Thorium-U233 cycle. Simplified designs running as fluid fuel convertors without salt processing as well as TRISO fueled, salt cooled reactors both hold much promise as potential small modular reactors. A background will be presented along with the most likely routes forward for a Canadian development program.

1. Introduction

Molten Salt Reactors were originally developed as a potential aircraft reactors with a successful test reactor built in 1954 which ran at up to 860 C. This work led to a major breeder power reactor program from the late 1950s to mid 1970s at Oak Ridge National Laboratories highlighted by the 8 MWth Molten Salt Reactor Experiment that ran from 1965 to 1969. Design work resulted in a Single Fluid, graphite moderated Molten Salt Breeder Reactor in competition with the sodium cooled fast breeder reactor. Given the belief at the time of very limited uranium resources a breeder design with as short a doubling time as possible was the ultimate goal (time to breed fuel needed for the next breeder). This led to an aggressive proposed salt processing of removing most fission products from the salt on a 10 day cycle giving an impressive 20 year doubling time. Ultimately though in the mid 1970s the U.S. decided to focus solely on the fast breeder option and the ORNL program was canceled.

Molten Salt Reactors saw a reemergence of interest when chosen as one of six GEN IV reactors in 2002. An objective review shows MSRs have unique attributes, that while foreign to many nuclear engineers, lead to clear potential advantages ranging from overall costs, safety, resource sustainability and long lived waste issues [1]. Much of this revival of interest has continued to focus on breeder options and while fluid fuel does simplify processing technology the degree of difficulty and costs can be underestimated by many, especially in terms of needed R&D. Recently however there is increasing interest in removing this aspect of MSR design by going to simplified convertor designs that skip salt processing at the modest expense of needing a small annual makeup of low enriched uranium (only a small fraction needed for LWR or CANDU). This work is based on the final funded efforts of ORNL in the late 1970s on a design termed a Denatured Molten Salt Reactor running on thorium and low enriched uranium that both greatly simplified plant design and also increased proliferation resistance by denaturing the U233.

Much of the advantages of MSRs come from the superior nature of the fluoride salts as coolants, operating at ambient pressure with very high boiling points and high volumetric heat capacity. This has led to a recent concept to use fluoride salts as coolants of TRISO solid fuels in the form of pebble beds or solid fuel blocks [2,3]. While not having as strong a case on resource sustainability and long lived waste profile as true molten salt fueled options, many view these new options, termed FHRs (Fluoride High Temperature Reactors) as potentially being faster to develop and gain acceptance. Many innovations have been made in the FHR field that may see use for fluid fuel MSRs as well.

2. Denatured Molten Salt Reactors (DMSR)

Work at ORNL in the late 1970s focused on greatly simplifying to converter design where both fuel salt and graphite would attain a full 30 year cycle [4]. Even without salt processing, resource utilization was determined to be excellent, roughly 1/6th that of LWR. A single batch processing after many years of use with transuranic recycle would give a waste profile virtually free of actinides. This simple design lends itself well to scaling to small modular reactor size of anything from a few tens to hundreds of MWe. While work by the author and others on various design simplifications is not ready for full disclosure several innovations made under the ORNL FHR program, specifically the SmAHTR design have obvious carry over to MSR designs.

3. Small Advanced High Temperature Reactor SmAHTR

Salt cooled designs or FHRs have been under development in the U.S. for roughly a decade. Led by MIT, UC Berkeley and ORNL the basic design principle is using fluoride salt coolants for TRISO fuel particles.   MIT and Berkeley have focused on pebble beds while ORNL work is on various fuel block forms. The relative advantages of each are reviewed in Table 1. Of particular interest is the SmAHTR design which has introduced many innovations including integrating both primary heat exchangers and decay heat removal systems within the primary vessel. This also relieves the vessel head of significant neutron flux. Details are available elsewhere [3] but this 125 MWth, 50 MWe design has many advantages and obvious direct overlap into fluid fueled MSR design as depicted in Figure 1 in which the solid TRISO fuel core is replaced by simple graphite and fuel is relocated to the salt. A simple filler void helps lower overall salt volume and should be depicted in the bottom plenum as well.

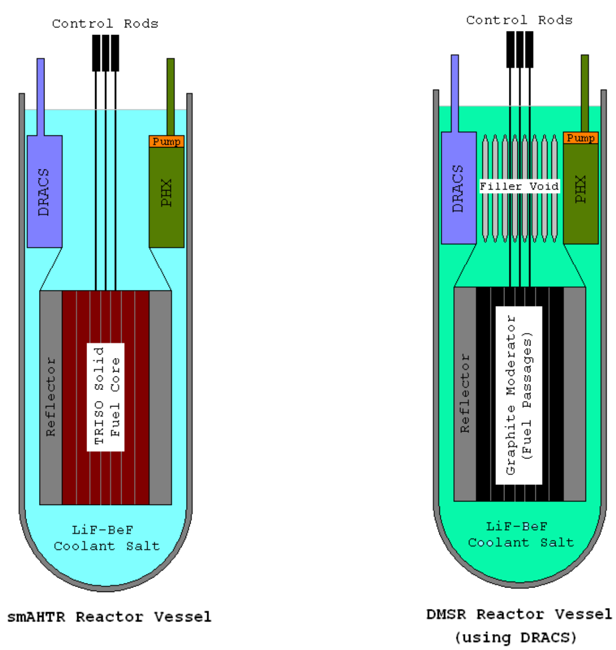

Figure 1 The ORNL SmAHTR.design on left and a simple DMSR counterpart on the right

Table 1 Contrasting DMSR and FHR. All share expected cost and safety advantages versus LWRs

	DMSR Converter	FHR Pebble Bed	FHR Fuel Blocks
Uranium Utilization	Far Superior to LWRs, roughly 1/6th	Slight Reduction to LWR (roughly CANDU levels)	Burnable poisons needed and up to twice LWR U needs
Fuel Cycle Costs	Less than 1/10th LWR, low U and no fabrication costs	Roughly the same as LWR, less U, high fabrication	Higher than LWRs and any FHR require new fuel factories
Waste Profile	With Batch Processing, almost zero TRU waste but potentially more contaminated components	Reprocessing fuel harder than LWRs. Larger solid waste volume but a well contained waste form	Same as Pebble FHR but less volume
Major Challenges	Periodic graphite replacements, Off Gas systems, servicing of Heat Exchangers, tritium	Pebble handling equipment, high pumping power needing cross flow, tritium management	Fuel block replacement (whole core or batch), tritium management

4. Conclusions

Both molten salt "fueled" (MSRs) and molten salt "cooled" (FHRs) show great potential as both base load power generators and more specifically as ideal Small Modular Reactors. Interest within Canada is growing, partly due to the halt of most advanced CANDU studies. Along with growing academic and corporate interest is the fact that an ideal proving ground exists in the western Oil Sands where the high temperature output (700 C) of these reactors appears ideal for replacement of natural gas use in Steam Assisted Gravity Drainage [5,6].

5. References

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