NTech
Lehrstuhl für
Nukleartechnik

Technische Universität München

MOLTEN SALT REACTOR

Lehrstuhl für Nukleartechnik - Technische Universität München

Boltzmannstr. 15 85747 Garching

www.ntech.mw.tum.de

1 MOLTEN SALT REACTOR

1.1 CONCEPT DEVELOPMENT

The Generation IV Roadmap selected the Molten Salt Reactor (MSR) concept as one of the six technologies for further development under Generation IV. The decision for setting up a Provisional System Steering Committee (PSSC) for the MSR was taken by the GIF Policy Group in May 2004. The participating members are France, the United States and Euratom. Other countries (Japan and Russia) have been represented occasionally as observers in the GIF meetings.

At present, the largest research program exists in Europe and a smaller program in USA. In Europe the main contractor of the last FP5 and FP6 projects, named MOST and ALISIA respectively, was the French CEA and the other partner of the project were the following European institutions:

- Centre national de la recherche scientifique, FR
- Électricité de France, FR
- Joint Research Centre, ITU, EU
- Nuclear Research Institute ŘeŽ, CZ
- SKODA JS a.s, CZ
- Energovyzkum Ltd, CZ
- Nuclear Power Plant Research Institute, SK
- Forschungszentrum Karlsruhe GmbH, DE
- Forschungszentrum Rossendorf, DE
- Ente per le nuove tecnologie, l’energia e l’ambiente (ENEA), IT
- Politecnico di Torino, IT
- Budapest University of Technology and Economics, HU
- Delft University of Technology, NL
- Kurchatov Institute, RU

Objective of the Euratom research programs is to strengthen, within an official European framework, the existing network on molten salts technologies, and to prepare future activities in the future FP7.

Molten salt reactors were first proposed by Ed Bettis and Ray Briant of Oak Ridge National Laboratory (ORNL) during the post World War II attempt to design a nuclear powered aircraft. Nuclear submarines were being developed at that time and the U.S. Air Force wanted an equivalent aircraft with unlimited range. The attraction of molten fluoride salts for that program was the great stability of the salts, both to high temperatures and to radiation. An active development program aimed at the development of an aircraft reactor was carried out from about 1950 to 1956. The Aircraft Reactor Experiment, a small reactor using a circulating molten fuel salt, operated for several days in 1953. In 1956 a new project started to see if this technology could be adapted to civilian power reactors. Until late 1959 the exploration of MSRs was not focused sharply on the breeding possibilities of the system. Starting in 1960, however, the financial support of the Molten Salt Reactor Program was dependent on its breeding possibilities, and thereafter the program was focused on the molten salt breeder reactor (MSBR).

MacPherson, deputy director until the 1970 at the ORNL, reports in a very detailed way the different phases of the project and regarding the MSR experiment (the research reactor was operated discontinuously between the 1966 and 1969 with different fuels) and his opinion is that it was a very successful experiment. He describes the reactor as quite practical for the following reason:

- it ran for long periods of time and the maintenance was accomplished safely and without excessive delay
- it demonstrated the expected flexibility and ease of handling the fuel

During the operation also the following operations were realized:

- the use of ^{233}U as fuel (MSRE was the first reactor in the world to operate with ^{233}U as the sole fuel
- ^{233}U was simple to handle because of the absence of solid elements
- the ^{235}U was removed from the carrier salt
- the uranium was decontaminated of gamma radiation so that it was possible to handle it without shielding
- the ^{233}U was introduced to the system

The technology, even if quite promising was left aside during the ´70s. The program, in fact, was ultimately cancelled when the United States decided to concentrate on development of a single breeder reactor concept. MacPherson tries to explicate the reason of the give up in the following way:

- The political and technical support for the program in the United States was too thin geographically. Within the United States, only in Oak Ridge, Tennessee, was the technology really understood and appreciated
- The MSR program was in competition with the fast breeder program, which got an early start and had copious government development funds being spent in many parts of the United States. When the MSR development program had progressed far enough to justify a greatly expanded program leading to commercial development, the U.S. Atomic Energy Commission could not justify the diversion of substantial funds from the Liquid Metal Fast Breeder Reactor to a competing program

Until now only two experimental reactors have been built and successfully operated:

- The Aircraft Reactor Experiment (ARE) was the first MSR. It was a 2.5 MWth reactor that was operated in at a peak temperature of 860 °C and used a sodium-zirconium fluoride salt
- The Molten Salt Breeder Reactor (MSBR), an 8 MWth reactor that used a lithium-beryllium fluoride salt and demonstrated most of the key technologies for a power reactor

In addition, test loops with molten salts were operated for hundreds of thousands of hours, materials of construction were code qualified to 750 °C, and a detailed conceptual design of a 1000 MWe MSBR was developed. Over a 1000 technical reports were produced.

Since the 1970s, smaller research programs examining the MSR, the use of molten salts for heat transport loops, and molten salts as coolants for fusion energy machines have been conducted in various countries.

Forsberg reports a detailed analysis of the several reasons of the renewed interest in MSRs. He says that while the nuclear power goals - economic and safe electricity production - remain unchanged, several other long-term goals for advanced reactors have changed since the 1960s, when there were large MSR programs.

- Goals. The goals for advanced reactors have changed in directions that match the intrinsic capabilities of MSRs.
- Technological advances. Major advances have taken place in the component technologies of MSRs and the development of new MSR concepts such as fast-spectrum MSRs to extend fuel supplies and burn actinides.
- Salt-cooled reactors. Fluoride salts have been developed as clean coolants to use
    - in high-temperature and fast reactor concepts using solid fuel
    - in fusion reactors
    - as a high-temperature heat-transport fluid. These other applications are developing technologies that further advance the required MSR technologies
- Actinide burning for waste management. There is growing interest in destroying actinides accumulated in light-water reactor (LWR) spent nuclear fuel (SNF) to reduce the long-term hazards of SNF, destroy the radionuclides that dominate long-term repository risk to the public, and reduce the size of the repository. The specific goals have not been defined; however, the key radionuclides are plutonium, neptunium, and americium.
- Fuel sustainability. Historically, advanced nuclear research programs have emphasized the development of breeder reactors with high breeding ratios because it was thought that uranium was very scarce. Today it is recognized that there are large uranium resources and that the economics do not require breeder reactors with high breeding ratios. What is desired is an economically viable transition strategy to advanced reactors with sustainable fuel supplies.
- Nonproliferation. A much greater emphasis presently exists on development of reactors and associated fuel cycles with greater proliferation resistance.

A complete database of documents related to the Molten Salt R&D is collected at the following internet address: http://www.energyfromthorium.com/pdf/.

1.2 TECHNICAL ASPECTS

In a MSR (Figure 1.1), the molten fluoride salt in which fissile and fertile material, and fission isotopes are dissolved, flows through the reactor core (Figure 1.2) moderated by unclad graphite.

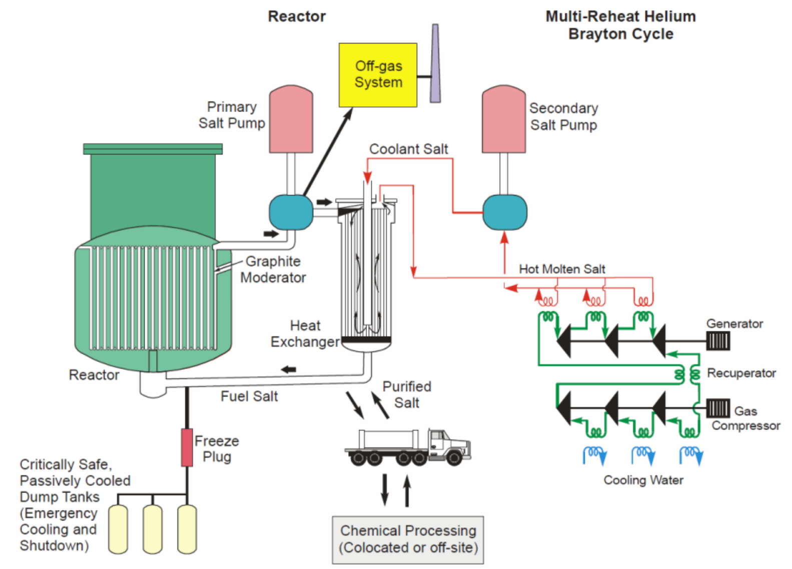

Figure 1.1: MSR with Multi-reheat Brayton Cycle

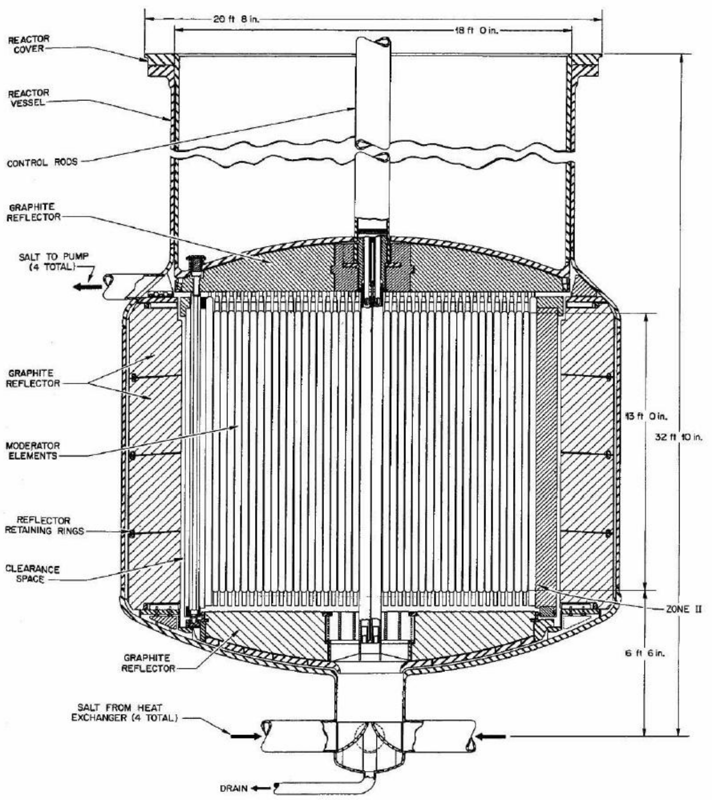

Figure 1.2: Cross section of the 1970s 2250-MWth MSBR vessel

In the core, fission occurs within the flowing fuel salt, which then flows into a primary heat exchanger, where the heat is transferred to a secondary molten salt coolant. The graphite-to-fuel ratio is adjusted to provide the optimal neutron balance (epithermal neutron spectrum). In the preconceptual 1000 MWe designs developed in the early 1970s, the liquid fuel salt typically enters the reactor vessel at 565 °C and exits at 705 °C at 1 atmosphere (coolant boiling point: ca. 1400 °C). The reactor and primary system are constructed of modified Hastelloy-N or a similar alloy to reach a high level of corrosion resistance. Volatile fission products (e.g., krypton and xenon) are continuously removed from the coolant.

Early designs of the MSR proposed the use of a steam cycle for electricity production. The newly layout by Forsberg proposes the multi-reheat helium or nitrogen Brayton cycle. The Brayton cycle has major advantages over the use of a steam Rankine cycle: simplified balance of plant with lower cost, improved efficiency, reduced potential for salt freezing in the heat exchangers, and simplified control of tritium within the reactor.

Forsberg reports also other aspects like increased efficiency and simplification of the system. The estimated helium Brayton power-cycle efficiency is 48% compared to 44% for the MSR with steam cycle this improved efficiency is a consequence of adopting a Brayton power cycle that is a better match to molten salt systems than steam power cycles. The helium or nitrogen Brayton cycle also minimizes difficulties in the control of tritium. In a liquid-fuel reactor, fission-product tritium is not trapped in solid fuel. It can migrate through hot heat exchangers to the power cycle. In a Brayton cycle, it is easy to remove any tritium that enters the power cycle from the dry gas. This is in contrast to a steam cycle where any tritium diffusing through hot heat exchangers with their very large surface area combines with the steam.

The parameters developed for the 1000 MWe MSBR conceptual design developed in the late 1960s are shown in Table 1.1. These parameters are for a large (2250 MWth) ^{233}U-Thorium, liquid-fuel breeder reactor designed for the production of electricity using a steam cycle.

Table 1.1: Design characteristics of the 1970s MSBR

Net electric generation	1000 MW	Maximum core flow velocity	2.6 m/s
Thermal efficiency	44.4% (steam cycle)	Total fuel salt	48.7 m^3
Core height	3.96 m	^{233}U	1,500 kg
Vessel design pressure	$5.2 \cdot 10^5$ N/m^2 (75 psi)	Thorium	68,100 kg
Average power density	22.2 kW/L	Salt components	$^7LiF\text{-}BeF_2\text{-}ThF_4\text{-}UF_4$
Graphite mass	304,000 kg	Salt composition (see entry above)	71.7-16-12-0.3 mol %

The Idaho National Laboratory (INL) reports that the reactor characteristics minimize the potential for accident initiation. Unlike solid-fuel reactors, MSRs operate at steady-state conditions with no change in the nuclear reactivity of the fuel as a function of time. Fuel is added as needed; consequently, the reactor has low excess nuclear reactivity. No excess fuel is needed at reactor startup to compensate for fuel depletion, and no excess reactivity is required to override xenon poisoning. No significant buildup of xenon occurs over time because the xenon gas continuously exits via the off-gas system. There is a strong negative temperature coefficient because increased temperatures lower the fuel-salt density and push fuel out of the reactor core. In normal operations, the control rods are fully removed from the reactor.

Many of the driving forces for an accident are reduced compared with those that exist for other reactors. Fission products (with the exception of xenon and krypton) and nuclear materials are highly soluble in the salt and will remain in the salt under both operating and expected accident conditions. The fission products that are not soluble (e.g., xenon and krypton) are continuously removed from the molten fuel salt, solidified, packaged, and stored in passively cooled storage vaults. There are no major stored energy sources within containment such as high-pressure fluids (helium and water) or reactive fluids (sodium). This reduces requirements for the containment.

1.2.1 Reactor Physics and Fuel Cycle

The INL reports some important characteristics of the MSR reactor physics and fuel cycle. MSRs are fluid-fuel reactors. Such reactors have several characteristics that are different from those of solid-fuel reactors.

- ***Nuclear reactivity.*** Negligible xenon effect occurs because xenon continuously escapes from the fuel salt into the off-gas system. There is no change in core reactivity with time, because fuel is continuously added as required. The fuel inventory in the reactor core is coupled to the reactor temperature. An increase in reactor temperature reduces the fuel inventory by expansion of the fuel salt with less mass of fuel salt in the reactor core.
- ***Fissile inventory.*** As a class, MSRs have very low fissile inventories compared with other reactors for several reasons

    - thermal neutron reactors require less fissile inventory than fast reactors
    - a low fuel-cycle fissile inventory exists outside the reactor system (no conventional SNF)
    - little excess reactivity is required to compensate for burn-up (because fuel is added on-line)
    - direct heat deposition in the fuel/coolant allows high power densities;
    - high absorption fission products such as xenon are continuously removed.

  As a consequence, the MSR requires <2 kg of fissile material per MWe to reach criticality, compared with 3 to 5 kg/MWe for LWRs and over 25 kg/MWe for fast-spectrum reactors. This implies that the MSR has the potential to provide long-term, sustainable energy production while limiting the global inventory of plutonium and minor actinides to a total quantity over an order of magnitude lower than solid fuel reactors.
- ***Burnup and plutonium isotopics. Relative*** to solid-fuel reactors, MSR fuel cycles have very high equivalent fuel burnups and unusual plutonium isotopics with high concentrations of ^{242}Pu.
    - In solid-fuel reactors, SNF (solid nuclear fuel) burnup is limited by fuel-clad lifetime that, in turn, limits fuel burnup and the burnout of plutonium. In non-breeder reactors, SNF burnup is also economically limited - independent of the technology. Excess fissile material is in fresh fuel when it is initially placed in the reactor core. This is required to compensate for fuel burnup over time. To assure reactor control, burnable neutron absorbers are then added to the fresh fuel to avoid

excessive nuclear reactivity in new fuel assemblies. There is a significant economic cost (extra enrichment) in "storing" excess fissile fuel in the new fuel assembly until it is needed toward the end of the fuel assembly lifetime. These factors fundamentally limit solid fuel burnup.

- In an MSR, fuel is added incrementally to the liquid as required. No excess fuel and associated burnable absorbers are required. Selected fission products are removed from the molten salt and solidified as a waste form. As a consequence, the normal burnup limits that define solid fuels do not apply to a liquid-fuel reactor. The plutonium remains in the salt, with the lighter plutonium fissile isotopes burned out faster than ^{242}Pu. This has major implications in terms of proliferation resistance. The high ^{242}Pu content makes the plutonium from an MSR much less desirable than plutonium from any other reactor type for use in weapons because of its very high critical mass.

- ***Delayed neutron fraction.*** In all reactors, some fraction of the fission neutrons are delayed neutrons emitted from the decay of very-short-lived fission products. This fraction is used for reactor control. Unlike solid fuel reactors, the flowing fuel implies that some fraction of the delayed neutrons will occur in flowing fuel that has left the reactor core. This must be accounted for in all reactor physics calculations and evaluations.

Forsberg reports in his work the different fuel cycle options. Four major fuel cycle options exist to address different goals of reactor operation. The basic reactor remains unchanged except for the salt composition, salt-cleanup systems, and fuel cycle operations. Any of the MSRs can be started up using low-enriched uranium or other fissile materials. With the exception of the breeder reactor fuel cycle, the fuel salt processing for all the other fuel cycles can be performed off-site with removal of the fuel salt every few years.

- ***Actinide burning.*** This fuel cycle burns multi-recycle Pu, Am, and Cm from LWR Solid Nuclear Fuel SNF or other sources to reduce the long-term hazard of wastes to the repository. It can also produce denatured ^{233}U as a by-product. The penalty for burning actinides in an epithermal neutron flux is partly offset by the greater fission neutron yield of the higher actinides. As an actinide-burner, the production of electricity from the MSRs will be up to 10% of the electricity that is produced by the other reactors that originally generated the actinides. This mode of operation requires a molten salt, such as a sodium-zirconium fluoride salt, that has a high solubility for actinides. In the process of burning actinides, the actinides with high fission cross sections are burnt out first. It requires substantially longer times to burnout low-nuclear-cross-section actinides. Consequently, there is a buildup of low-cross-section actinides in the reactor. This implies that any reactor burning actinides from LWRs will have a larger inventory of actinides in the reactor core than with other MSR fuel cycles.

Much of the current interest in MSRs is a result of the capabilities to burn actinides to reduce waste management burdens. Because they are liquid-fuel reactors, MSRs offer three advantages over solid fuel reactors in this application:

- No isotopic blending
- No fuel fabrication
- Minimal reprocessing

- ***Once-through fuel cycle.*** The once-through fuel cycle converts thorium to ^{233}U internally in the reactor and uses 20% enriched uranium as fresh fuel to the reactor. The annual fuel consumption is ~45 t/GWe, or about one-fifth that of a LWR. No recovery of fissile material from the discharged salt would be required.
- ***Thorium-^{233}U breeder cycle.*** MSRs can operate as breeder reactors. After startup, only thorium is added as a fuel. A breeder reactor with efficient fuel production also requires on-line processing of the fuel salt because of the nuclear characteristics of breeding fuel with thermal neutrons using the ^{233}U-Th fuel cycle. In a thermal neutron breeder reactor, the breeding reaction is $^{232}Th + n \rightarrow {}^{233}Pa \rightarrow {}^{233}U$. Unfortunately, ^{233}Pa has a moderately large absorption cross section and a half-life of 27 days. If it is left in the reactor, parasitic capture of neutrons by ^{233}Pa will occur, resulting in a significant reduction in the breeding ratio. To avoid this scenario and to obtain high breeding ratios, on-line processing is required for removal of the ^{233}Pa and storage outside of the reactor until it decays to ^{233}U. With an efficient

processing system, the breeding ratio is ~1.06, with an equilibrium ^{233}U inventory of about 1500 kg. If the reactor is to be a breeder reactor, the fuel salt characteristics must be optimized and will almost certainly be a mixture of ^{7}LiF, BeF_2, ThF_4, and UF_4. This salt mixture provides better neutron economy. The use of a thorium-^{233}U breeder reactor cycle results in a high level waste with a very low actinide content because, as neutrons are added to the thorium, the various fissile isotopes that are produced (^{235}U, ^{239}Pu, etc.) tend to fission.

- ***Denatured thorium-^{233}U breeder cycle*.** This is a breeder reactor fuel cycle designed to maximize proliferation resistance by minimal processing of the fuel salt and by addition of ^{238}U to isotopically dilute fissile uranium isotopes. This lowers the breeding ratio to slightly above 1 and results in a very low fissile plutonium (^{239}Pu and ^{241}Pu) inventory of ~0.16 kg/MWe. The use of a thorium-^{233}U breeder reactor cycle results in a high-level waste with a low actinide content because, as neutrons are added to the thorium, the various fissile isotopes that are produced (^{235}U, ^{239}Pu, etc.) tend to fission.

1.3 TECHNICAL PROBLEMS

The Idaho National Laboratory (INL) reports that the major advances in development and understanding of MSRs are expected to occur within the next decade with a modest investment of resources. A list of R&D requirements is done also by Forsberg and a list of the main items to focus on after the activities of MOST project is reported in the MOST final report

The highlights of the R&D activities can be divided in 4 main categories.

1.3.1 System Design and Evaluation

Design optimization

Determine the design parameters of a modern MSR reactor to update those of Robertson (1971):

- Incorporate the new high temperature technologies to eliminate previously identified technical issues
- Improve plant efficiency
- Reduce capital cost per kWe
- Incorporate remote operations, robotics and controls
- Change of mission: from maximization of fuel production (requires complex, high capacity on line salt processing) to actinide burner and hydrogen missions (possibility to eliminate most online fuel processing systems and simplify design)
- Implementation and efficiency of passive safety systems

Regulation

There is a different approach to reactor safety than in case of solid fuelled reactors:

- The current regulatory structure was developed with the concept of solid-fuel reactors.
- The comparable regulatory requirements for this system must be defined.
- Using current tools appropriate safety analysis required.

Safety

The critical safety requirement is that radionuclides remains dissolved in the molten salt under all conditions:

- Determines the limits of the solubility of trivalent actinides in candidate molten salts
- Assure control of noble metal fission products in primary system
- Need to modify the salt composition to assure solubility under all conditions
- Fission product noble metals may plate out on heat exchangers resulting in high decay heat loads and limited equipment lifetimes.
- Development and evaluation of tools for the simulation of MSR (operating conditions and accidental situations)

1.3.2 Fuel and Fuel Cycles

There is a variety of fuel cycle issues even if there is no need for a classical solid-fuel development program:

- There are unique chemical issues not associated with other reactors
- Need to develop a fluoride high-level waste form
- Need to develop an integrated fuel recycle strategy

1.3.3 Energy Conversion

The goal of the R&D in this field is to establish the technical basis for coupling the Brayton cycles for electricity production and thermochemical water cracking cycles for hydrogen production

- Development of heat exchangers for the coupling of systems
- Development of Multi-reheat Brayton power cycles
  - Most, but not all, of the components in this system are very similar to those required by the Next Generation Nuclear Plant (NGNP) program

1.3.4 Materials

The major goals of the R&D are to identify and qualify materials with properties appropriate for MSR operating conditions:

- Corrosion resistance
- Mechanical performance
- Radiation performance
    - The primary materials of interest are the moderator (graphite) and the reactor vessel/primary loop alloy (Ni-based alloy)
    - It is necessary to develop corrosion control and coolant monitoring strategies to protect reactor vessel and primary piping alloys

The old temperature limit for the MSBR fixed to 750°C was largely due to the coupling required for steam cycle operations and did not represent a fundamental limit.

1.4 ECONOMIC ASPECTS

Economical aspects of the MSR systems have been reviewed in the framework of the MOST project and the result of the analysis are available in the MOST Database (https://www-most.cea.fr).

This database is not public and the access is submitted to the decision of European partners of the MOST project.

The database contains also a Russian estimate of economic parameters of two molten salt reactors and American cost estimates for the MSBR reactor. The most detailed cost estimates provided in MSBR (ORNL) project are implemented into the review.

The MOST final report point out that the cost estimates are very influenced by conditions and backgrounds in the country where the estimates were performed (for example differences in annual operational costs etc.).

Other information on economical aspects regarding MSR has been collected regarding the Thorium fuelled reactor.

Thorium is abundant around the world (10 g/t), in the Earth's crust copper is present in the same order of magnitude as lead and lithium (Table 1.2). Uranium is less and ^{235}U is ca. 0.018 g/t.

Thorium is abundant around the world (see Table 1.3):

- Found in trace amounts in most rocks and soils
- India, Australia, Canada, US have large minable concentrations
- US has about 20% of the world reserve base

There is no need to horde or fight over this resource:

- A single mine site in Idaho could produce 4500 Mt of thorium per year
- Replacing the total US electrical energy consumption for one year would require ~400 Mt of thorium

Table 1.2: Chemical composition of the Earth´s crust

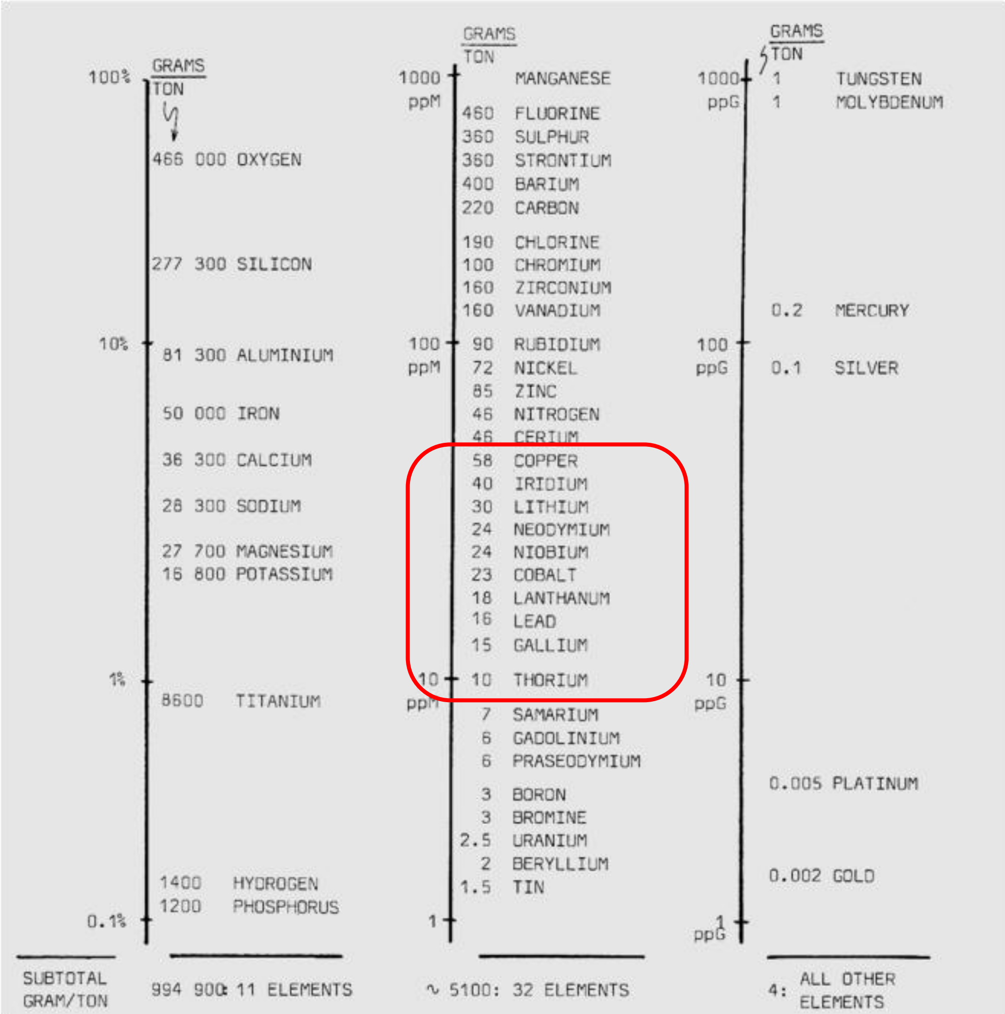

Table 1.3: World Thorium Resources

World Thorium Resources	
Country	**Reserve Base (tons)**
Australia	340,000
India	300,000
USA	**300,000**
Norway	180,000
Canada	100,000
South Africa	39,000
Brazil	18,000
Other countries	100,000
World total	1,400,000

Source: U.S. Geological Survey, Mineral Commodity Summaries, January 2008

Considering the mission of producing 1000 MW of electricity for one year, a molten salt reactor operated with thorium as fuel produces less operational waste than LWR.

Considering 1 t of thorium, at the end of the fuel like cycle, the wastes will be 1 t of fission products that contains no uranium, plutonium, or other actinides. Then, within 10 years, 83% of fission products are stable and can be partitioned and sold (isotopes for medical use). The remaining 17% fission products go to geologic isolation for ~300 years.

In fact a reactor operated with Thorium could produce many valuable by-products that may be as important as electricity production. A detailed overview is given by Bonometti at al. (Figure 1.3).

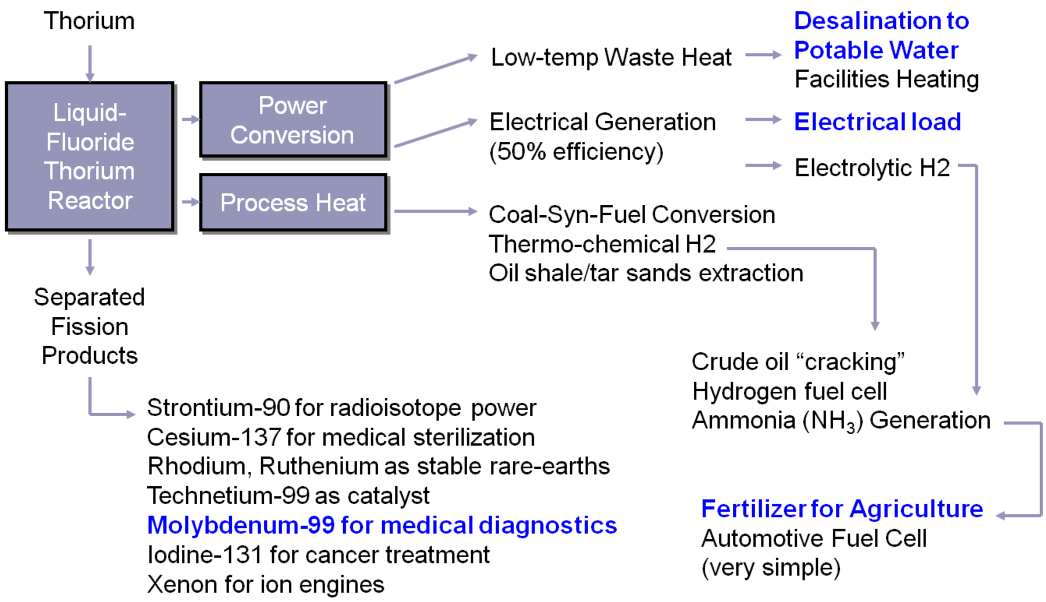

Figure 1.3: Valuable by-products of a Molten Salt reactor operated with Thorium

1.5 ENVIRONMENTAL AND SOCIAL ASPECTS

Nuclear waste is an important issue affecting the acceptability of any nuclear related system and reactors in particular. There is no way that a reactor that utilizes the fission process can eliminate the fission products. The MSRs, with their continuous processing and the immediate separation of the residual fuel from the waste, simplify the handling of the waste and contribute to the solution and acceptability of the waste issue.

- The on-line processing can significantly reduce the transportation of radioactive shipments.
- There is no shipping between the reactor and the processing facility.
- The on-site on-line processing allows for inclusion of some selected fission products along with the recycled actinides for transmutation in the reactor. For example, the long-lived products could be removed from the waste and retained in the core.
- The fission products, already being in a processing facility and in a fluid matrix, can be processed to the optimal form desired.
    - Reduced in volume by concentration or diluted to the most desirable constitution.
    - Transformed into the most desirable chemical state, shape, size, or configuration to meet shipping and/or storage requirements.
- The continuous processing also allows making the shipments to the final disposal site as large or small as desired:
    - This can reduce the risk associated with each individual shipment to an acceptable level.

The MSRs possess many inherent safety properties. As an MSR uses a molten fuel, a "meltdown" is of no particular consequence. The fuel is critical in the molten state in some optimal configuration. If the fuel escapes this environment or configuration because of relocation, it will become subcritical thus, recriticality in any reasonable design cannot occur.

GAT and ENGEL of the ORNL in 1991 proposed the MSRs suitable for burning fissile fuel from dismantled weapons. They declare that MSRs have the flexibility to utilize any fissile fuel in continuous operation with no special modifications, as demonstrated in the Molten Salt Reactor Experiment, while maintaining their economy. The MSRS further require a minimum of special fuel preparation and can tolerate denaturing and dilution of the fuel.

1.6 BIBLIOGRAPHY

2007 Annual Report, GEN IV International Forum

The Molten Salt Reactor Adventure, H. G. MacPherson, Consultant, Oak Ridge, Tennessee 37831, Nuclear Science and Engineering: 90, 374-380 (1985)

Thermal- and Fast-Spectrum Molten Salt Reactors for Actinide Burning and Fuel Production, Charles W. Forsberg, Oak Ridge National Laboratory, Paper in Global 07: Advanced Nuclear Fuel Cycles and System

INL FY2005 Report, Appendix 6.0 Molten Salt Reactor, Idaho National Laboratory, USA, 2005

MOST Final Report, March 2005, C. Renault, M. Delpech, European Commission 5th Euratom Framework Programme 1998-2002

Reactors with Molten Salts: Options and Missions FORSBERG Charles W., Oak Ridge National Laboratory- USA, The 2004 Frédéric JOLIOT & Otto HAHN Summer School AUGUST 25 – SEPTEMBER 3, 2004 CADARACHE, France

Molten Salt Reactors For Burning Dismantled Weapons Fuel, URI GAT and J. R., ENGEL Oak Ridge National Laboratory, H. L. DODDS University of Tennessee, FISSION REACTORS

LFTR Liquid Fluoride Thorium Reactor, What fusion wanted to be! , Dr. Joseph Bonometti and Mr. Kirk Sorensen NASA, presentation for Google Tech Talks November 18, 2008
http://www.energyfromthorium.com/ppt/LFTRGoogleTalk_Bonometti.ppt
http://www.youtube.com/watch?v=AHs2Ugxo7-8