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Cost of electricity from Molten Salt Reactors (MSR)*

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Abstract

The cost of electricity is estimated for a molten salt reactor based on evaluations at the Oak Ridge National Laboratory (ORNL) and compared to their pressurized water reactor and coal plant estimates of the same pre-1980 vintage plants. The results were 3.8, 4.1 and 4.2 ¢/kWh for molten salt reactor, pressurized water reactor and coal. Such cost estimates surprisingly have never before been published for the molten salt reactor.

Three decades ago a decision was made to discontinue the molten salt reactor experiment, which had been operating quite successfully at the Oak Ridge National Laboratory (ORNL), and to stop further development of the molten salt fission reactor (MSR). This reactor was different from other reactors. It could be fed any of the fission fuels—uranium, plutonium or thorium—but it operated best on thorium and could refuel on-line so as to continuously remove dangerous fission products while burning up actinides, even those from other sources. The program developed enough information to credibly evaluate and estimate the cost of electricity. Surprisingly, the project researchers documented the detailed capital cost estimate and operating costs for a 1000 MWe commercial plant but never used these costs to determine the cost of MSR-generated electricity. One reason was that the molten salt reactor was in an early stage of development. The purpose of this note is to make available the estimated cost of electricity (COE) based primarily on evaluations contained in early ORNL reports and values from elsewhere.

A detailed cost breakdown and description was given for a conceptual design of a 1000-MWe molten salt reactor, called MSR, as well as equal size pressurized water reactor (PWR) and coal plants(1). All three were for commercial so called Nth of a kind plants. The MSR was fueled with thorium and denatured U-235. The research and development needed on the molten salt reactor was estimated at $700 M (1978$) in addition to reactor construction projects(1). Delene(2) also compared to 600 MWe PWR and natural gas fired plants but these were not included here because they were not done on a common basis with the MSR and for the sake of brevity. To determine the cost of the electricity generated by these reactors, we need to know the operating costs and the amortized capital cost. Some, but not all, operating costs were given for the MSR in the referenced document. The annual capital charges can be computed based on the capital costs, using a capital charge factor of 0.1 recommended by Delene(2) (see Eq.1.). The results are shown in Table 1. (The source of each item in Table 1 is given in the foot notes.)

The cost of electricity in constant (non-inflating) dollars is given by a simplified formula recommended for comparison studies by Delene. Life cycle costs are averaged over the life of the plant from construction to decommissioning. The capital charge portion of cost of electricity is computed in Table 1 from the first term in Eq. 1.

$$COE = \frac{C \bullet i + fuel + O\,\&\,M + waste\ disposal + decom}{P_e \cdot 8760 \cdot C_f} \qquad (1)$$

COE is the cost of electricity in dollars per megawatt-hour or cents per kilowatt-hour

C = capital cost in dollars

i = fixed capital charge rate, typically 10%

fuel = annual cost for fuel

O&M = annual cost for operations and maintenance and similarly for waste disposal and decommissioning

P_e = net electrical power capacity of the plant

C_f = capacity factor

The capacity factor, C_f is taken as 0.9 for the MSR to account for the reduced down-time because of its on-line fueling feature and 0.8 for the PWR and coal cases. There are 8760 hours per year. To convert costs quoted in one year's dollars to those in another year we use deflation factors. For example, for 1978$ → 2000$ multiply by 2.43; for 1993→2000$ multiply by 1.17. If the capacity factor for the MSR increases from 0.9 to 0.95 its COE becomes 3.65 ¢/kWh. The net plant efficiency was 44% for MSR and coal and 33% for PWR.

The operations and maintenance (O&M), fuel and decommissioning costs from Delene(2) for coal and PWR are based on 2-600 MWe in the case of coal and one 1200 MWe evolutionary light water reactor. We are ignoring the differences due to size for our 1000 MWe examples. The capital cost evaluations were done on a common basis for the three options and are expected to be more reliable than the fuel and O&M costs, which were not done on a common basis.

We conclude that the cost of electricity generated by an MSR is competitive with other sources based on the old but comprehensive evaluations. Using the same methodology, the COE is 7% lower than that for water reactors and 9% lower than that for coal plants. The information in this note based on the three options as defined in 1978 does not include current safety, licensing, and environmental standards which will impact costs, as will CO_2 sequestering and increased HAP (Hazardous Air Pollutants) for coal. The low cost of electricity along with the MSR's many other potential advantages suggests that stopping the development of the MSR might have been a mistake and that restarting the program should be considered. These advantages include: the ability to burn thorium, the ability to burn most of its own actinide wastes (and some wastes from other plants), the ability to continuously add fuel and remove fission products, and the ability to provide an alternative to the plutonium cycle with its association with nuclear weapons. The fuel cycle is near to being closed, and fuel is burned with high conversion efficiency (near breeder). Again, it is emphasized that the MSR is a conceptual design several decades old. A new evaluation of MSR is strongly recommended based on current safety, licensing and environmental standards and comparisons made to alternative power plants.

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Bibliography

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2. J. G. Delene (1994), "Advanced fission and fossil plant economics—implications for fusion," Fusion Technology **26** 1105-1994).
3. The concept of the molten salt reactor has been advanced by a series of publications on a small reactor (7 MWe) called mini-Fuji and a mid-size reactor (155 MWe) called Fuji-II by K. Furukawa; see, for example K. Furukawa et al., "Small MSR with a rational Th fuel cycle." Nucl. Engineering & Design, **136,**157(1992).
4. For more information on the molten salt reactor, see the web site: http://home.earthlink.net/~bhoglund/

Table 1. Economic parameters

Item	1978$			2000$		
Direct costs, M$	MSR	PWR	Coal	MSR	PWR	Coal
Land and land rights	2	2	2	5	5	5
Struct. & improvements	124	111	245	301	269	594
Reactor plant equip	180	139	----	437	337	----
Turbine plant equip.	100	113	88	243	274	213
Electric plant equip	54	44	31	131	107	75
Misc. plant equip	17	13	11	41	32	27
Main cond. heat reject.	14	22	14	34	53	34
Total direct costs	491	444	391	1,191	1,077	949
Indirect costs						
Construction services	75	70	39	182	170	95
Home-office eng. Serv.	53	53	16	129	129	39
Field-office eng & serv.	34	30	10	82	73	24
Total indirect costs	162	153	65	393	371	158
Total capital cost, M$	653a	597a	456a	1584a	1448a	1106a
Cost/kWh, ¢/kWh						
Capital	0.83b	0.85b	0.65b	2.01b	2.07b	1.58b
O&M	0.24c	0.47d	0.33d	0.58c	1.13d	0.80d
Fuel	0.46c	0.31e	0.71f	1.11c	0.74e	1.72f
Waste disposal	0.04g	0.04g	0.04d	0.10g	0.10g	0.09d
Decom	0.02c	0.03d	--	0.04c	0.07d	--
Total	1.58	1.69	1.73	3.84	4.11	4.19

[a]From Engel et al. 1980, p152.

[b]From Eq. 1, capital charge=0.1, capacity factor 0.8 for PWR & coal & 0.9 for MSR.

[c]From Engel et al. 1980 for annual cost used in numerator of Eq. 1.

[d]From Delene 1994.

[e]From Delene, 1994, uranium at 65$/kg; the 0.74 doubles at a uranium cost of $260/kg.

[f]From Delene, coal at $1.45 /MBtu in 93$.

[g]Taken as 0.1 ¢/kWh in 2000$.