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

SMALL MODULAR REACTORS AND CURRENT GENERATION POWER REACTORS – FUEL COST COMPARISON

C. Pannier[1] and R. Škoda[2]
[1] Texas A&M University, College Station, Texas, USA
cpannier@tamu.edu
[2] Texas A&M University, College Station, Texas, USA
ABSTRACT – Small modular reactors (SMRs) offer simple, standardized, factory-built designs for new nuclear reactor construction. The construction cost for most SMR projects is not publicly available, but variable costs can be determined from the published parameters of fuel configuration, enrichment, average burn-up, and plant thermal efficiency. This paper calculates the fuel cost of electricity generation for selected SMRs, including calculation for optimal tails assay in the uranium enrichment process. The results are compared between one another and with light and heavy water reactors providing a rough comparison of long-run economics of a new nuclear reactor project.

1. Introduction

An exhaustive list of SMR types can be found in [1]. The SMR designs can be divided into two groups: those for early deployment based on a proven PWR technology, and those for longer-term deployment based on other advanced concepts.In this paper, emphasis is placed on those integral PWRs for early deployment. The primary aims of this study are to assess the economic viability of these SMRs and directions for technology developmentto improve SMR economics.

The following disadvantages of SMRs must be overcome if the SMRs are to be deployable in the near future: (1) Uncertainty in the lifecycle cost comparison between SMRs and large reactors; (2) Spent nuclear fuel transport logistics will be complicated by the increase in reactor sites and the remoteness of some SMR sites; (3) Public acceptance of new concepts; and (4) Obtaining design certification and license may take longer than expected.

After capital amortization, the variable costs of labour, maintenance and fuel drive the total cost of electricity generation in the long term. Labour costs depend on regional factors such as the cost of living, the availability skilled labour, and labour organization.One such labour uncertainty forSMRs is the number of licensed operators required for a multi-unit complex, a factor determined by the regulator. On the whole, labour costs are expected to disfavor SMRs in the economies of scale. Asite-specificlabour and maintenance costs comparison between large and small reactors is beyond the scope of this study and is left to the utility.

Since the fuel of water-cooled SMRs is similar to the fuel of current water reactors, it is straightforward to compare their fuel cost component of the variable cost of producing electricity. Fuel cost is largely independent of the reactor site, allowing a long run economic comparison of large and small technologies on this basis. The fuel cost issue is summarized and put into perspective with the initial capital investment, economy of scale and overall cost of construction in [2].

2. Methodology

Seven SMRs are studied in this paper: Westinghouse SMR, Nuscale, mPower, SMART, HI-SMUR, KLT-40S, and GT-MHR. The seven conventional large reactors studied in the paper are: Enhanced CANDU 6 (EC-6), AP 1000, ABWR, ESBWR, US-EPR, US-APWR, and VVER 1000. Their design parameters as taken as of early 2012 as found in [3,4].

Neglecting the cost of fuel fabrication, the fuel cost per unit electric power produced, C, can be approximated over an entire reactor core in Eq. 1 [5], where U is the cost of enriched uranium fuel per unit mass of uranium, η is the plant net thermal efficiency in megawatts electric per megawatt thermal, and B is the average fuel element burnup in megawatts thermal per unit mass of uranium in the fuel. The cost of fuel fabrication is proprietary, but averages 10% of the total cost of water reactor nuclear fuel, varying slightly for different fuel designs, justifying its exclusion in a fuels cost comparison between reactor classes. [6]

$$C = \frac{U}{\eta\ B} \qquad (1)$$

The U in Eq.1 is determined by the fuel enrichment and the market prices of U_3O_8,separative work units (SWU) and conversion to UF_6. [7] In uranium enrichment, the parameters of feed and product enrichment are set by nature and the reactor design, respectively. However the free parameter of uranium tails assay, or depletion, is optimized for lowest cost of enriched uranium product as given in [8]. This optimization is employed in the fuel cost calculation. As market prices are volatile, a distribution of market prices is used, with parameters given in Table 2.[9]

Table 2 Uranium Market Parameters

	Feed Cost (USD/kg U in U3O8)	Separative Work Cost (USD/kg SWU)	Conversion Cost (USD/kg U)
Mean	151.14	153.48	11.00
Standard Deviation	11.31	2.74	0.00

Reactor fuel costs were calculated for a distribution of possible near term uranium fuel costs considering optimization in the enrichment process. The means fuel cost for each design is displayed in Figure 1 for relative comparison between reactor classes. The large heavy water reactor, EC-6, had the lowest reactor fuel cost at 2.6 USD/MWh and the lowest uncertainty in fuel cost. The large light water reactors had similar fuel costs from 5.4 to 5.7 USD/MWh. The SMR designs all had higher fuel costs and more uncertainty than the large reactors, with fuel costs varying from 6.7 to 11.0 USD/MWh. The KLT-40S was an outlier at 42.9 USD/MWh, but it can be expected to use downblended highly enriched uranium to save the cost of enriching natural uranium. The gas cooled GT-MHR showed similar fuel costs to iPWRs.

3. Conclusions

In conclusion, pressurized water SMRs can be expected to have fuels costs 20% to 100% greater than large LWRs or about triple large HWR fuel costs. Fuels cost sensitivities to burnup, enrichment and plant net efficiency were calculated. Despite the predicted higher variable cost of operating an SMR, the savings in construction and amortization cost and the flexibility of SMRs may yet lead to worldwide deployment of small modular reactors for electric generation.

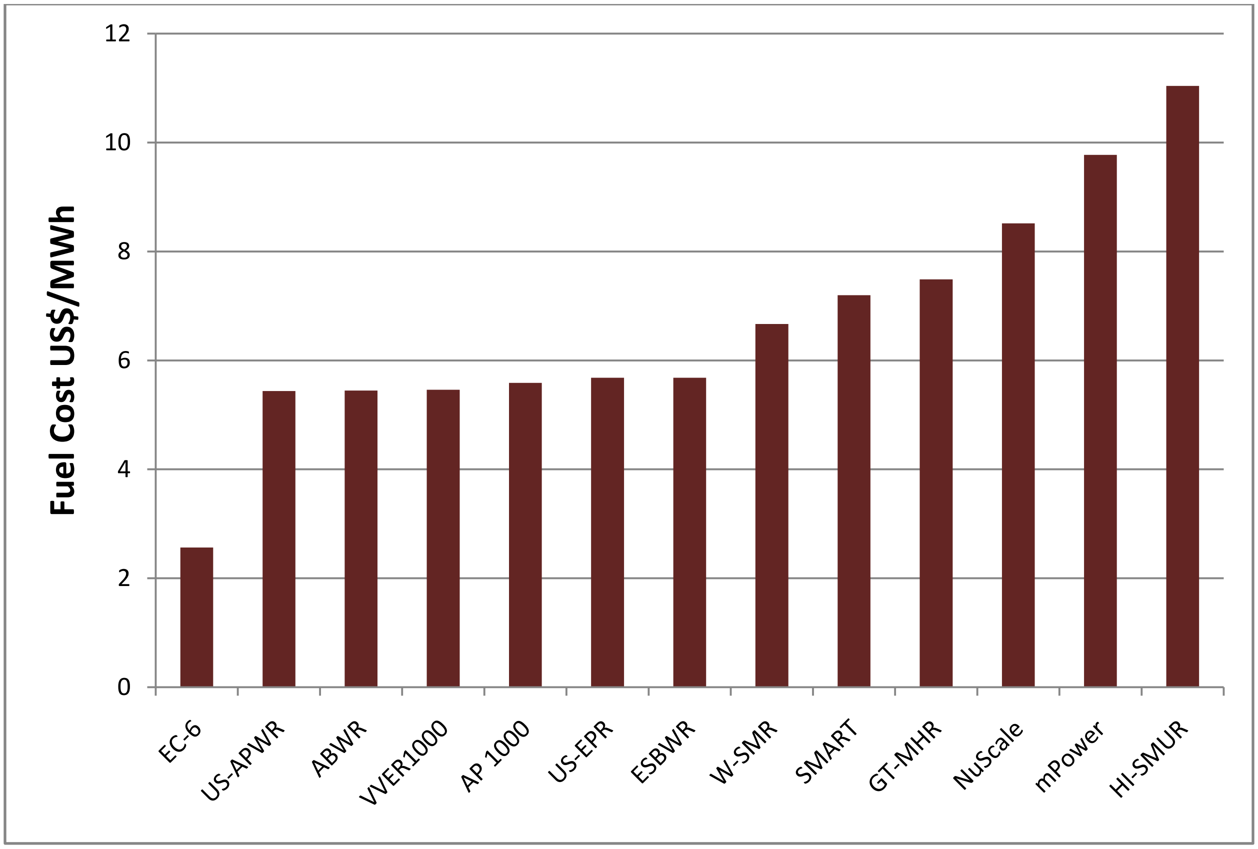

Figure 1 Comparison ofMean Fuel Cost Predicted by the Simulation.

4. References

[1] J. VUJIC, et. al., “Small Modular Reactors: Simpler, Safer, Cheaper?” Proc. of ECOS 2011, Novi Sad, Serbia (2011).

[2] G. LOCATELLI, “SMR Economics Evaluation,”Proc. of the 4th Asia-Pacific Forum on Nuclear Technology: The Small and Medium Reactors, Berkeley, California, USA(2010).

[3] C. P. PANNIER, Assessment of Small and Modular Reactor Nuclear Fuel Cost, Senior Scholars Thesis, Texas A&M University, College Station, Texas, USA (2012).

[4] Enhanced CANDU 6 Technical Summary, CANDU Energy Inc., Mississauga, Ontario, Canada (2012).

[5] C. P. PANNIER and R. SKODA,“Assessment of Small Modular Reactor Fuel Cost,”Proc. of the ASME 2011 SMR Symposium, ASME, Washington, DC, USA (2011).

[6] The Economics of the Nuclear Fuel Cycle, OECD-NEA, Paris, France (1994).

[7] R. COCHRAN and N. TSOULFANIDIS, The Nuclear Fuel Cycle: Analysis and Management, 2nd ed., American Nuclear Society, La Grange Park, Illinios, USA (1999).

[8] M. BENEDICT and T. PIGFORD, Nuclear Chemical Engineering, McGraw-Hill, New York, USA (1957).

[9] Ux Price Indicators, The Ux Consulting Company, LLC, USA (2011).