Fuel Cycle Economic Analysis Using an Excel Spreadsheet

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INTRODUCTION

In 2004 the Generation IV Economic Modeling Working Group commissioned the development of a Microsoft Excel-based model capable of calculating the Levelized Unit Electricity Cost (LUEC) for multiple types of reactor systems being developed under the International Generation IV Program. This model is now called G4-ECONS (Generation IV-Excel Calculation of Nuclear Systems) and is based on a Generation IV reactor cost estimating guidelines document [1]. The fuel cycle section of this model had to be capable of handling different types of nuclear fuels and able to calculate the economics of open, partially closed, and totally closed fuel cycles.

Basically, the model calculates the fuel cycle contribution to the "mills/kWh" or "$/MWh" busbar LUEC by multiplying unit costs for the required fuel cycle steps by the annual material flows or enrichment requirements (separative work units or "SWUs") for each appropriate fuel cycle processing step. The resulting annual "constant dollar" cash flows are then summed and divided by the annual "kilowatt-hour" electricity production projected for the reactor system. The fuel cycle is assumed to be operating under an "equilibrium reload" scenario projected to be typical of most of the plant's operating life. This G4-ECONS fuel cycle model is very simple in concept compared to the more complex fuel cycle models used by fuels managers and reload designers for today's commercial light-water reactors (LWRs); however, it is intended for comparison of vastly different reactors (multiple technologies) and their fuel cycles, not for day-to-day utility business decisions. Its benefit lies in the fact that (1) it can be used to consider not only fuel cycles for water reactors, but also for the fast reactor and gas-cooled reactor concepts being considered under the International Generation IV Program and (2) the model is totally transparent (i.e., all algorithms and cell contents are visible to the user).

MODEL STRUCTURE

For use in the Advanced Fuel Cycle Initiative Program (AFCI), and now the Global Nuclear Energy Partnership (GNEP), the fuel cycle model from G4-ECONS had to be adapted to handle the more complex "synergistic" fuel cycles proposed for GNEP, such as using separated but "grouped" actinides from LWR spent fuel to provide make up fissile material for fast neutron Advanced Burner Reactors (ABRs). The overall weighted fuel cycle cost for a system of LWRs feeding separated actinides from reprocessed LWR fuel to a system of ABRs operating on a closed cycle can now be calculated. Adding this flexibility required that the entire hybrid fuel cycle be broken up into ~25 possible steps or "modules" for which the selected processes can be connected on an Excel spreadsheet. Among the possible steps are ore mining and milling, U_3O_8 to UF_6 conversion, uranium enrichment, fuel fabrication (eight possible fuel types), aqueous spent fuel recycle separations, reprocessed uranium disposition, high-level waste (HLW) treatment and disposition, HLW geologic disposal, pyrochemical fuel recycle, wet and dry spent fuel storage, enrichment tails conversion and disposition, and repository emplacement of spent fuel. These and other steps are all assigned "module" designators, and a data base with ranges for unit costs for each is maintained and updated periodically for each module. Use of unit cost ranges rather than single point values allows the use of uncertainty analysis when calculating the overall "mills/kWh" fuel cycle cost.

A sensitivity analysis "driver" such as DPL (Decision Programming Language), "@Risk," or "Crystal Ball" can be linked with the Excel worksheet to produce "tornado diagrams" and risk profiles such as in Fig. 1. The paper will discuss the four cases in the figure: (1) the standard LWR open cycle, (2) a GNEP case where LWR-produced actinides feed a fast ABR or CFR (converter fast reactor) closed fuel cycle, (3) a closed cycle consisting of all fast reactors with a conversion ratio near 1.0 (near-breeder), and (4) a thermal reactor cycle where LWRs irradiate standard uranium oxide (UO_x) and mixed oxide (MOX) fuel with higher actinide laden targets interspersed in the core.

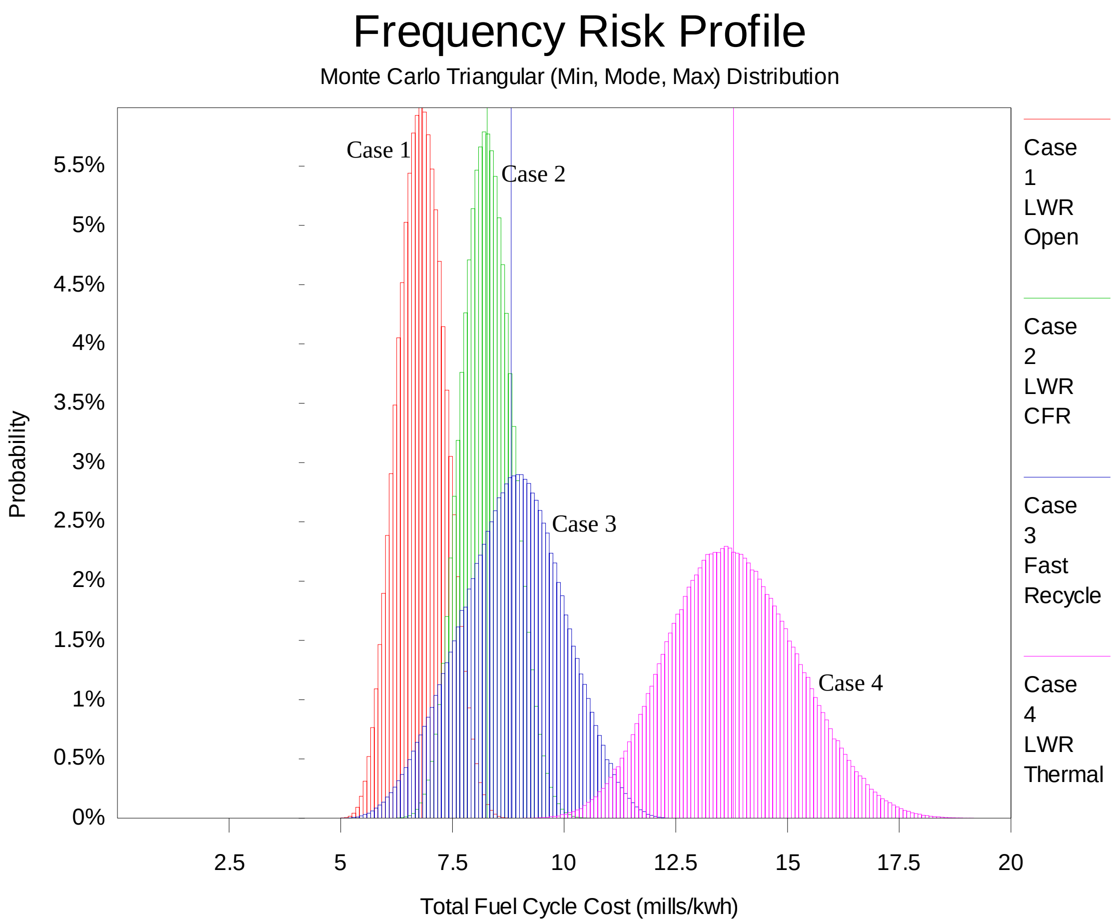

Fig. 1. Frequency risk profile for different fuel cycles.

EXAMPLE RESULTS

The fuel cycle unit cost ranges for the four cases described above and in Ref. [2] are shown below. The reader should keep in mind that reactor-associated costs are not included in these. Differences in capital costs between LWRs and ABRs will ultimately be reflected as differences in the "mills/kWh" amortized capital component of the overall LUEC. These reactor-related cost differences are likely to dwarf the fuel cycle-related differences shown and may result in making the overall ABR LUEC higher than the LWR LUEC. Use of G4-ECCONS for reactor analysis is described in another summary for this meeting [3].

REFERENCES

1. "Cost Estimating Guidelines for Generation IV Nuclear Energy Systems–Rev. 3;" Generation IV Economic Modeling Working Group (November 30, 2006); http://www.gen-4.org/Technology/horizontal/economics.htm
2. SHROPSHIRE, D., WILLIAMS, K., SMITH, J., and BOORE, B., *Advanced Fuel Cycle Economic Sensitivity Analysis*, INL/EXT-06-11947, Idaho National Laboratory (December 2006).
3. WILLIAMS, K. A., "The G4-ECONS Economic Evaluation Tool for Generation IV Reactor Systems," ANS Summer Meeting, Boston, MA (June 24–26, 2007) to be published.