§10. Upgrade and Benchmarking of the NIFS Physics-Engineering-Cost Code

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The Physics-Engineering-Cost (PEC) code was developed by NIFS to compare the cost of electricity (COE) from various fusion power plants, including tokamaks, heliotrons, and modular stellarators. [1] This code has been updated to add data from three blanket-shield designs, a new cost section based on the ARIES cost schedule, more recent unit costs, and improved algorithms for various computations. The PEC code has been benchmarked by modeling the ARIES-AT (advanced technology) tokamak and the ARIES-SPPS (stellarator power plant system).

The physics section of the code calculates the plasma density, current, fusion power density, and power balance. The engineering section estimates masses of the fusion reactor components, and the cost section applies unit costs ($/kg) to estimate the COE. The code does not calculate (1) magnet coil details, (2) plasma equilibrium, stability, and transport, (3) structural masses, and (4) divertor details. Where needed, such data must be calculated elsewhere and input to the code.

The PEC code has been used to model the ARIES-AT tokamak. The PEC code does not calculate the bootstrap current fraction f_{bs} accurately for this reversed shear tokamak, so that value was input to the code. The resulting PEC output parameters are compared with published ARIES-AT data in Table 1.

The somewhat smaller plasma size of the PEC plasma forces its electron density to be slightly higher. The PEC code's overestimate of the radiated power fraction (not shown in Table 1) needs further study. Other plasma parameters are consistent within 5%. The shield and vacuum vessel masses calculated by PEC are 17-18% higher than the published values. This error is partly caused by the approximation of the plasma and wall shapes as elliptical. The discrepancies of the shield, structure, and current drive costs are probably due to different unit costs ($/kg or $/W) used in the PEC and ARIES codes. (The unit costs assumed in the ARIES-AT study were not published.) Some cost items (22.3 to 22.7) were not published in the ARIES-AT report, so they cannot be compared here. The final PEC code estimate of the COE is 5% low. The consistency of most costs is due largely to the fact that the PEC code uses many algorithms from the ARIES systems code, especially for balance of plant and indirect costs.

The PEC code has also modeled the ARIES-SPPS modular stellarator. The vacuum vessel dimensions could not be determined from published information, so the vessel mass was input to the PEC code. The average modular coil perimeter is assumed to be 1.4 times the circumference of a circle with the same coil nominal radius. The resulting PEC output parameters are compared with published ARIES-SPPS data.

Table I. Comparison of PEC results with ARIES-AT data

<PLASMA>		PEC	ARIES-AT	%
Plasma major radius Rp	m	5.11	5.2	-2
Plasma minor radius ap	m	1.28	1.3	-2
Toroidal magnedtic field Bt	T	6.16	5.86	5
Plasma current	MA	12.67	12.8	-1
Average electron density	10^{20} m^{-3}	2.41	2.15	12
Density-weighted average temperature	keV	18.13	18	1
Thermal power	MW	1937	1982	-2
Average neutron wall load	MW/m^2	3.24	3.28	-1
Mass power density	kWe/t	182.7	191	-4

<COSTS 1992$>		PEC	ARIES-AT	%
22.1 Reactor equipment	M$	518	520	0
22.1.1 FW/blanket	M$	73	68	7
22.1.2 Shield	M$	57	73	-22
22.1.3 Magnets	M$	129	134	-4
22.2.4 CD & heating	M$	52	41	27
22.1.5 Structure & support	M$	35	30	17
22.1.6 Vacuum systems	M$	108	109	-1
22.1.7 Power supply	M$	55	56	-2
90. Total direct cost	M$	1684	1757	-4
99. Total capital cost	M$	3261	3390	-4
COE capital cost	mil/kWh	46.92	49.8	-5
Total COE	mil/kWh	60.33	63.5	-5

We can summarize our results as follows:

1. Some new features have been added to the PEC Code, such as new density and temperature profile models, blanket models, and improved algorithms for computation of the magnetic field, electron density, plasma current density, fusion power density, and bremsstrahlung radiation.
2. The PEC code has been used to model the ARIES-AT tokamak and ARIES-SPPS modular stellarator power plants. Some component values, such as the structure/coil mass ratio and modular coil size, are not calculated by the PEC code and must be input. The PEC code succeeds in predicting many of the pertinent plasma parameters and reactor component masses within about 10%.
3. There are some discrepancies in PEC estimates of blanket, shield, and vacuum vessel masses, which may be due to the approximation of the plasma and blanket shapes as toroidal ellipsoids.
4. There are cost differences greater than 10% for some fusion power core components, which may be attributed to differences of unit costs used by the codes. The COEs estimated by the PEC code differ from the COEs of the ARIES-AT and ARIES-SPPS studies by 5%.

Reference

1) K.Yamazaki et al., *"System assessment of helical reactors in comparison with tokamaks,"* 19th IAEA Fusion Energy Conference, Lyon, France, 14-19 October 2002.