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The NIFS Physics-Engineering-Cost (PEC) code for helical and tokamak fusion reactors is upgraded by adding 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 is also benchmarked by modeling the ARIES-AT (advanced technology) tokamak and the ARIES-SPPS (stellarator power plant system). The PEC code succeeds in predicting many of the pertinent plasma parameters and reactor component masses within about 10%. 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%.

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Key words:

fusion reactor economics, cost of electricity, code benchmark, heliotron, stellarator, tokamak

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Introduction

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. [K. Yamazaki 2000, 2002] This code has been updated to add data from three blanket-shield designs, a new cost section based on the ARIES cost schedule,[Bathke 1994] 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 PEC Code

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

- magnet coil details
- plasma equilibrium, stability, and transport
- structural masses
- divertor details.

Where needed, such data must be calculated elsewhere and input to the code. The main elements of the code are as follows.

1. Input.

Default parameters are specified for each type of system (tokamak, heliotron, modular coil stellarator). The magnet coils of a heliotron (like LHD) are shown in Figure 1. The input data include:

Control parameters (type of device, type of blanket, desired outputs,...)
Plasma parameters (aspect ratio, beta, elongation, profiles, T_o, ...)
Magnet coil parameters (coil pitch γ, B_{max}, j_{max}, ...)

The PEC code models the plasma, blanket, shield, and vessel as toroids of elliptical cross section with plasma elongation $k = b/a$. This is a good approximation for plasmas in heliotrons like LHD, as illustrated in Figure 2. For some helical coil designs the magnetic forces on the coils can be greatly reduced (a so-called "force-free helical reactor", FFHR). Modular-coil stellarator plasmas have shapes that may very toroidally from bean shaped to nearly elliptical to semi-triangular (Figure 3). (In this drawing the shield is expanded to allow toroidal movement of blanket segments for replacement.) The PEC code represents the density and temperature profiles by

$$n(x)/n_o = (1-y_{ed})(1-x^p)^q\,[d + (1-d)x^2] + y_{ed}$$

$$T(x)/T_o = (1-t_{ed})(1-x^r)^s + t_{ed}\,,$$

where $x=r/a_p$, a_p = plasma minor radius, and d, p, q, y_{ed}, r, s, and t_{ed} are adjustable parameters. For example, if d=q=s=1 and p=r=2, then the profiles are parabolic with edge values y_{ed} and t_{ed}. If d=0.7, q=1, and p=12, then a hollow density profile results, as observed in LHD and W7-AS at low collisionality. [Lyon and Ku 2004] Using these distributions, the code computes radial average density, temperature, pressure, plasma energy, fusion power density, and bremsstrahlung radiation.

The ratios

f_{pol} = (poloidal coil mass)/(toroidal or helical coil mass)

f_{sup} = (structure mass)/(total coil mass)

are inputs to the PEC code.

2. Dimensions.

The control parameter iblanket selects a given blanket-shield design. The preliminary radial build is calculated for the specified blanket-shield configuration and aspect ratio, using an arbitrary initial major radius. The fractions of the first wall area occupied by the divertor, inboard side, and outboard side are denoted by f_{div}, f_1, and f_2, respectively The blanket and shield compositions and thicknesses can be different in each region.

3. Plasma and magnetic field.

The PEC code can calculate approximate magnetic fields for tokamaks and for continuous-coil stellarators, like LHD. For modular coil stellarators, like ARIES-SPPS and Wendelstein 7-X, the magnetic fields must be computed elsewhere and input to PEC. Using the initial radial build and plasma parameters the plasma current, bootstrap current, and magnet coil current and volume are estimated. An optimization loop varies the major radius to achieve the desired net electric power output (such as 1.0 GWe). The plasma aspect ratio and desired net electrical power are input parameters that are held constant. During each iteration the average electron density is calculated from the central toroidal magnetic field B_t, the density-weighted average temperature, and the average beta value:

$$n_{av} = \beta\, B_t^2/(4\mu_o k T_{av})\,.$$

The density derived from beta is compared with empirical density limits (such as Greenwald), but not constrained by them in the PEC code. The DT fuel ion density is calculated using the assumed impurity fractions.

The impurity fractions, DT fuel ion density, fusion power density, and bremsstrahlung radiation power are calculated at each radius and integrated over the radial profiles.

For ignited plasmas the PEC code calculates the energy confinement time that would be required to achieve ignition, then compares the required time with various scalings, such as ISS-95, to find the required energy confinement "H factor". (This procedure is also used in the ARIES Systems Code.) The major radius is adjusted to achieve the desired net electrical output power P_e.

4. Masses

The final radial build and engineering parameters (such as component masses) are computed. The mass of the gravity support system, assumed to be 10% of the total coil mass, is costed separately from the structure. The code computes the masses and axial fields of tokamak TF coils and of stellarator helical coils, but not of modular coils, which must be input from other calculations.

5. Costs.

The PEC code then computes the costs of the fusion reactor plant equipment, balance of plant, time-related costs, and financial costs. The code converges rapidly and can automatically scan various parameter ranges, such as β, T_o, P_e, w/h (Figure 2), etc. to determine how COE scales with those variables.

Improvements to Code

The improvements made in the PEC code are listed in Table 1. The code has greater scope, and it runs faster and more accurately.

Code Benchmarking

The PEC code has been used to model the ARIES-AT tokamak. (Raffray 2001) Figure 4 shows an isometric view of this reactor. The PEC input parameters are listed in Table 1. 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 2 & 3.

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 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.) The cost discrepancy for impurity control is a large percentage, but a small dollar amount that does not impact the COE significantly. 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 (Lyon, 1994; Miller 1997). Figures 5 and 6 show drawings of the coils and fusion power core. The input parameters are listed in Table 4. 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 in Table 5.

The main plasma parameters are within 10% of the ARIES-SPPS parameters. The discrepancy of the PEC blanket mass may be attributed to the ellipsoidal shape approximation. The cost differences for the blanket, shield, structure, and vacuum system are probably due to different unit costs assumed in the two codes. (Unit costs were not published in the SPPS report.) The COE estimate by PEC is 5% higher than the SPPS value.

Summary

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%.

In the future the PEC code can be used to compare the COE from various blanket-shield combinations; to study how the COE varies with various parameters; and to compare various reactor types, including modular coil stellarators.

References

C. G. Bathke, R. A. Krakowski, R. L. Miller, K. A. Werley, "2. Systems Studies", ARIES Group, 1994, at http://aries.ucsd.edu/~miller/chap02.pdf

J. F. Lyon, K. Gulec, R. L. Miller and L. El-Guebaly, "Status of the U. S. Stellarator Reactor Study," *Fusion Engineering and Design* 25 85-103 (1994).

J. F. Lyon and L. P. Ku, presentation at ARIES-CS Meeting March 8-9, 2004. (Available on ARIES website: http://aries.ucsd.edu/ARIES/)

R. L. Miller, F. Najmabadi, X. Wang, "Stellarator power plant study," UCSD-ENG-004 (1997). (See also the ARIES website: http://aries.ucsd.edu/ARIES/)

A. R. Raffray et al., "High performance blanket for ARIES-AT power plant," *Fusion Engineering and Design* 58-59 (2001) 549-553. (See also the ARIES website: http://aries.ucsd.edu/ARIES/.)

K. Yamazaki et al., "Helical reactor design studies based on new confinement scalings," Proceedings of the 18th IAEA Fusion Energy Conference, Sorrento, Italy, 4-10 October 2000.

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

Table 1.

Improvements to the PEC4 code incorporated in the PEC6 code
(April, 2004)

Added data on three blanket types: RAF/flibe, V/Li, and SiC/PbLi, with appropriate energy conversion efficiencies.
Improved the computation of electron density from beta.
Improved the equations for computing B_{max}/B_o and for finding the optimum value of coil current density.
Adjusted the values of f_{pol} (=poloidal coil mass/TF or helical coil mass) and f_{sup} (= structure mass/total coil mass).
Increased frecov to 0.99 (formerly 0.7). This converts more heat into electricity, lowering the COE.
Improved speed and accuracy of convergence to desired major radius and power level by using a successive bifurcation method.
Improved accuracy of bremsstrahlung and fusion reaction rate parameter subroutines.
Improved the accuracy of numerical integration in the subroutines for profile averages.
Added multiple impurity species and computation of Zeff and $Zeff^2$ at each radius, with ability to concetrate impurities proportional to some power of n or T.
Added new profile models that include the capability for finite edge values and hollow density profiles.
Added optional algorithm for estimating favail from neutron wall loading.

Table 2.

Input data for the PEC model of the ARIES-AT tokamak power plant.

Plasma aspect ratio	R_p/a_p	4.0
Plant availability fraction	f_{avail}	0.76
Net electrical power output	P_e	1000 MWe
Elongation	k	2.179
Triangularity	δ	0.842
Safety factor on axis	q_o	3.56
Safety factor at edge	q_{95}	4.05
Average toroidal beta	β	9.2%
Central plasma temperature	T_o	30 keV
Profile parameter	d	1
Profile parameter	p	2
Profile parameter	q	0.472
Profile parameter	y_{ed}	0
Profile parameter	r	2
Profile parameter	s	0.964
Profile parameter	t_{ed}	0
Poloidal coil mass ratio	f_{pol}	1.67
Structure mass ratio	f_{sup}	0.6
Bootstrap current fraction	f_{bs}	0.915
Helium fraction	f_{He}	22.3 %
Argon fraction	f_{Ar}	0.2 %
Blanket energy multiplication factor		1.1
Thermal efficiency	η	59 %
Maximum magnetic field	B_{max}	11.4 T
Coil current density	j_{coil}	67 MA/m^2

Table 3. (continuing)

Comparison of PEC5 results with ARIES-AT data.
Costs are in 1992$.

The right-hand column shows the percent difference between PEC and ARIES-AT values.

A: Plasma and Masses

Plasma		**PEC**	**ARIES-AT**	**%**
Plasma major radius R_p	m	5.11	5.2	-2
Plasma minor radius a_p	m	1.28	1.3	-2
Toroidal magnetic field B_t	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
Radiated power fraction	f_{rad}	0.37	0.3	23
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
Masses				
First Wall & Blanket	kt	0.24	0.26	-8
Shield	kt	1.03	0.88	17
Toroidal coil	kt	0.56	0.57	-2
Poloidal coil	kt	0.94	0.95	-1
Structure & support	kt	1.04	1.03	1
Vacuum vessel	kt	1.67	1.42	18
Fusion Power Core Total	kt	5.52	5.23	6

Table 3. (continued)

B: Costs in 1992 $

Costs		PEC	ARIES-AT	%
20. Land & land rights	M$	10	11	-9
21. Structures & site facilities	M$	331	335	-1
22. Reactor plant equipment	M$	907	900	1
22.1 Fusion 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 Current drive & heating	M$	52	41	27
22.1.5 Primary structure & support	M$	35	30	17
22.1.6 Vacuum systems	M$	108	109	-1
22.1.7 Power supply, switching	M$	55	56	-2
22.1.8 Impurity control & divertor	M$	10	5	100
22.1.9 Direct energy conversion	M$	0	0	
22.1.10 ECRH breakdown system	M$	4	4	0
22.2 main heat transport systems	M$	252	209	21
23. Turbine plant equipment	M$	231	243	-5
24. Electric plant equipment	M$	123	110	12
25. Misc. plant-equipment	M$	59	50	18
26. Heat rejection system	M$	23	23	0
27. Special materials	M$	97	84	15
90. Total direct cost=sum (c20 to c27)	M$	1684	1757	-4
91. Construction services & equipment	M$	202	211	-4
92. Home office engr. & services	M$	88	91	-3
93. Field office engr. & services	M$	101	105	-4
94. Owners cost	M$	311	325	-4
95. Process contingency	M$	0	0	
96. Project contingency	M$	413	420	-2
97. Interest during construction	M$	462	481	-4
99. Total capital cost	M$	3261	3390	-4
COE capital cost	mil/kWh	46.92	49.8	-5
COE operations & maintenance	mil/kWh	9.19	9.4	-1
COE fuel	mil/kWh	0.03	0.03	0
COE blanket replacement	mil/kWh	3.69	3.8	-3
COE Decontamination & decommission.	mil/kWh	0.5	0.5	0
Total COE	mil/kWh	60.33	63.5	-5

Table 4.

Main input data for PEC model of the ARIES-SPPS.

Plasma aspect ratio	$R_p/<a_p>$	8.54
Plant availability fraction	f_{avail}	0.76
Net electrical power output	P_e	1000 MWe
Number of helical coils	l	2
Number of field periods	m	4
Elongation	k	2.0
Triangularity	δ	0
Safety factor on axis	q_o	0.91
Safety factor at edge	q_{95}	0.85
Average toroidal beta	β	5%
Central plasma temperature	T_o	16 keV
Profile parameter	d	1
Profile parameter	p	2
Profile parameter	q	1
Profile parameter	y_{ed}	0
Profile parameter	r	2
Profile parameter	s	1.1
Profile parameter	t_{ed}	0
Poloidal coil ratio	f_{pol}	0
Structure mass ratio	f_{sup}	1.2
Helium fraction	f_{He}	4.7%
Oxygen fraction	f_{Ox}	1%
Iron fraction	f_{Fe}	0.01%
Blanket energy multiplication factor		1.4
Thermal efficiency	η	46%
Maximum magnetic field	B_{max}	14.5 T
Toroidal magnetic field on axis	B_t	4.94 T
Coil radius	a_{coil}	4.0 m
Coil current density	j_{coil}	30 MA/m^2
Vacuum vessel mass		2.71 kt

Table 5 . (continuing)

Comparison of PEC5 results with ARIES-SPPS data. Costs are in 1992 $.

A : Plasma and Masses

Plasma		PEC	ARIES-SPPS	%
Plasma major radius Rp	m	14.02	13.95	1
Plasma minor radius ap	m	1.16	1.16	0
Electron density	10^{20} m^{-3}	1.48	1.46	1
Density-weighted avg.temp.	keV	10.32	10	3
Radiated power fraction	frad	0.25	0.21	19
Thermal power	MW	2244	2290	-2
Avgerage neutron wall load	MW/m^2	1.26	1.18	7
Mass Power Density	kWe/t	47.62	47.1	1
Masses				
First Wall & Blanket	kt	0.29	0.25	16
Shield	kt	8.96	9.45	-5
Toroidal coil	kt	4.09	4.19	-2
Poloidal coil	kt	0	0	0
Helical coil	kt	0	0	0
Structure & support	kt	5.25	5.36	-2
Vacuum vessel	kt	2.17	2.17	0
Fusion Power Core Total	kt	20.81	21.43	-3

Table 5. (continued)

B : Costs in 1992 $

Costs		PEC	ARIES-SPPS	%
20. Land & land rights	M$	10	10	0
21. Structures & site facilities	M$	342	333	3
22. Reactor plant equipment	M$	1635	1476	11
22.1 Fusion reactor equipment	M$	1223	1104	11
22.1.1 FW/blanket	M$	86	72	19
22.1.2 Shield	M$	352	290	21
22.1.3 Magnets	M$	381	381	0
22.2.4 Current drive & heating	M$	52	54	-4
22.1.5 Primary structure & support	M$	187	150	25
22.1.6 Vacuum systems	M$	98	85	15
22.1.7 Power supply, switching	M$	55	55	0
22.1.8 Impurity control & divertor	M$	12	12	0
22.1.9 Direct energy conversion	M$	0	0	0
22.1.10 ECRH breakdown system	M$	4	4	0
22.2 main heat transport systems	M$	274	218	26
23. Turbine plant equipment	M$	212	254	-17
24. Electric plant equipment	M$	117	104	13
25. Misc. plant equipment	M$	55	52	6
26. Heat rejection system	M$	0	0	
27. Special materials	M$	15	21	-29
90. Total direct cost=sum (c20 to c27)	M$	2373	2249	6
91. Construction services & equipment	M$	285	270	6
92. Home office engr. & services	M$	123	117	5
93. Field office engr. & services	M$	142	135	5
94. Owners cost	M$	438	416	5
95. Process contingency	M$	0	0	
96. Project contingency	M$	582	538	8
97. Interest during construction	M$	651	615	6
99. Total capital cost	M$	4594	4340	6
COE capital cost	mil/kWh	67.27	63.02	7
COE operations & maintenance	mil/kWh	8.89	9.16	-3
COE fuel	mil/kWh	0.03	0.03	0
COE blanket replacement	mil/kWh	1.58	1.9	-17
COE Decontamination & decommission.	mil/kWh	0.5	0.5	0
Total COE	mil/kWh	78.27	74.6	5

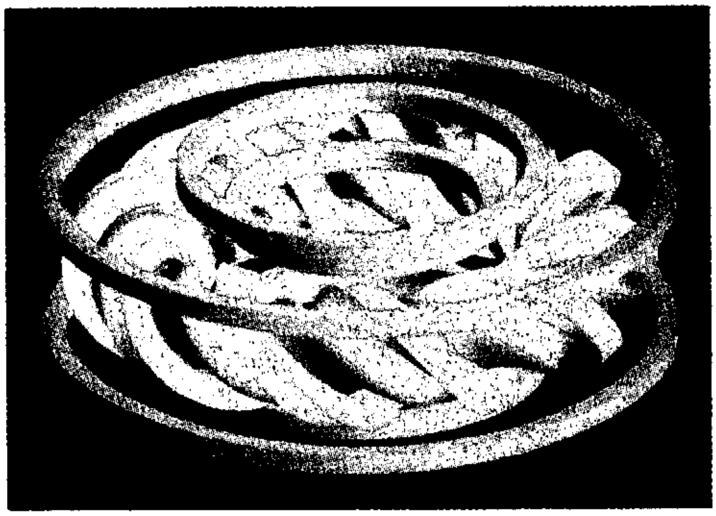

Figure 1. Heliotron with l = 2 helical coils and m = 10 (5 field periods), like LHD, plus three pairs of poloidal field coils.

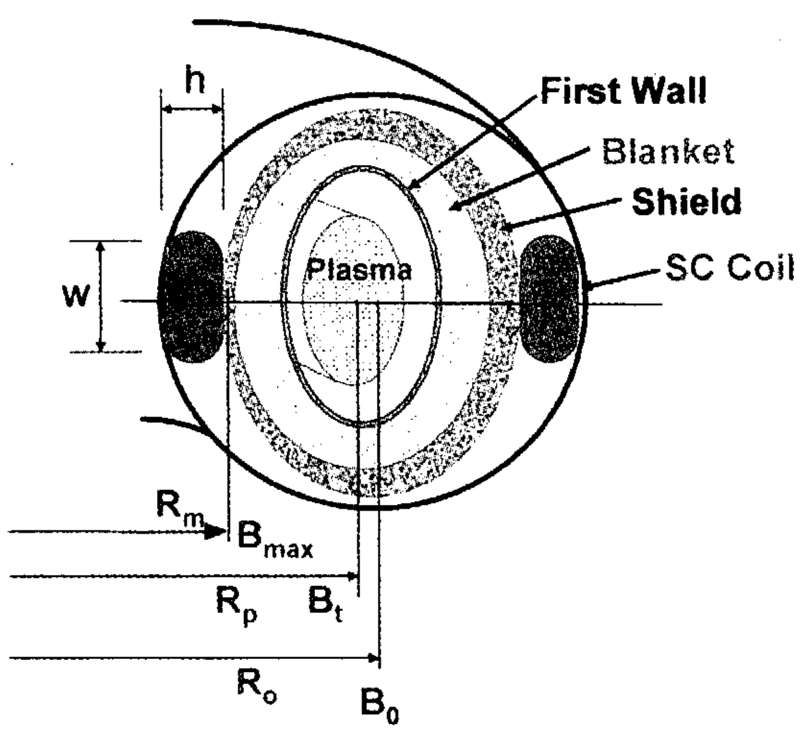

Figure 2. PEC Code model of heliotron plasma, showing elliptical cross section plasma, first wall, blanket, and shield. The poloidal field coils are not shown.

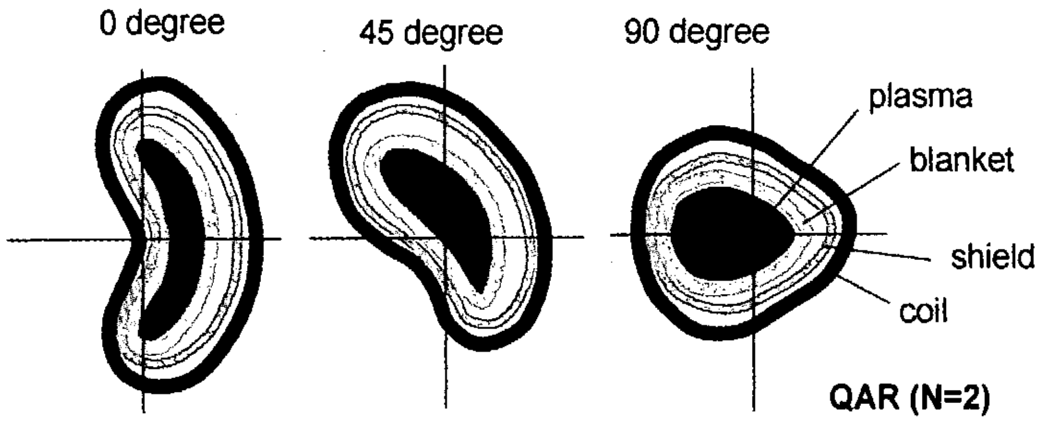

Figure 3. Modular stellarator plasma-blanket-shield-coil shapes at various angles within a field period. (N=2 QAR based on CHS-qa)

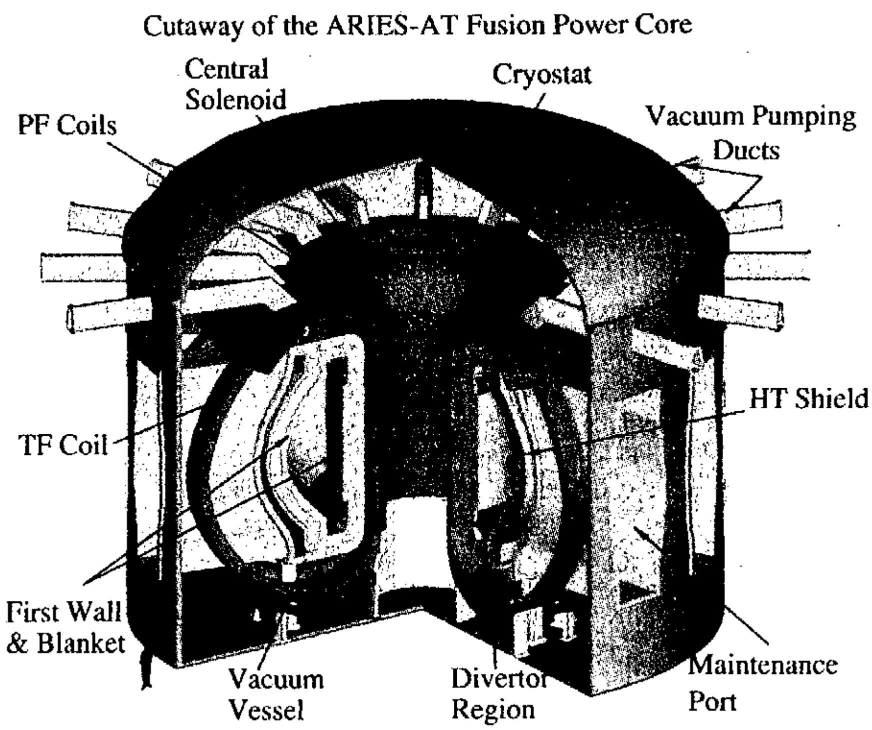

Figure 4. Cutaway view of the ARIES-AT tokamak reactor fusion power core. (Courtesy of the ARIES Group, from their website http://aries.ucsd.edu/LIB/CAD/FIGURE/ARIES-AT/aat-0009-powercore01.jpg .)

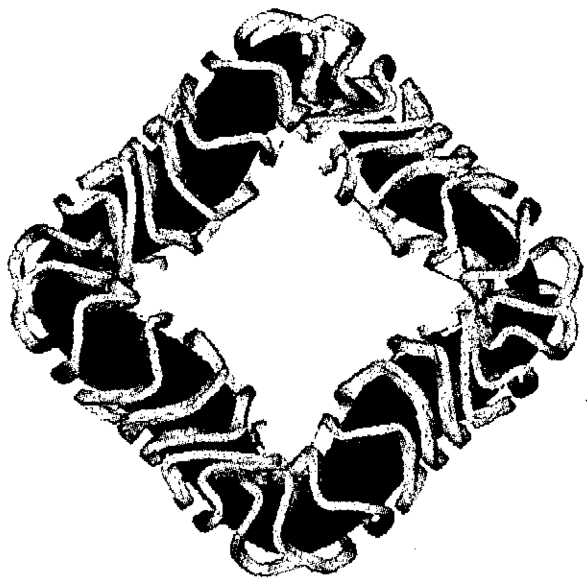

Figure 5. The ARIES-SPPS modular coils, with four field periods. There are 32 coils with 4 different shapes. (Courtesy of the ARIES Group, from their website: http://www-ferp.ucsd.edu/LIB/REPORT/SPPS/FINAL/)

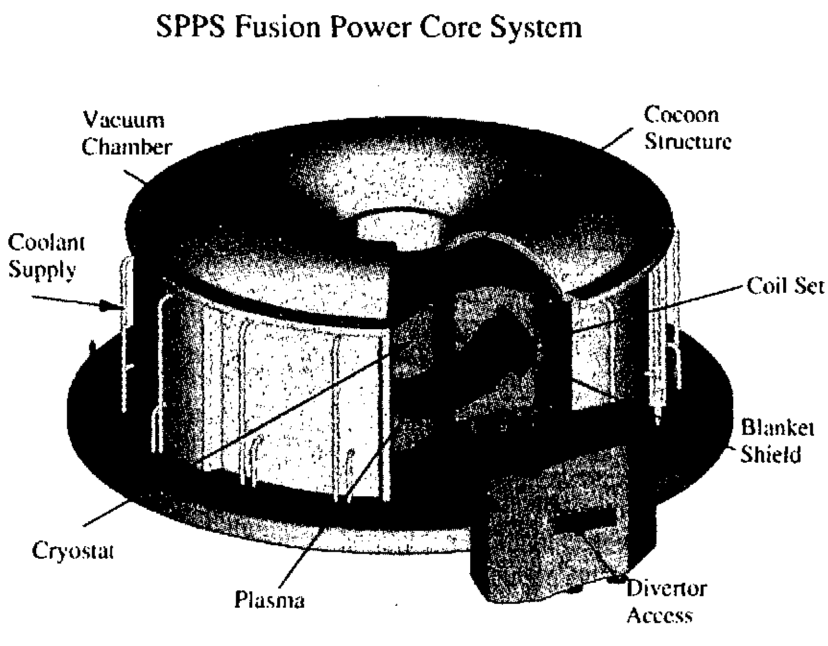

Figure 6. Isometric view of the ARIES-SPPS fusion power core. (Courtesy of the ARIES Group, from their website: http://www-ferp.ucsd.edu/LIB/REPORT/SPPS/FINAL/)

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