Ignition/Burn is a Done Deal – Or is It?

The Experience of Fission's "Ignition/Burn" Experiment

L. John Perkins
Lawrence Livermore National Laboratory

UFA Burning Plasma Science Workskop II
General Atomics, San Diego CA
May 1-3, 2001

The Rapid Advance of
Fission's "Burning Plasma" Science

1932 ◆ *Chadwick (UK)* discovers the neutron

1933 ◆ *Szilard (UK)* conceives of nuclear chain reactions (and files a patent)

1935-7 ◆ *Fermi (Italy), Joliot-Curies (France)* study fast and thermal neutron-induced reactions (and both miss fission!)

1938 ◆ *Hahn & Strassman (Germany)* discover fission

1939 ◆ *Meitner & Frisch (Sweden,UK)* confirm Hahn & Strassman's results as U fission

◆ *Bohr-Wheeler (US)* theory of fission; resolution of U^{235}/U^{238} fast/thermal puzzle

◆ *Zinn & Szilard (US)* measure secondary neutrons from fission (⇒ thermal and fast chain reactions are possible)

◆ *Fermi & Szilard (US)* construct exponential sub-critical piles at Columbia

1940 ◆ *Peierls & Frisch (UK)* make first realistic estimate of ^{235}U critical mass

1942 ◆ *Fermi (US)* CP-1 zero power pile critical in Chicago

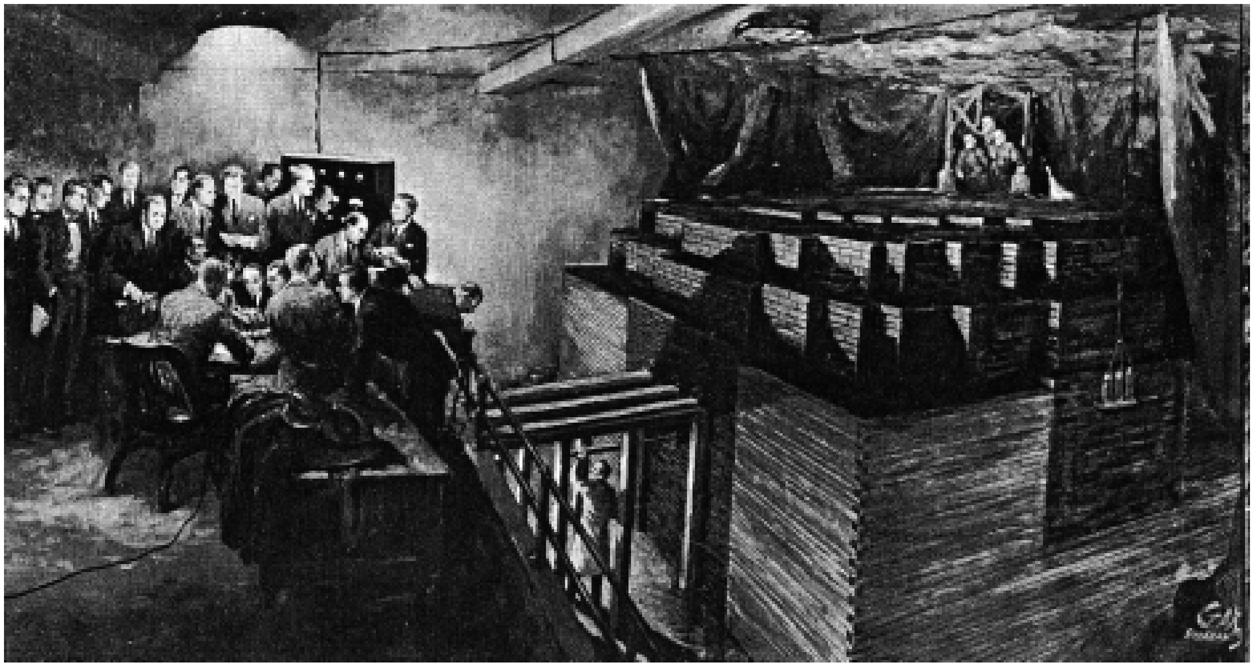
1943 ◆ *Fermi/Compton/DuPont* (US) X-10 low power reactor critical in Oak Ridge

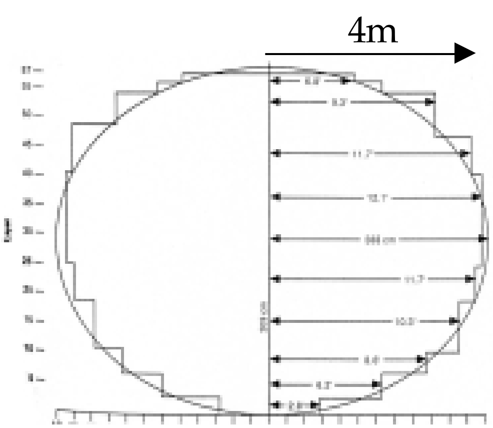
1944 ◆ *Wigner/Fermi/Wheeler/DuPont (US)* 100-B high power reactor critical at Hanford (fission's "ignition/burn" experiment)

1945 ◆ The rest is history!

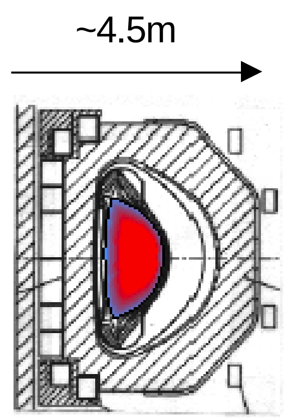
The First Self-Sustaining ("Q=Infinity") Fission Reactor was Fermi's Pile CP-1

There is No Fusion Analogy (Unfortunately!)





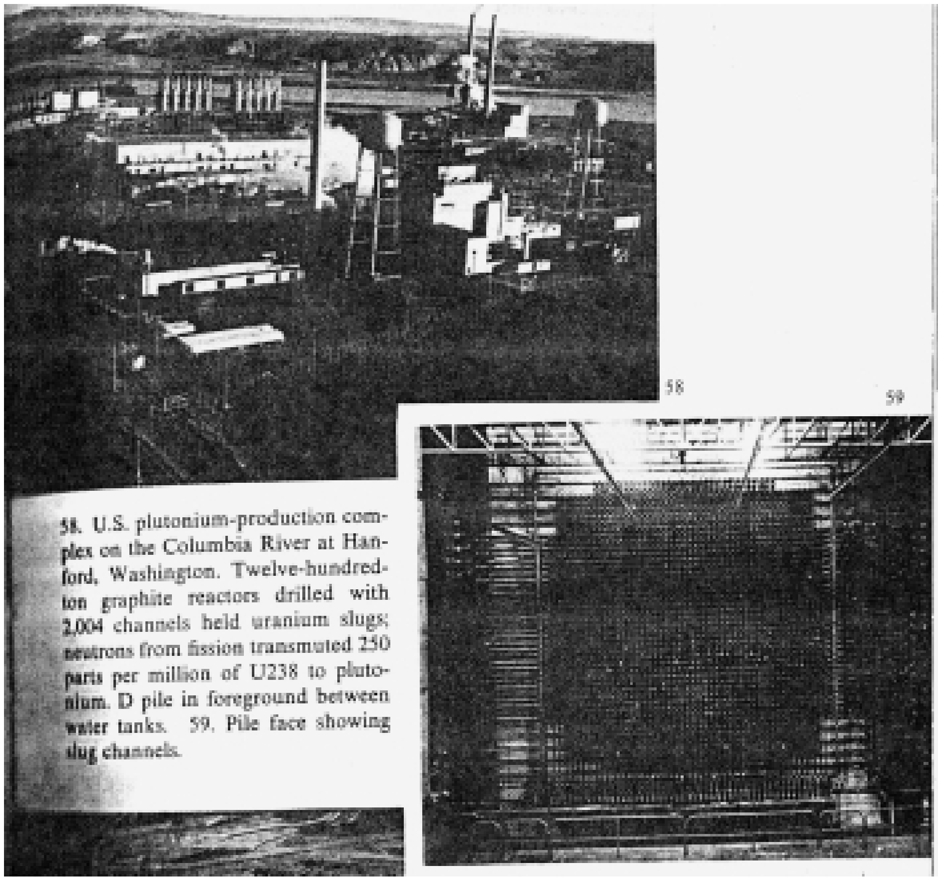
CP-1



FIRE

L. John Perkins

The Hanford Pile B-100 was Fission's "Ignition/Burn" Experiment



Design Start —1942

Construction Start —1943

Operation Start—1944 (Weep!)

Moderator – Graphite

Fuel — U-metal in Al cladding

Cooling — Water

Core size – 9 X 10 m cylinder

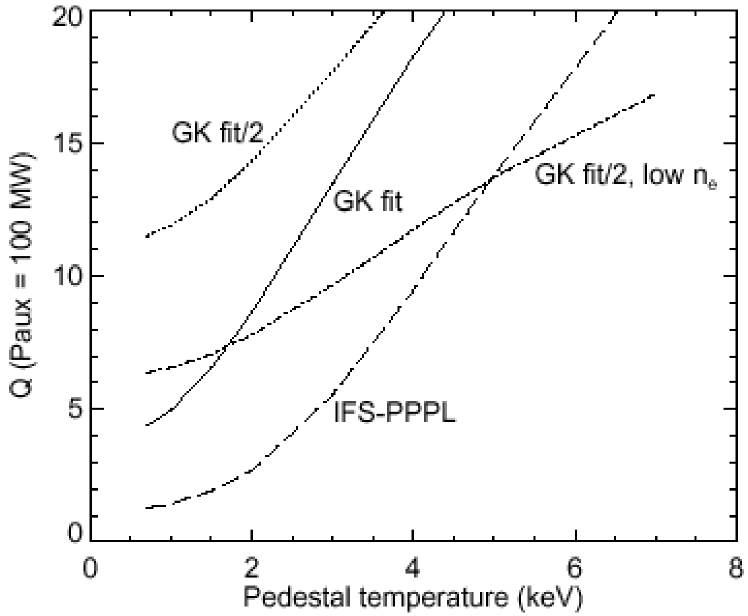
Fission (thermal) Power — 250MW

(FIRE fusion power ~200MW!)

There are Interesting Parallels Between the First Burning Fusion and Fission Experiments

Fusion	Fission
TFTR / JET	Fermi's sub-critical experiments
(No parallel)	Fermi's CP-1 zero power pile
ITER / FIRE / Ignitor….	Hanford 100-B high-power pile
Fusion power	Fission power
Ignition margin	$k_{effective}$ for criticality
Alpha heating profile	Neutron flux profile
Initial impurities at plasma start up (H, O, Fe,.)	Moderator and fuel impurities at startup
Te/Ti profiles	Thermal temperature profiles
Density profiles	Fuel matrix profile
Temp. coeffs of reactivity (+ve and –ve)	Temp. coeffs of reactivity (+ve and –ve)
d<__V(T)> /dT	$d\_{}_f /dE_n$
d_Other/dT	(Core) temperature-dependent effects: Doppler broadening of resonances Moderator void perturbations,
Short term transients: Alpha slowing down time Sawteeth/ELMS	Delayed neutron production and thermalization Local core oscillations (10's-100's msec)
Medium term transients: Alpha ash buildup Impurity influx from walls/divertor	Direct fission product poisons
Long term transients: Long term impurity evolution; Current profile evolution	Buildup of poisons from fission product decay Fuel depletion
Vertical/horizontal stability (~msecs –seconds)	Gross core oscillations (~seconds)
Density control	Neutron flux profile control
Burn control systems	Control rods
Shutdown control (killer pellets…)	Scram rods
Neutron wall loading	Neutron flux in fuel pin cladding (<<1%! of fusion's)
Surface heat flux at first wall /divertor	Surface heat flux @ fuel pin(~10% of fusion's)
Plasma disruption	Core scram (or worse…..!)

Will There be Surprises in the BP Experiment(s)? Predicted Performance Sensitivities are Wide-Ranging



1996 ITER Baseline

Fig. (8) The predicted fusion gain Q vs. assumed pedestal temperature, for the IFS-PPPL 95 model, for a modified model to fit the gyrokinetic flux-tube results of Fig.3 ("GK fit"), and for a further reduction in χ_i by a factor of 2 ("GK fit/2"). These 3 cases are at 1.5 times the Greenwald density. Also shown is a lower density case at 1.15 times the Greenwald density using the "GK fit/2" χ_i.

A. Dimits et al "Comparison and Physics Basis of Tokamak Transport Models and Turbulence Simulations", Phys Plasmas, ***7*** *969 (2000)*

Will There be Surprises in the BP Experiment(s)?
Predicted Performance Sensitivities are Wide-Ranging

Sensitivity of Fusion Power to Some Assumptions

Baseline assumptions:

IFS-PPPL model for $\chi_{i,e}$ **modified with** $\Delta(R/L_{Tcrit}) = 2$ **to roughly fit Dimits shift seen in gyrokinetic simulations.**

$\langle n_e \rangle / n_{\text{Greenwald}} = 0.74$. **Modest density peaking,** $n_0/\langle n_e \rangle = 1.18$, $n_{ped}/\langle n_e \rangle = 0.65$.
$n(r) = (n_0 - n_{ped})(1 - (r/a)^2)^{0.5} + n_{ped}$.

P_{aux} **adjusted to keep** $P_{net} \geq 1.2 P_{99L \rightarrow H}$ **= 30 MW for baseline FIRE, =57 MW for baseline ITER-FEAT.**

	n_0 $10^{20}/m^3$	n_{ped} $10^{20}/m^3$	T_{ped} keV	P_{fusion} MW	Q	T_{i0} keV	P_{aux} MW
FIRE baseline case	6.75	3.6	4.8	264	620.0	18.6	0
$\downarrow T_{ped}$ 30%	6.75	3.6	3.4	142	9.7	15.3	14
flatten $n(r)$	3.60	3.6	4.8	117	22.0	21.7	5
original IFS-PPPL	6.75	3.6	4.8	155	13.0	12.9	11
original IFS-PPPL $\downarrow T_{ped}$ 30%	6.75	3.6	3.4	69	2.6	10.2	26
ITER-FEAT baseline case	1.09	0.58	2.9	192	5.8	18.3	32
$\downarrow T_{ped}$ 30%	1.09	0.58	2.0	111	2.4	15.5	45
ITER-FEAT with FIRE T_{ped}	1.09	0.58	4.8	381	816.0	23.5	0
ITER-FEAT with FIRE $T_{ped} \downarrow 30\%$	1.09	0.58	3.4	241	10.1	19.8	23

G. Hammett et al. "Exploring Possible High Fusion Power Regimes with the IFS-PPPL Model", UFA Worshop on Burning Plasma Sciences, Austin TX (2000)