Helium-cooled Liquid Breeder FW/blanket/divertor system

(For average Γn=8 MW/m^2, φ=2 MW/m^2, peaking factor =1.4)

- COE and Γn
- Design Example
- Design and Functional Requirements
- Critical issues and tasks for APEX

(Green color indicates beyond BCSS)

Clement Wong

APEX project meeting

UCLA, Ackerman Union 2408

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Functional Requirements (FR-x)

FR-1. The FW/blanket/divertor must have adequate tritium breeding

- Recovery ⇒ extraction from breeder, fueling system and FPC environment
- Control and accountability ⇒ permeation, deposition and transport

FR-2. The FW/blanket/divertor must be designed to be compatible to different plasma operation scenarios (startup/shutdown, SS and transients "disruptions and ELMs")

- Surface heat load and neutron power
- Partial power operation
- Plasma facing materials
- Module alignment and geometry
- Acceptable plasma Zeff
- MHD shells location
- Penetrations: RF, neutral beams, diagnostics, fueling
- Ash removal
- Vacuum pumping, helium enrichment factor, (core helium concentration)

FR-3 The FW/blanket/divertor must be able to recover energy with high gross power conversion efficiency of (e.g. ≥45%) and minimize re-circulating power

- Power conversion system- Gas turbine cycle
- Minimize pumping power

FR-4 The FW/blanket/divertor must be designed to complement the maintenance and repairing scenario of the reactor design

- Optimize FW/blanket/divertor design simplicity that matches the confinement geometry, (e.g. vertical, horizontal, sectors, segments, modules...)
- Optimize coolant routing and manifolds arrangements
- Minimize number of modules, joints and penetrations
- Optimize ease of fabrication, construction, and inspection

FR-5 The FW/blanket/divertor must be designed to complement the inboard and outboard shielding requirements.

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(For average Γn=8 MW/m^2, φ=2 MW/m^2, peaking factor =1.4)

Critical Issues and <u>Tasks</u> for APEX

(Engineering and feasibility)

DR-1 The FW/blanket/divertor must meet all design criteria

- **Temperature limitations:**

  Structural: FS, V, W, Ta, Nb, or Mo alloys

- **Mechanical stresses:**

  ASME and others

  <u>We need a conceptual design to work on design details</u> (FW, blanket, divertor, plenum, coolant routing, structural support... etc.)

- **Compatibility:**

  PFC material to plasma

  <u>Low-Z (e.g. Si or B) in-situ coating on W-coating and keep watching</u>

  Materials to vacuum

  Structural/coolant/breeder/multiplier

  <u>Coolant cleanup, coating and bi-metallic approach</u>

  Coolant velocity and channel wall material erosion

  In-vessel and ex-vessel corrosion material mass transfer

  Magnetic property, keep watching

- **Fluid:**

  He velocity

  Flow, power, and temperature stability

- **Design to adequate engineering design safety margins**

  Needs to find out how to properly applied

DR-2 The FW/blanket/divertor must have acceptable lifetime:

(Impacted by: neutron fluence, inspection, operating conditions and scenarios)

- Radiation damage:

  (swelling, ductility, creep, mechanical and thermal properties)

  PFC materials: Coatings (e.g. W), in-situ low-Z coating (?)

  Structural materials:(crack growth: initial detection and critical flaw size)

  Reliability analysis

  Welds

  Multiplier

- Effects from hydrogen/tritium embrittlement

(Safety and environment)

DR-3 The FW/blanket/divertor design must optimize safety and environment features with high-Z first wall and low activation structures

- Operation safety
- Accidental releases: tritium and radioactivity

  (afterheat, coolant pressure, chemical reactivity, credible releases)

  High pressure helium depressurization and system response
- Waste materials: recycling and disposal (Class-A, Class-C, high-level)

(R&D, risk and program plan)

DR-4 The FW/blanket/divertor design activity must outline R&D requirements, test program, program plan and schedule, and the possibility of product improvement

- <u>R&D requirements</u>
- Minimum extrapolation from available technology
- <u>Credible test program</u>: small, medium and large scale (scalability) experiments
- Possibility of product improvement

DR-5 The FW/blanket/divertor design must be sensitive to the following issues:

- Economics

  Capital cost, sensitivity on cost projection

  Resources utilization

- <u>Balance of Plant</u>

Functional Requirements (FR-x)

FR-1. The FW/blanket/divertor must have adequate tritium breeding

- Recovery ⇒ extraction from breeder, fueling system and FPC environment from Li or LiPb
- Control and accountability ⇒ permeation, deposition and transport

FR-2. The first wall must be designed to be compatible to different plasma operation scenarios (startup/shutdown, SS and transients "disruptions and ELMs")

- Surface heat load and neutron power
- Partial power operation
- Plasma facing materials
- Module alignment and geometry
- Acceptable plasma Zeff, this is physics concept dependent
- MHD passive and active shells location, (look into the use of existing metal structure)
- Penetrations: RF, neutral beams, diagnostics, fueling
- Ash removal
- Vacuum pumping, helium enrichment factor, (core helium concentration) , Keys to acceptable radiation fraction

FR-3 The FW/blanket/divertor must be able to recover energy with high gross power conversion efficiency of (e.g. ≥45%) and minimize recirculating power

- Power conversion system- Gas turbine cycle, @ high helium pressure
- Minimize pumping power

FR-4 The FW/blanket/divertor must be designed to complement the maintenance and repairing scenario of the reactor design

- Optimize FW/blanket/divertor design simplicity that matches the confinement geometry, (e.g. vertical, horizontal, sectors, segments, modules...)
- Optimize coolant routing and manifolds arrangements
- Minimize number of modules, joints and penetrations
- Optimize ease of fabrication, construction, and inspection (Initial identification)

FR-5 The FW/blanket/divertor must be designed to complement the inboard and outboard shielding requirements.

Helium-cooled Liquid Breeder FW/blanket/divertor system

APEX Tasks summary

Design

- Conceptual FW/blanket/divertor design
- Optimize coolant routing and manifolds arrangements
- Minimize number of modules, joints and penetrations
- MHD passive and active shells location, (look into the use of existing metal structure)

Fabrication

- Initiate the consideration of ease of fabrication, construction, and inspection

Nuclear design and Engineering analysis

- Adequate tritium breeding
- Components reliability analysis

Research and Development

- Document R&D requirements
- Formulate credible test program plan
- Coolant Flow, power, and temperature stability
- Tritium recovery from Li or LiPb
- Coolant compatibility: cleanup, coating and bi-metallic approach
- Low-Z (e.g. Si or B) in-situ coating on W-coating and keep watching
- Develop gas turbine cycle system at high helium pressure

Safety

- Safety and environment features with high-Z first wall and low activation structures
- High pressure helium depressurization and system response

Data base

- Materials radiation damage
- Helium enrichment factor, core helium concentration , key to acceptable radiation fraction

System integration

- Balance of Plant
- Economics

COST OF ELECTRICITY

ARIES-RS

@ 1 GWe, ave Γ_N @ 4 MW/m^2, COE=76 mill/kWh,
@ 1 GWe, ave Γ_N @ 8 MW/m^{2*}, COE~70 mill/kWh,
@ 2 GWe, ave Γ_N @ 8 MW/m^{2*}, COE~ 63 mill/kWh

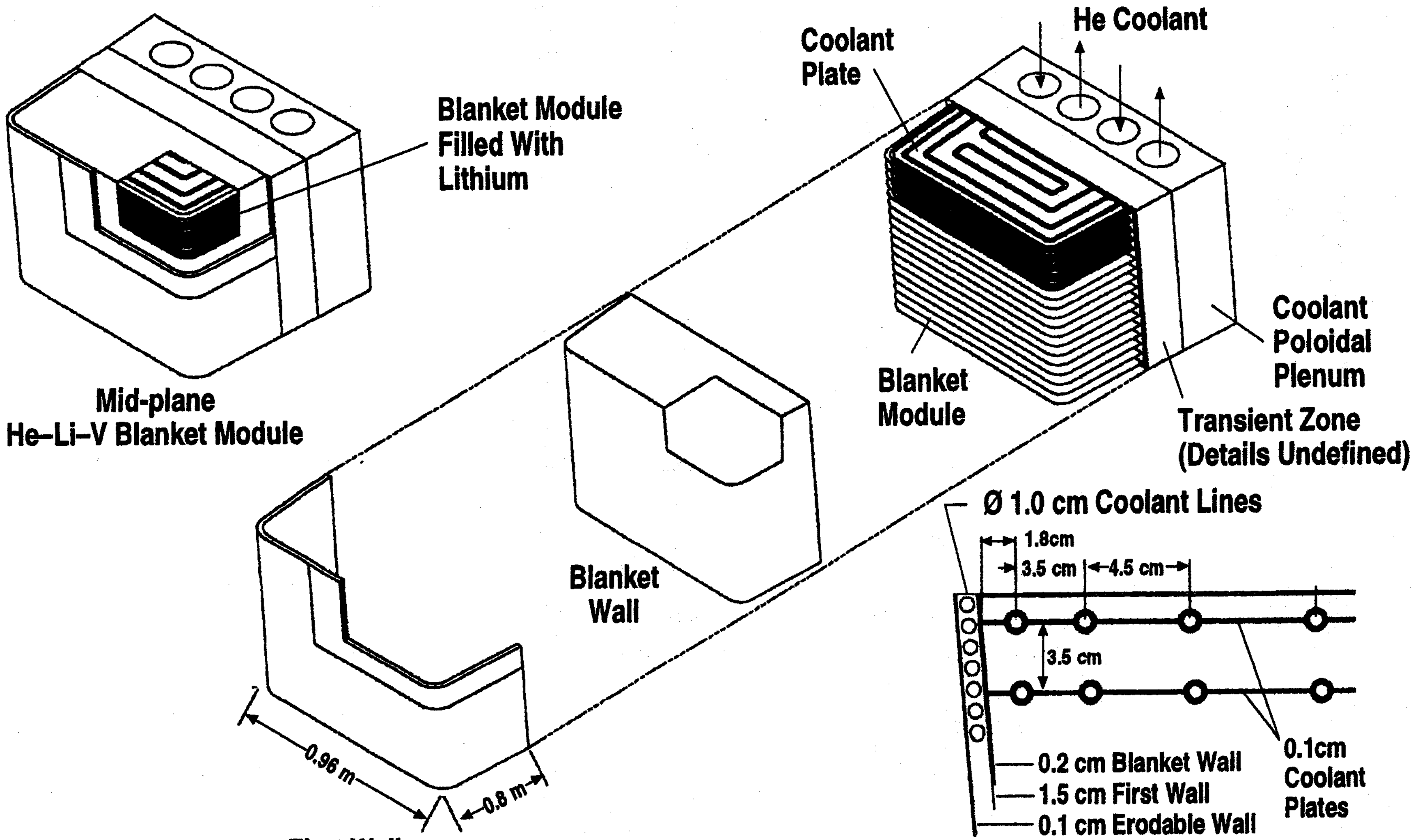
*via lower aspect ratio to 3.0 and/or with β_N improvement

NORMAL COIL LAR REACTOR

@ 2 GWe, ave Γ_N @ 8 MW/m^2, COE ~ 50-60 mill/kWh

(Higher Γ_N means higher plasma power density)

HIGH PERFORMANCE He – Li – V BLANKET



First Wall
(Toroidal Flow Channels)

First Wall and Blanket Tubing Arrangement for LAR

GENERAL ATOMICS

Design variations for magnetic fusion PFC material and FW design

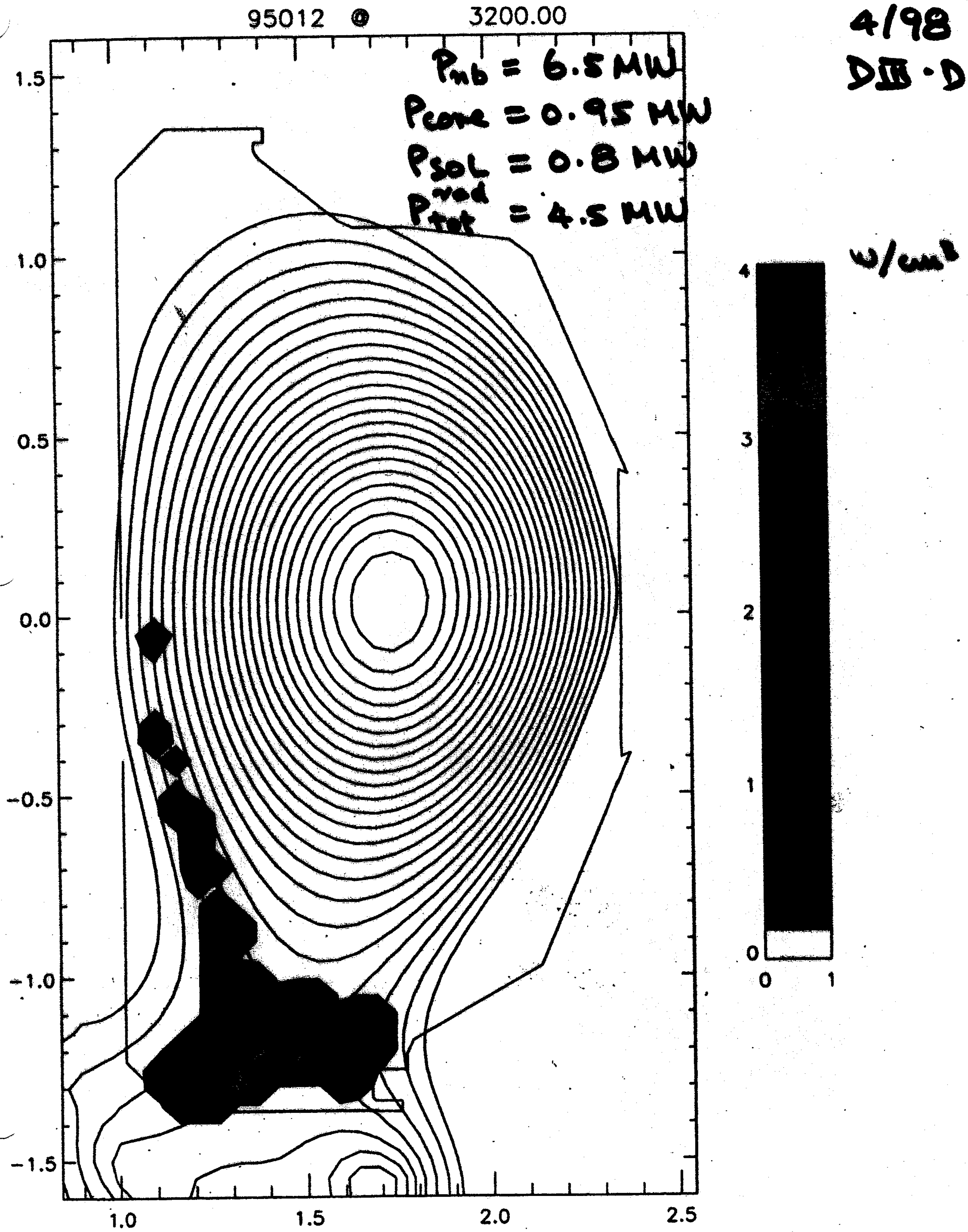
	Minimum radiation[1]	Optimum radiation[2]
Solid surface	√	√
Liquid surface	√	√

Radiation ⇒ divertor, mantle and core

1. **Minimum radiation, e.g. min. first wall surface loading**
2. **Optimum radiation,**

   e.g. first wall peak heat flux = divertor peak heat flux

ELMing H-mode with Ar.
4/98
DIII-D



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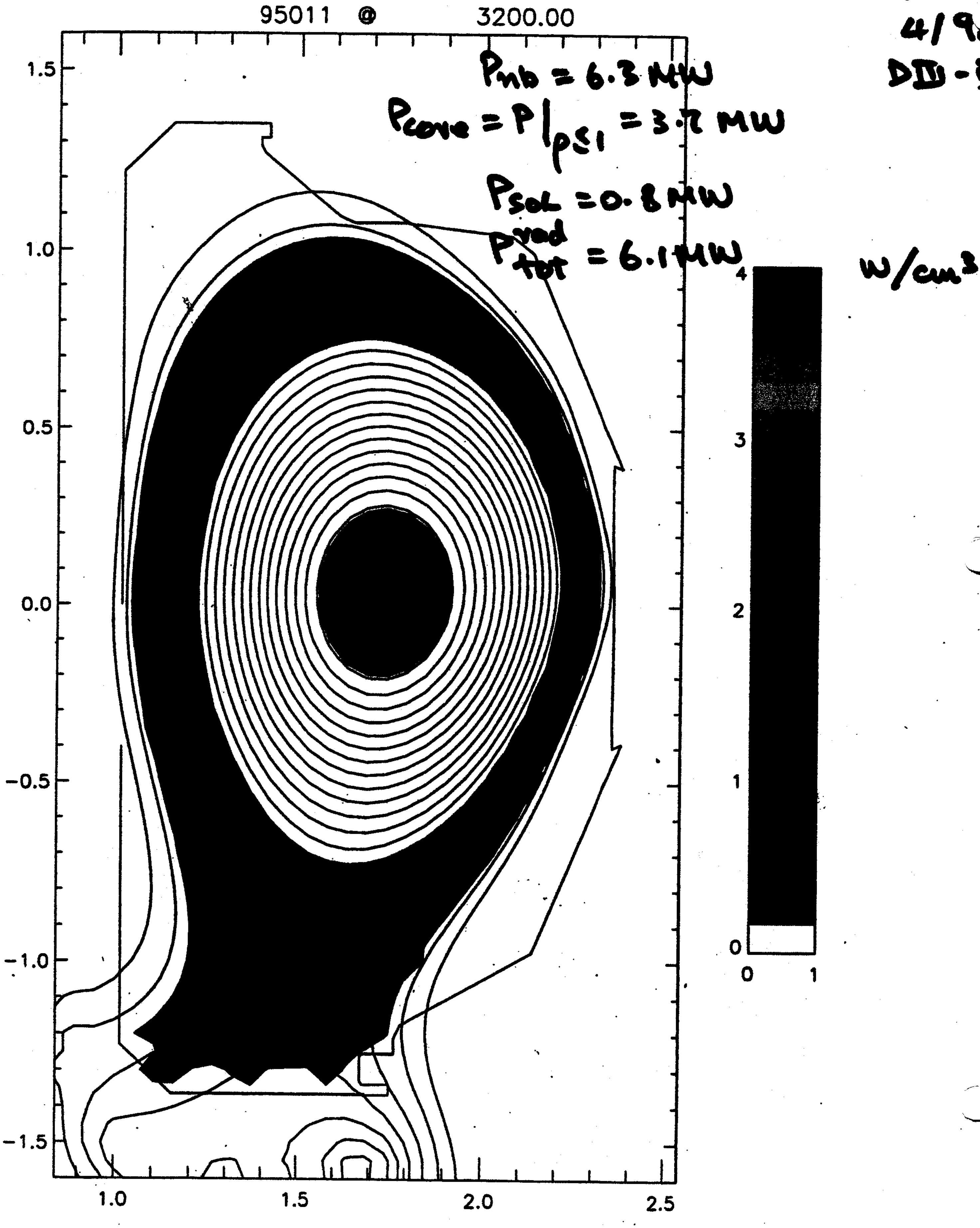

Design Requirements (DR-x)

(Engineering and feasibility)

DR-1 The FW/blanket/divertor must meet all design criteria

- **Temperature limitations:**

  Structural: FS, V, W, Ta, Nb, or Mo alloys

  Breeder: liquid

  Multiplier: Be, Pb

- **Mechanical stresses:**

  ASME and others

- **Compatibility:**

  PFC material to plasma

  Materials to vacuum

  Structural/coolant/breeder/multiplier

  Coolant velocity and channel wall material erosion

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