CHAPTER 4: EVALUATION CRITERIA

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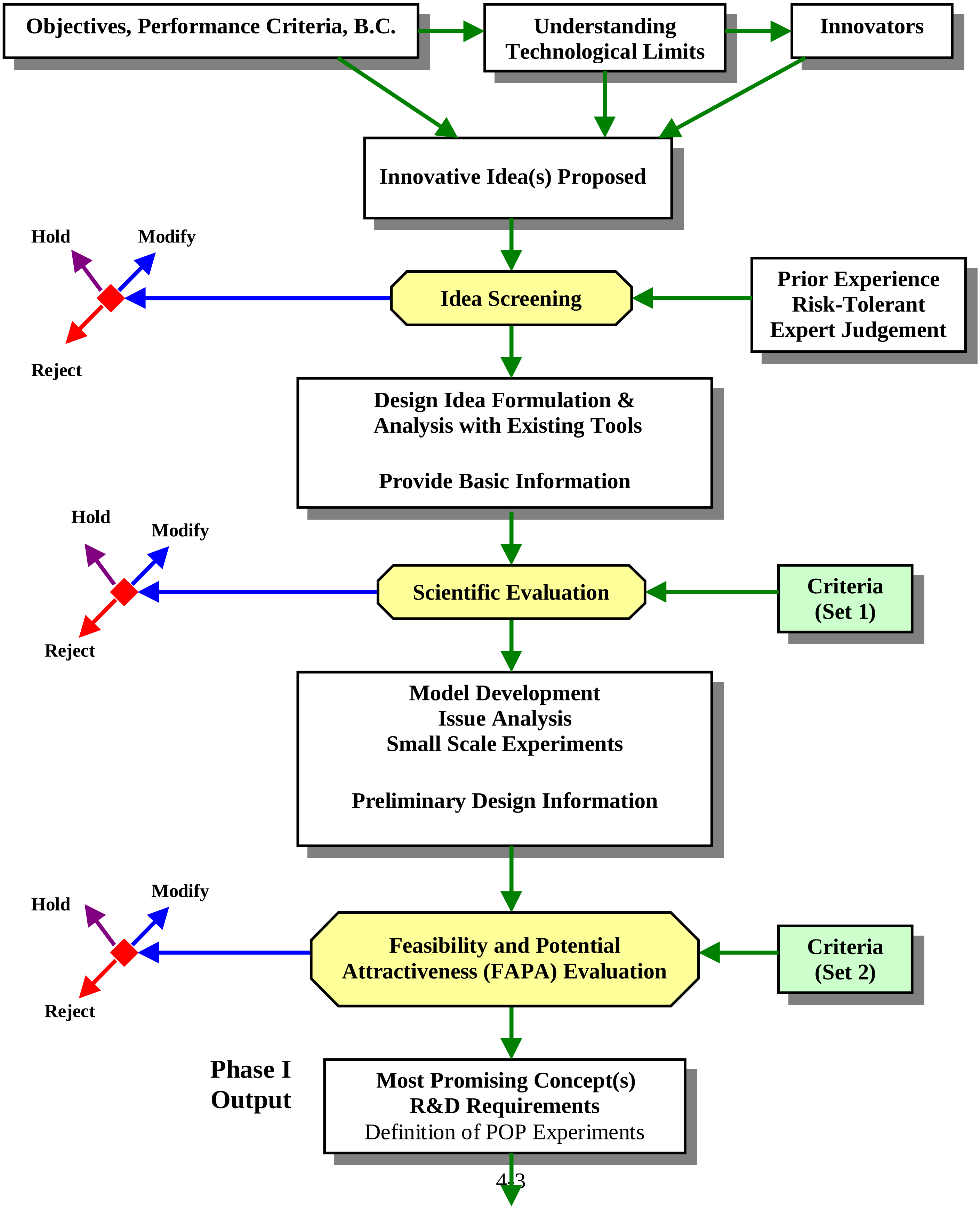
4. EVALUATION CRITERIA

4.1 Introduction

The APEX study is aimed at exploring innovative first wall and blanket concepts that can tremendously enhance the potential of fusion as an attractive and competitive energy source. These concepts should have high power density handling capability, high power conversion efficiency, potential to achieve high availability, and safety and environmental attractiveness. In addition the concepts considered should meet the minimum functional requirements in a fusion system. Therefore, it is necessary to develop a set of evaluation criteria that help in the process of evaluating the concepts with respect to their attractiveness. In addition, these criteria provide guidance to the concept developers regarding improving the attractiveness of the concept by comparing design variations or material choices within the concept. An example for this is applying the evaluation criteria to compare the performance of the liquid wall concept with different liquid breeders.

Fig. 4-1 gives the different steps included in the APEX process. The concepts go through two major evaluations. The first one, referred to as the scientific evaluation, takes place in the early stage of the project and is aimed at determining if the concept can proceed into a more detailed level of analysis beyond the initial exploration phase. Following more detailed analysis of the concepts, more information about the concept performance will be available to allow carrying out the feasibility and potential attractiveness evaluation at the end of Phase I of the project. This evaluation is aimed at determining the most promising concepts to move to the proof-of-principle phase with R&D requirements and experiments being identified. Following this evaluation further design conceptualization will be initiated for the most promising concepts. In this report, we provide the evaluation criteria developed for the scientific evaluation process. The criteria to be used in the feasibility and potential attractiveness evaluation process will be developed latter.

APEX PROCESS



4.2 Information Required for Scientific Evaluation

The minimum information required for each concept to facilitate performing the scientific evaluation has been identified. Although no detailed analysis is expected in the early stage of the concept development, the design parameters required are essential for the evaluation process and could be based on preliminary scoping analysis. The required information is listed below.

A) Sketches of the geometry of the in-vessel components
B) Outline of FW/blanket/shield radial build including approximate dimensions
C) Candidate materials for PFC, structure, breeder, and coolant
D) Estimated values of the following parameters, based on a peak neutron wall loading of 10 MW/m^2, a peak surface heat flux of 2 MW/m^2, and a peaking factor of 1.4 for both:
    a) Coolant parameters (temperature, pressure) at inlet/outlet of:
        - plasma facing surface (liquid FW)
        - FW cooling channel (solid FW)
        - breeding zone
    b) Maximum/minimum temperatures of
        - breeder material
        - structural material
    c) Maximum primary and total (primary+secondary) stress in the structural material
    d) Tritium breeding ratio (Overall TBR estimated from local 1-D calculations with heterogeniety)
    e) Maximum power density in structure, breeder and coolant material
    f) Energy multiplication in in-vessel components
    g) Maximum structure damage
    h) Structure activity, decay heat, and radwaste classification

E) For a typical unit size module, which could be one of the following elements:
(Include the sketch of coolant routing)
    - ■ a chunk with a FW surface of 1m^2
    - ■ a cut out of a blanket segment with a poloidal height of 1m
    - ■ a sector cut of a segment with full height and a toroidal width of 1m
    - ■ a complete outboard segment
    - ■ a full sector

    estimates for the following parameters have to be provided, assuming the heat loads given under D):
    a) total surface heat load
    b) total heat load (surface heat load + volumetric heat generation)
    c) coolant mass flow rate (either total or for the different zones, depending on the concept)
    d) coolant velocities in FW and breeding zone
    e) coolant inlet and outlet manifold sizes
    f) coolant inlet and outlet piping location and sizes

g) coolant pumping power
h) a brief indication of structural support needed
i) identification of external primary or secondary coolant pumping system

4.3 Scientific Evaluation Criteria

The scientific evaluation criteria fall into four categories. The first one addresses the question of whether the concept meets the minimum functional requirements. The second one addresses the issue of the concept's potential for improved attractiveness. The third category relates to the design margins and uncertainties associated with the concept. The fourth category identifies the major critical issues and R&D needs.

4.3.1 Minimum Functional Requirements

These are the absolute minimum requirements for a concept to be proposed for use in a fusion power plant.

- Tritium breeding
  - The overall (3-D) tritium breeding ratio estimated from 1-D calculations coupled with the appropriate coverage fractions should be at least 1.1

- Tritium extraction
  - Keep tritium inventory in the blanket system at a reasonable value
  - Have sufficient containment to reduce routine site tritium release
  - Allow for suitable tritium extraction

- Vacuum and plasma exhaust
  - Sufficient vacuum pumping is provided for initial evacuation and for operation

- Power extraction
  - The concept should utilize materials that efficiently convert the fusion power generated in the plasma to useful thermal power
  - Sufficient cooling is provided to remove the thermal power and carrying it to an efficient power conversion cycle without exceeding thermal and structural design limits of the concept components

4.3.2 Potential for Improved Attractiveness

The potential of the concept for improved attractiveness is measured by addressing several issues. These are the high power density and heat flux handling, power conversion efficiency, availabilty, safety and environmental attributes, and cost.

4.3.2.1 High Power Density and Heat Flux Handling

The minimum requirements are:
- Maximum neutron wall loading 10 MW/m^2
- Maximum surface heat flux 2 MW/m^2

Assuming a peaking factor of 1.4, the minimum average values are:
- Average neutron wall loading 7 MW/m^2
- Average surface heat flux 1.4 MW/m^2

It is highly desirable that a concept has the potential for handling higher wall loads. It should have at least comfortable margins to these threshold values because these margins determine to a certain degree the reliability of a concept.

Potential parameters determining the allowable power density are:
a) Lower limit for the thickness of the FW to satisfy erosion and primary stress requirements,
b) Maximum temperature of structure, breeder, or at the interface between the two,
c) Maximum thermal stresses in FW or blanket structure,
d) Required coolant manifold size,
e) Pressure drop and/or pumping power in the cooling cycle.

4.3.2.2 High Power Conversion Efficiency

The predicted power conversion efficiency is used as a measure of the potential of the concept for improved attractiveness as follows.

> 55%	High
40-55%	Medium
<40%	Low

4.3.2.3 Availability

Achieving high availability is an important factor in improving the concept's attractiveness. Both low failure rate and short maintenance time lead to high availability. The specific goals of the project are:

Availability for blanket system > 97.8
MTBF/MTTR > 43.8

The attributes used in the evaluation are:

A. Design is tolerant of a few failures
   High if many welds or seals can fail, low if no welds or seals can fail
B. High maintenance items can be accessed easily (e.g., cassette access)
   High for easy access and few high maintenance items, low for many hard to get at, high maintenance items
C. Maximize hands-on operations (provide sufficient shielding)
   High if all operations are remote at machine, medium if in hot cell, low if many operations are hands-on
D. Minimize the number of parts whenever possible

High is given for low complexity, one or two of the main component or subsystem
Medium is for three or four main components or subsystems
Low is for 5 or more main components or subsystems

E. Use inherently reliable parts
High is for much use of passive components (those that do not need control signals or a power source). Examples of those are pipes, walls, vault rooms, heat exchangers, shielding slabs, natural draft air flow or natural circulation coolant flow, rupture disks, screens, etc.
Medium is for a system using a mix of passive and active components combined, which is typical
Low is for a system of all active components (requires extensive control system and support systems)

F. Use standard rather than specially designed parts whenever possible
High is for all off the shelf components that have known track records of fair to good reliability
Medium is keeping specialty components to a minimum
Low is for mostly specialized components

G. Derate parts (i.e., operate at less than manufacturer operating values) whenever possible
High is when an additional "safety" factor of 0.5 or more is found via operating at reduced parameters
Medium is operating a few percent under manufacturer's ratings
Low is operating at or above manufacturer's ratings

4.3.2.4 Safety and Environmental Attributes

The following criteria are used to screen concepts at an early development stage based on limited design information. It may not be possible to apply all the criteria to a given concept, however they should be used to the extent possible. In some cases, it may only be possible to make a judgement as to whether a concept has reasonable potential to meet a particular criterion.

1. Mobilizable in-vessel tritium inventories
   - A. <100 g-T and/or <100 g dust; Excellent (can meet no-evacuation with little confinement)
   - B. 100 g to 1 kg-T and/or 100 g – 10 Kg dust; Acceptable (some confinement degradation is acceptable and yet still meet no-evacuation)
   - C. > 1 kg-T and/or 10 kg of dust; Poor (significant confinement performance expected under all conditions to meet no-evacuation)
2. Decay heat
   - A. Peak temperature < 500°C; Excellent, little activation product mobilization expected, not a major threat
   - B. Peak temperature 500-800°C; Acceptable, activation product mobilization is a concern and this source term must be considered; can probably accept

some confinement degradation and still meet no-evacuation with proper design

   C. Peak temperature >800°C; Poor, significant activation product mobilization expected; level of confinement needed may be high and may threaten ability to meet no-evacuation

3. Chemical reactivity/combustible gas generation
   A. Inert coolant; Excellent, no reactions that can threaten confinement
   B. Endothermic reaction; Acceptable, cannot be self-sustaining and removes energy from the system; must still consider the need for and ability of confinement to accommodate any reaction products
   C. Exothermic reaction; Poor, could be self-sustaining, energy production can lead to overheating of structures and additional mobilization of radioactivity, confinement of reaction products is a concern and hydrogen production is a major concern with water coolant
4. Waste/environmental
   A Waste volume
      i. low ex-vessel activation (WDR<1); Excellent, good potential for recycle or clearance
      ii. significant ex-vessel activation (WDR>1); Poor, low potential for recycle or clearance
   B. Radiotoxicity
      i. WDR<1 in all components; Excellent
      ii. WDR>1 in some components; Acceptable if volume of waste is significantly reduced
   C. Mixed hazardous waste
      i. None; Excellent
      ii. Some; Poor/Unacceptable

4.3.2.5 Cost

The cost includes the following elements:

Concept Development cost (R&D):
How far is the concept from present technology?

Initial capital cost:

Overall size:	Power density, IB shield thickness
Design:	Simple or complex analyses, few or many different parts Standard design code for safety boundary or not
Materials:	Type, quantity, enrichment of structure, breeder, coolant
Fabrication:	Exotic or conventional forming, machining, joining Simple or complex parts
Assembly:	Many or few coolant connections Complex or simple structural connections Many or few parts precisely located
Bal. of plant:	Large and complex or simple piping and heat transfer loops

Many or few hot cells, maintenance buildings
Exotic or standard tritium separation facilities
Safety analyses: Siting and licensing appears straightforward or difficult

Operating cost:
Normal operating costs: % recirculating power
Energy multiplication
Power conversion efficiency
Complexity of tritium breeding / separation
Maintenance costs: Component lifetime: %/yr scheduled replacement
Complexity of testing/checkout of replacements
Complexity of routine inspections/diagnostics
Complexity of maintenance equipment
Operating availability: What percentage of its life is it operational

Decommissioning and disposal cost:
Disassembly: Activation level after 10 years
Disposal class: wt % in various disposal classes

4.3.3 Design Margins and Uncertainties

- Determine how far are the calculated parameters from the operational design limits for the concept components and the minimum functional requirements
- Define the uncertainties in estimating the parameters that determine the attributes used to assess the potential of the concept for improved attractiveness
  - Determine how big are the uncertainties
  - Identify source of uncertainties (e.g., data, modeling, analysis tools)
  - Can these uncertainties be reduced by the R&D program
- Compare the uncertainties to design margins

4.3.4 Critical Issues and R&D Needs

Describe the key issues for this design concept. (Use this list as a starting point)

- Plasma interface issues
- Thermal hydraulic issues including MHD
- Materials issues
  - Mechanical properties
  - Physical properties
  - Compatibility
  - Coatings
  - Irradiation effects
  - Fabrication/joining
- Off-normal event response
  - Disruptions
  - Loss of flow
  - Overpower/underpower conditions
- Safety issues
  - Activation/decay heat
  - Chemical reactivity

    - Tritium inventory/containment
- Integrated performance issues
    - Neutronics performance
    - Power conversion efficiency
    - Reliability/maintenance
    - Thermo-mechanical response
- Balance of plant issues
    - Tritium extraction system
    - Heat exchangers
    - Piping/manifolds
    - Penetrations

Describe the R&D required to resolve these issues
- Experiments needed
    - Lab scale
    - Intermediate scale
    - Prototype scale
- Codes and modeling
    - R&D using existing codes
    - New codes needed to be developed

Describe facility needs for the R&D
- Existing facilities
- New facilities