System Studies Activities (FY 1999 & Beyond)

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VLT PAC Meeting

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Electronic copy: http://aries.ucsd.edu/najmabadi/TALKS
ARIES Web Site: http://aries.ucsd.edu/ARIES

Program Elements

- **Strategic planning and forecasting -- role of fusion energy in a sustainable global energy strategy.**
  - A new initiative in FY99 ($555k in FY99)**;**

- **Power Plant Studies:**
  - National power plant studies team (ARIES). New projects started in 1/99 ($1,655k in FY99).
  - Pre-conceptual designs (analysis of critical issues) of advanced fusion concepts (no new studies in FY99).

* VLT director budget for FY2000 is $2,400k

Role of Fusion in a Sustainable Global Energy Strategy

- It became clear a couple of years ago that there is a need to make a case for fusion energy in the context of a sustainable global energy future.
- Most of the socioeconomic studies were launched in FY 99:
  - Study of options to deploy large fusion power plant including hydrogen production and co-generation. (ORNL & Partners).
  - Establish the merits and address issues associated with fusion implementation (PPPL).
  - Macro-economics modeling of global energy market and role of fusion (PNL) (Continuation of previous work).
  - Comparison of various sources of energy based on equivalent CO_2 emission (U. Wisc.).

Socioeconomic Studies of Fusion Power Plans for FY 2000

- In FY99, $555k is allocated to this research. Some of these projects will be completed in 9/99.
- PAC's recommendation: "At present, studies of the role of fusion energy are limited to a handful of disparate tasks performed by fusion researchers. The VLT can perform the much needed function of formulating a coherent plan to integrate fusion energy into the planning and vision of the larger energy research community."
- In discussion with VLT director and OFES, it is decided to form a planning group to draft a white paper on this subject. This white paper will be forwarded to the PAC for comments.

Socioeconomic Studies of Fusion Power (ORNL & Partners)

- **Objective:** An assessment of the projected competitiveness of future fusion-based electrical power generation with fission, fossil, and renewable electricity sources.
  - Principal Jerry Delene.
  - To be completed: 9/99.
- **Objective:** Study of options to deploy large fusion power plant including hydrogen production and co-generation.
  - Principals: Boeing, Center for Energy and Environment at Princeton University, Duke E&ES, TVA, and ORNL).
  - Completion date nominally 9/99, realistically 12/99.

Extra

Socioeconomic Studies of Fusion Power (PPPL)

- **Objective:** To establish the merits and address issues associated with fusion implementation.
- **Focus:** With potential implementation scenarios establish the:
  - Environmental impact of reduced CO2 emission, waste disposal, and waste recycling;
  - Resource needs of special materials and tritium;
  - Economics;
  - Potential role of fusion/fission combinations.
- To be completed: 9/99.

Extra

Socioeconomic Studies of Fusion Power (PNL)

- **Objective:** Establish economic benefit of fusion research and fusion energy using macroeconomic models.
- **Focus:** Economic impact on GNP and balance of trade using parametric variations of
  - Busbar cost of fusion electricity;
  - Time of introduction and growth of fusion electricity.
- **Timeframe**: on-going for several years.

Extra

Socioeconomic Studies of Fusion Power (U. of Wisconsin)

- **Objective:** To calculate the energy payback ratio and CO_2 gas emission rates from fusion and natural gas electrical power generating stations.
- **Plans for FY 99**: To calculate the energy payback ratio and CO_2 emission rates for DT fusion and comparison to coal, LWR, and wind electrical generating facilities.
  - To be completed: 9/99
- **Plan for FY 00:** To apply the same analysis techniques to natural gas power plants and compare them to fusion, fission, coal, and wind power plants .

Extra

National Power Plant Studies Program
VLT PAC Review (12/98)

- "The ARIES program has performed a series of key tokamak system studies, and is a valuable resource for continued evaluation of power plants based on various fusion concepts. As new studies are initiated, we recommend that they be planned and executed as a partnership between ARIES Team members and advocates from the fusion concept under study."
- **Note:**
  - The national team has studied a variety of confinement concepts: TITAN (RFP), SPPS (compact stellarator), ARIES-ST.
  - National team is a "dynamic" team. Membership has evolved based on technical needs of the project and has always included advocates.

The ARIES Team Has Examined Several Magnetic Fusion Concept as Power Plants in the Past 10 Years

- TITAN reversed-field pinch (1988)
- ARIES-I first-stability tokamak (1990)
- ARIES-III D-^{3}He-fueled tokamak (1991)
- ARIES-II and -IV second-stability tokamaks (1992)
- Pulsar pulsed-plasma tokamak (1993)
- SPPS stellarator (1994)
- Starlite study (1995) (goals & technical requirements for power plants & Demo)
- ARIES-RS reversed-shear tokamak (1996)
- ARIES-ST spherical torus (1999)

Extra

Options for National Power Plant Studies Team Future Initiatives

- The current national team projects started about 1/99. The current projects will be completed either by 3/00 or 9/00 depending on the outcome of the research (as described later).
- Traditionally, we have started the planning process through private discussions with OFES, program leaders, and advocates.
- Per PACs request, VLT PAC is the starting point for the planning process this time.
- “Buy-in” and thorough planning with advocates is necessary before a complete plan is developed.

National Power Plant Studies Program Initiated New Projects in 1/99

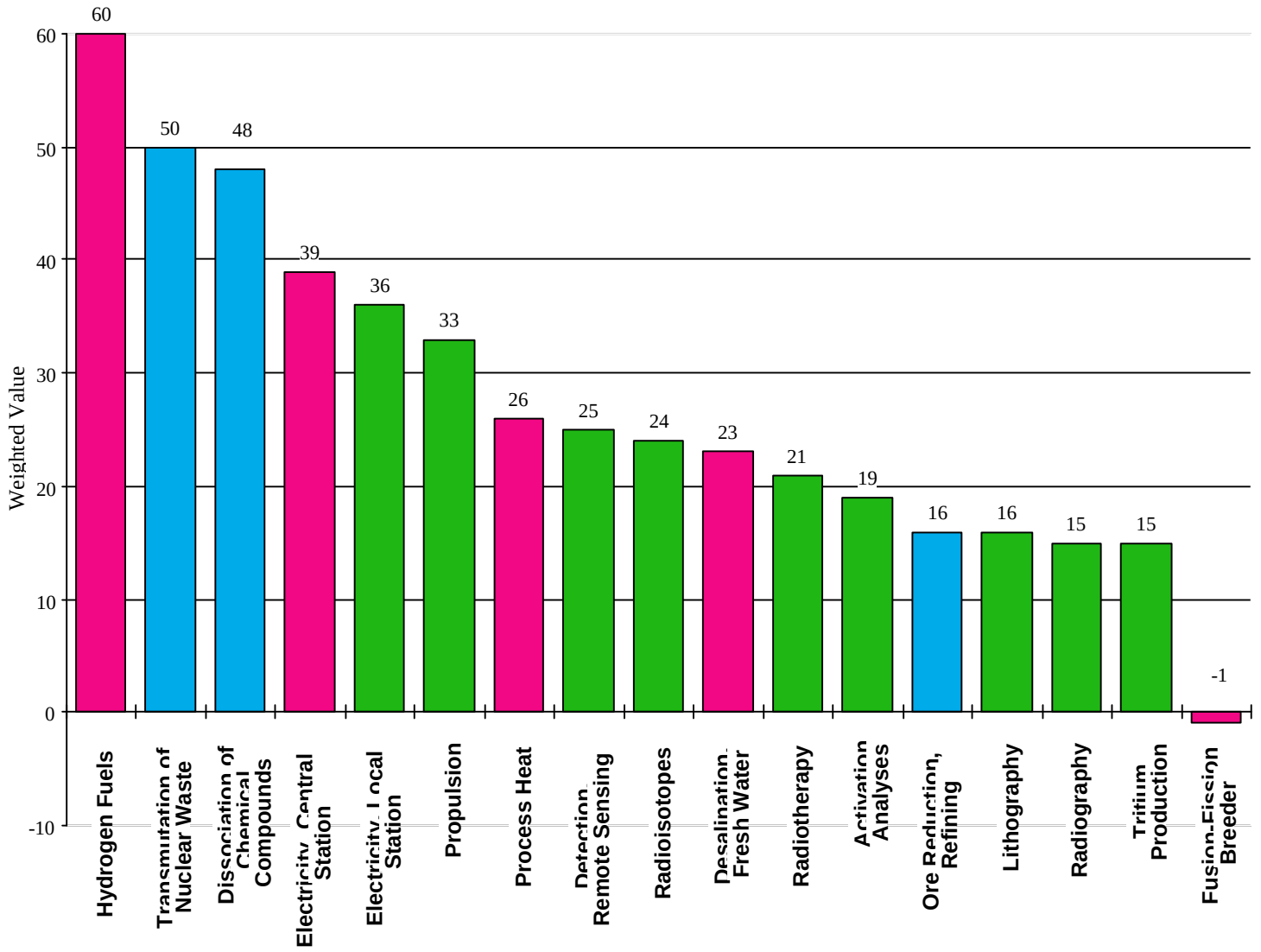
- **Proposed topics were developed under the VLT framework and discussion with physics and technology program leaders**

- Advanced ARIES-RS (45% of effort)
- Non-electric Application of Fusion (45% of effort)
- Support for on-going examination of fusion systems as producers of hydrogen (5% of effort)
- Selected critical issues, e.g., (5% of effort)
  - Impact of ferromagnetic material on plasma performance
  - Support for proof-of-principle concepts

Non-Electric Applications

- Arguments have been made that non-electric applications of fusion, specially those resulting in near-term products may lead to new clients and to additional resources for fusion.
- An assessment based on “Decision-Tree Analysis” Technique was performed by the national team which identified some attractive applications:
  - Hydrogen production for transportation fuel in light of recent attention to curbing concentration of green-house gases in the atmosphere (under study by Sheffield et al.)
  - Neutron production for transmutation of nuclear waste, tritium production, Pu burning, etc (under study by the national team)

ARIES Non-Electric Application Study (1998)



Non-Electric Applications of Fusion Neutrons

- Typical applications (~10^{19}-10^{21} n/s) :
  - Transmutation of fission waste;
  - Hybrids for fuel and/or energy production;
  - Fusion materials and engineering testing.
- Post-cold-war additions:
  - Tritium production;
  - Burning of plutonium from dismantled weapons.
- Recent application (~10^{11}-10^{13} n/s)
  - Radioisotope production;
  - Medical radiotherapy;
  - Detection of explosives.

Non-Electric Applications Study

- Several scoping studies (Cheng et al., Stacey et al., etc.) have proposed several applications for fusion neutron sources.
- These studies, however, have focused mainly on whether certain application can be performed with fusion devices as opposed to providing quantitative response to following questions:
  - Potential competition: Can we make a convincing argument that fusion has a clear advantage?
  - Time-frame and cost of development: Can we make a convincing argument that fusion can be developed in the required time-frame?
  - Additional resources for the fusion program: What is the value of potential additional resources and/or good will that may become available to develop fusion?

Fusion Non-Electric Applications Study

- Study will be performed in two phases. Concept definition phase would be completed by 9/99 with a preliminary report for the Snowmass meeting. A detailed design will be launched assuming favorable results.

- Metrics to evaluate the potential of a fusion neutron source:
  - Cost (capital cost, neutron cost in $/mole)
  - Total moles of neutrons produced per year;
  - Value of the product;
  - Magnitude of the extrapolation from the current physics and technology databases;
  - Complexity of the system;
  - Environmental, safety and health effects;
  - Timeframe and cost of the development plan;
  - Political issues associated with certain applications (e.g., association with nuclear weapons, etc.)

Fusion Neutron Source Study has focused on high-strength (~10^{19}-10^{21} n/s) applications -- Tasks

- Continued assessments to identify the most useful application and product (Boeing);
- Continued interactions with the fission and accelerator communities to understand the potential of reactors and accelerators for neutron source applications (RPI, INEEL, U.Wisc., ANL, UCSD);
- System studies to assess the performance/metrics of fusion-based neutron sources for both the D-T and D-D-T fuel cycles (UCSD, Team input);

Extra

Fusion Neutron Source Study has focused on high-strength (~10^{19}-10^{21} n/s) applications -- Tasks

- A compilation and assessment of the engineering and nuclear performance of the various concepts proposed for neutron-source applications including fusion, fission and accelerator systems (UCSD, U.Wisc., ANL, TSI);
- An assessment of the environmental, safety and licensing implications of fusion neutron-source applications such as plutonium disposition and radioactive waste transmutation (INEEL, Team input);
- Assessment of the political issues associated with certain applications (e.g., association with nuclear weapons, attacks from environmental and/or fission communities, etc.)

Extra

Advanced ARIES-RS Study

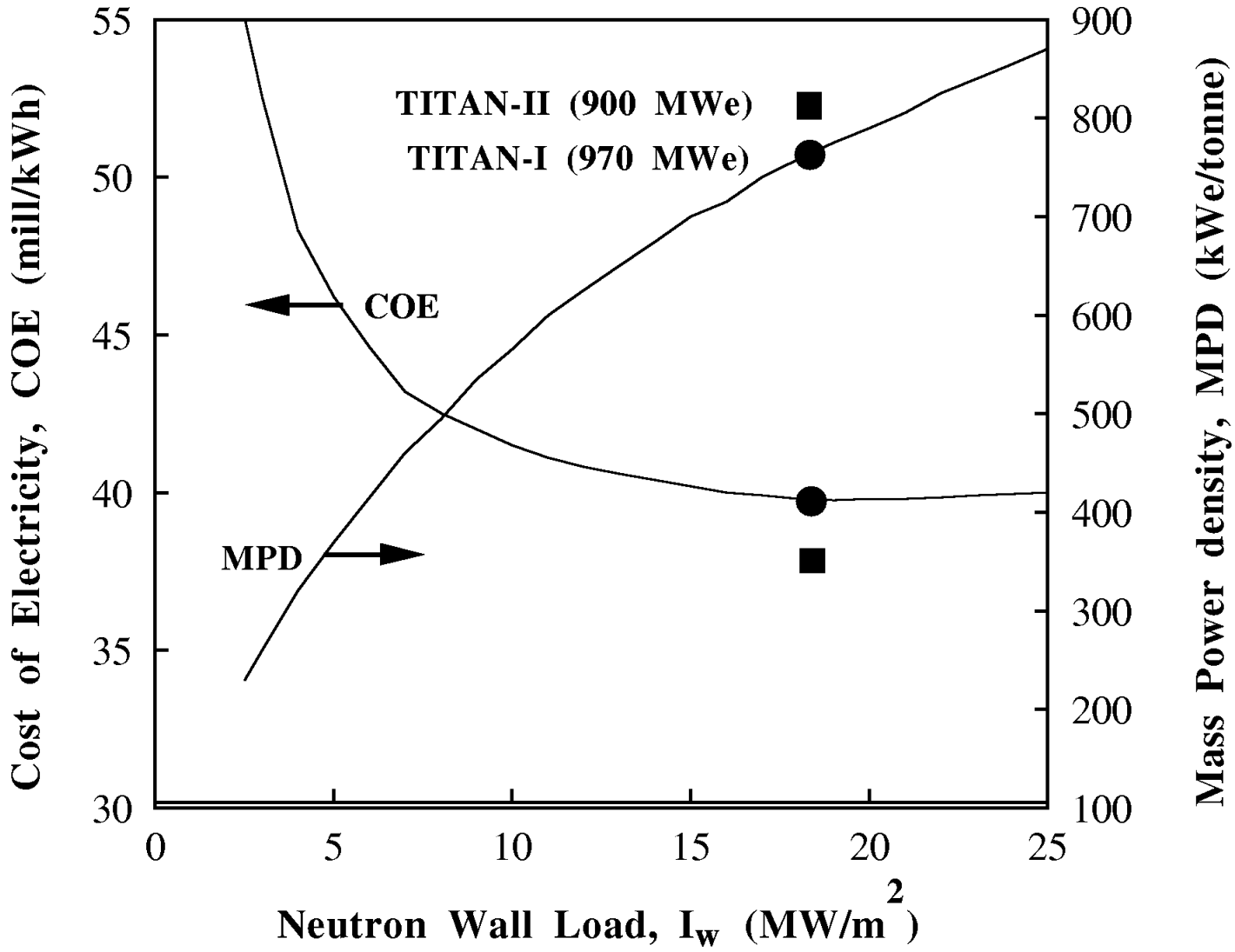
- ARIES-RS is the vision for the advanced tokamak program and is used to plan R&D directions.
- Advanced ARIES-RS study assesses “how good” advanced tokamaks can be using higher performance physics (more optimized profiles, reduced current drive power, etc.) and higher performance technologies (high-temperature superconductors, SiC blankets with liquid metal breeder/coolant, etc.)
- This is an important study as the fusion program debates the future of tokamak research and its balance against other elements of the program.

Advanced ARIES-RS: Optimization Strategy

$$\textbf{Capital Cost} \propto \Sigma\, c_i\, M_i + \Sigma\, c_k\, P_k$$

- Reduce mass of fusion core (M_i) by increase fusion power density & neutron wall loading.
  - **Higher Performance Physics:** RS equilibria have been developed with about 50% higher β than ARIES-RS and reduced current-drive power.
  - **Higher Performance Magnets:** High-temperature superconductors.
- We may have already passed the knee of the curve for wall load:
  - ARIES-RS & ARIES-ST did not optimize at the highest wall load,
  - In TITAN reducing wall load from 18 to 10 MW/m^2 resulted in 4% change in COE.
  - Advanced ARIES-RS will clearly show the potential gain of going to higher wall loads.

Impact of Wall loading on TITAN Design



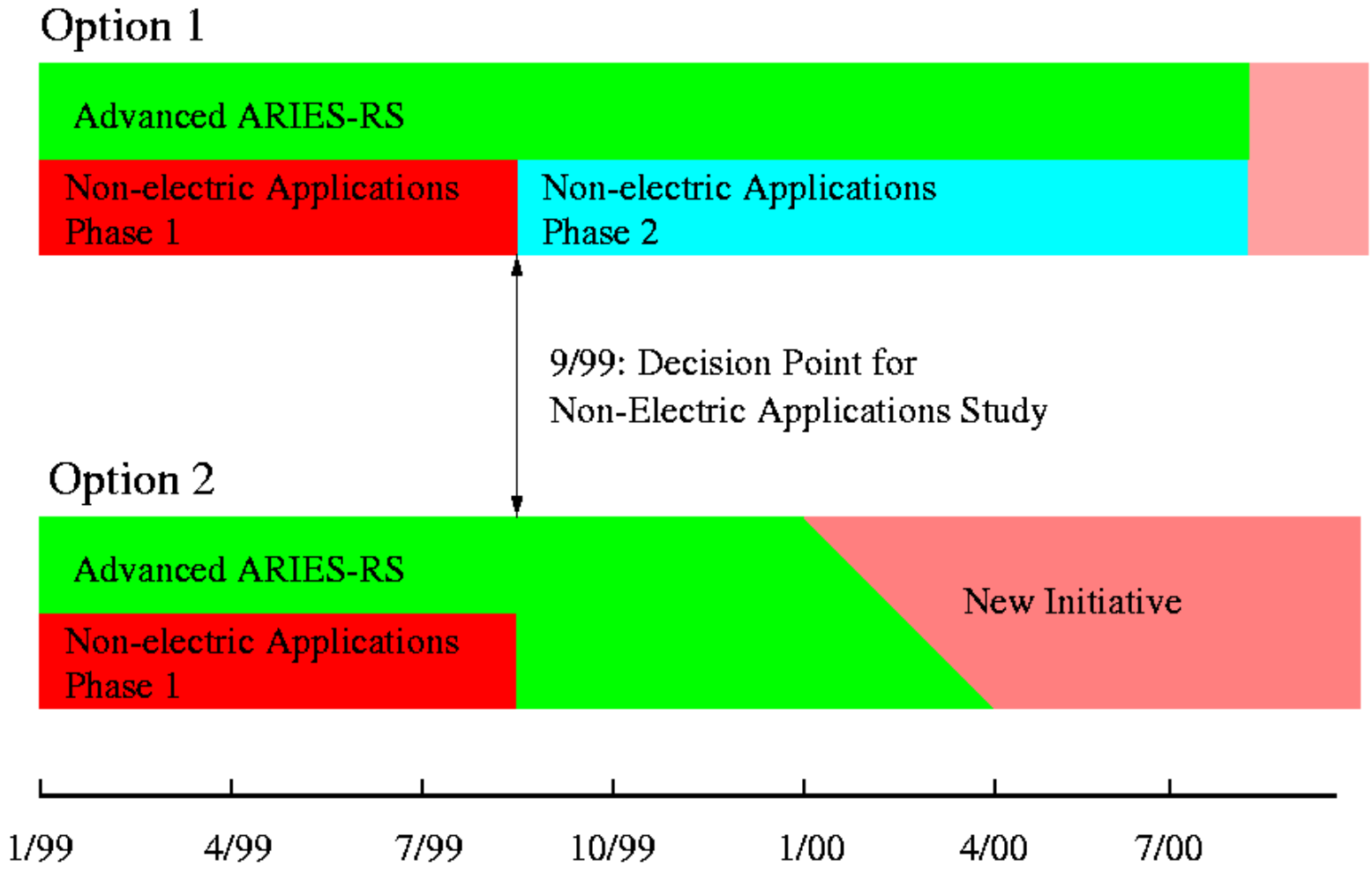
Advanced ARIES-RS: Optimization Strategy

- Reduce recirculating and thermal power (P_k):
  - **Higher Performance Physics:** Reduce current-drive in mid-plasma.
  - **High Performance Blanket:** New high-temperature SiC composite blanket design of capable of achieving ~60% thermal conversion efficiency.
- Reduce unit cost of components (c_i and c_k):
  - **Advanced manufacturing techniques** can reduce the magnet cost drastically (promising specially for high-temperature superconductors).

Advanced ARIES-RS Study -- Task Leaders

• Systems Studies	UCSD
• Physics:	
– MHD and overall lead	PPPL
– Current drive	UCSD
– Transport, Divertor	GA
• Engineering	
– Magnets (high T_c)	MIT, PPPL, ORNL
– Blanket & Divertor	UCSD, ANL
– Neutronics and shielding	U. Wisc.
– Safety	INEEL
– Configuration & maintenance	UCSD

National Power Plant Studies Program
Options for 2000



Options for New Initiatives -- Summary

* **RFP:** Modest scale study to map the RFP physics space and understand the trade-off of physics parameters in the context of a power plant
* **Stellarators:** In-depth study to further optimize the configuration, resolve some of the critical issues, and help in defining the experimental program
* **MTF:** Small-scale study to identify energy-production application of MTF.

* **IFE:** In-depth study to address several critical feasibility issues in an "integrated" study. It will underscores that IFE and MFE programs are coming together into a cohesive national fusion program.

Planning for the new initiatives is in its early stage. Discussions with OFES and advocates are needed to define the scope of each program. Per PACs request, VLT PAC is the starting point for this exploration.

New Initiatives: Stellarators

- Major worldwide stellarator program with two proof-of-performance stellarator experiments, LHD and W7X.
- Five years ago, SPPS study by the National Team provided the impetuous for advanced compact stellarators. SPPS represents a factor of two improvement over conventional stellarators. SPPS was a “part time” study aiming at identifying the potential of advanced stellarator. Many critical issues were identified but not resolved. Considerable progress has been made since that time.
- An in-depth stellarator power plant study can built upon SPPS and recent accomplishments to further optimize the configuration, resolve some of the critical issues, and help in defining the experimental program.

New Initiatives: RFP

- Ten years since TITAN study. TITAN was mainly aimed at addressing the feasibility of operation at high power density.
- Compact RFPs require efficient current drive system. OFCD was used in TITAN.
- Recent improvements in RFP transport has been obtained by suppressing turbulence, moving away from Taylor relaxed states.
- There is a need to map the RFP physics space and understand the trade-off of physics parameters in the context of a power plant. This represent a valuable input for RFP proof-of-principle program.
- Such an assessment can be performed with a modest-scale effort "borrowing" from TITAN and other studies.

New Initiatives: IFE

- Eight years since major IFE studies. Substantial progress has been made since that time.
- Declassification of the ICF program allows, for the first time, a thoroughly integrated IFE power plant study.
- Such a study will develop a framework to assess options and help define key high-leverage directions for the R&D program.
- It will underscore that IFE and MFE programs are coming together into a cohesive national fusion program.
- It uses MFE community expertise to resolve challenges of IFE. It enhances the credibility of IFE options with the MFE community.

New Initiatives: IFE

- Heavy-ion option with a liquid wall can be deferred until the completion of APEX/ALPS investigation of liquid walls for MFE systems because a large portion of research can be transferred to IFE.
- Several critical feasibility issues for laser-driven option with a “dry wall” can be addressed in an “integrated” study and will have a large impact on near-term chamber R&D plans.
- As with all other projects of the national team, support and participation of advocates are essential in success of such a study.
- This study will probably require more resources than is allocated to the national team for FY 99 as many new expertise should be brought into the program.

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