INTERIM REPORT ON TPA FUSION TECHNOLOGY

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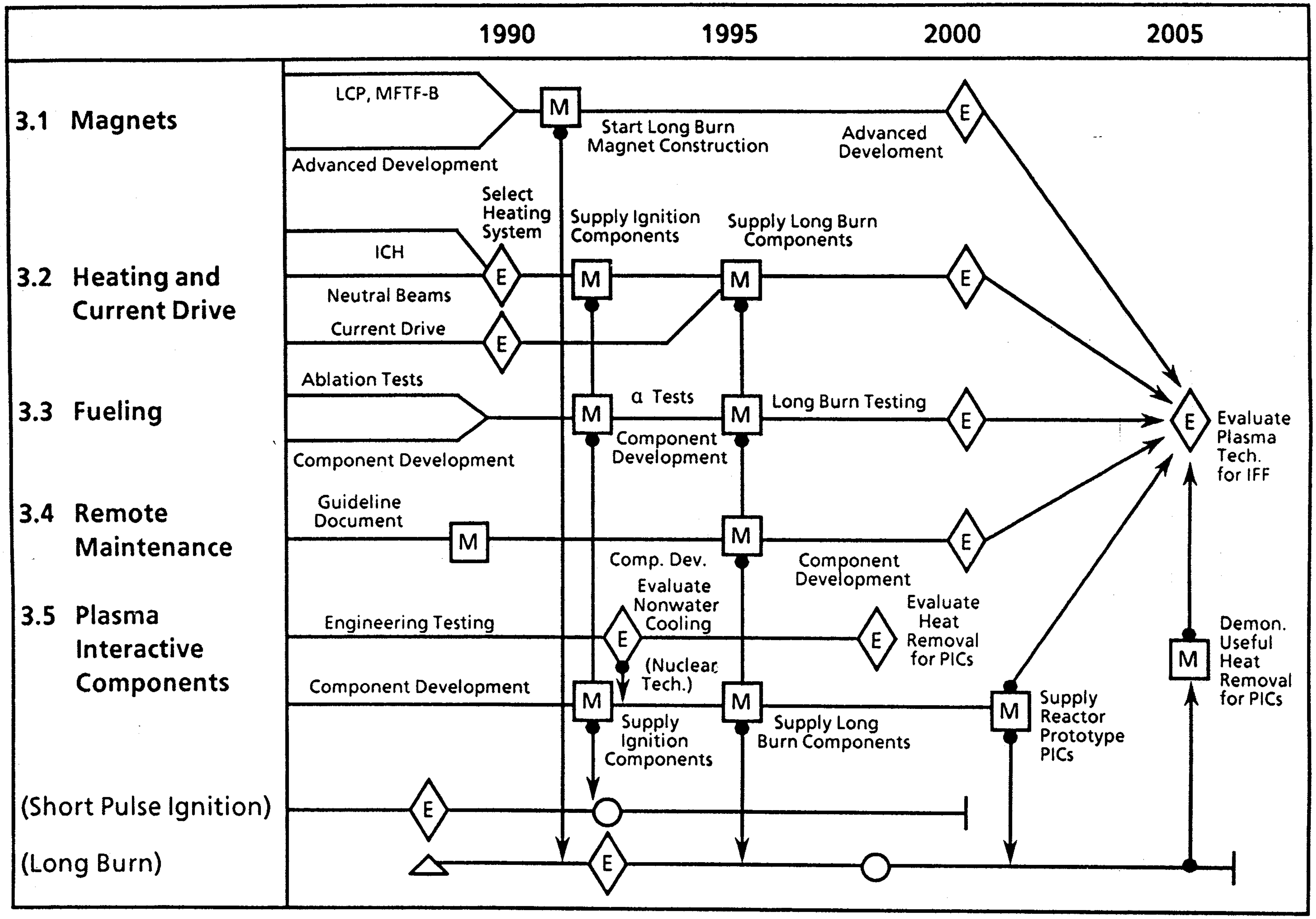
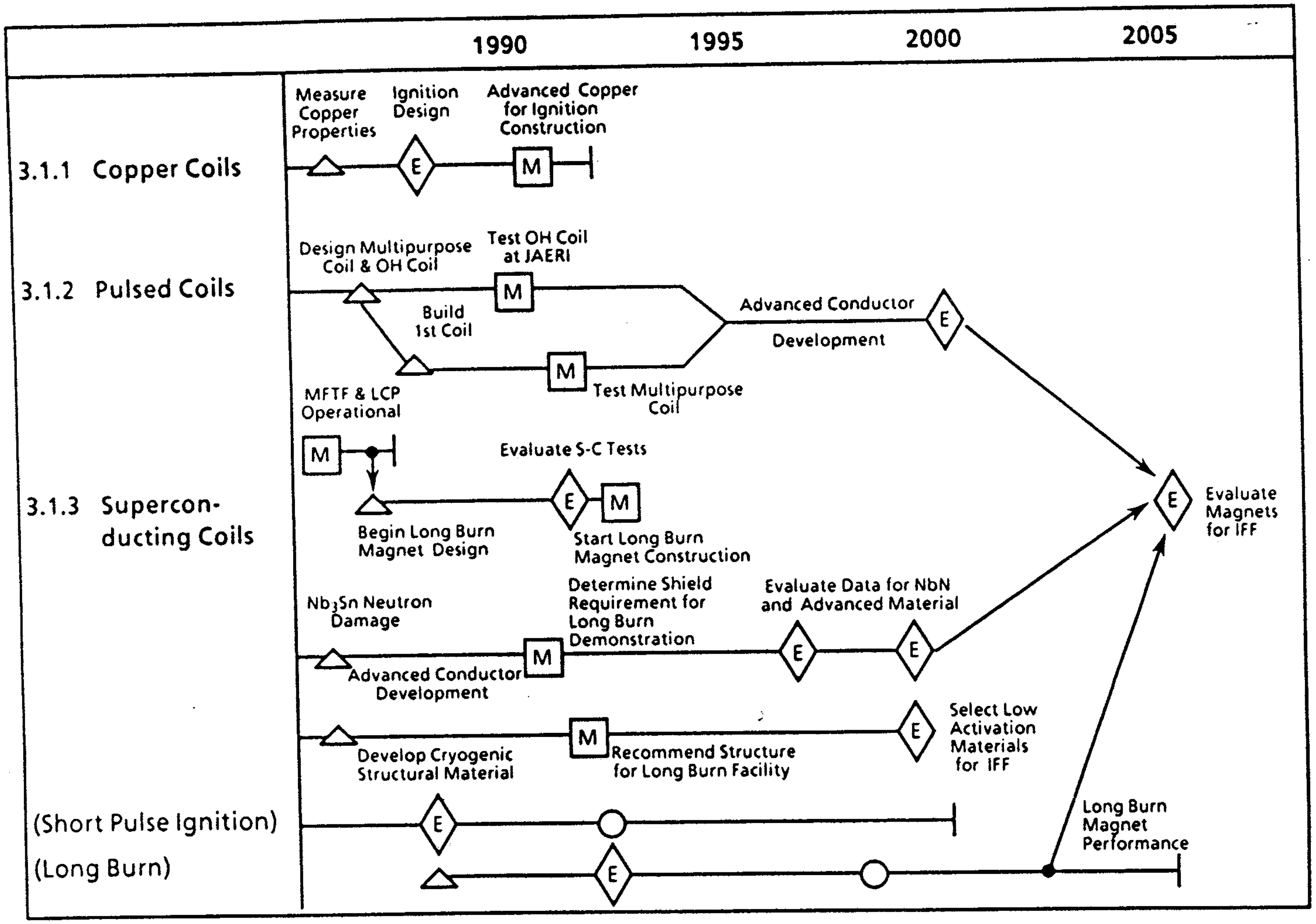
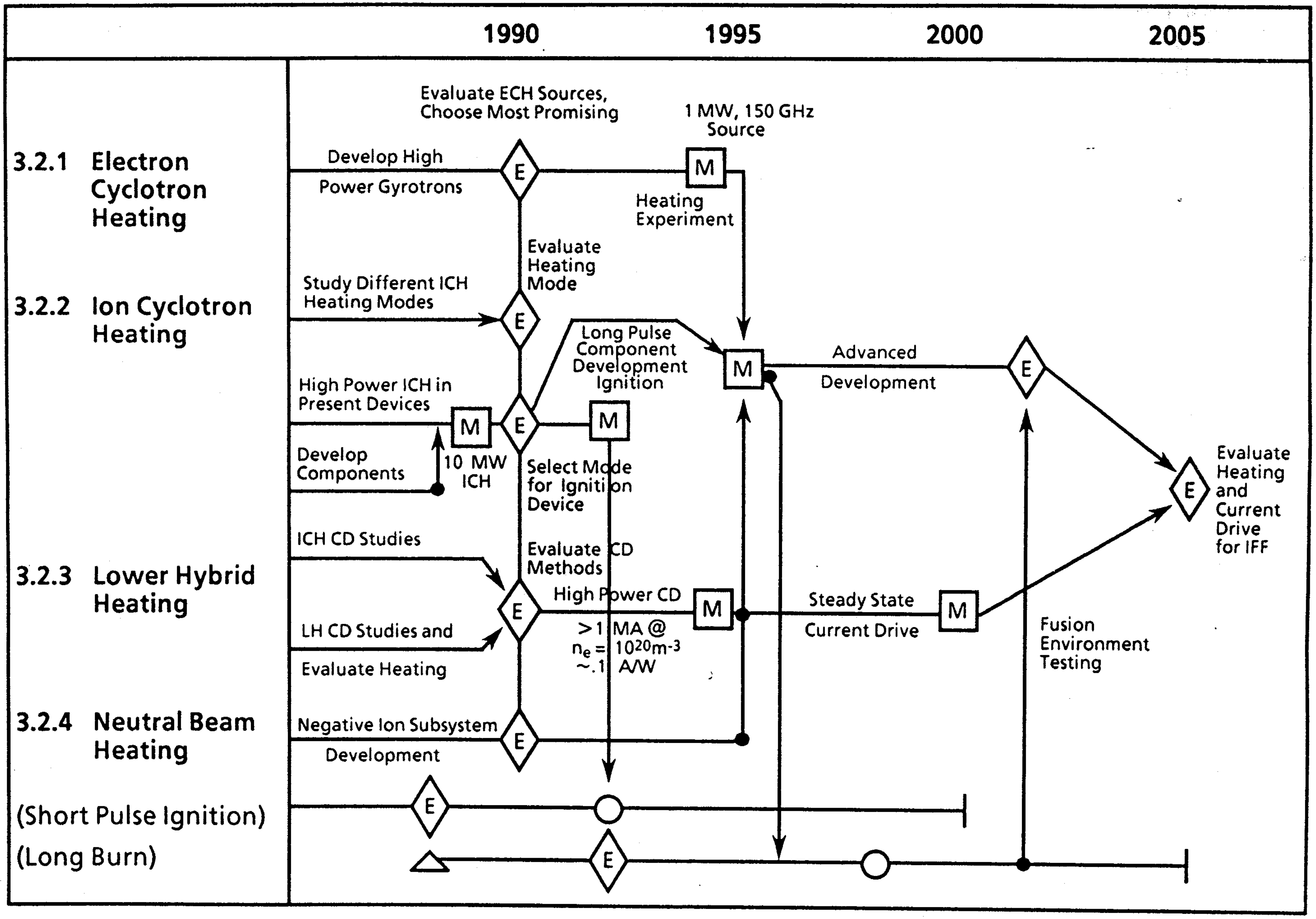
Presentation to
TPA Industrial Advisory Committee
La Jolla, CA
13 March 1986



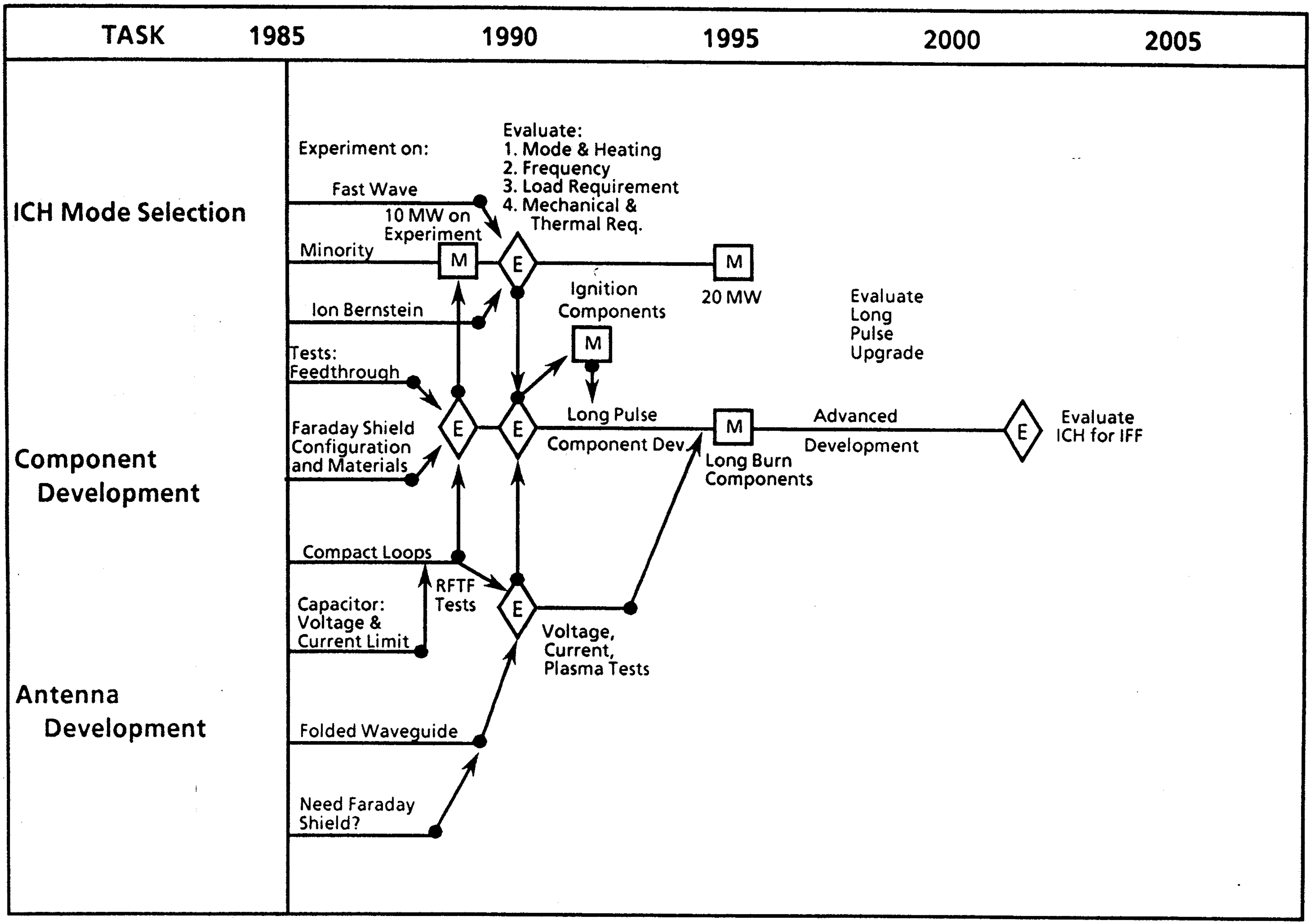
3. PLASMA TECHNOLOGY


1990
1995
2000
2005
3.1.1 Copper Coils
Measure Copper Properties
Ignition Design
Advanced Copper for Ignition Construction
3.1.2 Pulsed Coils
Design Multipurpose Coil & OH Coil
Test OH Coil at JAERI
Build 1st Coil
Advanced Conductor Development
Test Multipurpose Coil
3.1.3 Supercon-ducting Coils
MFTF & LCP Operational
Evaluate S-C Tests
Begin Long Burn Magnet Design
Start Long Burn Magnet Construction
Evaluate Magnets for IFF
Nb_3Sn Neutron Damage
Determine Shield Requirement for Long Burn Demonstration
Evaluate Data for NbN and Advanced Material
Advanced Conductor Development
Develop Cryogenic Structural Material
Recommend Structure for Long Burn Facility
Select Low Activation Materials for IFF
(Short Pulse Ignition)
(Long Burn)
Long Burn Magnet Performance

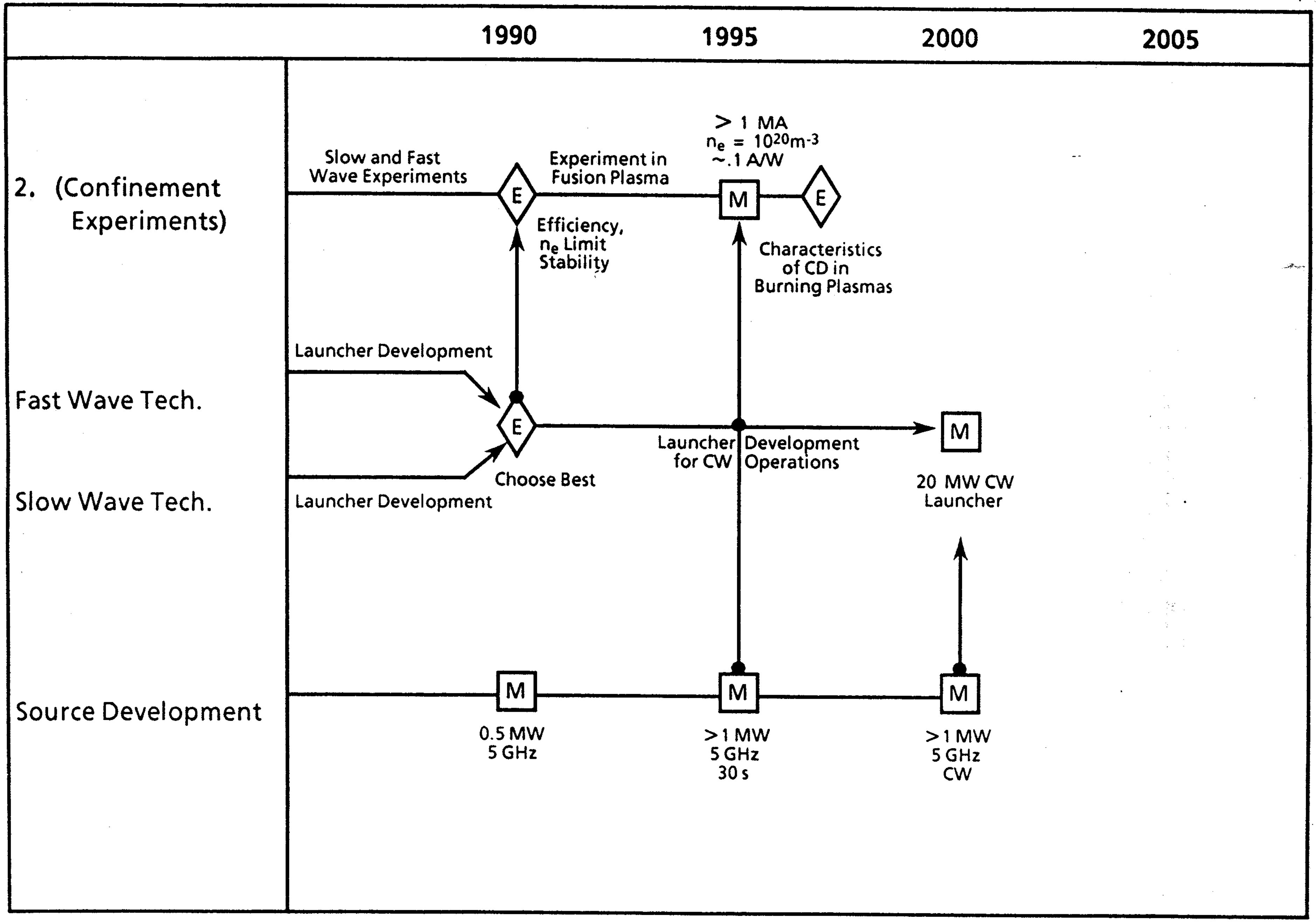
3.1 MAGNETS



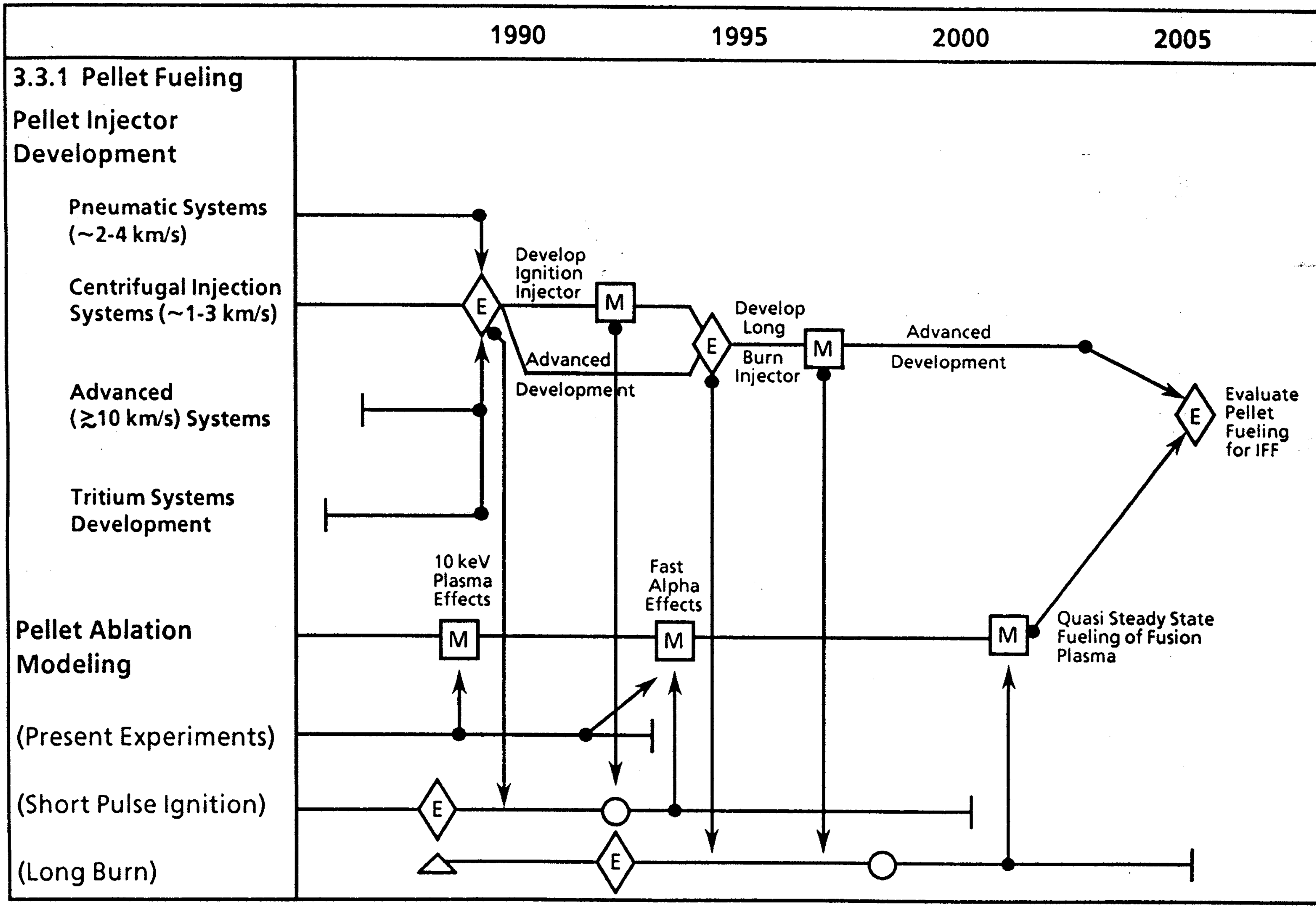
3.2 HEATING AND CURRENT DRIVE



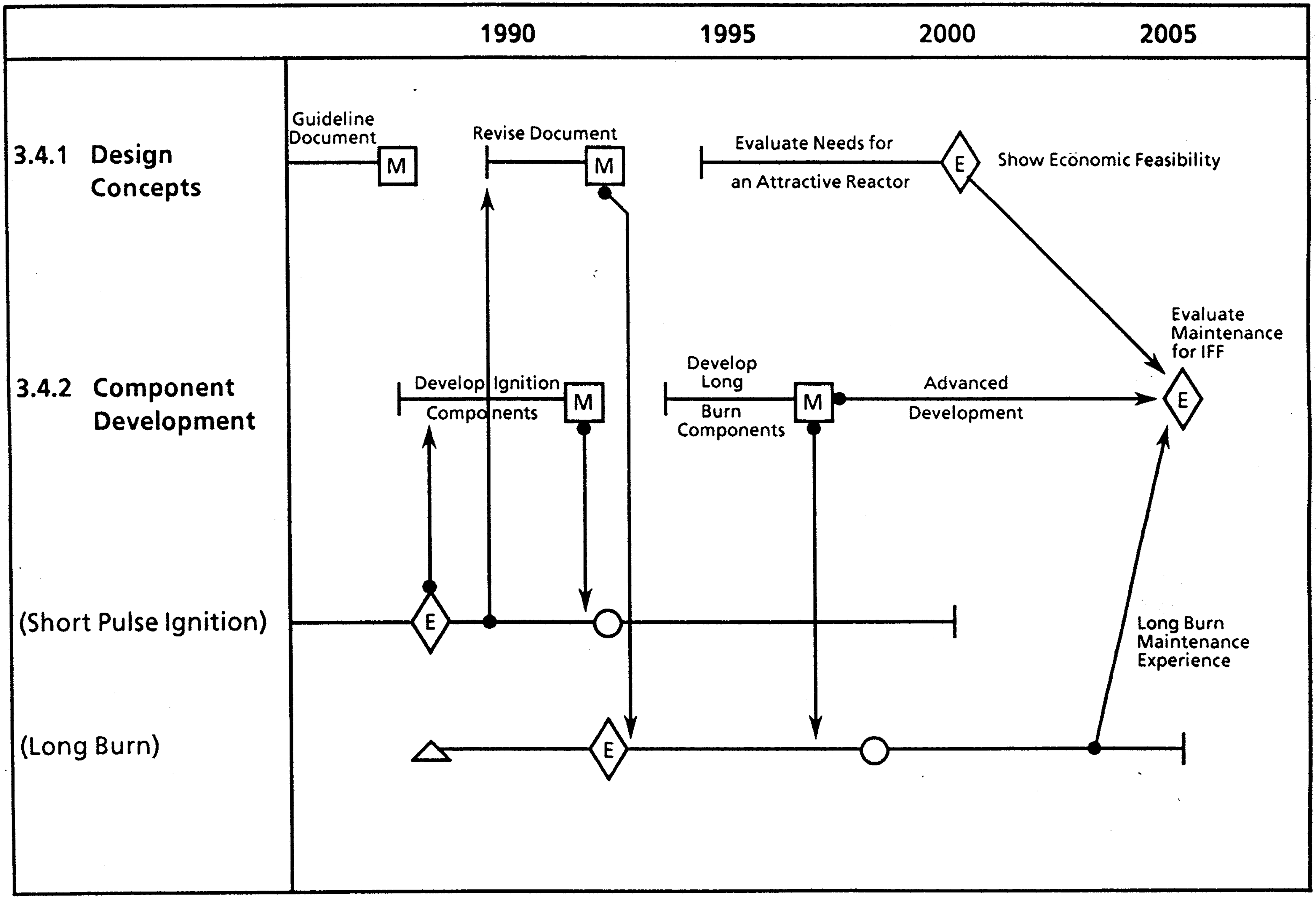
3.2.2 ION CYCLOTRON HEATING



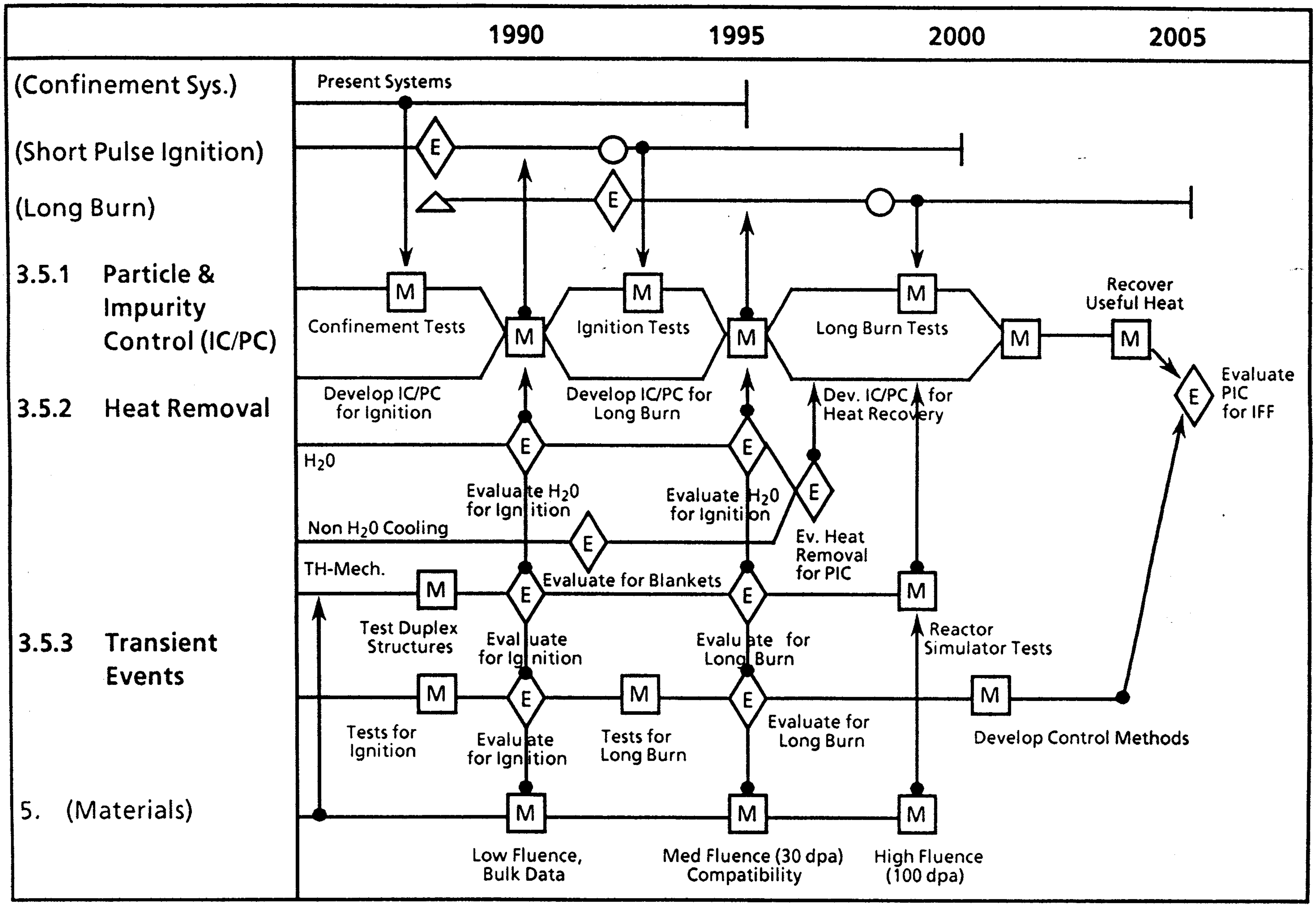
3.2.3 LOWER HYBRID HEATING


1990
1995
2000
2005
3.3.1 Pellet Fueling
Pellet Injector Development
Pneumatic Systems (~2-4 km/s)
Centrifugal Injection Systems (~1-3 km/s)
Advanced (≳10 km/s) Systems
Tritium Systems Development
Pellet Ablation Modeling
(Present Experiments)
(Short Pulse Ignition)
(Long Burn)
E
Develop Ignition Injector
M
Advanced Development
E
Develop Long Burn Injector
M
Advanced Development
E
Evaluate Pellet Fueling for IFF
10 keV Plasma Effects
M
Fast Alpha Effects
M
M
Quasi Steady State Fueling of Fusion Plasma
E
E

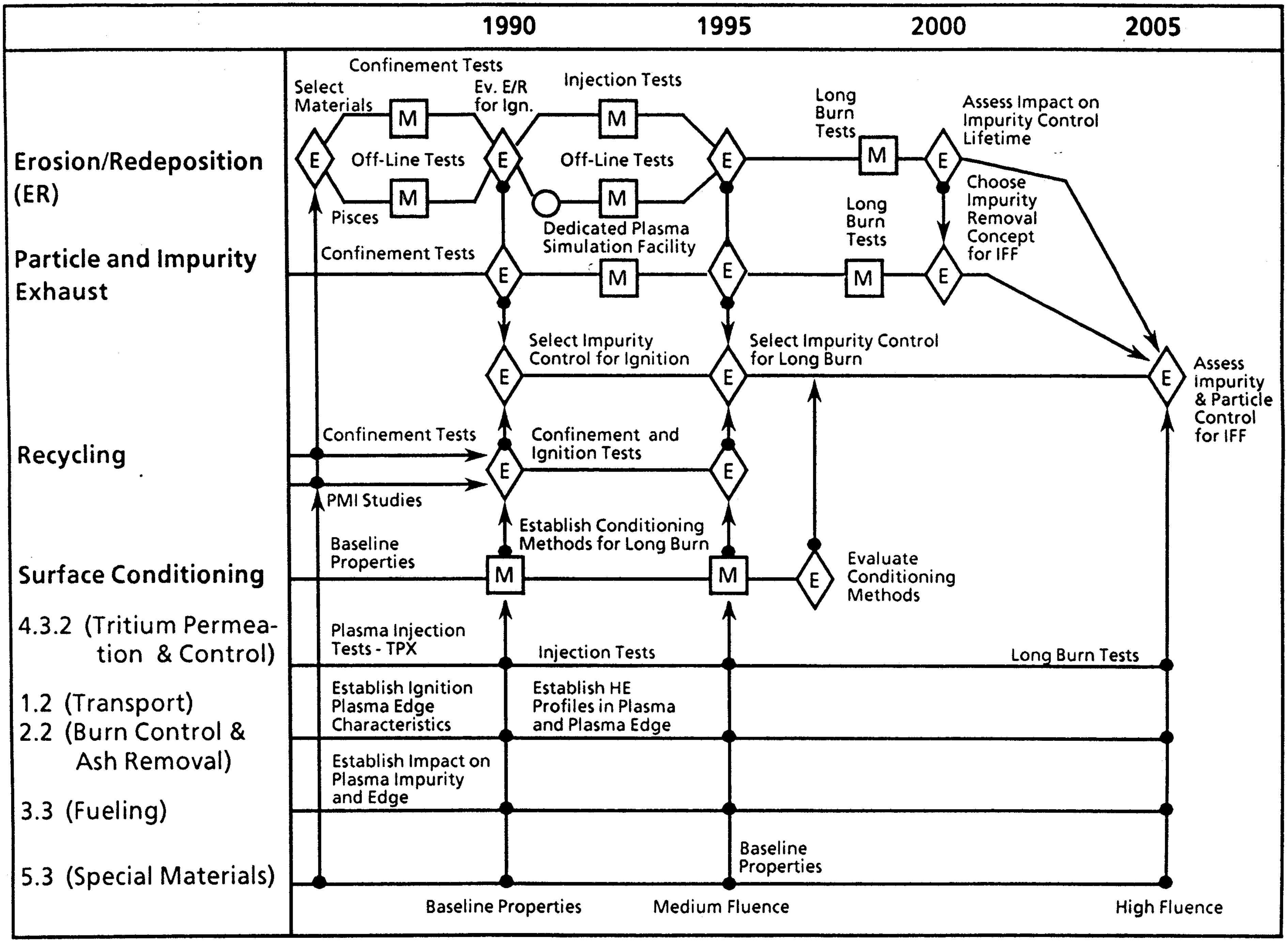
3.3 FUELING



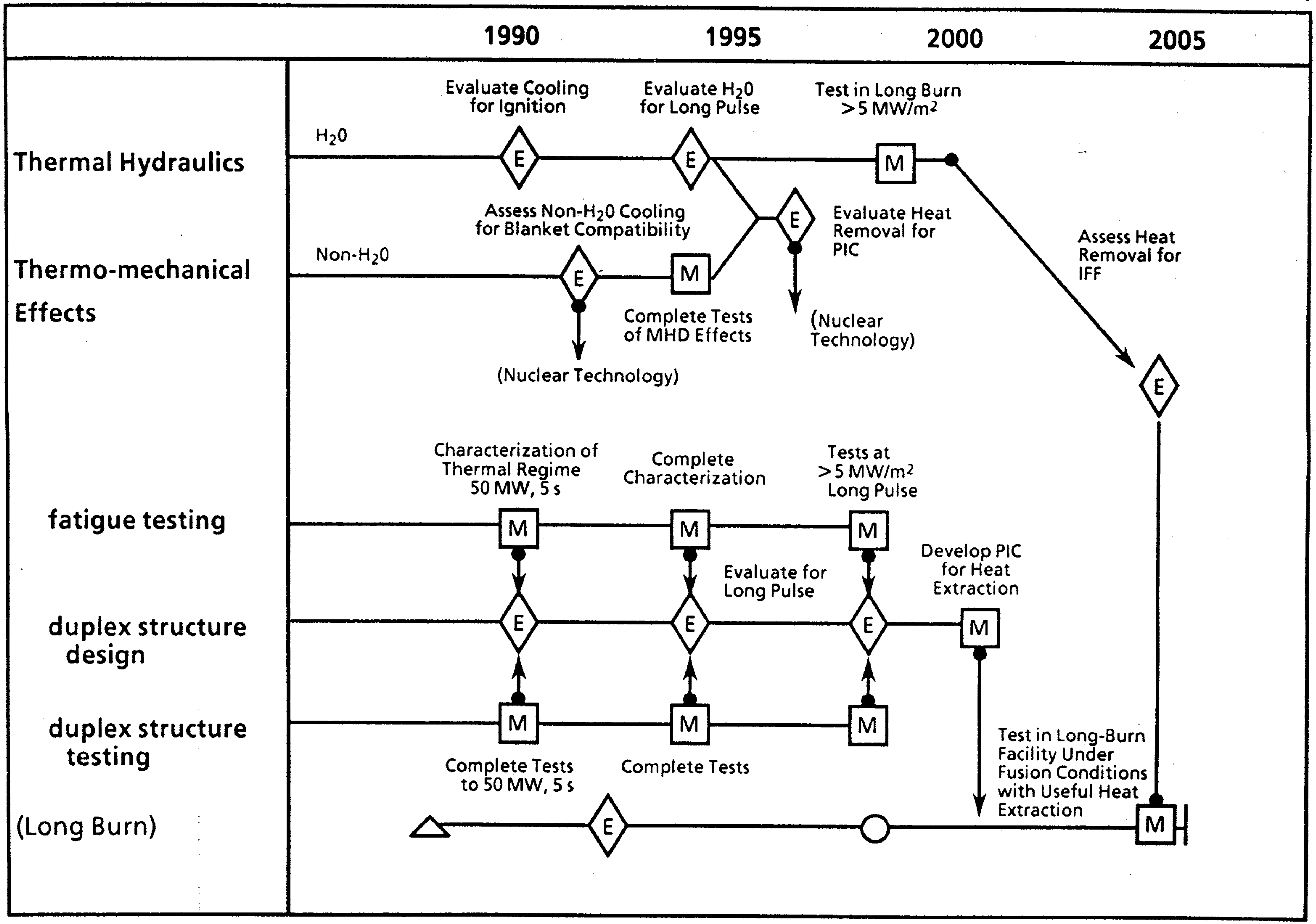
3.4 REMOTE MAINTENANCE



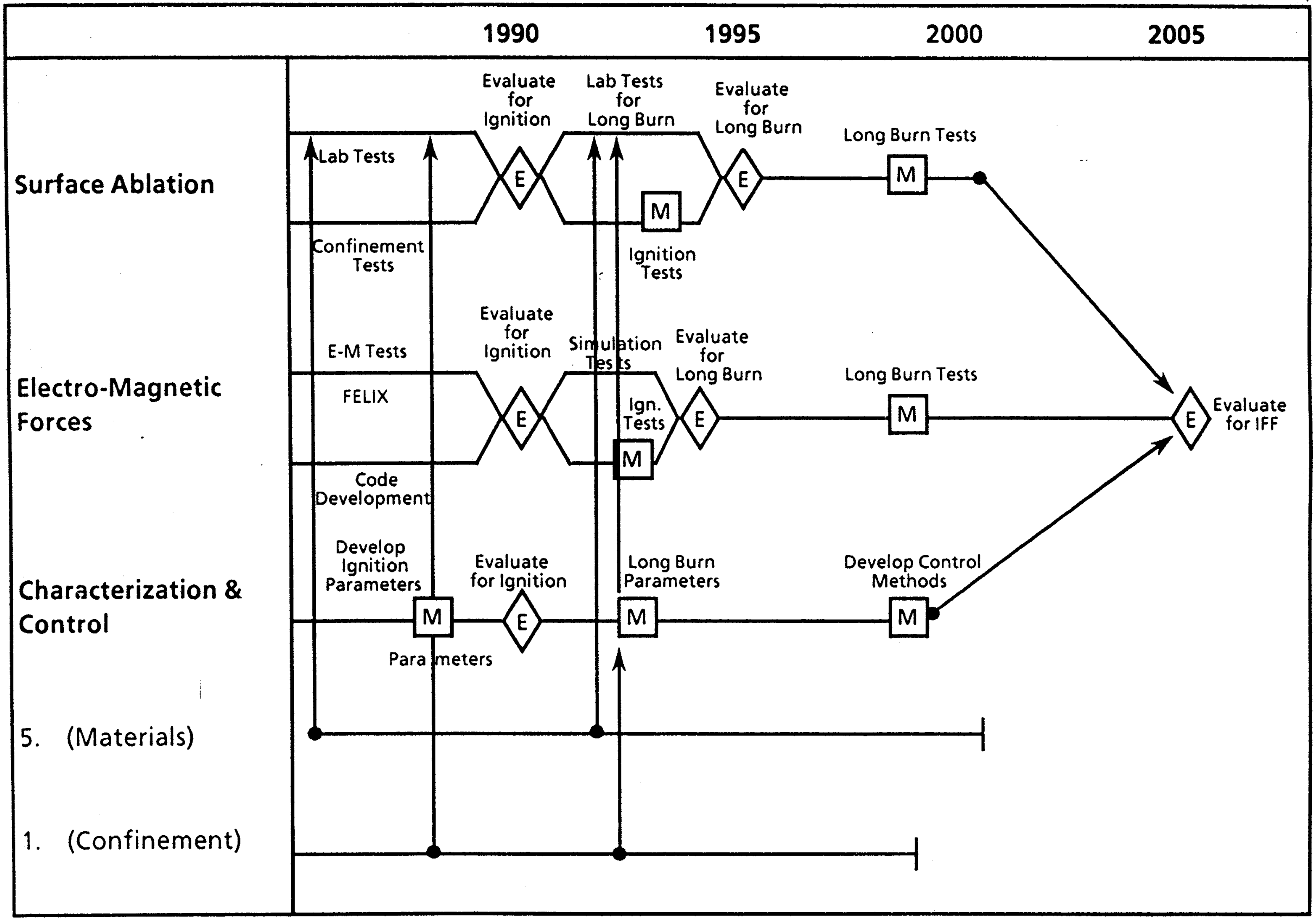
3.5 PLASMA INTERACTIVE COMPONENTS



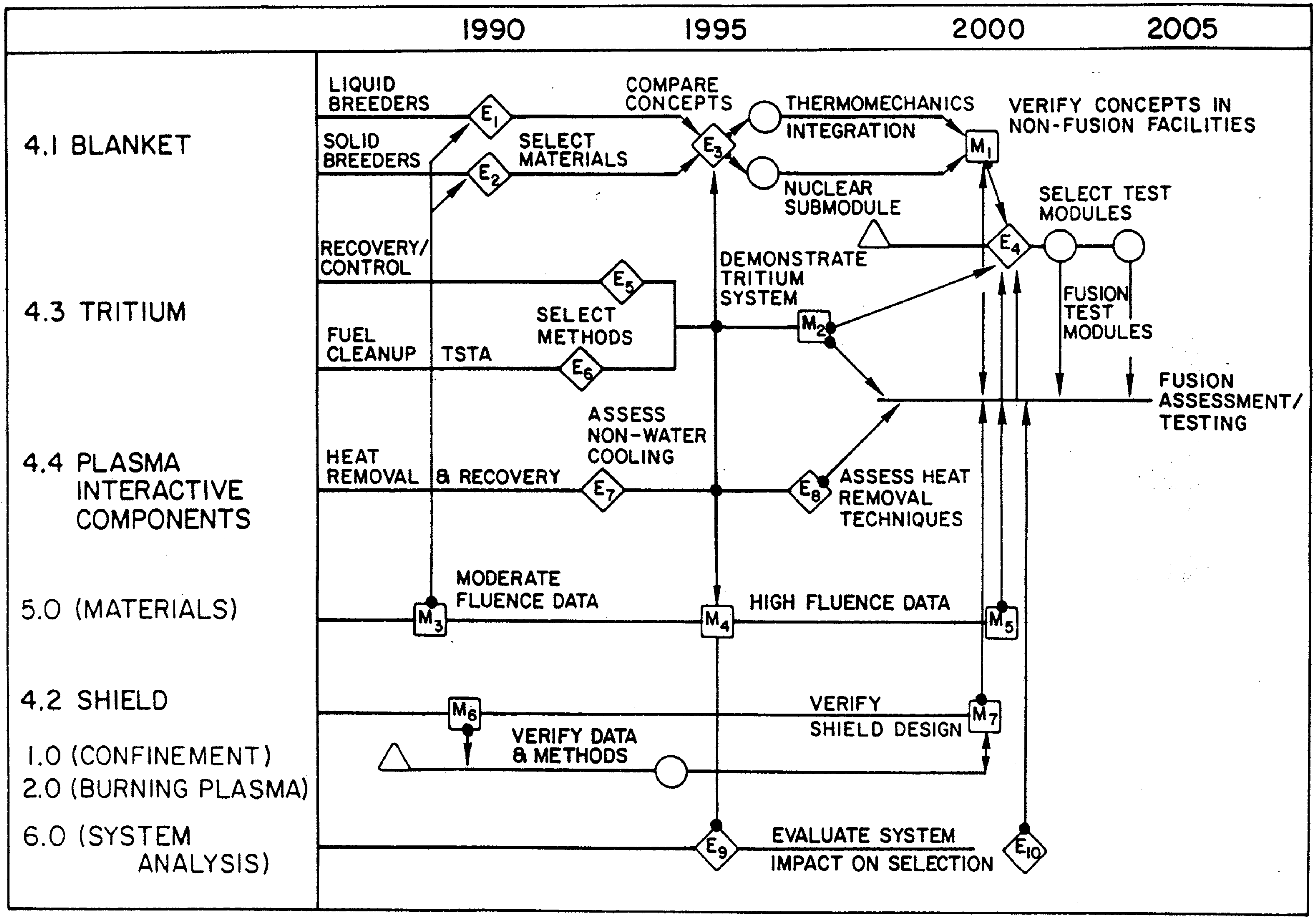
3.5.1 PARTICLE AND IMPURITY CONTROL



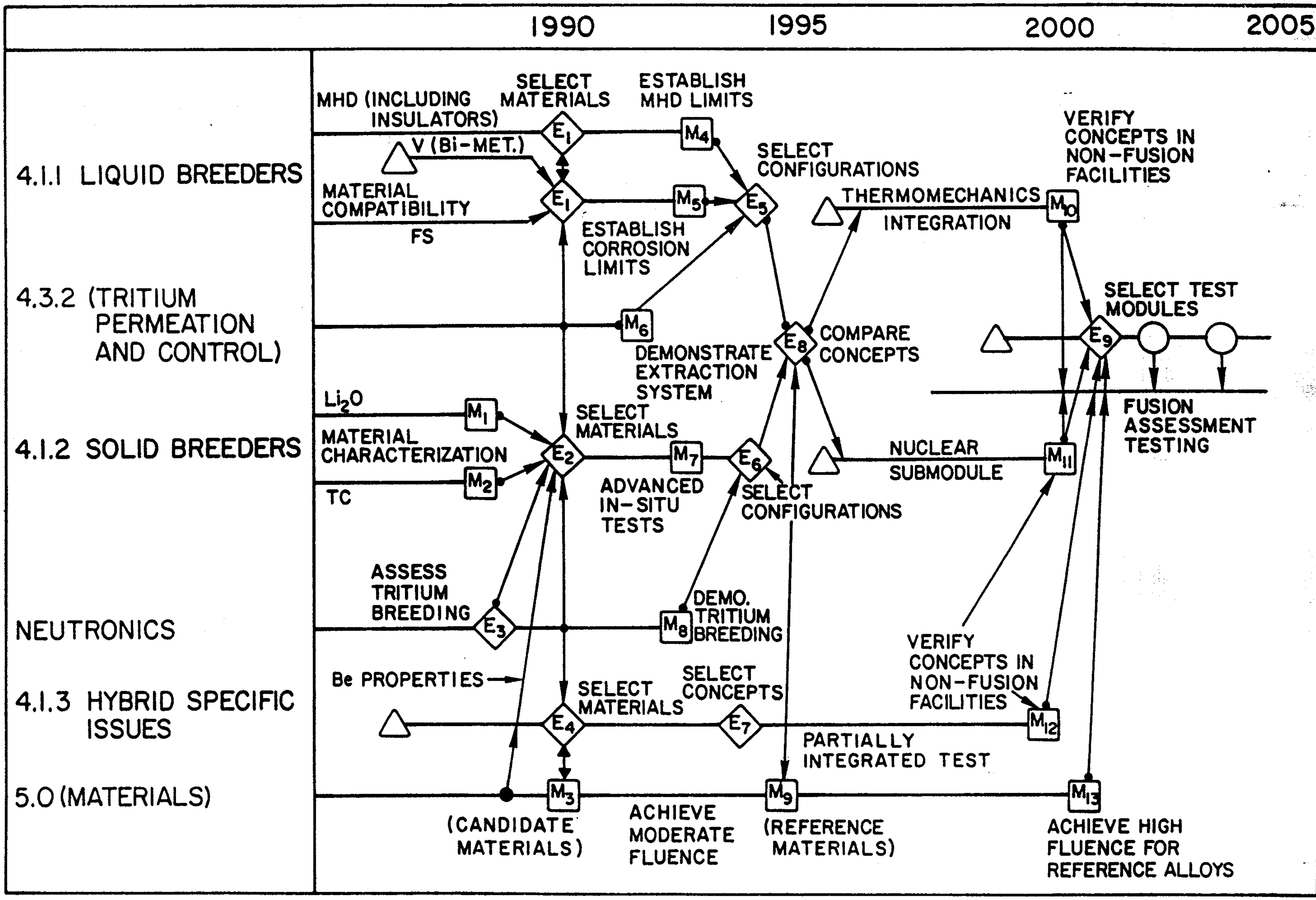
3.5.2 HEAT REMOVAL



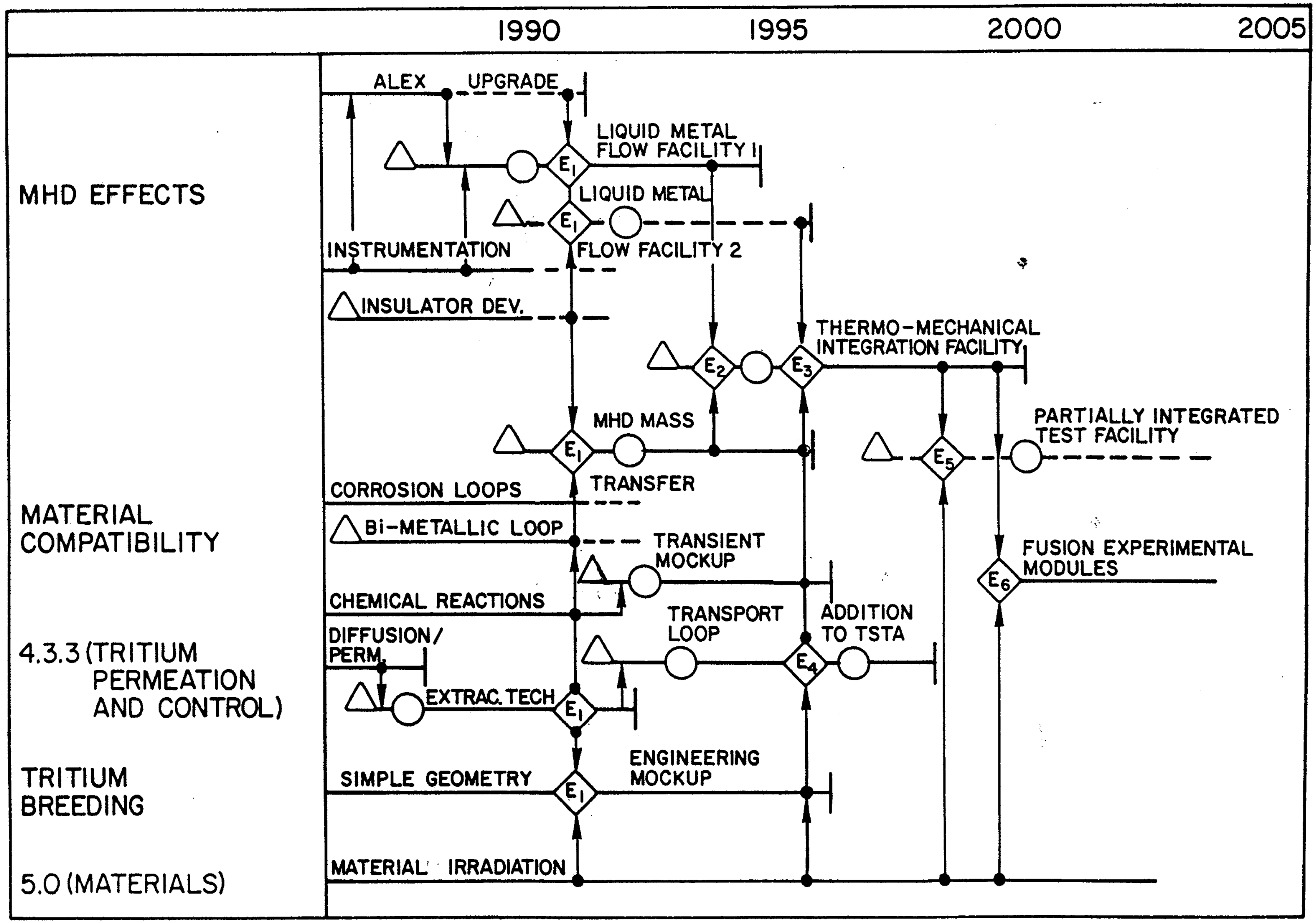
3.5.3 TRANSIENT EVENTS



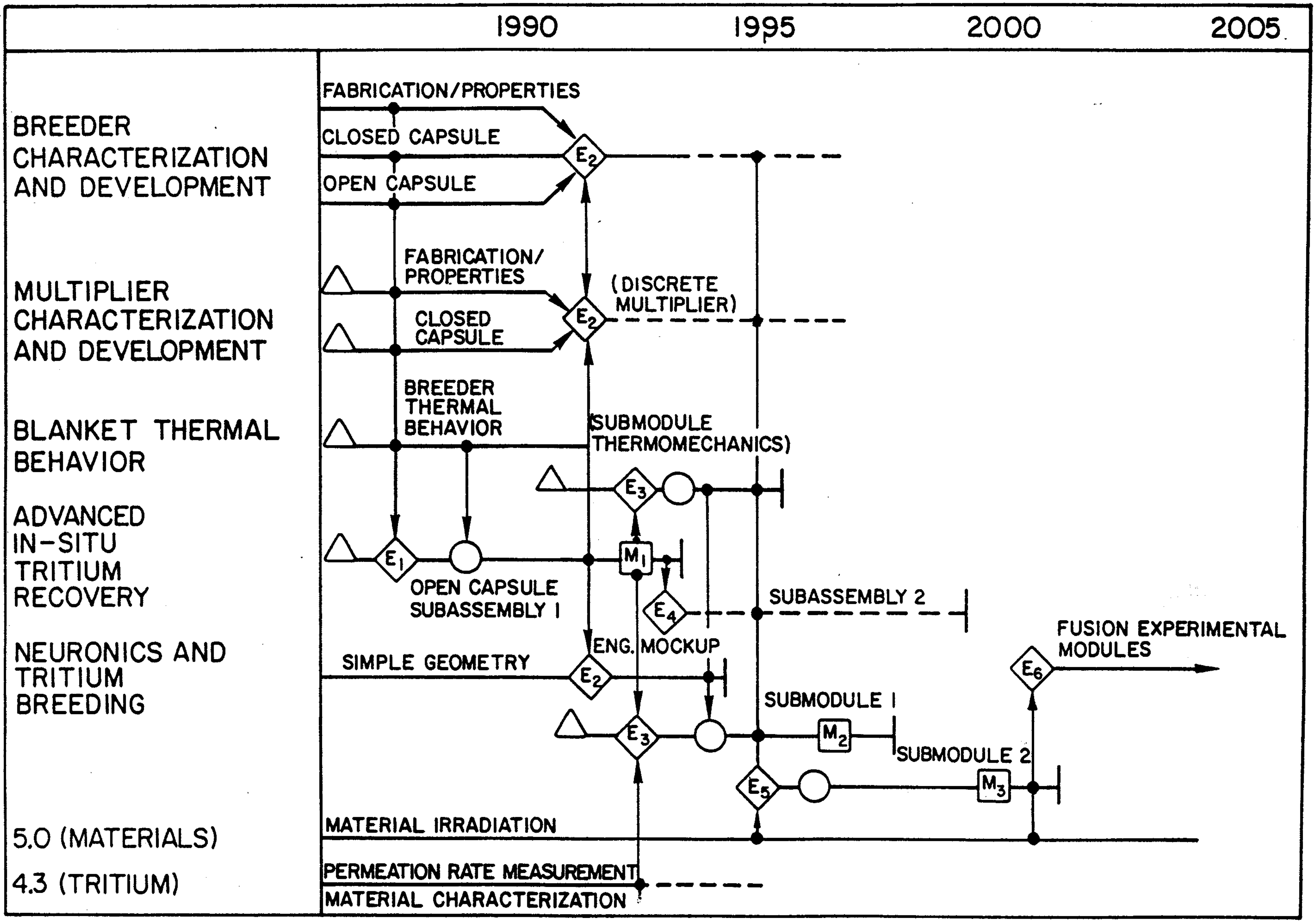
4.0 NUCLEAR TECHNOLOGY



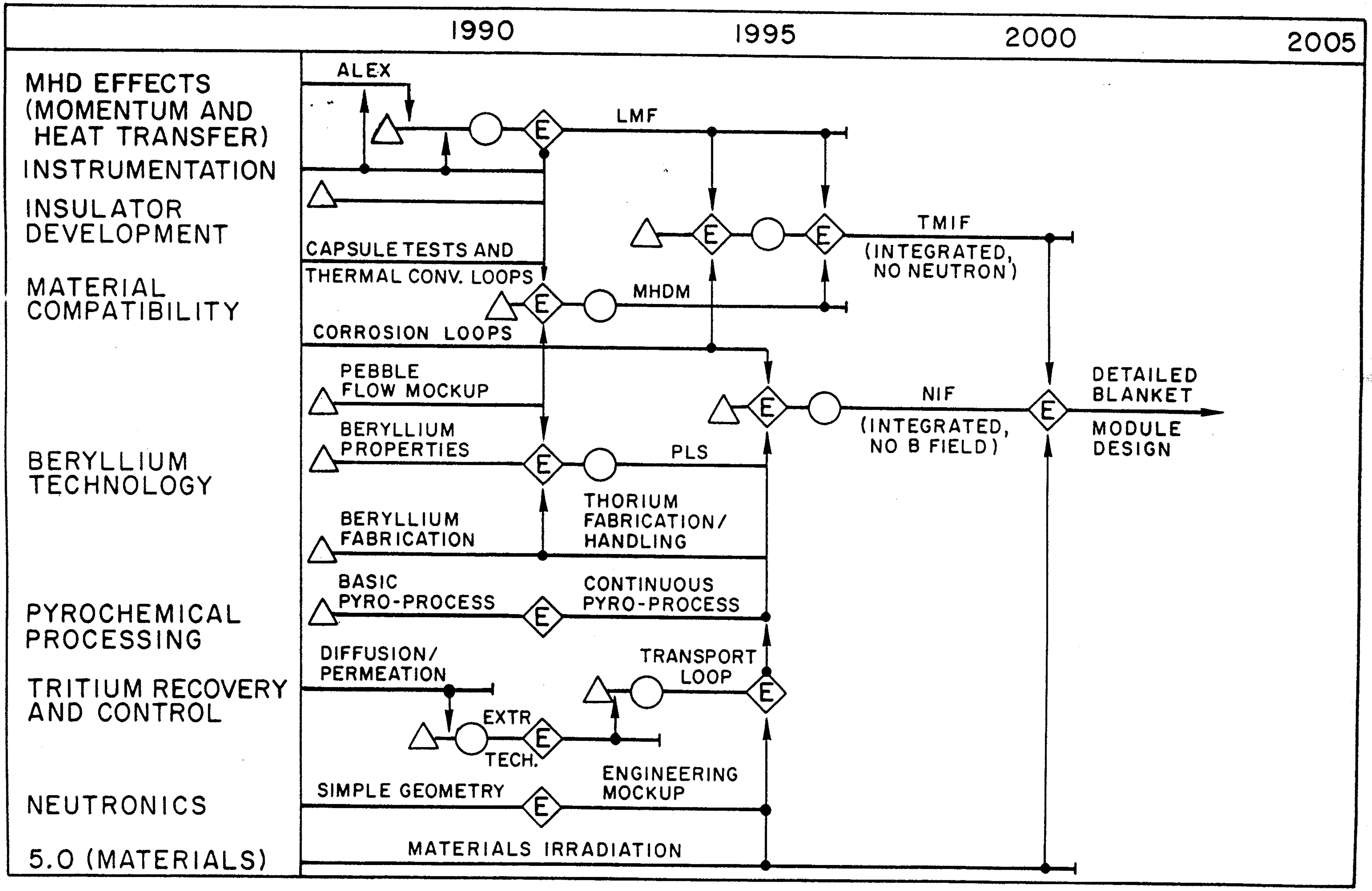
4.1 BLANKET/FW



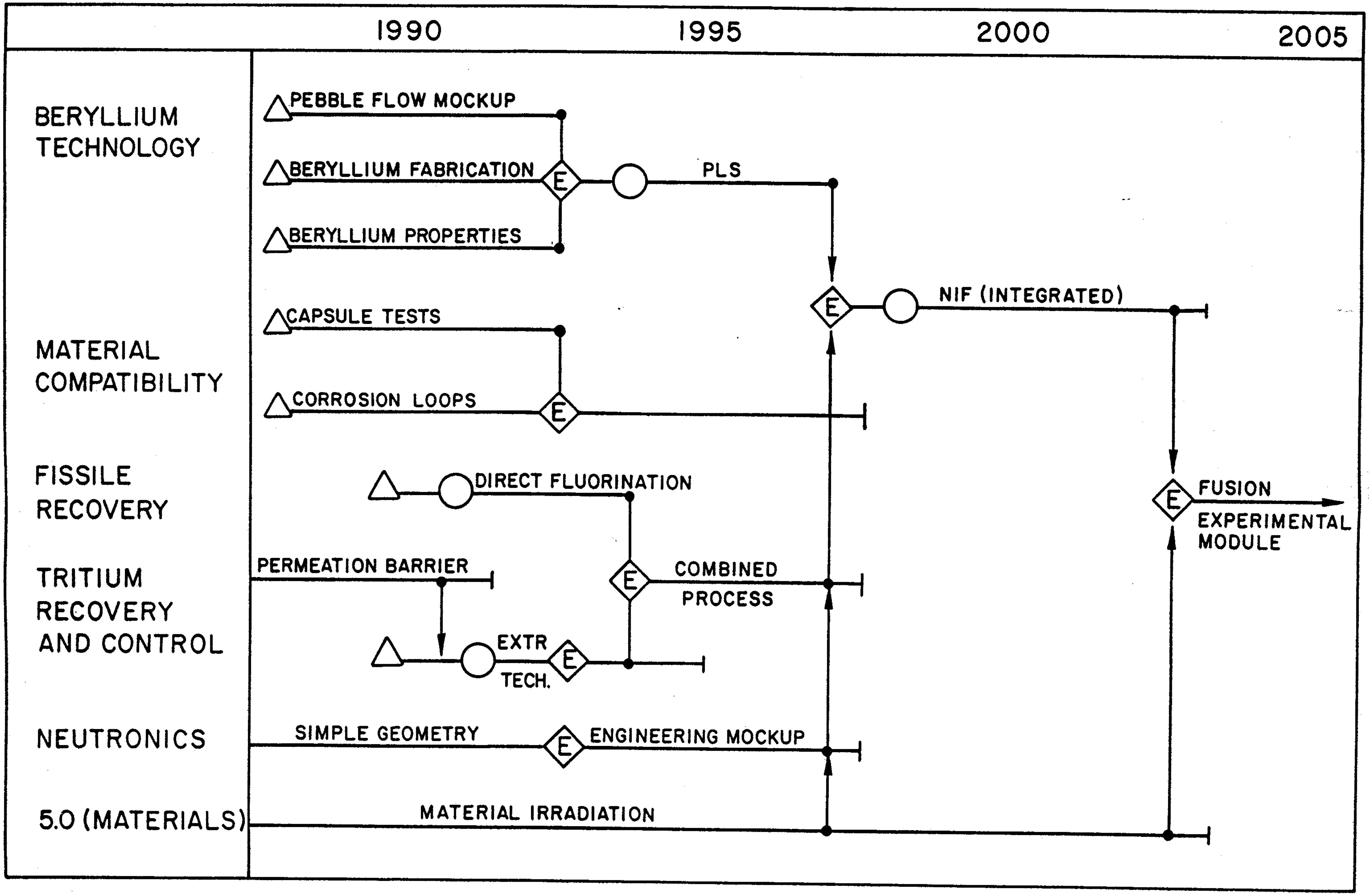
4.1.1 LIQUID BREEDER BLANKETS



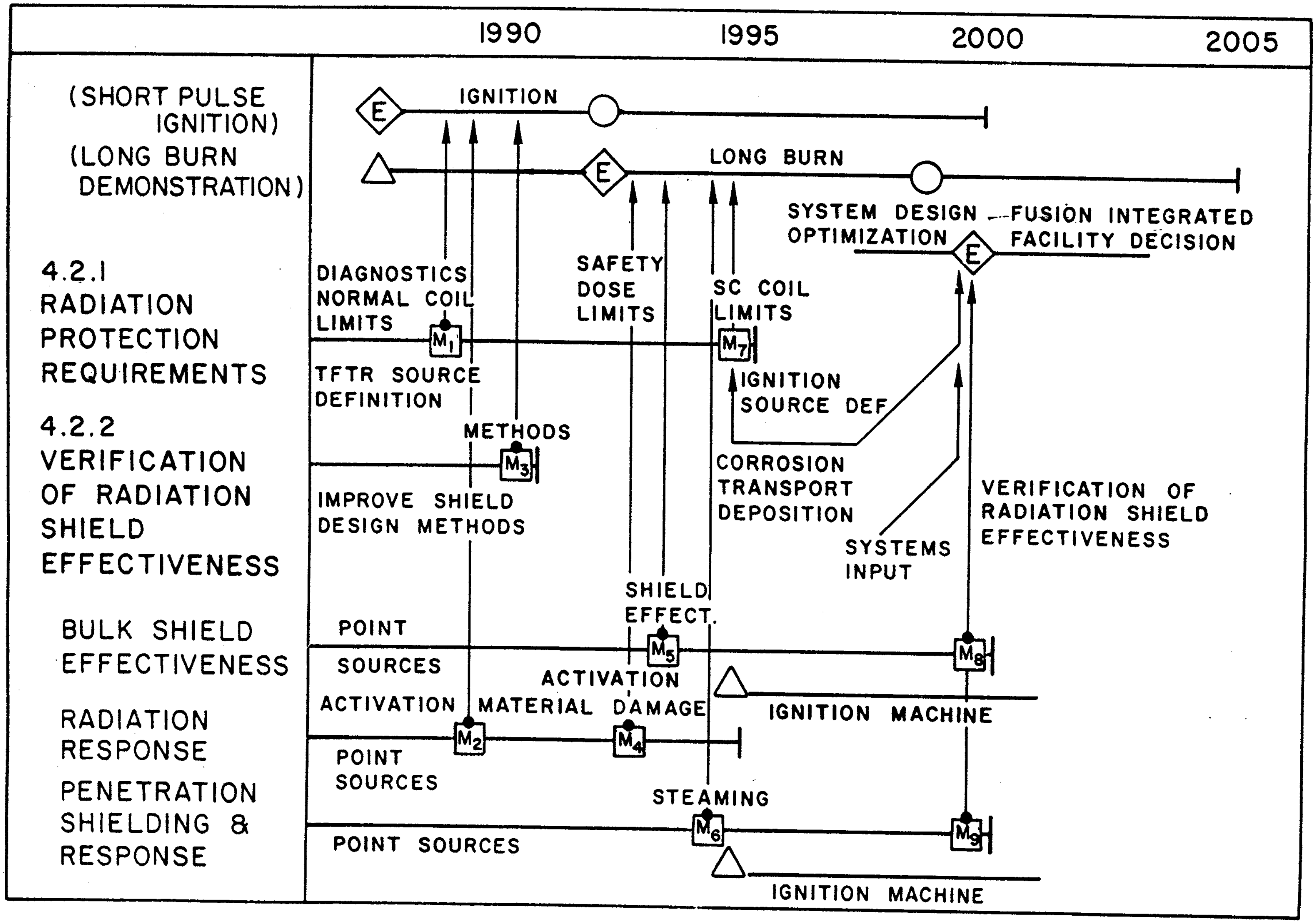
4. I. 2 SOLID BREEDER BLANKETS



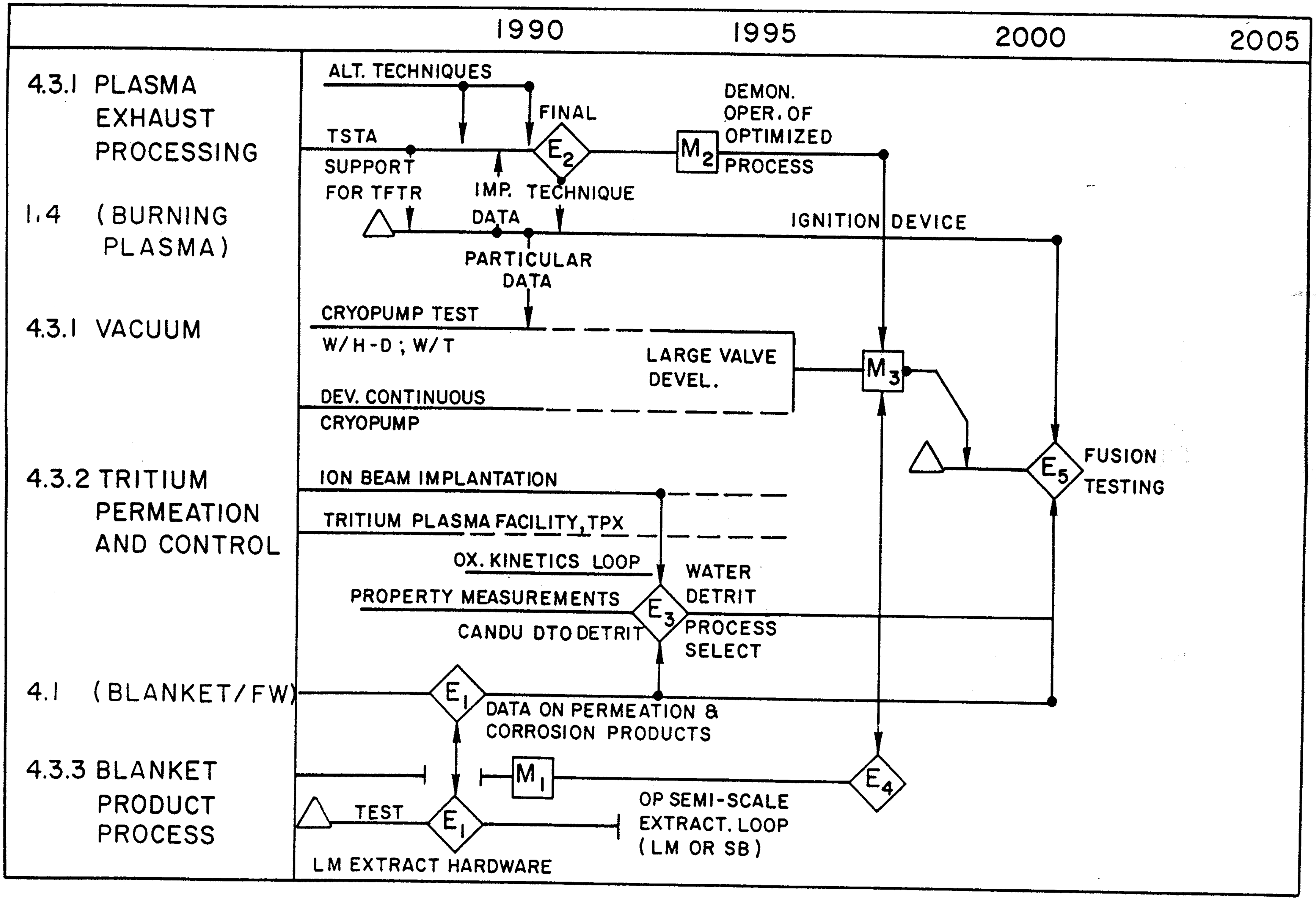
4.1.3 HYBRID BLANKETS (LIQUID METAL)



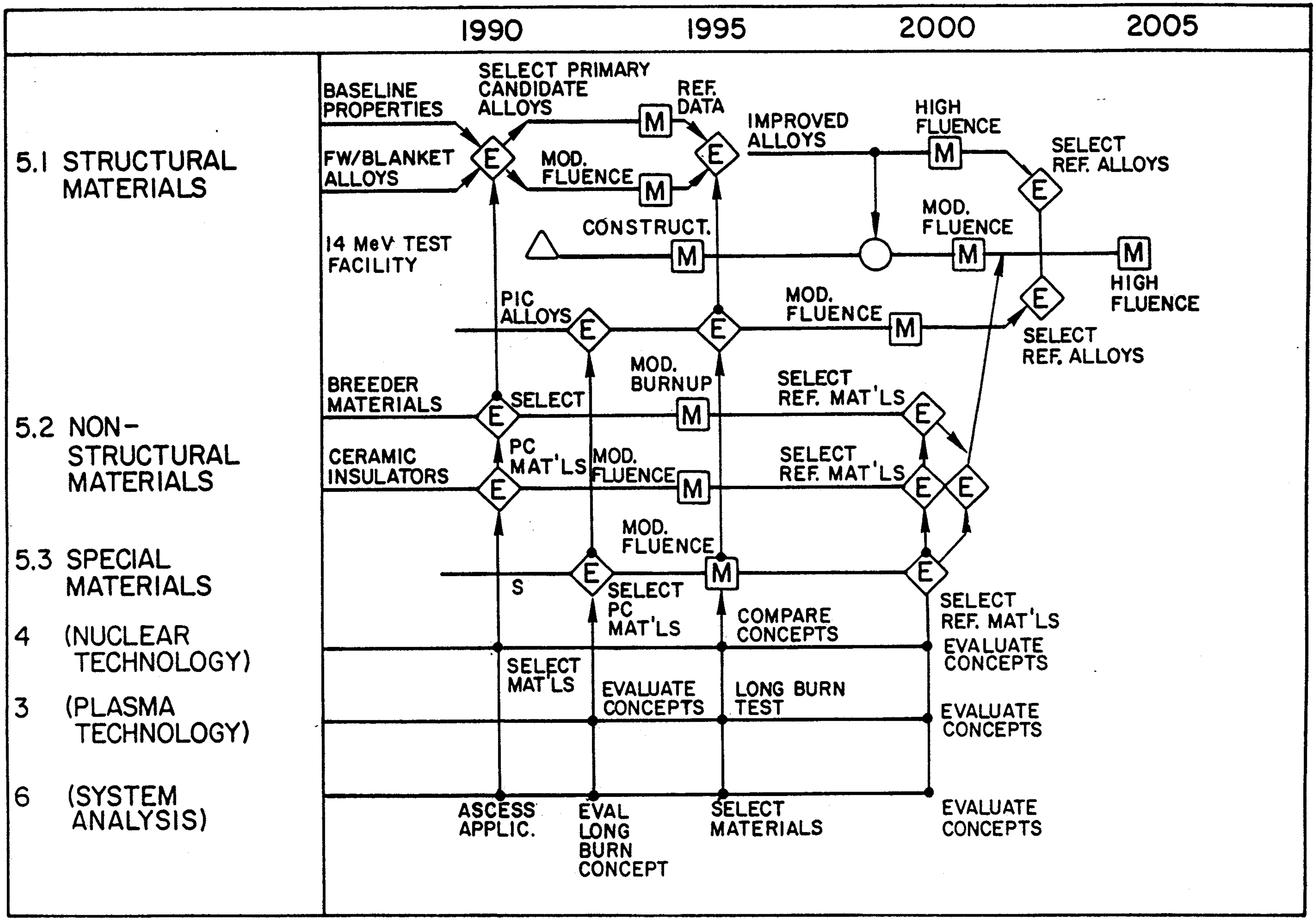
4.1.3 HYBRID BLANKETS (MOLTEN SALTS)


1990
1995
2000
2005
(SHORT PULSE IGNITION)
(LONG BURN DEMONSTRATION)
4.2.1 RADIATION PROTECTION REQUIREMENTS
4.2.2 VERIFICATION OF RADIATION SHIELD EFFECTIVENESS
BULK SHIELD EFFECTIVENESS
RADIATION RESPONSE
PENETRATION SHIELDING & RESPONSE
IGNITION
LONG BURN
SYSTEM DESIGN OPTIMIZATION
FUSION INTEGRATED FACILITY DECISION
DIAGNOSTICS NORMAL COIL LIMITS
SAFETY DOSE LIMITS
SC COIL LIMITS
TFTR SOURCE DEFINITION
IGNITION SOURCE DEF
METHODS
CORROSION TRANSPORT DEPOSITION
IMPROVE SHIELD DESIGN METHODS
VERIFICATION OF RADIATION SHIELD EFFECTIVENESS
SYSTEMS INPUT
SHIELD EFFECT.
POINT SOURCES
ACTIVATION
ACTIVATION
MATERIAL DAMAGE
IGNITION MACHINE
POINT SOURCES
STEAMING
POINT SOURCES
IGNITION MACHINE

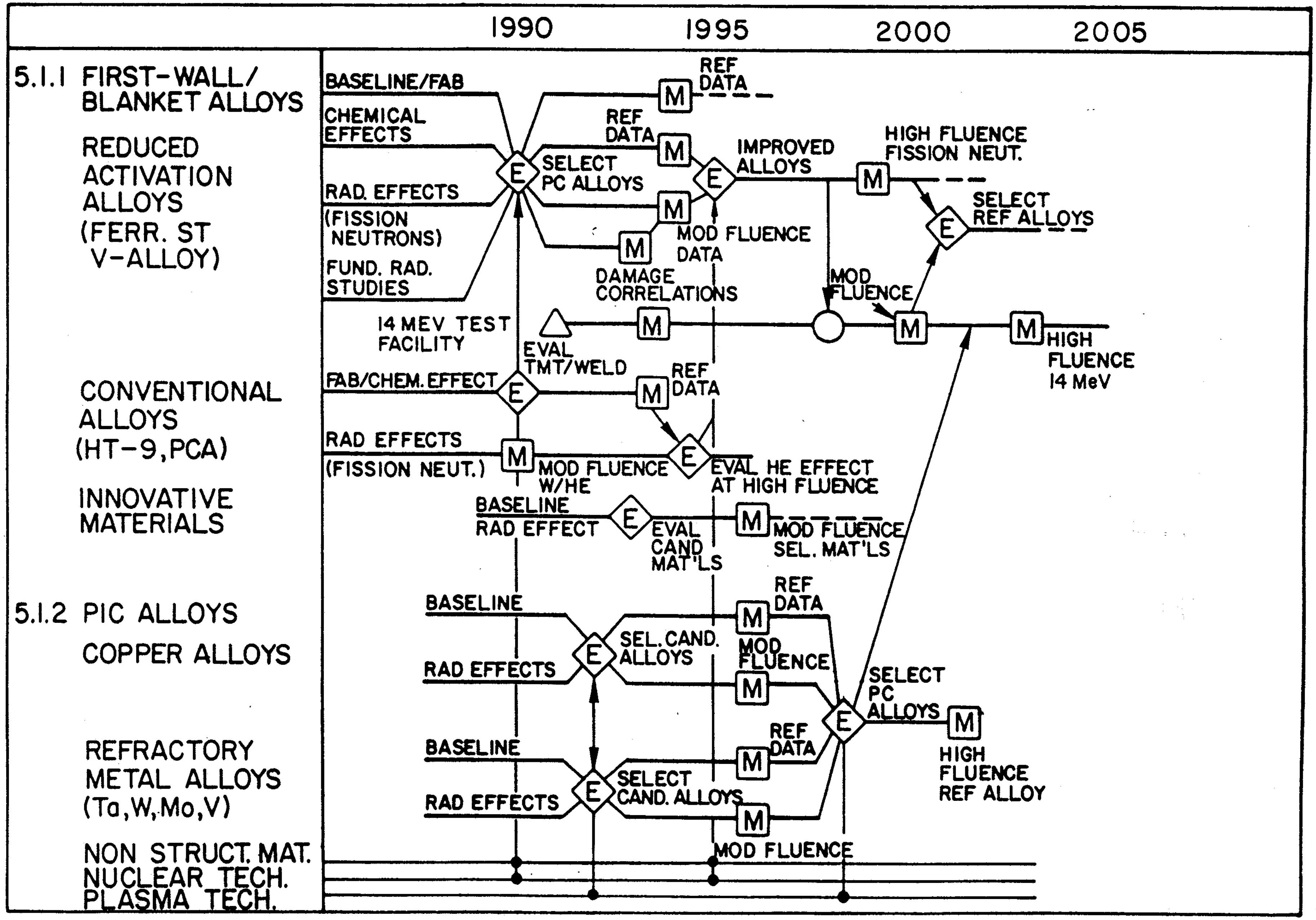
4.2 SHIELD


1990
1995
2000
2005
4.3.1 PLASMA EXHAUST PROCESSING
1.4 (BURNING PLASMA)
4.3.1 VACUUM
4.3.2 TRITIUM PERMEATION AND CONTROL
4.1 (BLANKET/FW)
4.3.3 BLANKET PRODUCT PROCESS
ALT. TECHNIQUES
FINAL
DEMON. OPER. OF OPTIMIZED PROCESS
TSTA
E_2
M_2
SUPPORT FOR TFTR
IMP. DATA
TECHNIQUE
IGNITION DEVICE
PARTICULAR DATA
CRYOPUMP TEST W/H-D ; W/T
LARGE VALVE DEVEL.
M_3
DEV. CONTINUOUS CRYOPUMP
E_5
FUSION TESTING
ION BEAM IMPLANTATION
TRITIUM PLASMA FACILITY, TPX
OX. KINETICS LOOP
WATER DETRIT
PROPERTY MEASUREMENTS
E_3
CANDU DTO DETRIT
PROCESS SELECT
E_1
DATA ON PERMEATION & CORROSION PRODUCTS
M_1
E_4
TEST
E_1
OP SEMI-SCALE EXTRACT. LOOP (LM OR SB)
LM EXTRACT HARDWARE

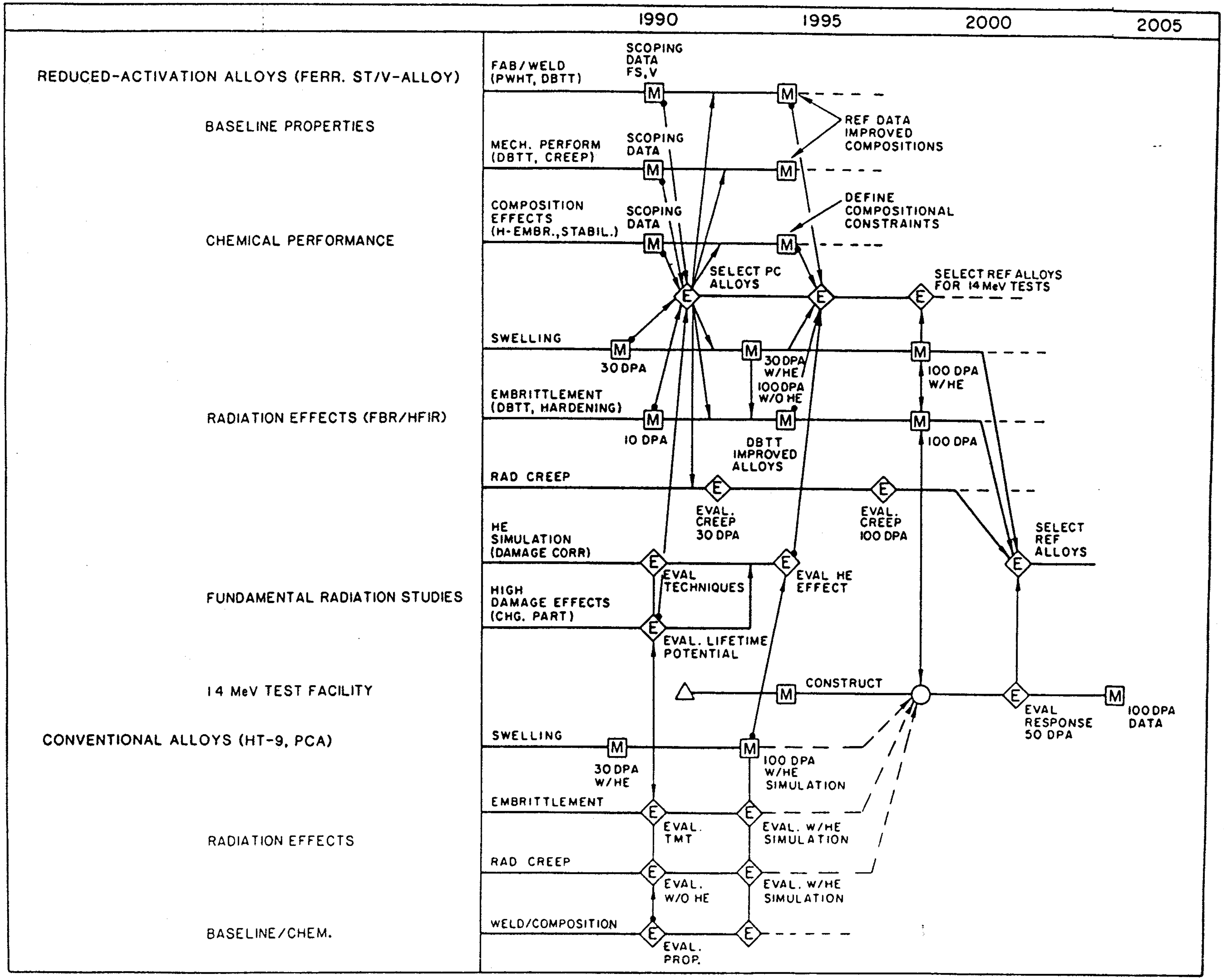
4.3 TRITIUM

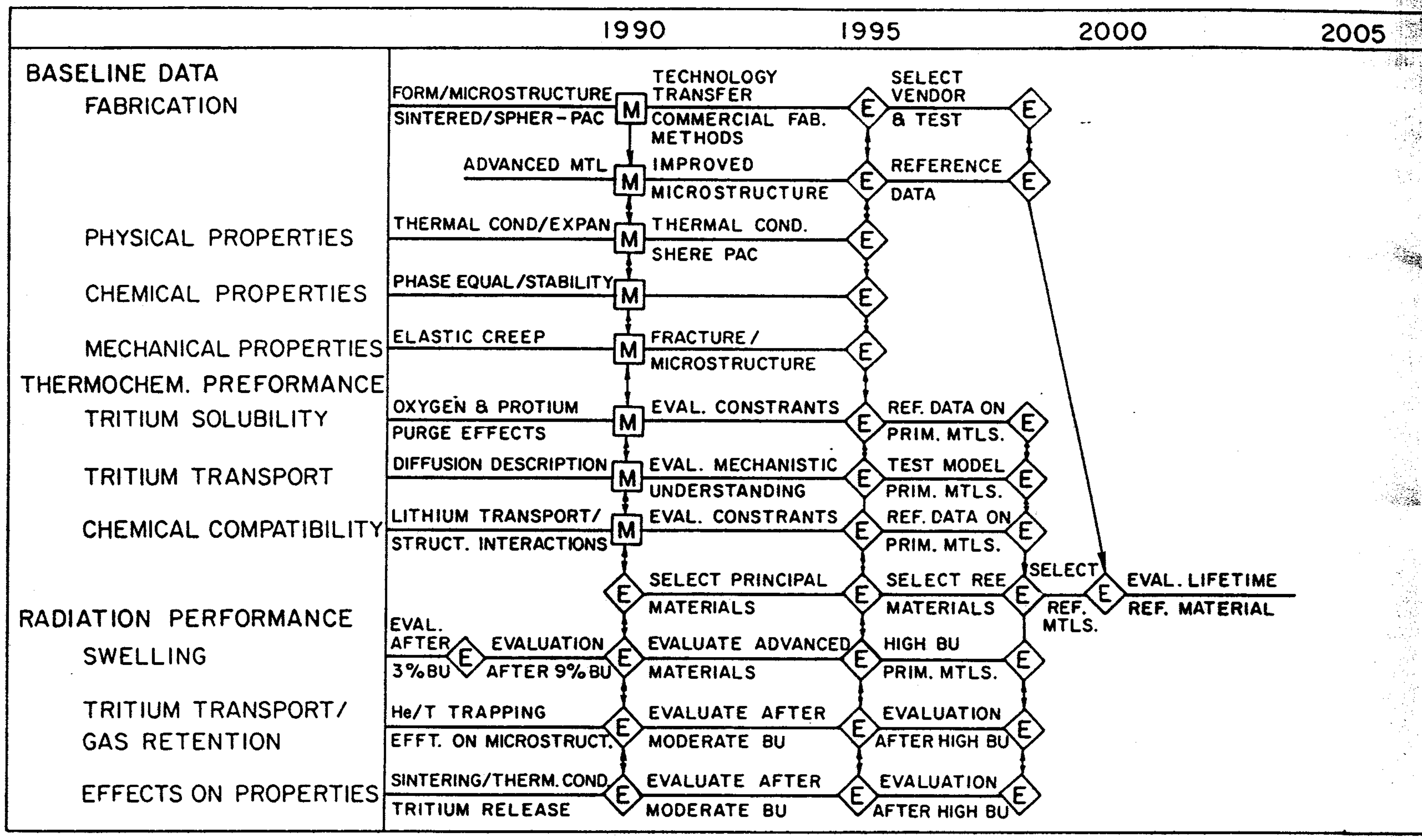


5.0 MATERIALS

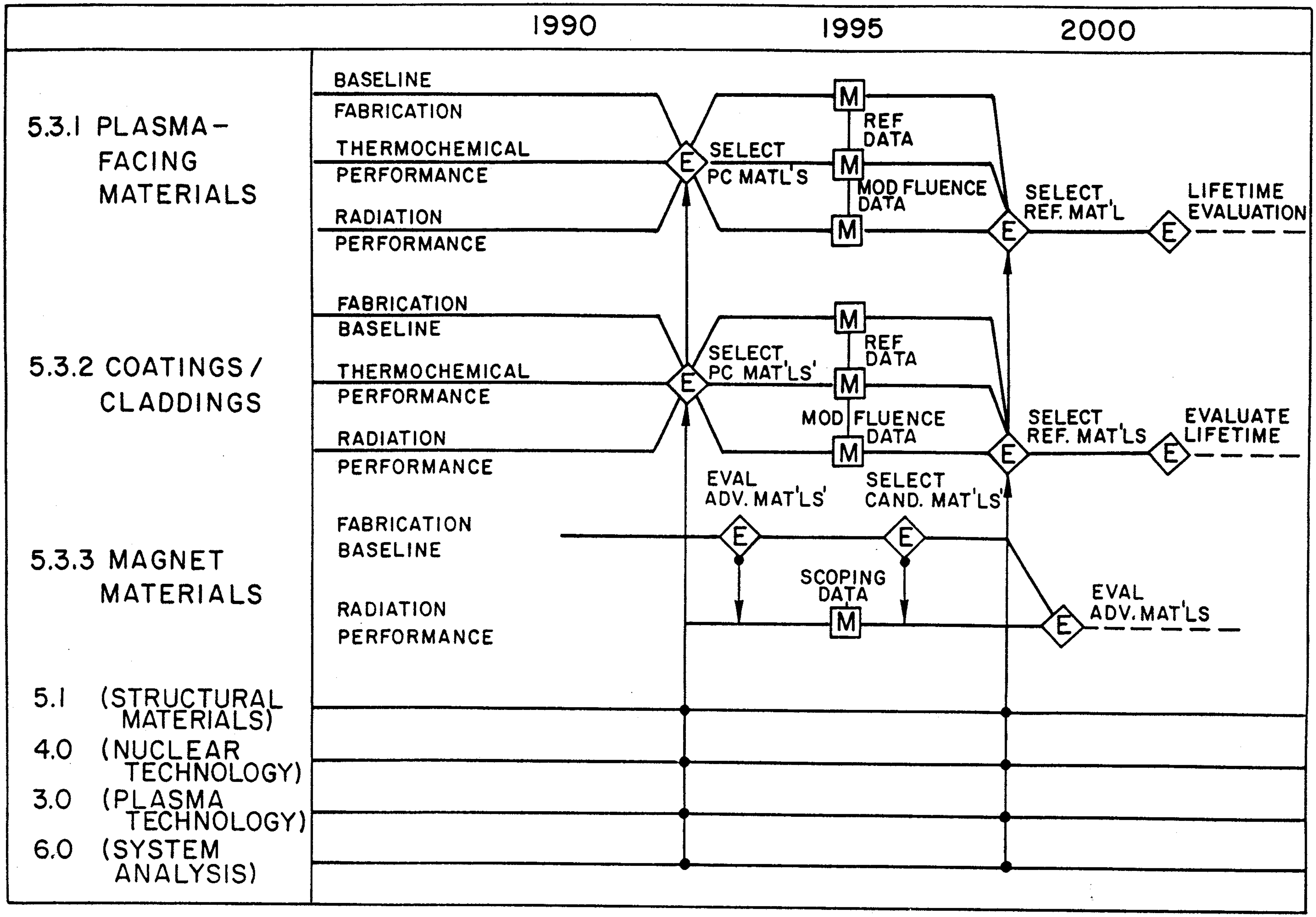


5.1 STRUCTURAL MATERIALS


1990
1995
2000
2005
REDUCED-ACTIVATION ALLOYS (FERR. ST/V-ALLOY)
BASELINE PROPERTIES
CHEMICAL PERFORMANCE
RADIATION EFFECTS (FBR/HFIR)
FUNDAMENTAL RADIATION STUDIES
14 MeV TEST FACILITY
CONVENTIONAL ALLOYS (HT-9, PCA)
RADIATION EFFECTS
BASELINE/CHEM.
FAB/WELD (PWHT, DBTT)
SCOPING DATA FS,V
REF DATA IMPROVED COMPOSITIONS
MECH. PERFORM (DBTT, CREEP)
SCOPING DATA
COMPOSITION EFFECTS (H-EMBR., STABIL.)
SCOPING DATA
DEFINE COMPOSITIONAL CONSTRAINTS
SELECT PC ALLOYS
SELECT REF ALLOYS FOR 14 MeV TESTS
SWELLING
30 DPA
30 DPA W/HE 100 DPA W/O HE
100 DPA W/HE
EMBRITTLEMENT (DBTT, HARDENING)
10 DPA
DBTT IMPROVED ALLOYS
100 DPA
RAD CREEP
EVAL. CREEP 30 DPA
EVAL. CREEP 100 DPA
SELECT REF ALLOYS
HE SIMULATION (DAMAGE CORR)
EVAL TECHNIQUES
EVAL HE EFFECT
HIGH DAMAGE EFFECTS (CHG. PART)
EVAL. LIFETIME POTENTIAL
CONSTRUCT
EVAL RESPONSE 50 DPA
100 DPA DATA
SWELLING
30 DPA W/HE
100 DPA W/HE SIMULATION
EMBRITTLEMENT
EVAL. TMT
EVAL. W/HE SIMULATION
RAD CREEP
EVAL. W/O HE
EVAL. W/HE SIMULATION
WELD/COMPOSITION
EVAL. PROP.



5.2.1 SOLID BREEDER MATERIALS



5.3 SPECIAL MATERIALS

Table 1

TOP LEVEL OBJECTIVES FOR MFPP KEY TECHNICAL ISSUES

MFPP Key Issue	1985 - 1990	1990-1995	1995-2000	2000-2005	Overall Objective
• Confinement Systems	• Identify potentially attractive reactor concepts and perform experiments to address selected technical issues	• Resolve technical issues that support development of attractive reactor concepts and a predictive plasma science capability		• Operate leading confinement concept under fusion conditions	Demonstrate one or more confinement concepts (or commercially competitive fusion applications) and develop predictive plasma science capability
• Burning Plasmas	• Demonstrate scientific breakeven (Q ~ 1 in one concept)	• Demonstrate ignition in short pulses in one confinement concept	• Demonstrate ignition (or high Q) with long pulses in one confinement concept		Demonstrate ignition for high Q), long pulse burning plasma conditions in the leading confinement concept
• Nuclear Technology	• Conduct scoping nuclear technology experiments	• Acquire engineering data from interactive effects testing	• Verify selected nuclear technology concepts in non-fusion facilities	• Perform experiments of leading nuclear technology concepts and materials in fusion environment	Show that nuclear technology can be developed that leads to commercially competitive fusion applications
• Materials	• Develop scoping data on improved materials	• Acquire moderate fluence data on leading materials in non-fusion facilities	• Acquire high fluence data on leading materials in non-fusion facilities		Show that improved materials can be developed that lead to enhanced economic and environmental features for commercially competitive fusion applications

Table 3-1

CHARACTERIZATION OF PLASMA TECHNOLOGY TASKS

1985-1990	1990-1995	1995-2000	2000-2005
Subsystems feasibility tests on existing devices, component development for ignition	Testing on ignition device, evaluation of approaches to provide long burn design basis	Component development for long burn facility	Advanced development of systems based on quasi steady-state testing in fusion environment

Table 4-1

NUCLEAR TECHNOLOGY - LEVEL 1

	1985-1990	1990-1995	1995-2000	2000-2005
• Blanket/First Wall	• Perform separate effect tests and obtain scoping data.	• Perform multiple interaction experiments to explore and characterize phenomena.	• Perform integrated tests in non-fusion facilities for concept verfication.	• Operate blanket experimental modules in fusion test facility.
• Tritium	• Perform permeation and plasma exhaust processing experiments. Test cryopump module.	• Demonstrate plasma exhaust processing technology. Test tritium extraction techniques on laboratory scale.	• Demonstrate tritium extraction. Operate vacuum test stand.	• Operate tritium systems in fusion test facility.
• Shield	• Perform point source shield tests. Obtain data on component radiation protection criteria.	• Design and test shields in tritium-burning devices. Verify shield effectiveness and predictive capability.		• Verify shield performance in fusion test facility.
• PIC	• Perform separate effect tests. Develop predictive capability for plasma edge and recycling.	• Demonstrate energy removal techniques for PIC systems.	• Design and test PIC systems for long pulse device. Verify predictive capability.	• Operate PIC systems in fusion test facility.

Table 4-2

EVALUATION POINTS AND MILESTONES FOR NUCLEAR TECHNOLOGY

E_1	Select leading material combinations for liquid breeders.
E_2	Select leading material combinations for solid breeders.
E_3	Compare results for solid and liquid breeders. Select one breeder if possible. Select leading configurations.
E_4	Select primary design for experimental blanket test modules in fusion test.
E_5	Select tritium extraction and control methods.
E_6	Select method for fuel clean-up.
E_7	Assess feasibility of non-water cooling of PIC.
E_8	Assess heat removal techniques for PIC.
E_9	Evaluate system impact on selection of blanket concepts.
E_{10}	Evaluate system impact on selection of blanket test modules.
M_1	Verify blanket concepts in non-fusion facilities.
M_2	Demonstrate tritium system operation.
M_3	Achieve moderate fluence (30 dpa) for candidate alloys in non-fusion facilities.
M_4	Achieve moderate fluence (30 dpa) for reference alloys and high fluence (100 dpa) for candidate alloys in non-fusion facilities.
M_5	Achieve high fluence (100 dpa) for reference alloys in non-fusion facilities.
M_6	Verify data and methods for shield design.
M_7	Verify shield design effectiveness. Obtain data on component radiation protection criteria.

Table 4.1-1

BLANKET/FW OBJECTIVES				
	1985-1990	1990-1995	1995-2000	2000-2005
• MHD (Including Insulators)	• Explore MHD phenomena in simple geometry tests	• Explore MHD phenomena in complex geometry tests. Perform scoping experiments for macroscopic effects.		
• Material Compatibility	• Explore basic material interactions in loop tests.	• Perform further loop testing to determine design limits and impurity control techniques		
• (Tritium Recovery and Permeation)	• Explore tritium recovery techniques in small-scale experiments. Measure basic permeation properties and rates. Develop tritium design goals.	• Verify tritium recovery techniques in small-scale experiments. Operate transport loops to demonstrate tritium control.	• Perform non-fusion concept verification testing for selected liquid and/or solid breeder material combinations and concepts.	
• Solid Breeder Tritium/Thermal Behavior	• Measure basic properties of solid breeders.	• Perform advanced in-situ tritium recovery experiment on selected material combinations.		• Perform fusion testing for selected concepts.
• Neutronics	• Perform simple geometry experiments.	• Perform engineering mockup experiments.		
• (Materials)	• Generate moderate fluence data for initial alloys in fission reactors. Measure basic properties.	• Generate moderate fluence data for improved alloys in fission reactors. Develop fabrication and recycling techniques.	• Generate high fluence data for improved alloys in fission reactors.	

BLANKET/FW EVALUATION POINTS AND MILESTONES

E_1	Narrow coolant/breeder and structural material options for liquid breeder blankets.
E_2	Narrow solid breeder/multiplier material options.
E_3	Assess tritium breeding potential of Li_2O.
E_4	Select fuel form and fuel processing methods.
E_5	Select material combinations and configurations for non-fusion concept verification testing of liquid breeder blankets.
E_6	Select material combinations and configurations for non-fusion concept verification testing of solid breeder blankets.
E_7	Select material combinations and configurations for non-fusion concept verification testing of hybrid blankets.
E_8	Compare solid breeder and liquid breeder concepts. Select a small number of concepts from one or both categories.
E_9	Select and design blanket modules for fusion testing.
M_1	Complete characterization of Li_2O ceramic breeders.
M_2	Complete characterization of ternary ceramic breeders.
M_3	Achieve moderate fluence for initial candidate alloys and select advanced reference alloys.
M_4	Complete MHD experiments. Establish feasibility of self-cooling and optimize cooling methods. Determine MHD design limits.
M_5	Complete basic material interaction experiments. Determine operating limits and demonstrate adequate impurity control techniques.
M_6	Demonstrate tritium extraction system for Li and/or LiPb.
M_7	Complete advanced in-situ tests.
M_8	Complete neutronics engineering mock-up tests. Demonstrate margin for achievable tritium breeding ratio.
M_9	Achieve moderate fluence non-fusion irradiation for reference alloys
M_{10}	Complete non-fusion concept verification for liquid breeder blankets.
M_{11}	Complete non-fusion concept verification for solid breeder blankets.
M_{12}	Complete non-fusion concept verification for hybrid blankets.
M_{13}	Achieve high fluence non-fusion irradiation for reference alloys.

Table 4.2-1

SHIELD OBJECTIVES				
	1985-1990	1990-1995	1995-2000	2000-2005
• **Radiation Protection Requirements**	• Verify DT source specification. • Specify radiation limits for magnet insulations and diagnostics.	• Specify radiation limits for S/C coils and vacuum pumps. • Estimate corrosion, transport and deposition in piping and heat exchangers.		
• **Verification of Shield Effectiveness**	• Perform bulk shield benchmark experiments. • Verify activation response. • Perform penetration benchmark experiments. • Improve design methods: activation, streaming, and sensitivity.	• Perform bulk shield mockup experiments. • Verify materials damage response. • Perform penetration mockup experiments. • Develop optimized shield designs.	• Perform bulk shield prototype experiments. • Perform penetration prototype experiments. • Develop fully integrated shield designs.	

Table 4.3-1

TRITIUM				
	1985-1990	1990-1995	1995-2000	2000-2005
• <u>Plasma Exhaust Processing</u>	• Operate TSTA integrated loop for plasma exhaust processing (including safety systems). Develop alternative cleanup techniques (e.g. palladium, diffuser).	• Demonstrate reliable operation of final processes for plasma exhaust processing.		• Operate tritium systems in fusion test facility.
• <u>(Plasma Experiments)</u>	• Support TFTR tritium operations.	• Support ignition experiment.	• Support long burn experiment.	
• <u>Vacuum</u>	• Test cryopump module with tritium at TSTA valve.	• Initiate development of large (1-m dia.) vacuum.	• Operate vacuum test stand.	
• <u>Tritium Permeation and Control</u>	• Perform small experiments to measure permeabilities of fusion materials (incl. use of tritium plasma).	• Establish understanding of permeation characteristics of fusion materials.		
• <u>Blanket Product Processing</u>	• Test blanket extraction techniques.	• Operate semi-scale blanket tritium extraction loop (LM and/or SB).	• Add blanket extraction interface to TSTA.	

Table 5-1

MATERIALS (LEVEL 1)				
	1985-1990	1990-1995	1995-2000	2000-2005
• Structural Materials	• Develop baseline and low fluence scoping data on low activation FW/B materials. • Improve radiation resistance through composition and thermomechanical treatment modifications • Develop helium simulation techniques	• Develop reference data and moderate fluence property data with simulated He effects on primary candidate alloys • Provide data on conventional alloys at high damage levels (100 dpa) and high helium concentrations	• Provide high fluence (100 dpa) property data on primary candidate alloys with improved compositions and microstructures	• Evaluate effects of high fluence 14 MeV neutron irradiation on properties of selected FW/B reference alloys
	• Develop scoping data on selected PIC alloys	• Develop selected PIC alloys with improved composition/microstructure	• Provide high fluence (up to 100 dpa) property data on primary candidate alloys	• Evaluate 14 MeV radiation effects on reference PIC alloys
		• Design high fluence 14 MeV neutron materials test facility	• Construct high fluence 14 MeV neutron materials test facility	• Irradiation testing in 14 MeV neutron facility
• Non-Structural Blanket Materials	• Develop baseline and low fluence scoping data on candidate breeder materials	• Provide moderate fluence data on selected breeder materials	• High fluence/burnup data on prime candidate breeder materials	
	• Develop insulator materials with improved composition/microstructure	• Provide low fluence scoping data on improved ceramic insulator materials	• Provide high fluence data on prime candidate materials	• Provide 14 MeV radiation data on selected reference materials
• Special Materials		• Provide baseline and low fluence scoping data on selected materials	• Define material operating limits based on fission reactor irradiation data	• Evaluate 14 MeV neutron radiaton effects

Table 5.1-1

STRUCTURAL MATERIALS (LEVEL 2)

	1985-1990	1990-1995	1995-2000	2000-2005
FIRST-WALL/BLANKET ALLOYS • Reduced Activition Ferritic Steels and Vanadium Alloys	• Develop scoping baseline data and fabrication requirements for selected low activation alloys	• Develop reference baseline and fabrication data on primary candidate alloys		
	• Evaluate effects of chemical and microstructural variations on properties of selected low activation alloys	• Determine chemical and thermomechanical treatments (TMT) on properties of primary candidate alloys		
	• Determine effects of low fission neutron fluences on embrittlement of selected low activation alloys	• Moderate fluence radiation effects on properties (including simulated He effects)	• High fluence fission neutron data on improved compositional microstructures	• High fluence (fission) mechanical property data on reference alloys
	• Develop simulation techniques for evaluating helium effects	• Provide helium and damage correlations	• Evaluate helium effects on primary candidate alloys	
		• Design high fluence 14 MeV materials test facility	• Construct high fluence 14 MeV materials test facility	• Test selected reference alloys in 14 MeV materials test facility
• Conventional Alloys (HT-9, PCA)	• Develop improved composition and microstructures of conventional alloys			
	• Evaluate effects or moderate fluence neutron irradiations on properties of conventional alloys	• Evaluate helium effects at high fluence (100 dpa) on conventional alloys	• Assess performance to 100 DPA (with He), refining alloy design in iterative process	
• Innovative Alloys		• Scoping baseline and radiation effects data on selected innovative materials	• Moderate fluence data on selected innovative materials	
PIC ALLOYS • Copper and Refractory Metal Alloys	• Develop scoping baseline data on selected copper and refractory metal alloys	• Develop baseline data on selected refractory metal alloys	• Moderate fluence data with simulated helium effects on improved alloys	• Test selected reference alloys in 14 MeV Materials Test Facility
	• Low fluence scoping data on copper and refractory metal alloys	• Moderate fluence radiation data on selected copper alloys	• Select primary candidate alloys for 14 MeV tests	

Table 5.1-2
FIRST WALL/BLANKET STRUCTURAL ALLOYS (LEVEL 3)

Reduced Activation Alloys (Ferritic Steels and Vanadium Alloys)

Baseline Properties

- Determine effects of fabrication and weld procedures and thermomechanical treatment on baseline properties, particularly DBTT, including effects of post-weld heat treatment.

- Determine baseline mechanical performance, viz., DBTT and creep properties.

Thermochemical Performance

- Determine effects of chemical environment, particularly interstitial element interactions such as H, C, N, and O, and thermal aging effects on materials performance.

Radiation Effects

- Determine swelling characteristics on fission neutron irradiations (FBR/HFIR) of alloys as function of composition and TMT.

- Determine low fluence (< 30 DPA), low temperature (< 400°C) fission neutron irradiation on embrittlement. Later evaluate high fluence irradiation hardening.

- In the longer term, evaluate radiation creep characteristics.

Fundamental Radiation Studies

- Develop helium simulation techniques and displacement damage correlations for fission reactor irradiations.

- Evaluate potential for long lifetime by high fluence FBR and charged particle irradiations.

14 MeV Test Facility

- Design and construct a high fluence 14 MeV neutron test facility for materials testing.

Conventional Alloys (HT-9, PCA)

Radiation Effects

- Use expanded radiation data base to develop better understanding of radiation effects on materials and for more rapid development of new low activation alloys.

Baseline/Chemical Effects

- Develop improved composition/microstructures as reference for developing improved low activation alloys.

Table 5.2-1

NON-STRUCTURAL BLANKET MATERIALS

	1985-1990	1990-1995	1995-2000	2000-2005
• **Solid Breeders**	• Develop baseline properties data and fabrication methods	• Develop reference data and fabrication methods	• Evaluate commercial fabrication methods	
	• Collect thermochemical and transport data for candidate materials	• Evaluate effects of oxidizing environment on material properties	• Complete properties data on prime materials	
	• Determine effects of low fluence irradiation on material behavior	• Moderate fluence data on selected materials	• High fluence data on prime candidate materials	• Dynamic in-situ tritium recovery test of prime material in relevant neutron energy environment
• **Liquid Breeder/Coolant**	• Develop baseline physical properties data	• Evaluate performance of primary candidate materials		
	• Develop baseline thermochemical properties data			
• **Multiplier/Moderator**	• Establish fabrication requirements	• Develop improved microstructures and fabrication methods	• Evaluate commercial fabrication methods including recycle of Be	
	• Evaluate thermochemical performance	• Determine tritium thermodynamic and transport properties	• High fluence data on prime candidates	• Qualify materials for fusion applications
	• Evaluate effects on low fluence irradiation on materials behavior	• Moderate fluence data on selected material		
• **Ceramic Insulators**	• Establish baseline properties and fabrication requirements	• Develop improved forms of candidate materials	• Evaluate selected materials in detailed test matrix	• Qualify materials for fusion applications
	• Collect baseline electrical and mechanical properties data	• Develop optimized microstructures		
	• Evaluate effects of low fluence irradiation on properties data	• Moderate fluence irradiation effects on materials properties	• High fluence data on prime candidates	