Evaluation of Existing Information on INTOR Related Research and Development

A.F. Knobloch

IPP 4/196 March 1981

MAX-PLANCK-INSTITUT FÜR PLASMAPHYSIK

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Die nachstehende Arbeit wurde im Rahmen des Vertrages zwischen dem Max-Planck-Institut für Plasmaphysik und der Europäischen Atomgemeinschaft über die Zusammenarbeit auf dem Gebiete der Plasmaphysik durchgeführt.

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Abstract

During the INTOR workshop sessions (phase I) an attempt was made to arrive at a preliminary and qualitative assessment of INTOR relevant R+D in Europe, Japan, United States and USSR. All four delegations contributed in an iterative way.

The results achieved so far have been used to compare the actual situation with an idealized schedule for a possible INTOR realization. Also they enable a preliminary insight into the degree of completeness in R+D required for INTOR to be expected in various partner combinations.

Pending a detailed evaluation of all mentioned facilities and programmes together with their schedule and expected quantitative results it is seen already, that only under the most favouralbe conditions one could decide by the mid to end '80s to build INTOR. International collaboration strongly increases the completeness of R+D required for INTOR.

Contents

Introduction

Since 1978 under the auspices of IAEA the INTOR study concerning a next generation Tokamak (after JET - JT-60 - TFTR - T-15) is carried out with the participation of EURATOM, Japan, USA and USSR. After the conclusion of the data base assessment phase end of 1979 the definition phase was started. For these first two phases workshops have been organized in Vienna.

The contents of this report have been prepared for INTOR workshop sessions during the definition phase (Phase One).

In the frame of the international effort to define INTOR an assessment of the required R+D has been prepared (see International Tokamak Reactor Zero Phase Report, IAEA Vienna, 1980). Basing on this assessment during Phase One of the INTOR workshop a comparison was made between the anticipated INTOR design and construction schedule and the schedule of INTOR related R+D required before design freezing and/or start of fabrication.

In this comparison, which takes the form of bar charts for 16 different R+D topics with their pertaining subtopics, both an idealized R+D programme schematic and the actual timing of running and planned programmes are contained thus enabling a rather direct rough judgement on the coverage of INTOR related R+D requirements and on the possible time scale of INTOR realization. (For bar charts see Enclosure 1.)

The information collected in an iterative manner from all delegations to the INTOR workshop on running and planned programmes is qualitative so far in the sense that only indications have been given as to whether certain facilities or programmes can (or could) provide results pertaining to a certain subtopic at a certain time. Quantitative information like parameters to be achieved, cost involved for tackling additional questions in existion facilities, possibility to provide in practice all answers requested from certain facilities a.s.o. will have to be collected later as the INTOR work proceeds.

Despite this more qualitative character of the bar charts thus far, a re-arrangement of the information permits some quantitative conclusions such as on a possible overloading of certain facilities, lacking programme parts and coverage of the INTOR related R+D requirements in national or cooperative international programmes.

Contributions to INTOR related R+D

Table 1 shows a summary of all present entries (as of February 1981) in the INTOR bar charts (Enclosure 1). The R+D topics are regrouped in order to distinguish between plasma physics and technology, whereas the facilities besides of this aspect have been ordered roughly in chronological sequence according to their respective date of commissioning. This leads to the accumulation of data mainly in the left upper and right lower part of the Table. A few observations are the following:

- The solution of the open plasma physics questions bears on about ten tokamaks including the four large ones, which show by far the majority of entries. This calls for a careful review whether this would lead to overloading their programme in practice.
  Overloading of experiments due to a considerable number of technological contributions expected for INTOR may not be of comparable importance since these contributions are mostly results achieved in constructing and operating these machines.

- Roughly about 70% of the entries concerning technical topics mean expected results from plasma physics experimental programmes, whereas only about 30% of the entries refer to results expected from specialized technology test facilities.

- About 55% of the entries refer to open plasma physics questions, which underlines the necessity to make the most efficient use of the available machines in order to supply all necessary information in time for INTOR.

Coverage of INTOR R+D demand

From Table 1 it cannot be seen to what extent the subtopics under the different R+D topics are covered by the entries. Some subtopics are not covered at all (see Table 2). It appears, however, that the effort needed to cover also those missing ones should not change the overall picture.

In order to estimate the existing coverage of INTOR related R+D demand one has to assume for the time being that the subtopics are items of equal importance. In a possible subsequent assessment subtopics covered just by one programme in one country may be weighted in a different manner as compared to other subtopics with many entries from several national programmes a.s.o. In the INTOR Zero Phase Report the R+D topics had been classified as adequately or inadequately covered. In the meantime further assessment and planning has changed the initial picture considerably which can be seen in the charts where the subtopics are still grouped in the sequence of the initial classification.

With a total number of 620 specific entries on R+D activities in INTOR participants' programmes (running, started, planned) the coverage of INTOR R+D demand has been evaluated in the following way. Assigning 100% coverage to the total R+D demand listed under the 16 topics and relating to this the percentage of subtopics actually covered by at least one entry the relative fulfillment of R+D requirements has been calculated for the four INTOR participants individually and for all possible combinations of two or three of them together with the case of all four cooperating.

The result is given in Table 4, in which also a classification of the degree of coverage is indicated. The classification into three categories of different relevance is explained on page 5.

In short this classification distinguishes between

coverage	100% - 67%	= relevant	= category	I
	66% - 34%	= questionable relevance	= category	II
	33% - 0%	= irrelevant for INTOR	= category	III

The two lower categories are indicated in each column of Table 4. Assuming larger uncertainties about the R+D programmes found in the two lower categories the partner combinations can be mainly considered for their number of category I topics.

Coverage of INTOR R+D demand until end of 1985

The INTOR R+D bar charts in their present form infer from the anticipated INTOR design and construction schedule (see top part of each chart) that in an ideal R+D programme schematic all information should be available until end of 1985. Neglecting the inconsistency that the entries in the charts often refer only to data base assessment stages, leaving out decision making stages and their required time, and taking the optimistic view that - if information is indicated until end of 1985 - subtopics mentioned by at least one entry count for coverage one can set up a more stringent listing (see Table 5), in which all entries after end of 1985 are left out. This then characterizes the near term situation of INTOR related R+D.

Since there is hidden overlap sometimes in the subtopics a further Table 3 is added from which to see which participant contributes to which subtopic in the listings of Tables 4 and 5.

Completeness of INTOR R+D

Defining completeness as the percentage of R+D topics in category I one can set up the result of the present R+D assessment in a rather condensed form. Fig. 1 shows completeness of INTOR R+D versus all possible partner combinations and indicates the clear tendency to high completeness in multilateral cooperation. In addition the percentage of topics in category II is drawn up. Also the effects of restricting INTOR R+D to what could be expected until end of 1985 are to be seen.

It must be stated, however, that more conclusive results could only be expected from detailed assessments of quantitative R+D needs for INTOR and the possibility to quantitatively fulfill the needs by the times indicated. Insofar the present assessment cannot really judge whether INTOR R+D can be provided to a sufficient degree when called for by the anticipated schedule.

In order to illustrate the specific European situation with respect to INTOR related R+D Fig. 2 shows the completeness of R+D in the EURATOM programme for the individual topics. The influence of specific results expected from some planned experiments is indicated assuming that their contribution will not greatly change the picture under topics with entries from existing facilities.

Conclusions

On the basis of existing information as of the INTOR bar charts (February 1981) one can derive the following conclusions:

- International collaboration strongly increases the completeness of R+D required for INTOR construction.

- For a further assessment of R+D related to INTOR it is important to collect more data and facts about the experiments and facilities listed and on the real possibility that they respond to all the INTOR demands to the required degree and by the time necessary.

- Also a more detailed planning network for INTOR design and construction is needed in order to check with a realistic R+D programme.

- Only under the most favourable conditions as
  - a) rapid implementation of supporting programmes
  - b) successful completion of all required R+D by the date indicated
  - c) very efficient international cooperation

  does it seem possible that in the mid to end '80s a decision to build INTOR could be taken.

Classification of coverage for INTOR R+D

The implementation time of any major facility from which R+D questions shall be answered for INTOR may be so long, that its present nonexistence means that INTOR could only be realized with considerable delay if it had to wait for construction of that facility. In a very general sense this holds similarly for important R+D programmes yet to be started. Therefore, as a crude indication for the coverage of any existing INTOR oriented R+D programme one can use the following definitions:

67% - 100% of necessary R+D existing, started, planned = relevant
34% - 66% of necessary R+D existing, started, planned = questionable relevance
0% - 33% of necessary R+D existing, started, planned = irrelevant for INTOR

Irrelevant as used here means that a sufficiently broad R+D programme could only be implemented with drastic programme changes und funding increase and considerable delay of INTOR realization. Questionable relevance means the same but to a lesser degree such that INTOR could in the end be realized with some tolerable delay. A relevant programme would be such that with some augmentation a decision to build INTOR could be taken in the mid to end '80s.

Fig. 1 R+D required for INTOR

Completeness of R+D for various partner combinations
according to INTOR R+D bar charts as of February 1981

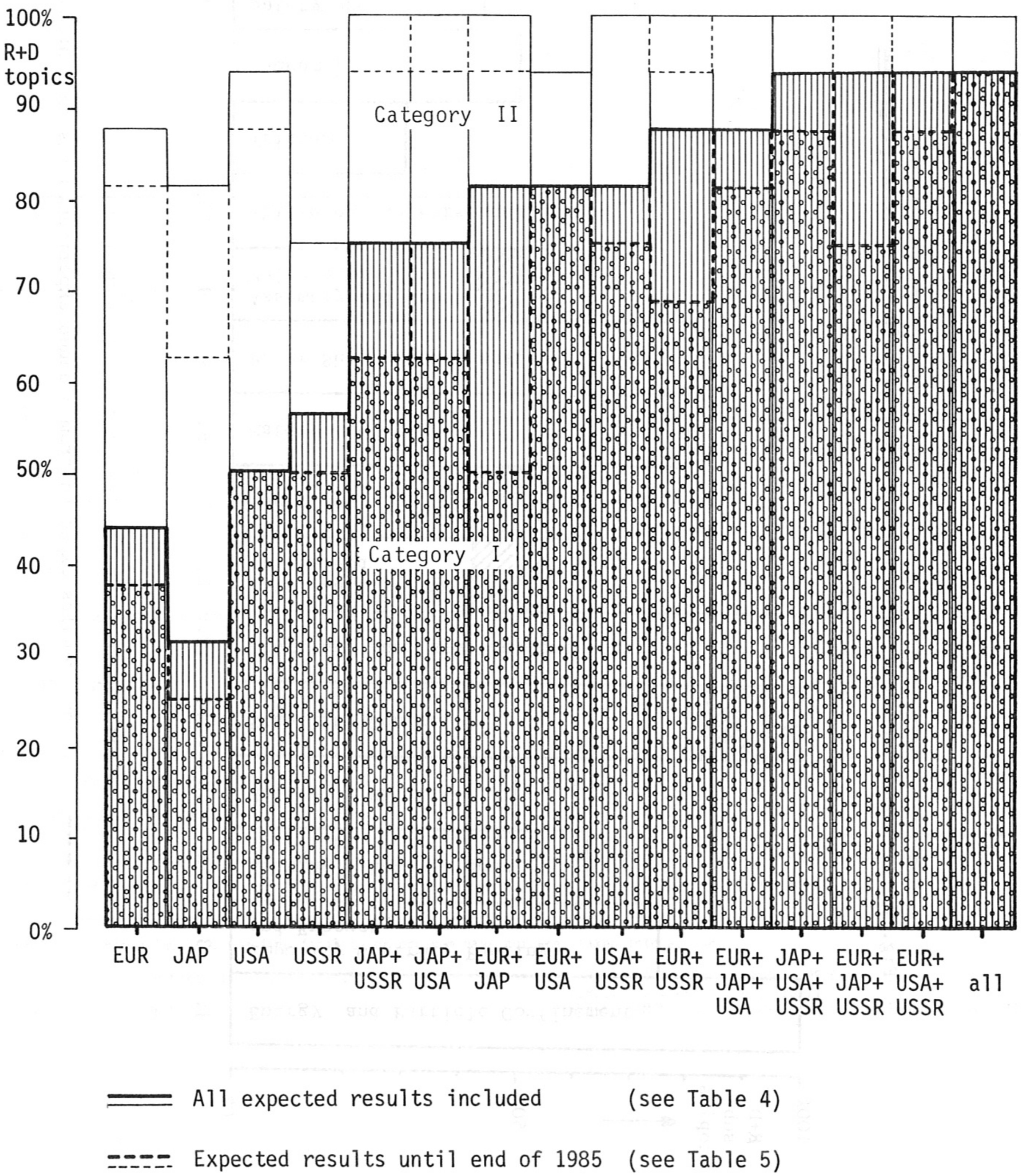

Fig. 2 Completeness of INTOR related R+D topics in the EURATOM programme

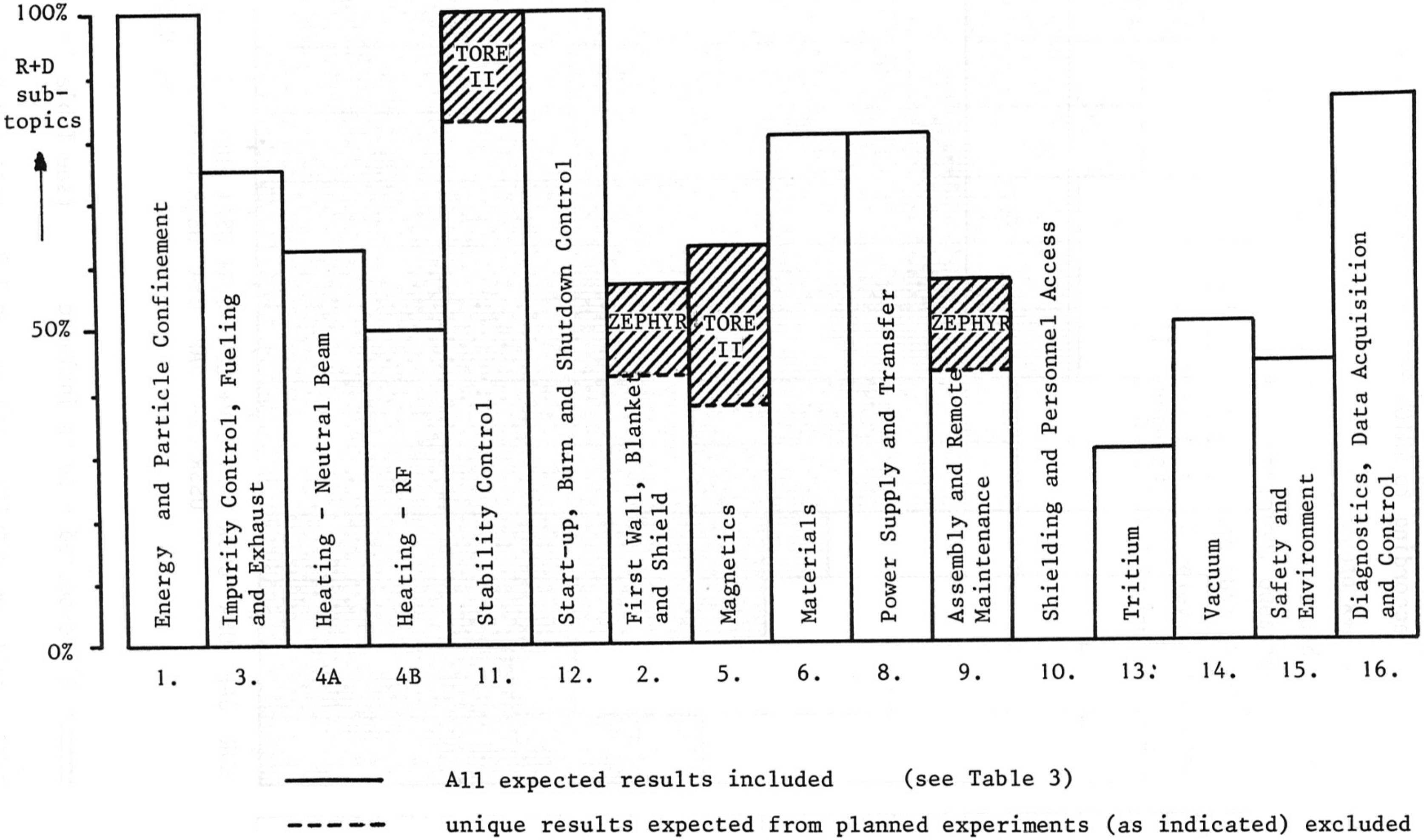

Table 1

	R+D TOPICS	PLT	JAP-EXPS	PETULA	RINGBOOG	TO-2	TM-3	TM-4+FT-1	T-7	T-10	T-11	T-13	TBO	FT	ISX-B	ALCATOR-C	DITE	TFR	PDX	DOUBLET 3	ASDEX	TEXTOR	ISX-C	TFTR	JET	T-15	TORE 2	JT-60	ZEPHYR	USA-FCLTS	USSR-FCLTS	IREK	MIN	SIMS	NG-150	KRIS	WWR-2	BOR-60	SM-2	TSTA	LCTF	20MJ-COIL	INEL	HINSF	VTS	TETL+FNS	Nr. of entries /topic
PLASMA PHYSICS	1. Energy and Particle Confinement	2	9			1		1		3	1	1	1	1	10		4	1	4	5	4		3	7	9	5		5	5																		83
	3. Impurity Control, Fueling and Exhaust	2	8	1	1				1	3	2		2	1	7		4	1	7	3	7	3	6	3	2	4		4			1																73
	4A Heating - Neutral Beam																								5	2		1		10	6	3	1														28
	4B Heating - RF	2	3					1	1	3				2	1			2	2	1	1		3	2	2	2	2	1			1																32
	11. Stability Control	2	6		1	1	1			3	3	1			4		2		4	4	5	1	4	9	6	6	2	6	2																		73
	12. Start-up, Burn and Shutdown Control	4	8					1	2	4	2				3	3	1	1	3	6	4		1	8	10	6		5	4																		76
	Σ	12	34	1	2	2	1	3	4	16	8	2	3	4	25	3	11	5	20	19	21	4	17	29	34	25	4	22	11	10	8	3	1	-	-	-	-	-	-	-	-	-	-	-	-	-	365
TECHNOLOGY	2. First Wall, Blanket and Shield																	1			1			4	6	1		2	3						2									1		1	22
	5. Magnetics		2						1								1		1		1		1	1		4	4	2					1	2							2	1					24
	6. Materials										1							1				1		4	3	2					14				1			5	2						1		35
	7. System Integration and Support Structure																																														-
	8. Power Supply and Transfer																							6	6	8		7			2	1															30
	9. Assembly and Remote Maintenance									1														3	3	1			2																		10
	10. Shielding and Personnel Access																																		3			1								2	6
	13. Tritium																							4	4	1		1									1			8					1	4	24
	14. Vacuum							1	3		1	1								2	1	3		3	4	6		1			1	7	2			2		2		1							41
	15. Safety and Environment									1														3	3	1									1		2		2	2			1		1	2	19
	16. Diagnostics, Data Acquisition and Control					1			1		1													10	10	5		4			1						1	5	5								44
	Σ	-	2	-	-	1	-	1	5	2	3	1	-	-	-	-	1	2	1	2	3	4	1	38	39	29	4	17	5	-	18	8	3	2	7	2	4	13	9	11	2	1	1	1	2	9	255
	Number of entries per facility	12	36	1	2	4	1	4	9	18	11	3	3	4	25	3	12	7	21	21	24	8	18	67	73	54	8	39	16	10	26	11	4	2	7	2	4	13	9	11	2	1	1	1	2	9	620

) Entries not referring to a specific facility or program have not been taken into account.

JAP-Experiments: Doublet III (J), JFT-2, JFT-2M

USA-Facilities: METF, HPTF, NBETF

USSR-Facilities: U-3, MIN II, IREK II, ISTRA, RF-C, LUMSI, CYCL, WWR-M, IRT, ESU-VI, WWR-K, MAMONT, ILU-4, IWW-2M, TFC

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Table 2

INTOR R+D SUBTOPICS NOT COVERED SO FAR

4A Heating - Neutral Beam

- Reliability and remote maintenance

4B Heating - RF

- Vacuum windows resistant to thermal loading, neutron radiation and high RF power

2. First Wall, Blanket and Shield

- Study of heat storage devices for smoothing out the power output

5. Magnetics

- Divertor test stand

9. Assembly and Remote Maintenance

- PF coil joints if required for internal coils

10. Shielding and Personnel Access

- General shield design methods
- Multi-dimensional transport techniques for streaming

13. Tritium

- Resolve tritium shipping, accountability and safeguard issues
- Study the influence of a divertor on the tritium system

15. Safety and Environment

- Assess the consequences of earthquakes on the safe operation of INTOR
- Exposure to electromagnetic radiation (guidelines)

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Table 3

R+D CONTRIBUTIONS TO SUBTOPICS

1.	EUR	JAP	USA	USSR
-	x	x	x	x
-	x	x	x	x
-	x	x	x	x
-	x	x	x	x
-	x)		x)	
-	x	x	x	
-	x)		x	x)
-	x	x)	x	x)

3.	EUR	JAP	USA	USSR
-	x	x	x	x
-	x	x	x	x
-	x		x	x
-	x	x	x	x
-	x		x	
-		x	x	
-	x	x	x	
-			x	x

4A	EUR	JAP	USA	USSR
-	x	x)	x	x
-	x	x	x	x
-	x	x)	x	x
-		x)	x	x
-	x	x)		x
-	x			
-	.	.	.	.
-			x	x

4B	EUR	JAP	USA	USSR
-	x	x	x	x
-		x	x	x
-	.	.	.	.
-	x		x	x

11.	EUR	JAP	USA	USSR
-	x	x	x	x
-	x	x	x	x
-	x	x	x	x
-	x	x	x	x
-	x	x	x	x
-	x)	x	x	x)

12.	EUR	JAP	USA	USSR
-	x	x	x	x
-	x	x	x	x
-	x	x	x	x
-	x	x)	x	
-	x	x	x	x
-	x	x	x	x
-	x)		x	x

2.	EUR	JAP	USA	USSR
-	x	x	x	x
-			x	
-	.	.	.	.
-	x		x	
-	x	x		
-	x)			
-		x	x	x

5.	EUR	JAP	USA	USSR
-	x	x	x	x
-	x			
-	x	x	x	x
-	x	x		x
-		x	x	
-		x	x	x
-	x	x	x	
-	.	.	.	.

6.	EUR	JAP	USA	USSR
-	x			x
-	x			x
-				x
-			x	x
-	x)		x	x
-	x			x
-	x)		x	x
-	x			x
-	x		x	x
-	x			x

8.	EUR	JAP	USA	USSR
-	x	x	x	x
-	x	x	x	x
-		x		
-	x	x	x	x
-	x	x	x	x

9.	EUR	JAP	USA	USSR
-	x	x	x	
-		x		
-	x		x	
-	x	x)	x	
-				x
-	.	.	.	.
-	x)	x)		

10.	EUR	JAP	USA	USSR
-		x		x
-	.	.	.	.
-				x
-	.	.	.	.
-		x		x

13.	EUR	JAP	USA	USSR
-		x)	x	x
-		x)	x	
-		x)	x	
-		x)		x
-	x	x	x	x
-	x)		x	
-	x)		x	
-	.	.	.	.
-			x	
-	.	.	.	.

14.	EUR	JAP	USA	USSR
-	x			x
-	x		x	x
-	x		x	
-		x	x	x
-				x
-				x
-	x			x
-	x	x	x	x
-			x	x
-			x	

15.	EUR	JAP	USA	USSR
-	x	x)	x	x
-				x
-		x)	x)	
-	x			
-	x)	x	x	
-	x		x	
-	.	.	.	.
-	.	.	.	.
-				x

16.	EUR	JAP	USA	USSR
-	x	x)	x	x
-			x	x)
-	x	x	x	x
-	x	x	x	x
-	x	x	x	x
-	x)		x	x
-	x		x	x

1. Topic-Number (for characterization see Table 1)

\- Subtopics (the number and sequence is the same as in the R+D bar charts as of Febr. 1981)

x Contributions until end of 1985

x) Contributions after 1985

. Subtopic not covered (see Table 2)

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Table 4

Coverage of INTOR Related R+D for Different Combinations of INTOR Partners

R+D TOPICS	Single				2 Partners						3 Partners				
	EUR %	JAP %	USA %	USSR %	JAP+ USSR %	JAP+ USA %	EUR+ JAP %	EUR+ USA %	USA+ USSR %	EUR+ USSR %	EUR+ JAP+ USA	JAP+ USA+ USSR	EUR+ JAP+ USSR	EUR+ USA+ USSR	all %
1. Energy and Particle Confinement	100	75	100	75	88	100	100	100	100	100	100	100	100	100	100
3. Impurity Control, Fueling and Exhaust	75	(63)	100	(63)	88	100	88	100	100	88	100	100	100	100	100
4A Heating - Neutral Beam	(63)	(63)	(63)	75	75	75	75	88	75	88	88	75	88	88	88
4B Heating - RF	(50)	(50)	75	75	75	75	75	75	75	75	75	75	75	75	75
11. Stability Control	100	100	100	100	100	100	100	100	100	100	100	100	100	100	100
12. Start-up, Burn and Shutdown Control	100	86	100	86	100	100	100	100	100	100	100	100	100	100	100
2. First Wall, Blanket and Shield	(57)	(43)	(57)	[29]	(43)	71	71	86	(57)	71	86	71	71	86	86
5. Magnetics	(63)	75	(63)	(50)	75	75	88	88	75	75	88	75	88	88	88
6. Materials	80	[0]	(40)	100	100	(40)	80	90	100	100	90	100	100	100	100
8. Power Supply and Transfer	80	100	80	80	100	100	100	80	80	80	100	100	100	80	100
9. Assembly and Remote Maintenance	(57)	(57)	(43)	[14]	71	71	71	(57)	(57)	71	71	86	86	71	86
10. Shielding and Personnel Access	[0]	(40)	[0]	(60)	(60)	(40)	(40)	[0]	(60)	(60)	(40)	(60)	(60)	(60)	(60)
13. Tritium	[30]	(50)	70	[30]	(50)	80	70	70	80	(50)	80	80	70	80	80
14. Vacuum	(50)	[20]	(60)	80	80	(60)	(60)	80	100	90	80	100	90	100	100
15. Safety and Environment	(44)	[33]	(44)	[33]	(56)	(44)	(56)	(56)	67	67	(56)	67	78	78	78
16. Diagnostics, Data Acqu. and Control	86	(57)	100	100	100	100	86	100	100	100	100	100	100	100	100

) Topic 7 being not really a R+D subject has been omitted in this table

[box] 0 - 33% = irrelevant for INTOR (category III)

(circle) 34 - 66% = questionable relevance (category II)

67 -100% = sufficient, relevant (category I)

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Table 5

Coverage of INTOR Related R+D for Different Combinations of INTOR Partners until end of 1985

R+D TOPICS	Single				2 Partners						3 Partners				
	EUR %	JAP %	USA %	USSR %	JAP+ USSR %	JAP+ USA %	EUR+ JAP %	EUR+ USA %	USA+ USSR %	EUR+ USSR %	EUR+ JAP+ USA	JAP+ USA+ USSR	EUR+ JAP+ USSR	EUR+ USA+ USSR	all %
1. Energy and Particle Confinement	75	63	88	50	63	88	75	88	88	75	88	88	75	88	88
3. Impurity Control, Fueling and Exhaust	75	63	100	63	88	100	88	100	100	88	100	100	100	100	100
4A Heating - Neutral Beam	63	13	63	75	75	63	63	88	75	88	88	75	88	88	88
4B Heating - RF	50	50	75	75	75	75	75	75	75	75	75	75	75	75	75
11. Stability Control	83	100	100	83	100	100	100	100	100	83	100	100	100	100	100
12. Start-up, Burn and Shutdown Control	86	71	100	86	86	100	86	100	100	100	100	100	100	100	100
2. First Wall, Blanket and Shield	43	43	57	29	43	71	57	71	57	57	71	71	57	71	71
5. Magnetics	63	75	63	50	75	75	88	88	75	75	88	75	88	88	88
6. Materials	60	0	40	100	100	40	60	90	100	100	90	100	100	100	100
8. Power Supply and Transfer	80	100	80	80	100	100	100	80	80	80	100	100	100	80	100
9. Assembly and Remote Maintenance	43	29	43	14	43	57	57	43	57	57	57	71	71	57	71
10. Shielding and Personnel Access	0	40	0	60	60	40	40	0	60	60	40	60	60	60	60
13. Tritium	10	10	70	30	30	70	10	70	80	30	70	80	30	80	80
14. Vacuum	50	20	60	80	80	60	60	80	100	90	80	100	90	100	100
15. Safety and Environment	33	11	33	33	44	33	44	44	56	56	44	56	56	67	67
16. Diagnostics, Data Acqu. and Control	71	43	100	86	86	100	71	100	100	86	100	100	86	100	100

) Topic 7 being not really a R+D subject has been omitted in this table

[box] 0 - 33% = irrelevant for INTOR (category III)

[circle] 34 - 66% = questionable relevance (category II)

67 -100% = sufficient, relevant (category I)

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INTOR R+D BAR CHARTS

including comments from all delegations during INTOR workshop phase I (March 1980-Febr. 1981)

compiled by A. Knobloch

Comments to bar charts

In a conventional undertaking bar charts are the results of a planning network which includes all cross links and interdependencies between items included. For INTOR at the present state R+D bar charts can only give a very first overview on the situation. Thus a considerable degree of inconsistency will have to be resolved yet.

For the present version of bar charts a separation between the bar charts concerning R+D for INTOR (with its data base assessment and decision making stages) and the stages of relevant experiments and R+D programs has been made, the latter being indicated on transparent sheets. This offers the possibility to

- discuss separately the appropriate R+D program plan in accordance with the realization stages of the INTOR project as worked out during the workshop sessions, and the overall situation of the INTOR relevant R+D programs;

- get an indication on a proper and realistic timing of the INTOR project.

During the discussions it became clear that a number of further steps have to be taken in order to make the R+D bar charts a useful tool. These include:

- Improvement of the R+D definitions

- Getting more details on expected results from experiments and programs and on their status of approval

- Evaluation of required results from R+D according to INTOR design and construction schedule

- Discussion of consequences for INTOR definition and planning

Procedure followed in present bar chart version

- In order to give an indication for the realization stages of the INTOR project, the general definitions from the March 1980 versions together with the INTOR schedule as of the INTOR workshop were used. It was felt practical to show the assumed duration and overlap of the phases of INTOR realization since this eases the discussion of the principal R+D bar charts and their future extrapolation for the needs of later stages of INTOR operation which are not included so far. Also the implications for decision making become more clear.

- The entries concerning stages of experiments and R+D programs at which certain degrees of data base assessment are expected from them have been optimistically made one year after the pertinent scheduled start of operation. Multiple appearance of the same experiment or program means consecutive achievement of relevant portions of information. Especially the underlined entries refer to operation with tritium.

BAR CHART - INTOR R+D DESIGNATIONS

1. Realization stages of the project

   - [D] - Conceptual design
   - [E] - Engineering design
   - [P] - Production design
   - [C] - Construction, equipment fabrication
   - [A] - Assembly
   - [T] - Testing
   - [O] - Operation

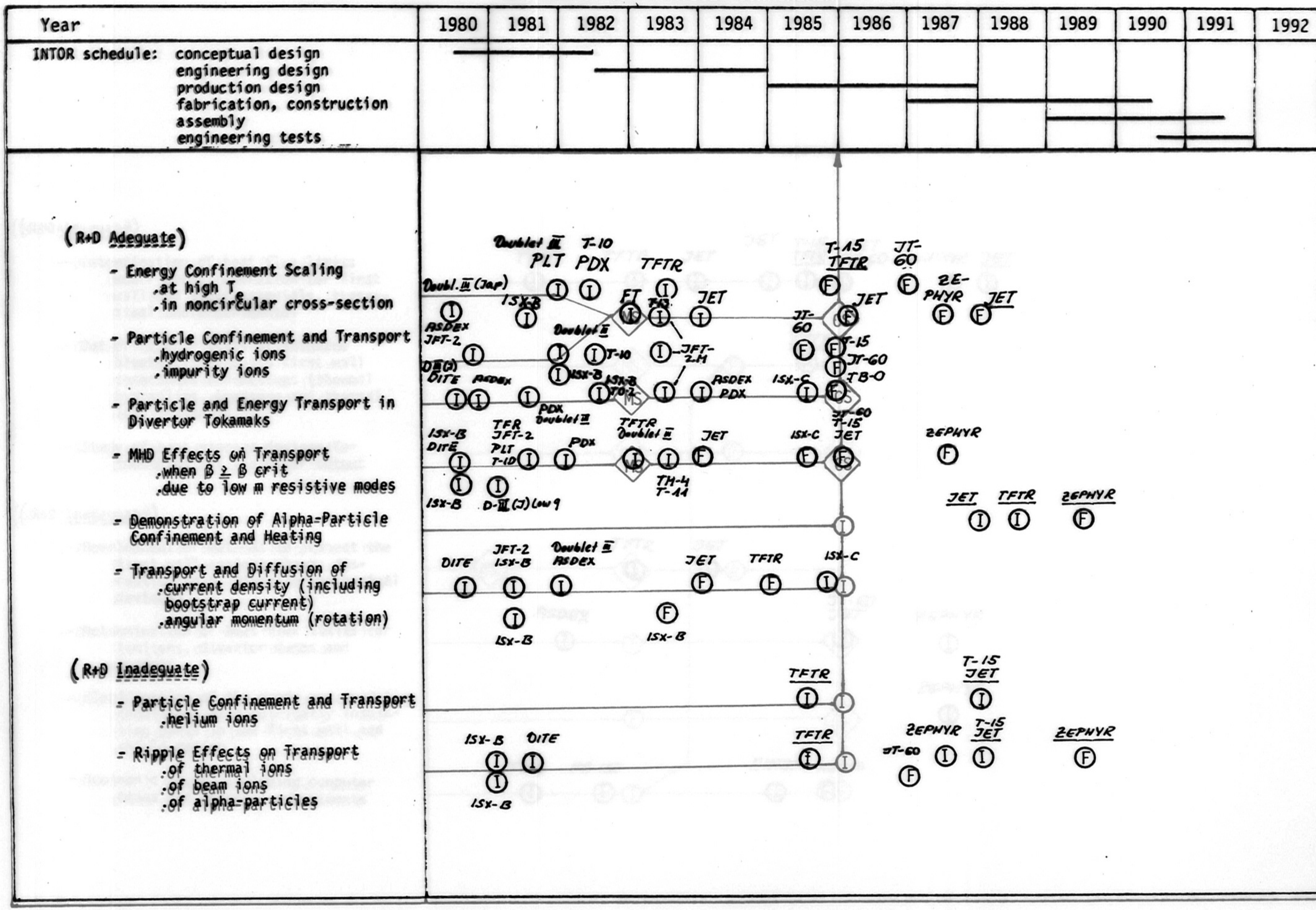
2. Decision-making stages

   - ◇MS - Concept selection
   - ◇CS - Final version selection, final check

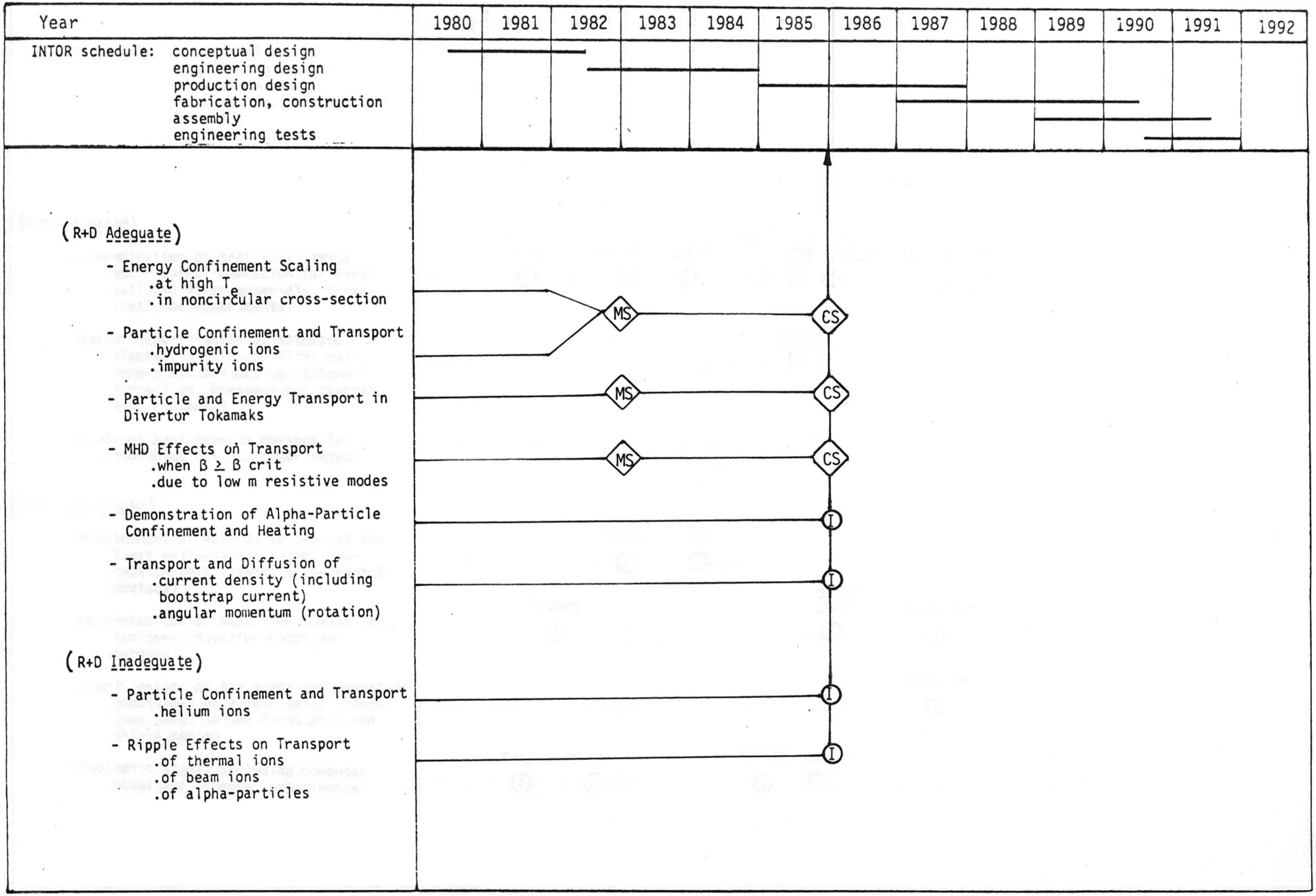
3. Data base assessment stages

   - (I) - Information collection
   - (F) - Feasibility justification
   - (P) - Prototype construction
   - (FP) - Full power testing

1. ENERGY and PARTICLE CONFINEMENT



1. ENERGY and PARTICLE CONFINEMENT



2. FIRST WALL, BLANKET and SHIELD

Year

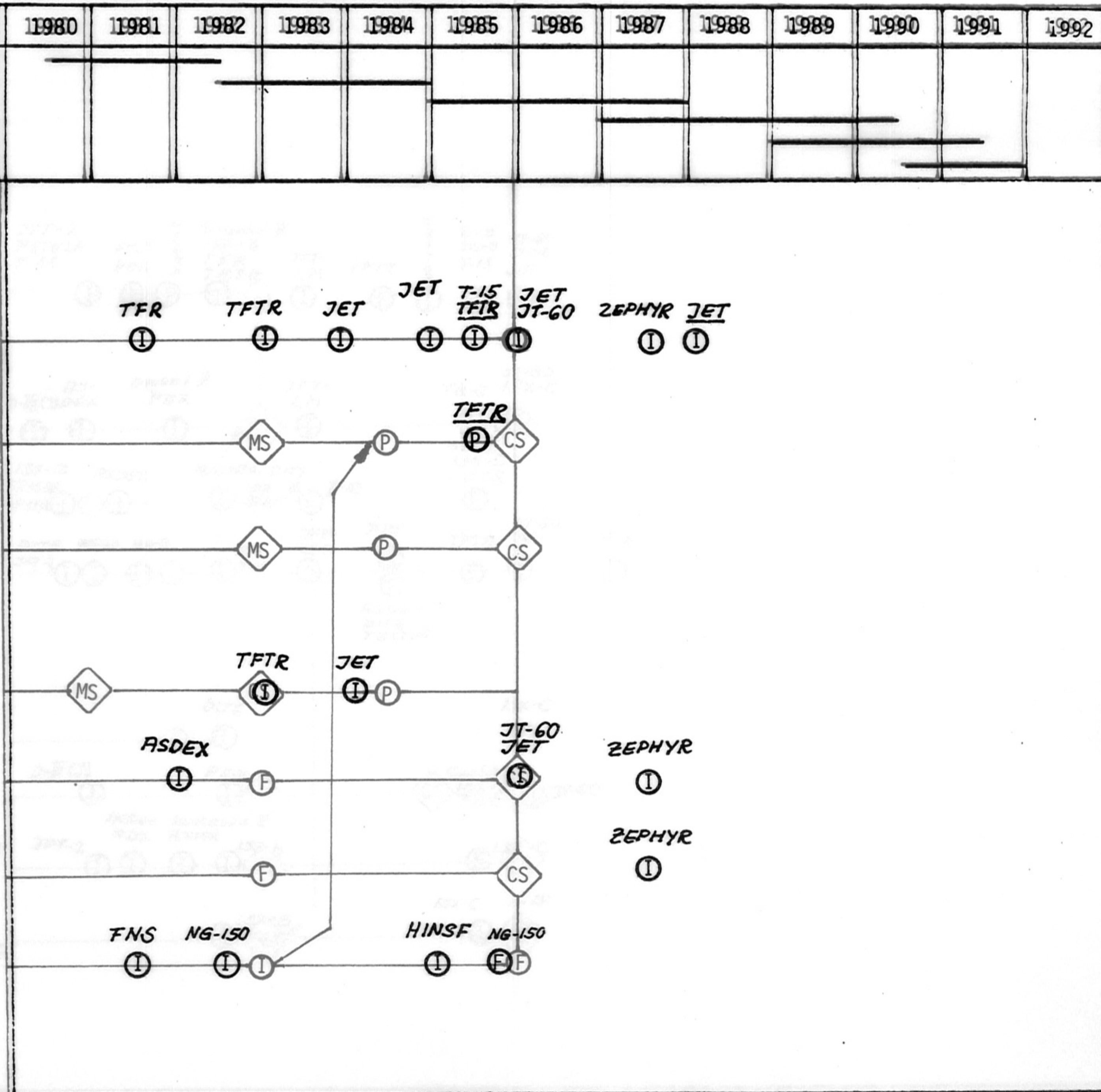
INTOR schedule: conceptual design
engineering design
production design
fabrication, construction
assembly
engineering tests

(R+D Adequate)

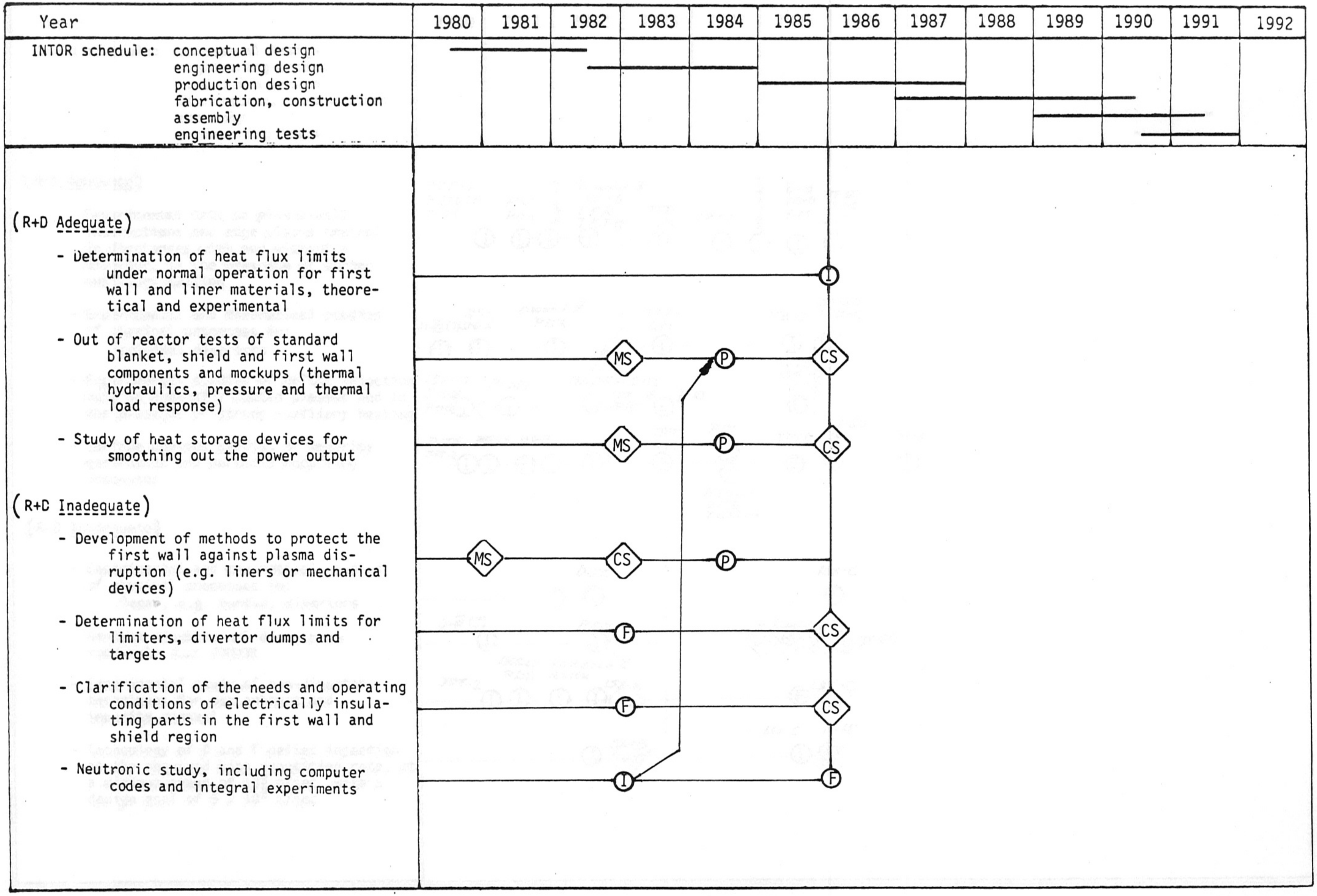
- Determination of heat flux limits under normal operation for first wall and liner materials, theoretical and experimental
- Out of reactor tests of standard blanket, shield and first wall components and mockups (thermal hydraulics, pressure and thermal load response)
- Study of heat storage devices for smoothing out the power output

(R+D Inadequate)

- Development of methods to protect the first wall against plasma disruption (e.g. liners or mechanical devices)
- Determination of heat flux limits for limiters, divertor dumps and targets
- Clarification of the needs and operating conditions of electrically insulating parts in the first wall and shield region
- Neutronic study, including computer codes and integral experiments



2. FIRST WALL, BLANKET and SHIELD



3. IMPURITY CONTROL, FUELING and EXHAUST

Year

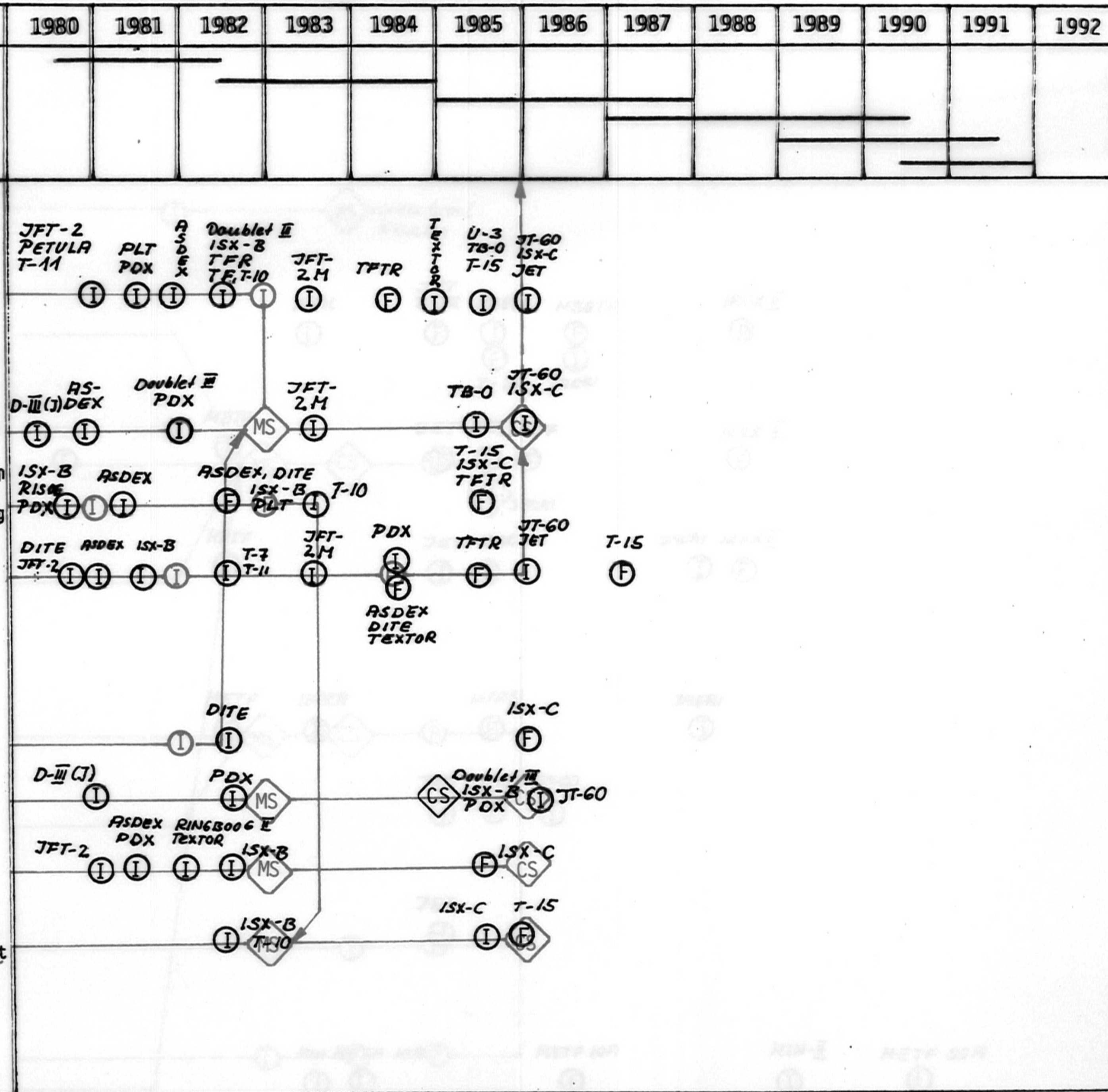
INTOR schedule:
- conceptual design
- engineering design
- production design
- fabrication, construction
- assembly
- engineering tests

(R+D Adequate)

- Experimental data on plasma-wall interactions and edge plasma control in discharges with and without a divertor, in the presence of strong auxiliary heating
- Experimental and theoretical studies of physical processes in:
  - poloidal divertors
- Experimental studies of pellet injection both in ohmically heated plasmas and in the presence of strong auxiliary heating
- Surface physics studies of impurity generation and particle recycling processes

(R+D Inadequate)

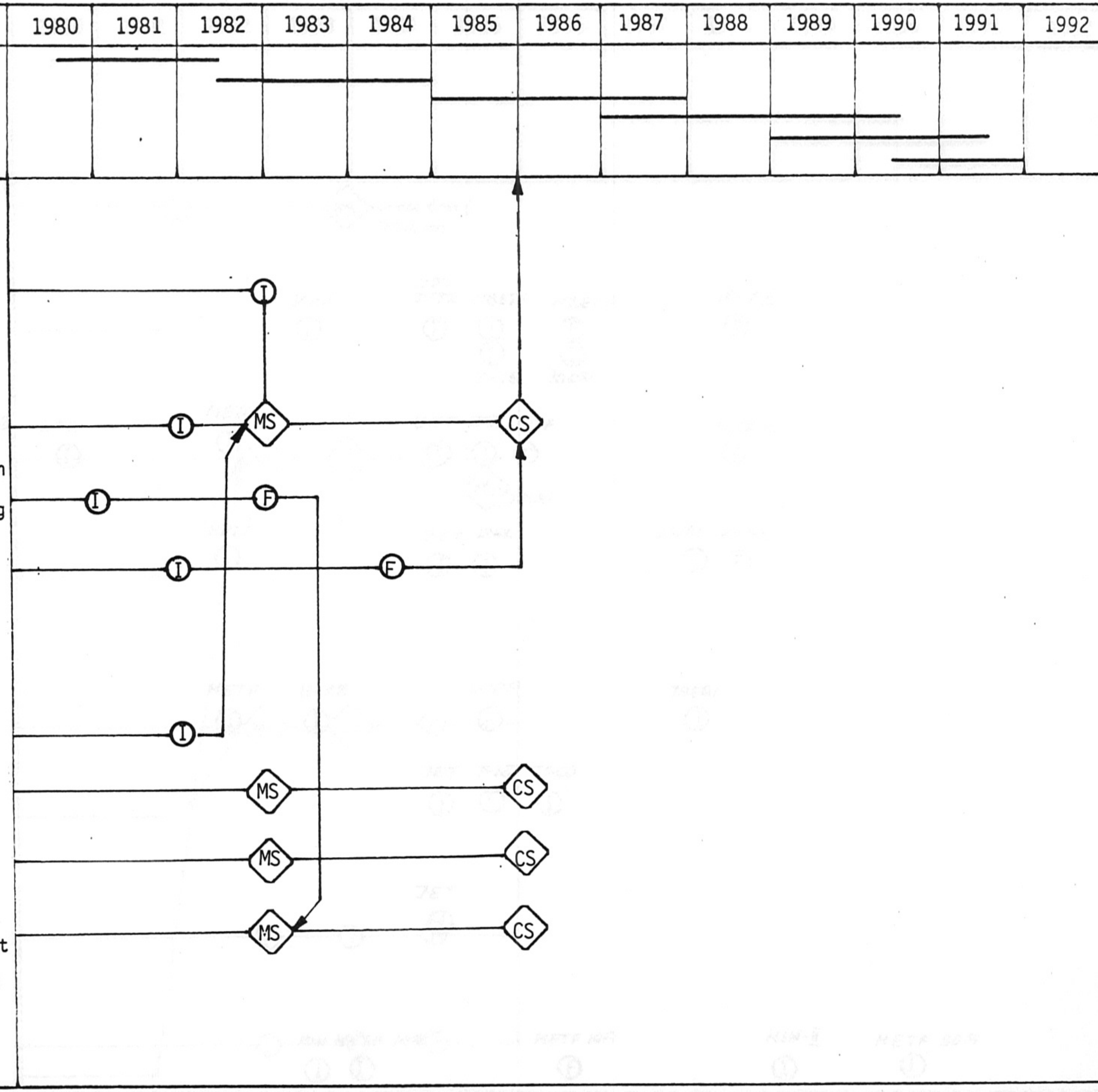
- Experimental and theoretical studies of physical processes in:
  - local, e.g. bundle, divertors
- Design studies of divertors suitable for INTOR
- Experimental study of non-divertor techniques for ash exhaust and impurity removal
- Technology of D and T pellet injection at the required high repetition rate, at a minimum speed of 10^3 m/sec, with a design goal of 5×10^3 m/sec



3. IMPURITY CONTROL, FUELING and EXHAUST

Year

INTOR schedule: conceptual design
engineering design
production design
fabrication, construction
assembly
engineering tests



(R+D Adequate)

- Experimental data on plasma-wall interactions and edge plasma control in discharges with and without a divertor, in the presence of strong auxiliary heating
- Experimental and theoretical studies of physical processes in:
  ·poloidal divertors
- Experimental studies of pellet injection both in ohmically heated plasmas and in the presence of strong auxiliary heating
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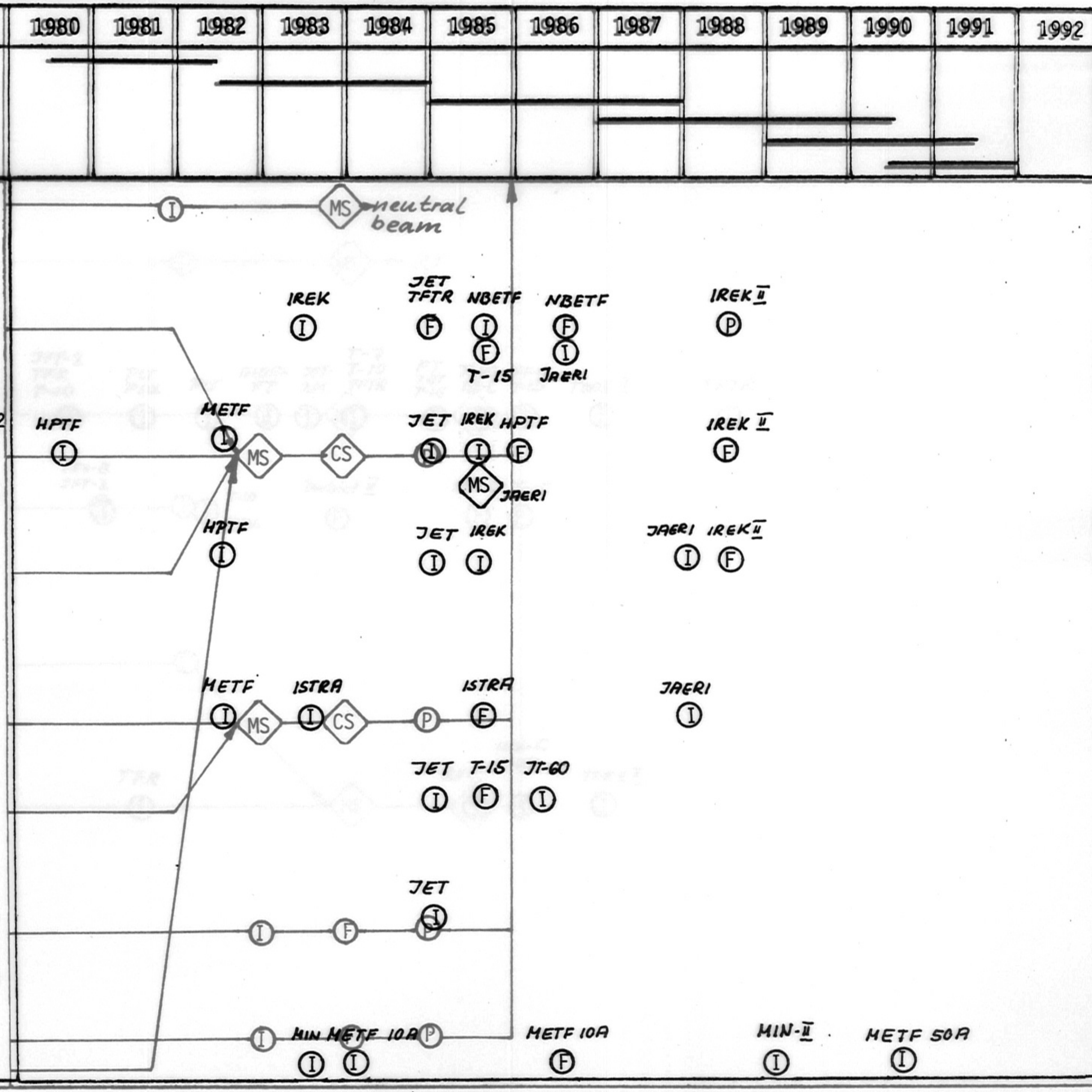
4A. HEATING - NEUTRAL BEAM

Year

INTOR schedule: conceptual design
engineering design
production design
fabrication, construction
assembly
engineering tests



- Heating (NB and/or RF)

(R+D Adequate)

- Ion Beam. Development of high-current (~100 A) ion beam at 175 keV (preferably 200 keV if practicable)

- Pulse Length. Development of a 10 s pulse capability for the ion source and the beam dump, which must handle ~0.5 kW/cm^2 with direct recovery and ~2 kW/cm^2 without direct recovery. In addition, certain of the units should have a 100 s capability

- Monatomic Fraction. A 90% D^+ fraction in the ion beam should be a design goal, with 80% a minimum requirement

(R+D Inadequate)

- Direct Recovery. Development of a direct recovery system for the unneutralized beam ions with at least 60% efficiency is almost certainly required

- Efficiency. Simultaneous achievement of high neutralization efficiency, high transmission efficiency, long ducts and low gas flow to the plasma

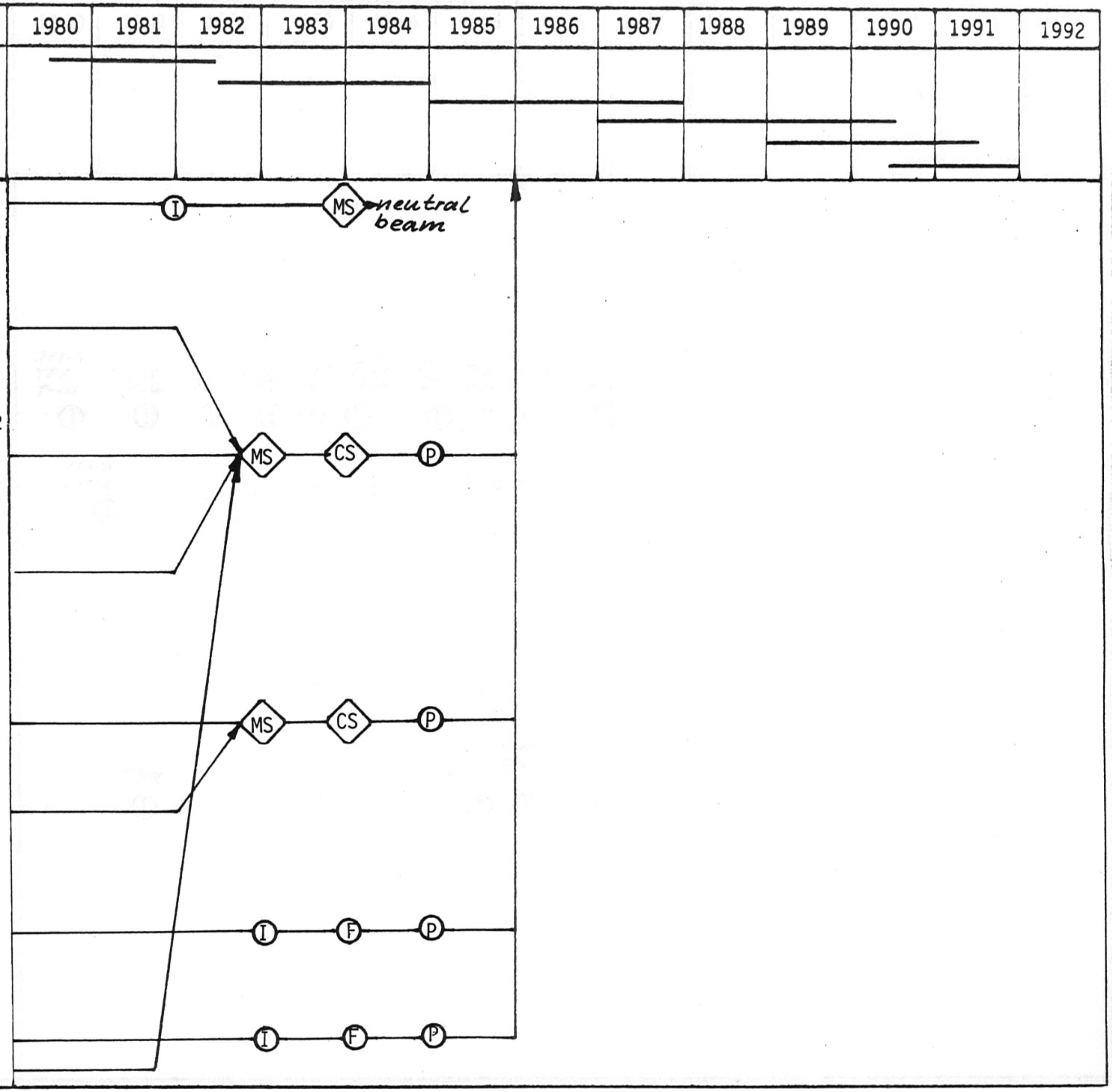
- Radiation Hardening. Adequate lifetime of all injector components against the expected neutron bombardment and other radiation must be insured. A plug valve shield should be developed for insertion in the beam ducts at the end of the heating pulse

- Reliability and Remote Maintenance.
- Negative ion beams

4A. HEATING - NEUTRAL BEAM

Year

INTOR schedule: conceptual design
engineering design
production design
fabrication, construction
assembly
engineering tests



- Heating (NB and/or RF)

(R+D Adequate)

-Ion Beam. Development of high-current (~100 A) ion beam at 175 keV (preferably 200 keV if practicable)

-Pulse Length. Development of a 10 s pulse capability for the ion source and the beam dump, which must handle ~0.5 kW/cm^2 with direct recovery and ~2 kW/cm^2 without direct recovery. In addition, certain of the units should have a 100 s capability

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(R+D Inadequate)

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-Radiation Hardening. Adequate lifetime of all injector components against the expected neutron bombardment and other radiation must be insured. A plug valve shield should be developed for insertion in the beam ducts at the end of the heating pulse

-Reliability and Remote Maintenance.

-Negative ion beams

4B. HEATING - RF

Year: 1980 1981 1982 1983 1984 1985 1986 1987 1988 1989 1990 1991 1992

INTOR schedule:
- conceptual design
- engineering design
- production design
- fabrication, construction
- assembly
- engineering tests

- Heating (NB and/or RF)

(R+D Adequate)

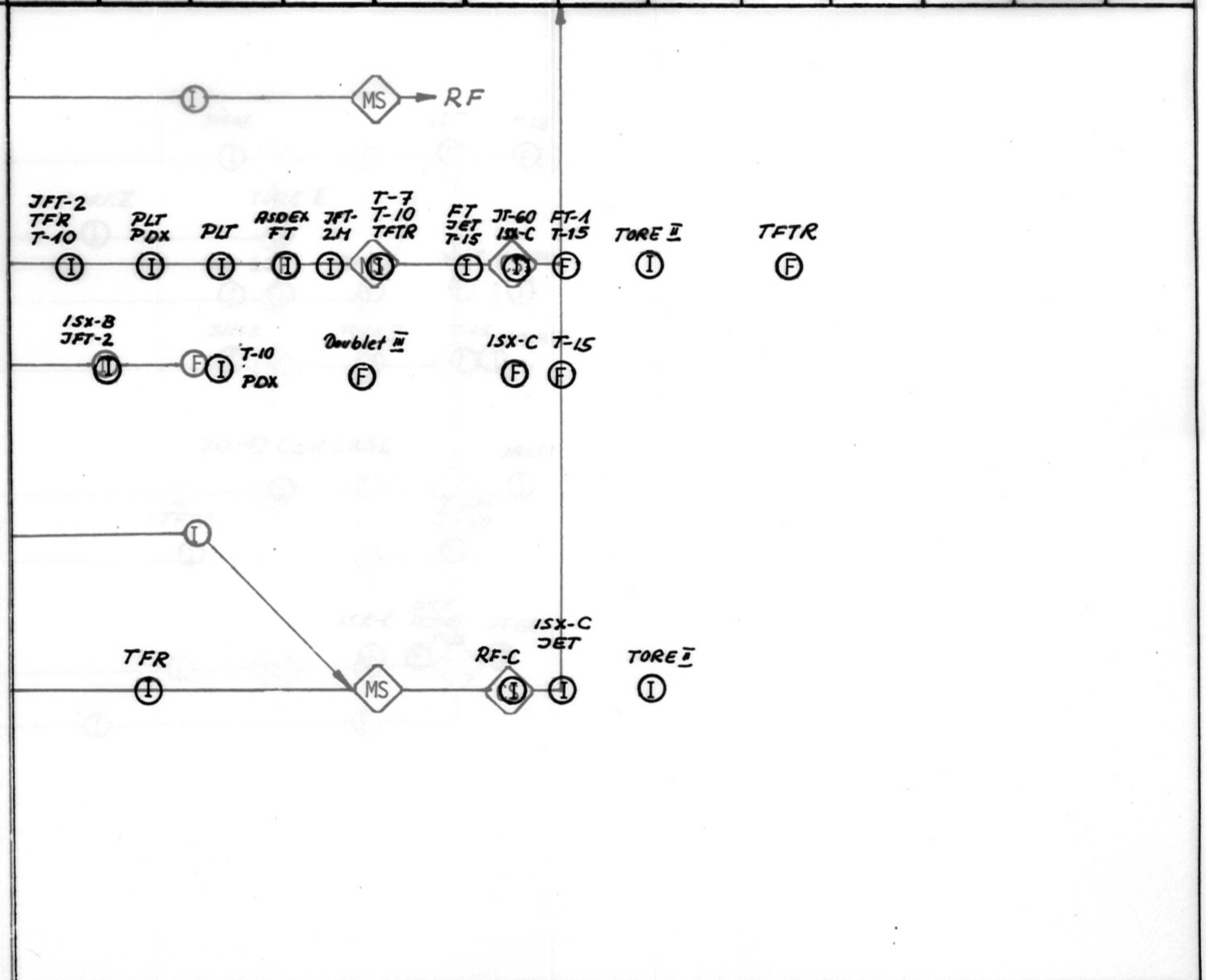
- MW-level experiments to prove heating effectiveness, followed by demonstrations of heating larger plasmas to reactor temperatures (ICRF. LHH)
- Experimental verification of absorption and heating by ECH at the 200-400 kW level, followed by MW level experiments

(R+D Inadequate)

- Vacuum windows resistant to thermal loading, neutron radiation and high RF power

(R+D Inadequate, New Facility Required)

- ICRF and LHH launching structures resistant to thermal loading and neutron radiation



4B. HEATING - RF

Year

INTOR schedule: conceptual design
engineering design
production design
fabrication, construction
assembly
engineering tests

- Heating (NB and/or RF)

(R+D Adequate)

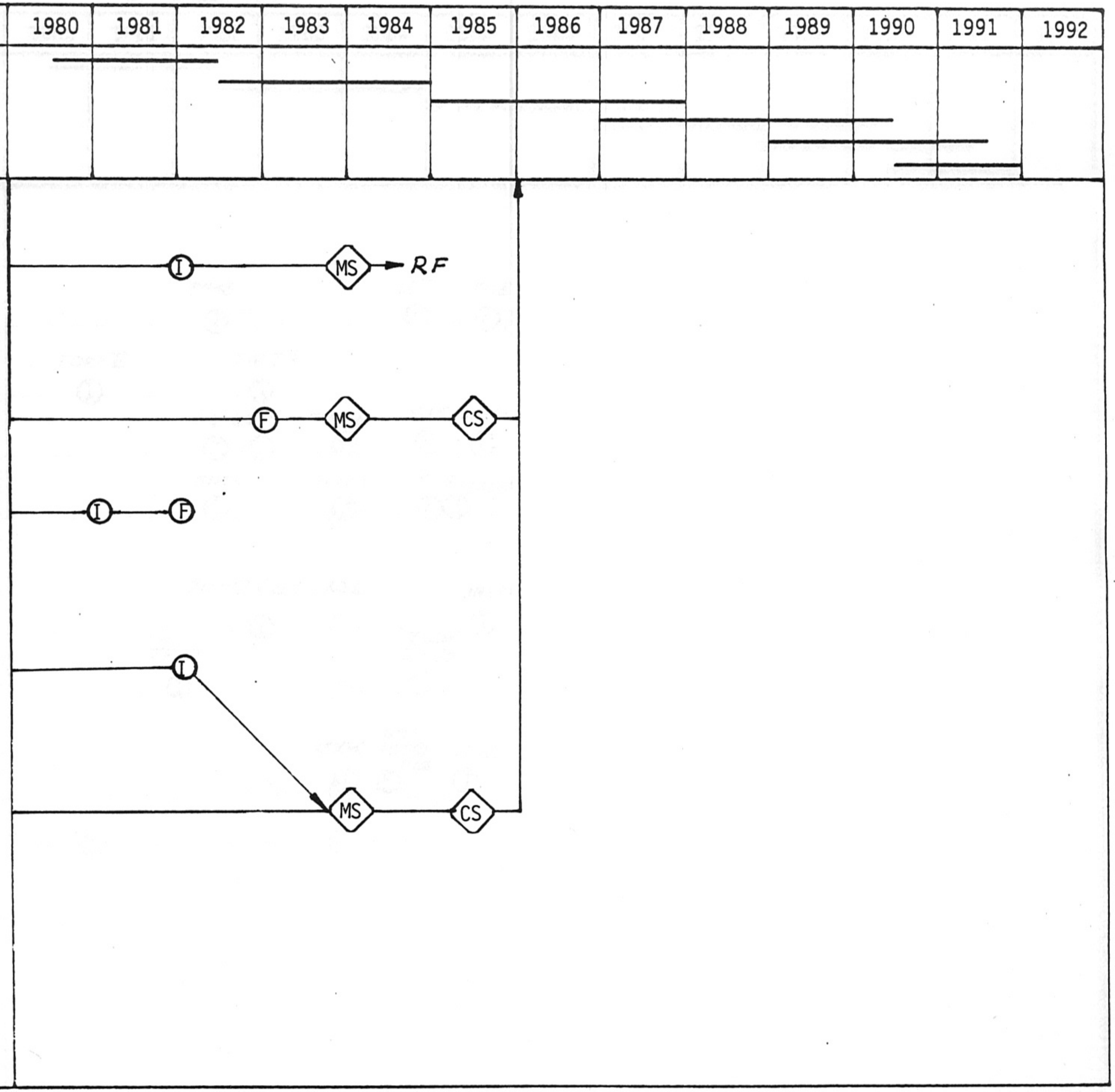
- MW-level experiments to prove heating effectiveness, followed by demonstrations of heating larger plasmas to reactor temperatures (ICRF. LHH)
- Experimental verification of absorption and heating by ECH at the 200-400 kW level, followed by MW level experiments

(R+D Inadequate)

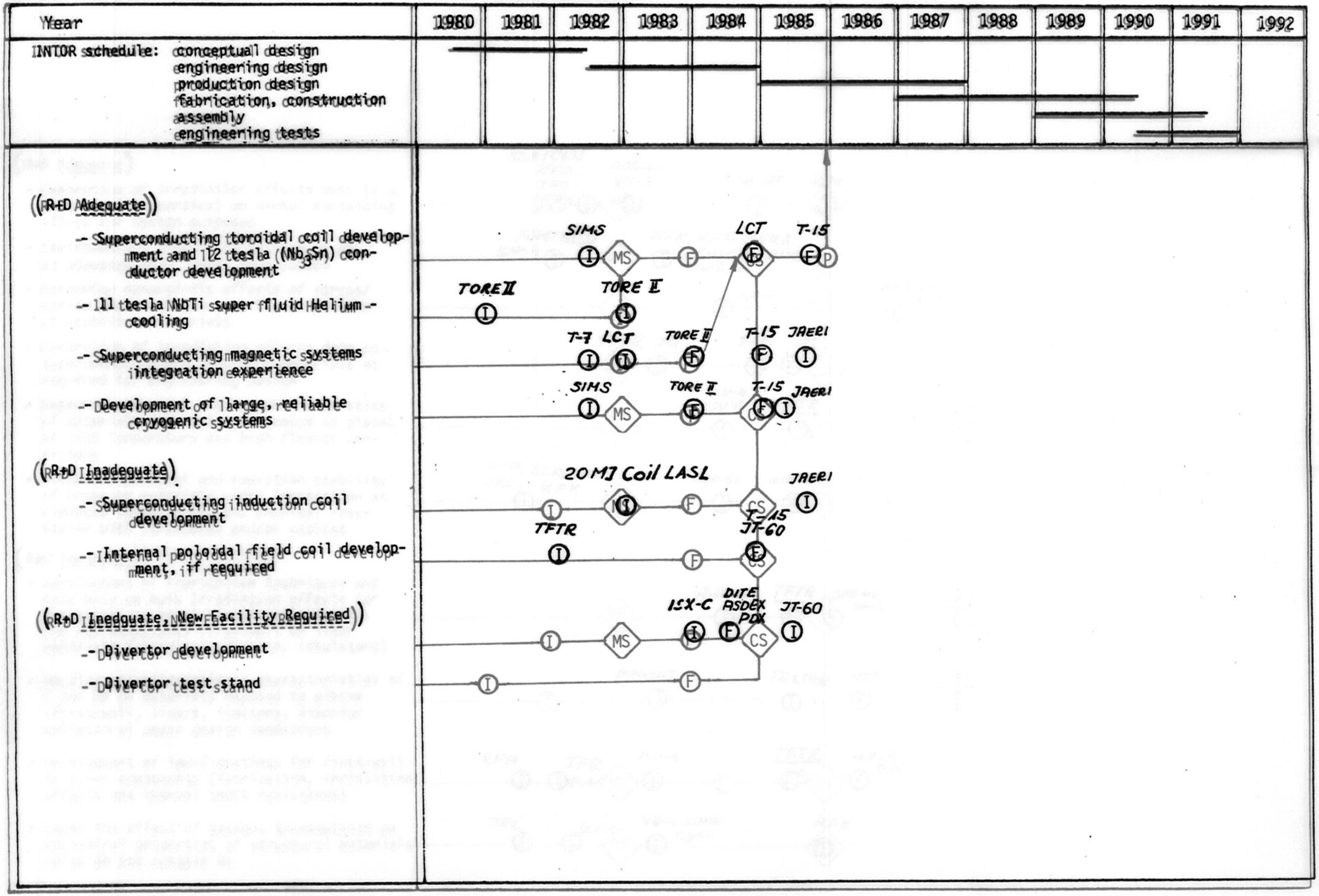
- Vacuum windows resistant to thermal loading, neutron radiation and high RF power

(R+D Inadequate, New Facility Required)

- ICRF and LHH launching structures resistant to thermal loading and neutron radiation



5. MAGNETICS



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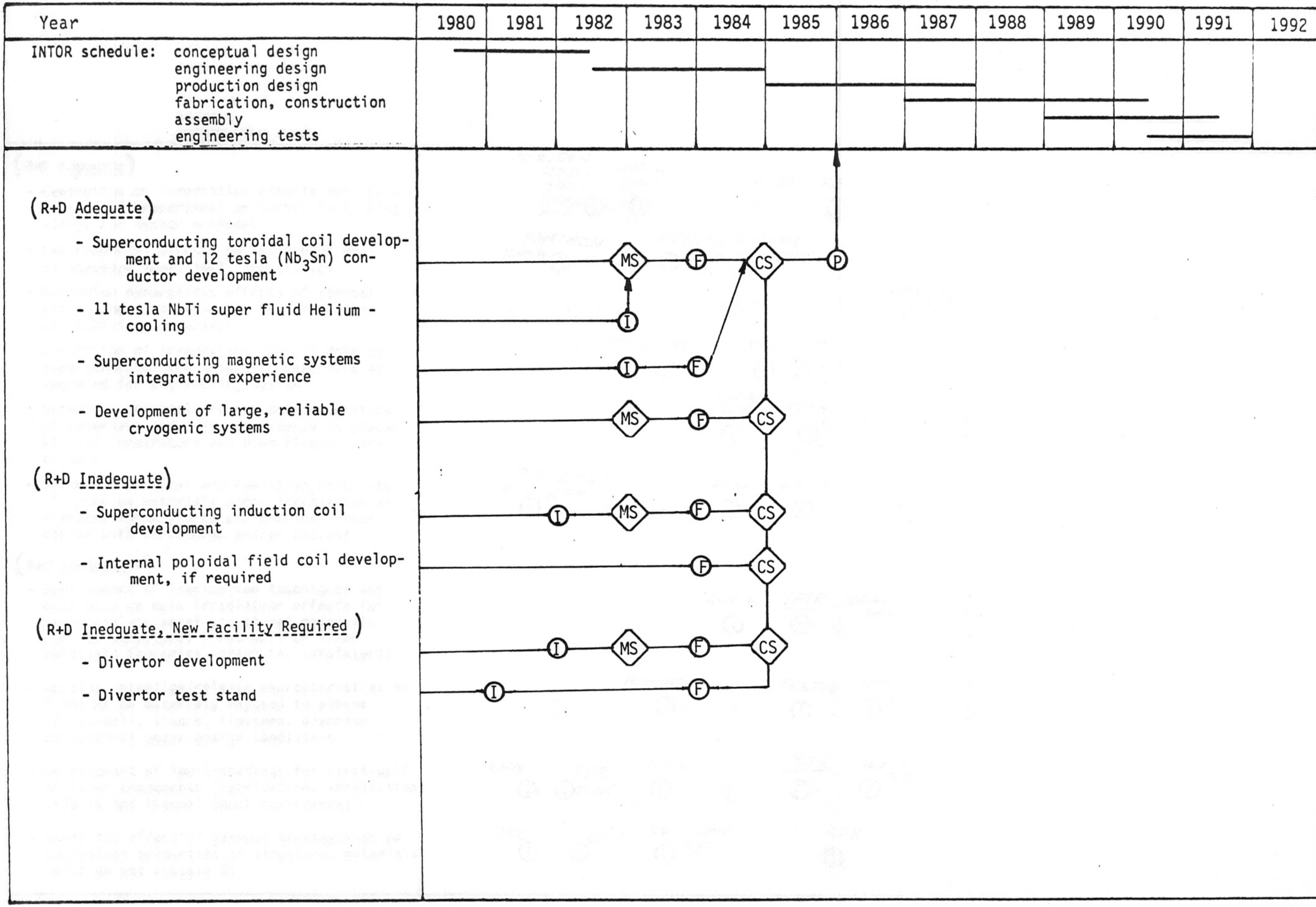
INTOR schedule: conceptual design
engineering design
production design
fabrication, construction
assembly
engineering tests
(R+D Adequate)
- Superconducting toroidal coil development and 12 tesla (Nb_3Sn) conductor development
- 11 tesla NbTi super fluid Helium-cooling
- Superconducting magnetic systems integration experience
- Development of large, reliable cryogenic systems
(R+D Inadequate)
- Superconducting induction coil development
- Internal poloidal field coil development, if required
(R+D Inedquate, New Facility Required)
- Divertor development
- Divertor test stand
SIMS
MS
F
LCT
CS
T-15
P
TORE II
T-7
JAERI
20MJ Coil LASL
TFTR
JT-60
ISX-C
DITE
ASDEX
PDX
I

5. MAGNETICS


Year
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INTOR schedule: conceptual design
engineering design
production design
fabrication, construction
assembly
engineering tests
(R+D Adequate)
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- 11 tesla NbTi super fluid Helium - cooling
- Superconducting magnetic systems integration experience
- Development of large, reliable cryogenic systems
(R+D Inadequate)
- Superconducting induction coil development
- Internal poloidal field coil development, if required
(R+D Inedquate, New Facility Required)
- Divertor development
- Divertor test stand
MS
F
CS
P
I

6. MATERIALS

Year

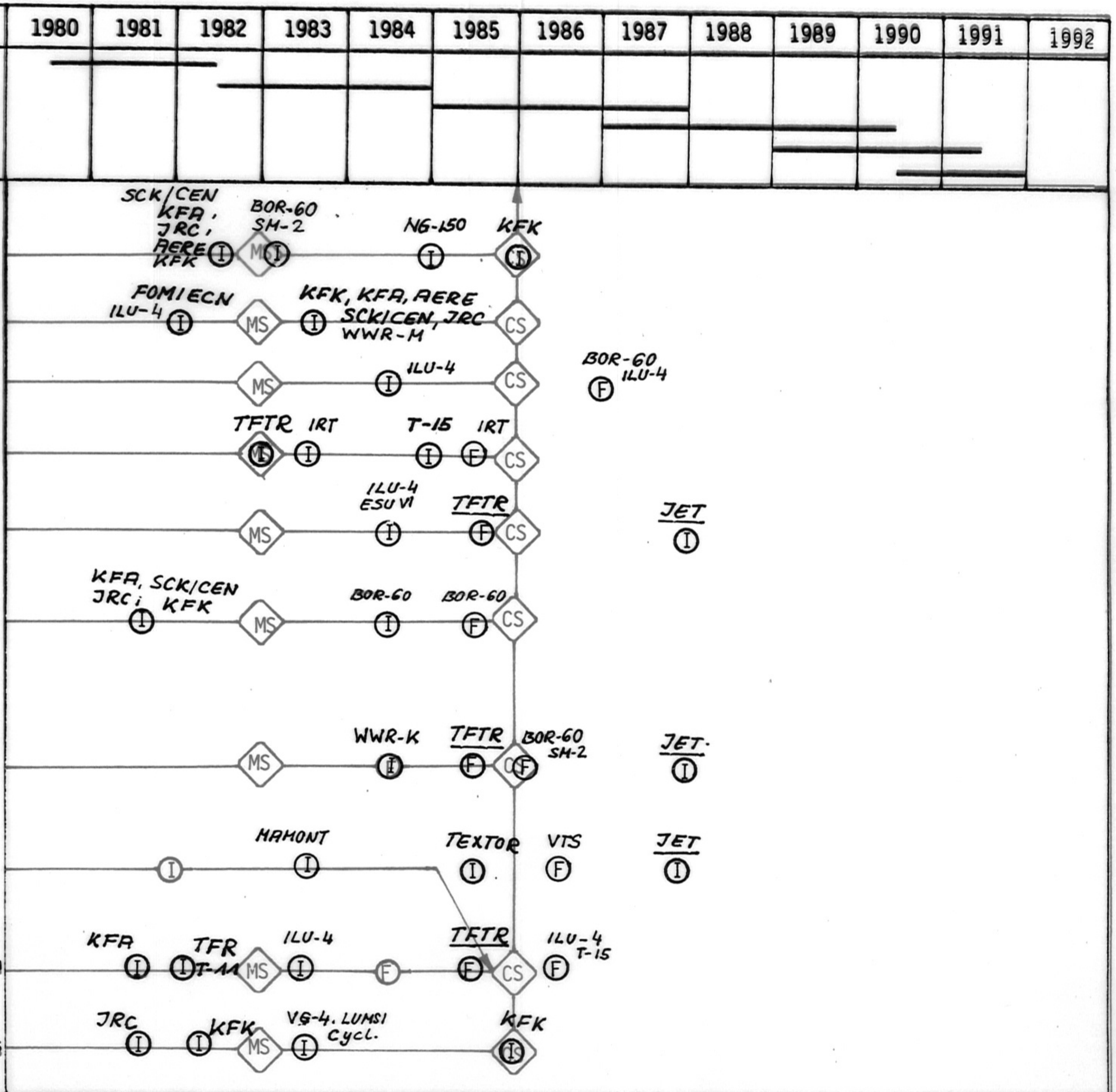
INTOR schedule: conceptual design
engineering design
production design
fabrication, construction
assembly
engineering tests

(R+D Adequate)

- Generation of irradiation effects data (e.g. mechanical properties) on nickel containing alloys for design purposes
- Environmental effects on fatigue of SS at elevated temp. incl. irradiation
- Determine synergistic effects of stress/strain and irradiation on key properties of stabilizer materials
- Generation of irradiation effects data on superconductor and insulator materials as required for engineering design
- Determine chemical erosion characteristics of materials and coatings exposed to plasma at high temperature and high fluence conditions
- Determine chemical and radiation stability of breeding materials under irradiation at elevated temperatures and chemical reactivity with structures and/or coolant

(R+D Inadequate)

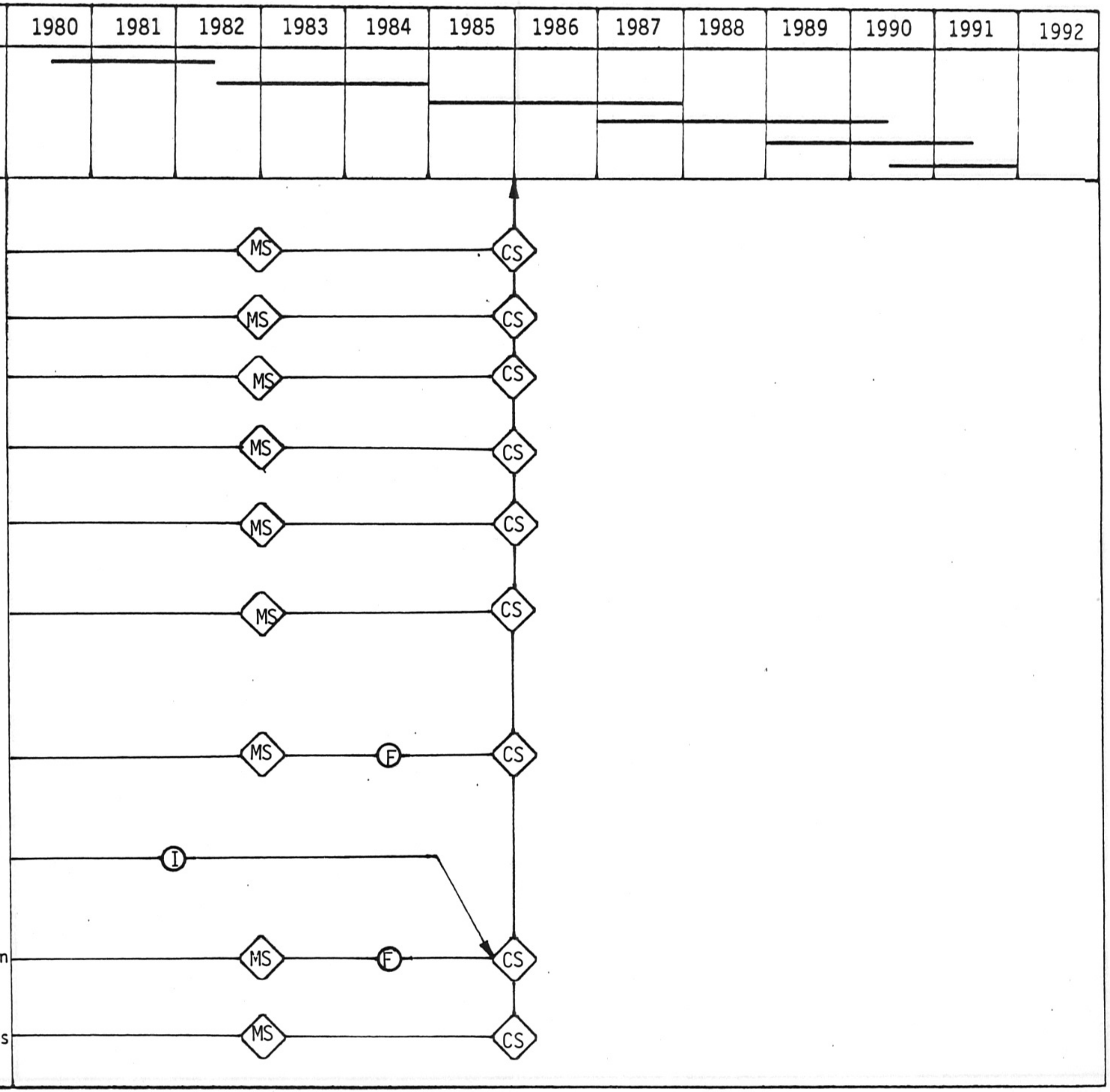
- Development of fabrication techniques and data base on bulk irradiation effects for non-stainless steel structural materials and non-structural first-wall or liner materials (ceramics, graphite, insulators)
- Develop retention/release characteristics of T and He on materials exposed to plasma (first-wall, liners, limiters, divertor collectors) under design conditions
- Development of low-Z coatings for first-wall or liner components (fabrication, irradiation effects and thermal shock resistance)
- Study the effect of gaseous transmutants on mechanical properties of structural materials which do not contain Ni



6. MATERIALS

Year

INTOR schedule: conceptual design
engineering design
production design
fabrication, construction
assembly
engineering tests



(R+D Adequate)

- Generation of irradiation effects data (e.g. mechanical properties) on nickel containing alloys for design purposes
- Environmental effects on fatigue of SS at elevated temp. incl. irradiation
- Determine synergistic effects of stress/strain and irradiation on key properties of stabilizer materials
- Generation of irradiation effects data on superconductor and insulator materials as required for engineering design
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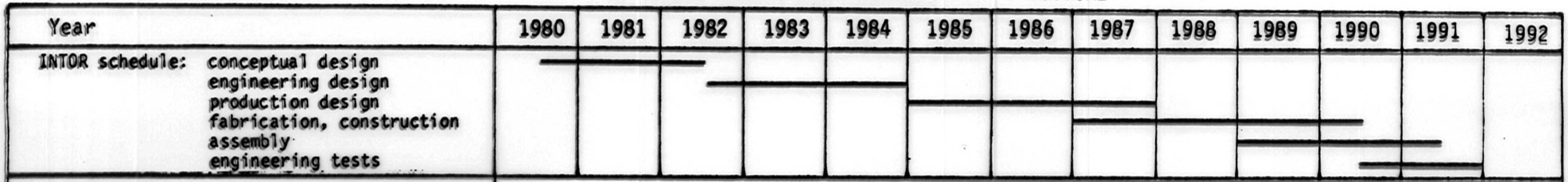
- Study the effect of gaseous transmutants on mechanical properties of structural materials which do not contain Ni

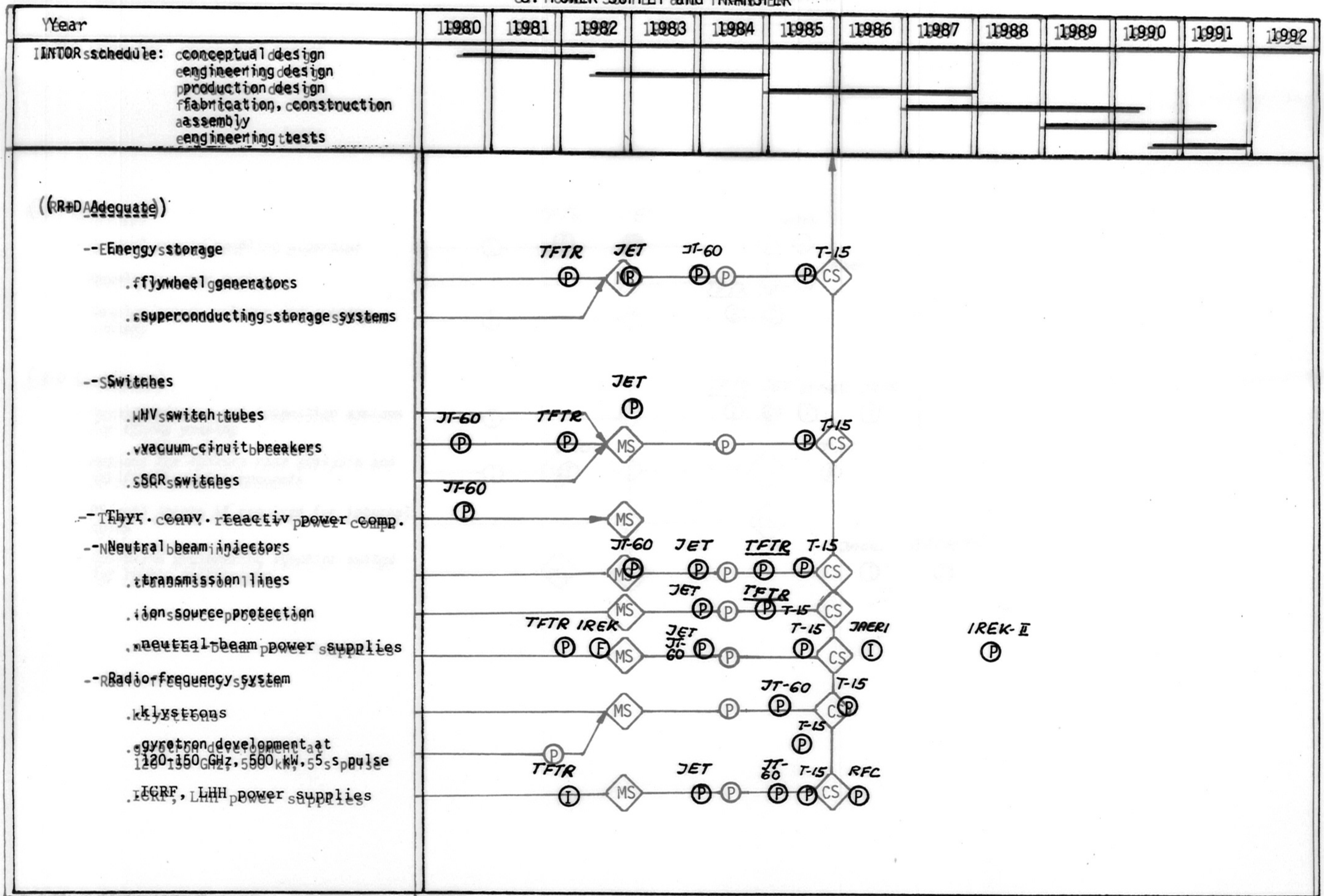
7. SYSTEMS INTEGRATION and SUPPORT STRUCTURE



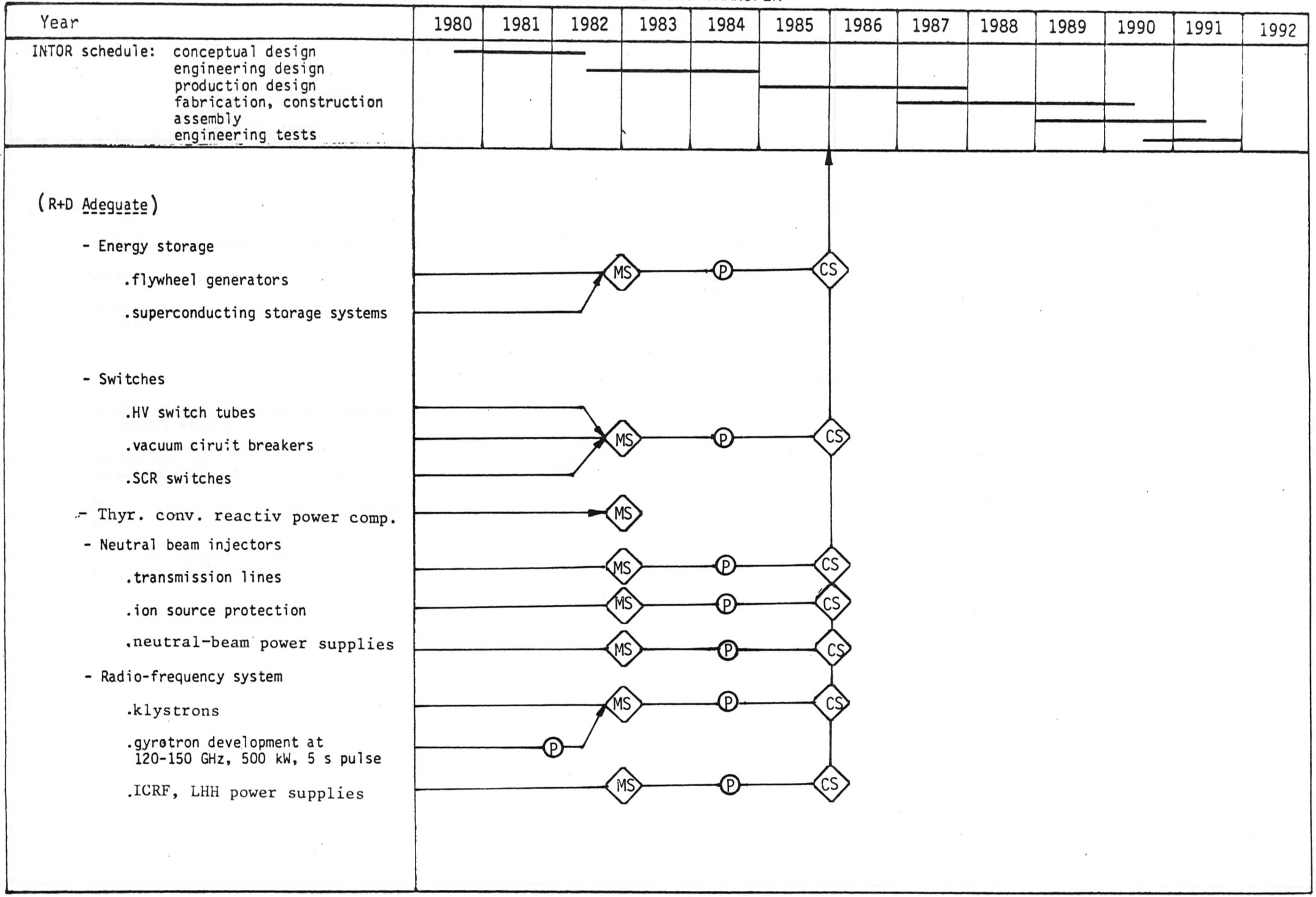
7. SYSTEMS INTEGRATION and SUPPORT STRUCTURE

Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
INTOR schedule: conceptual design													
engineering design													
production design													
fabrication, construction													
assembly													
engineering tests													

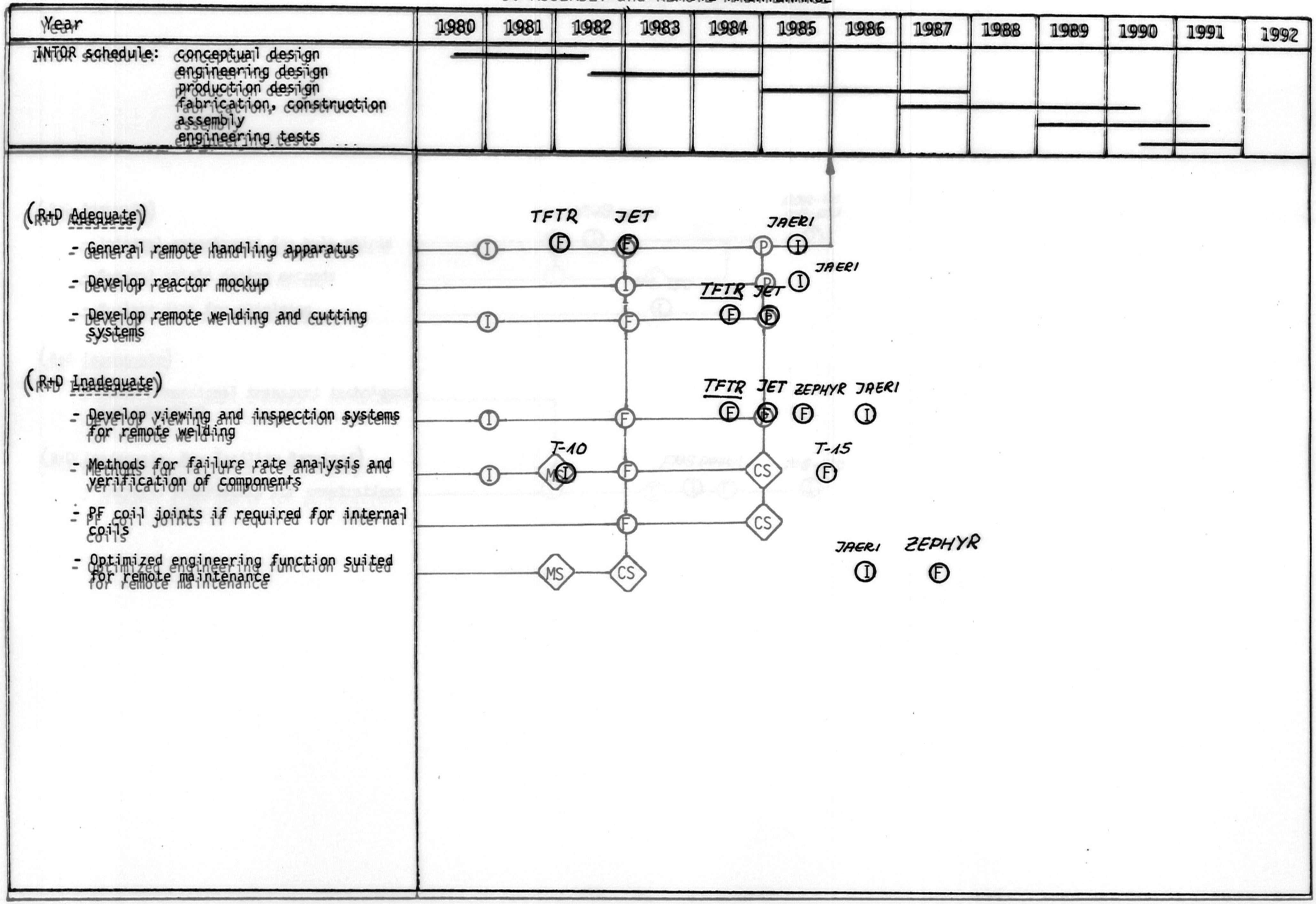
8. POWER SUPPLY and TRANSFER



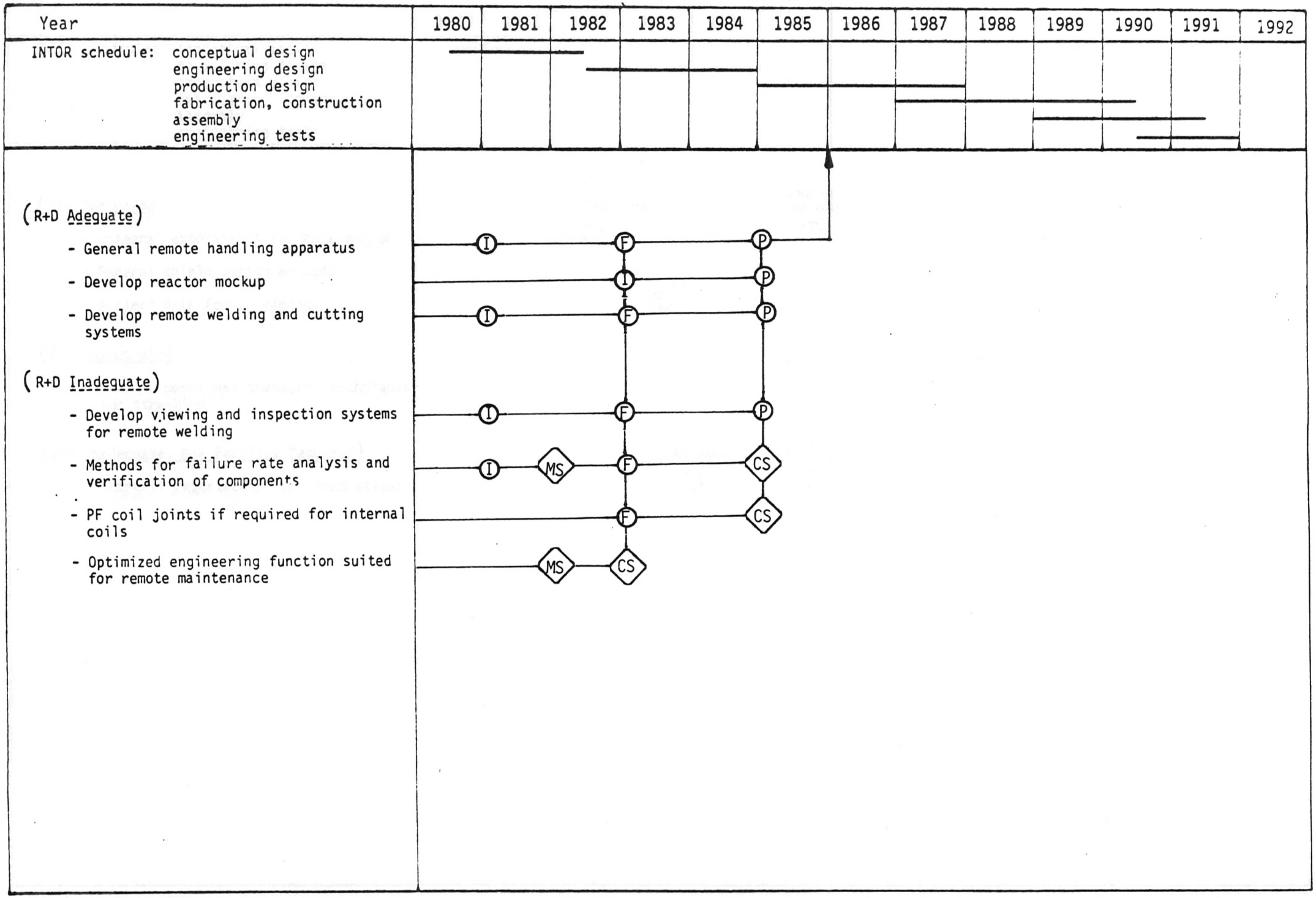
8. POWER SUPPLY and TRANSFER



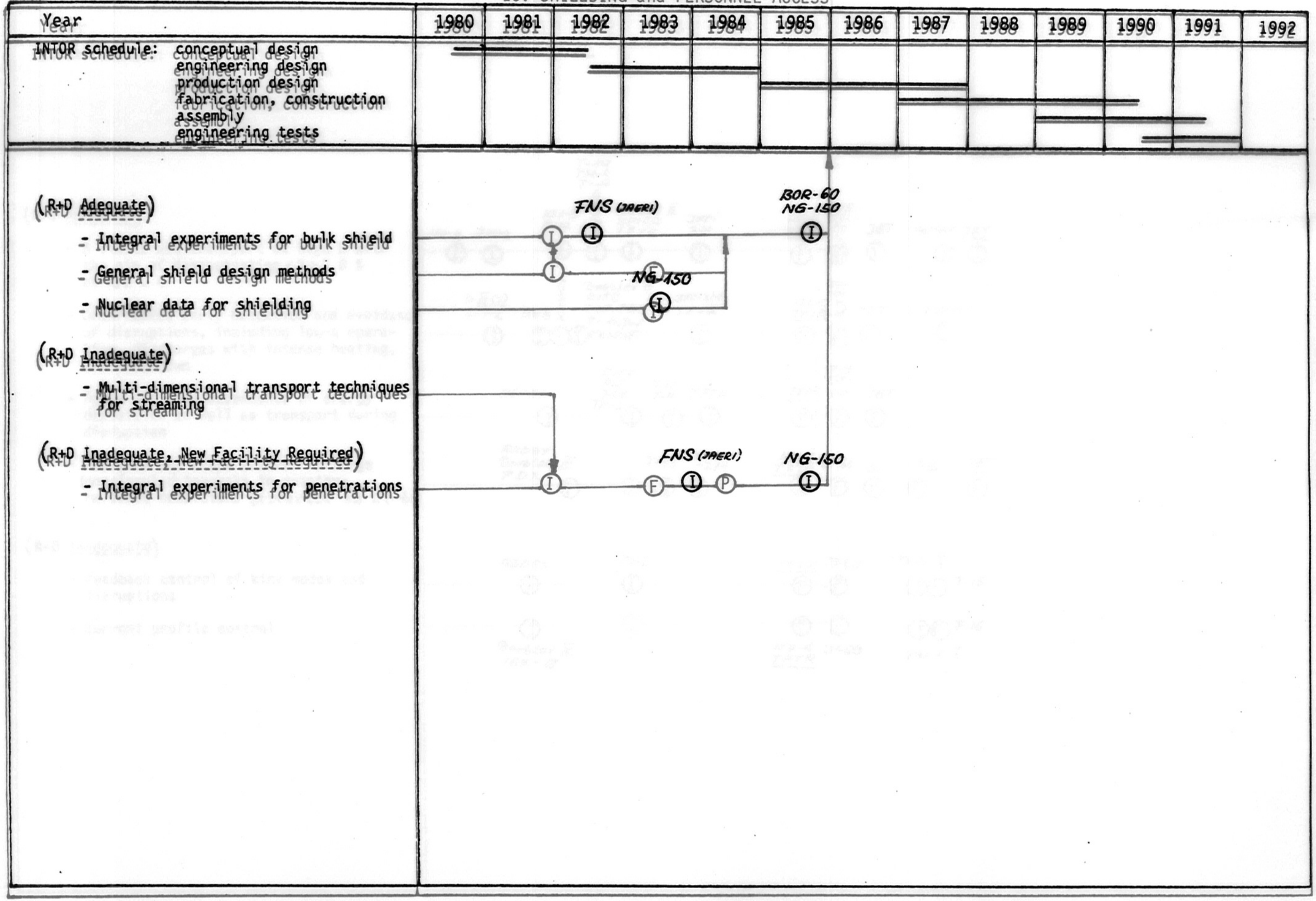
9. ASSEMBLY and REMOTE MAINTENANCE



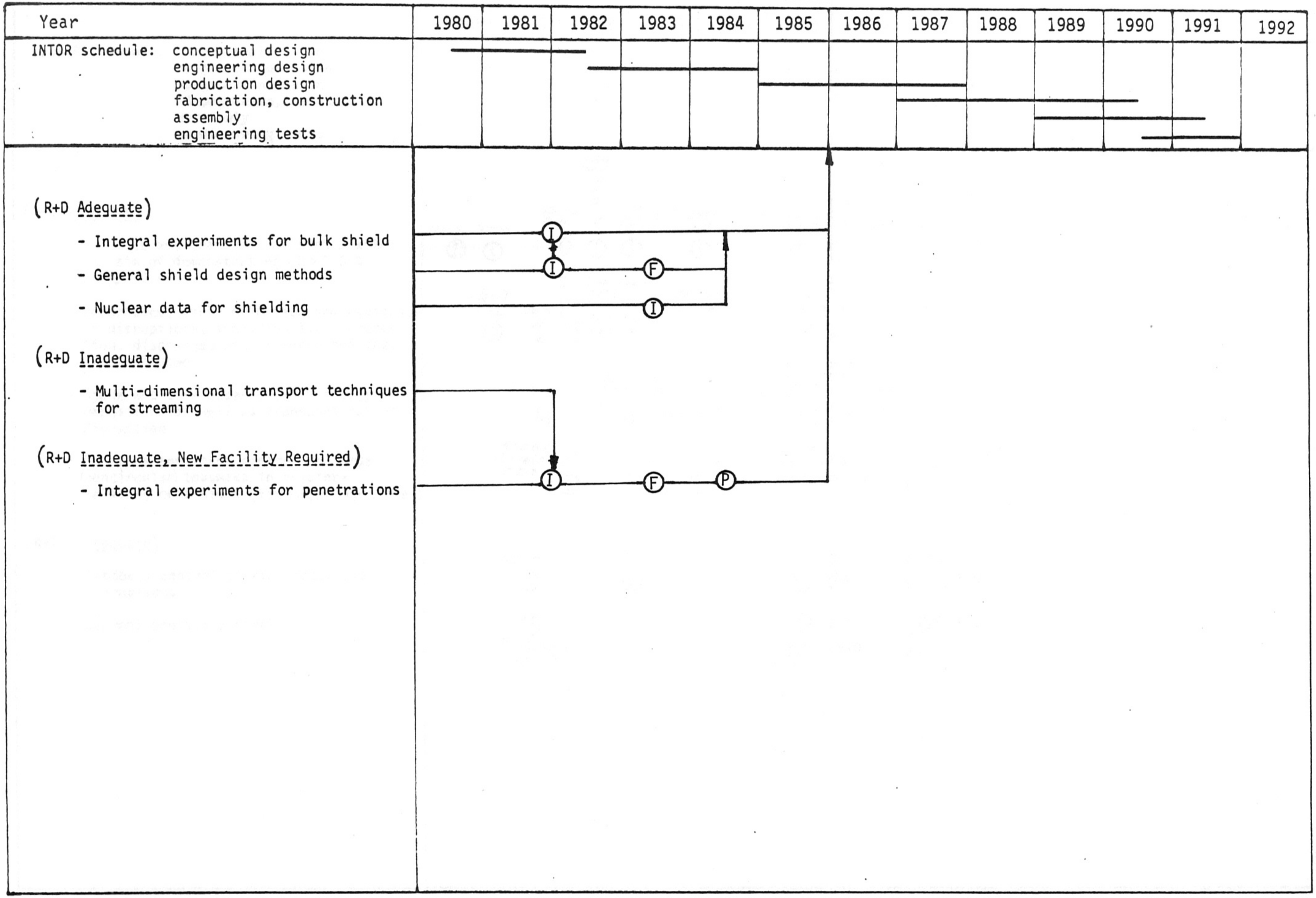
9. ASSEMBLY and REMOTE MAINTENANCE



10. SHIELDING and PERSONNEL ACCESS



10. SHIELDING and PERSONNEL ACCESS



11. STABILITY CONTROL

Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
INTOR schedule: conceptual design	—	—											
engineering design			—	—	—								
production design						—	—	—					
fabrication, construction								—	—	—			
assembly										—	—		
engineering tests											—	—	
(R+D Adequate)													
- β limits and transport at high β with the aim of demonstrating $\langle\beta\rangle \gtrsim 6$ % at $R/a \simeq 4$	ISX-B (I)	JFT-2 (I)	ISX-B, PDX (I); T-10, TM-4, T-11, ASDEX (I)	Doublet III, SPICA, TFTR (I)	JFT-2M (I)	ISX-C, TFTR (F)	T-15, JT-60 (F); JET (I)	ZEPHYR (F)	JET (I)				
- Occurrence, early detection and avoidance of disruptions, including low-q operation, discharges with intense heating, and shut-down		D-III(J), JFT-2 (I); ISX-B (I); ASDEX (I)	Doublet III, DITE, PLT, PDX, T-10, T-11, TEXTOR (I)	(I)	JFT-2M, TFTR (I)	ISX-C, TFTR (F)	JT-60, T-15 (F); JET (F)	ZEPHYR (F)					
- Space and time dependence of energy deposition as well as transport during disruption		ASDEX (I)		DITE, PLT, PDX, TM-3 (I); T-10, T-11 (I)	TFTR (I)	TFTR (F)	T-15, JT-60 (F); JET (F)						
- Position and shape control in large (noncircular) tokamaks in reactor-relevant conditions (divertor in JT-60)			ASDEX, Doublet III, PDX (I)	(I); T-13 (I)	JET-2M (I)	ISX-C, TFTR (I)	JT-60 (F); JET (F)	T-15 (F)	JET (F)				
(R+D Inadequate)													
- Feedback control of kink modes and disruptions		ASDEX (I)		TO-2 (I)		TFTR (F)	JT-60 (F)	TORE II (I)(F); T-15					
- Current profile control		Doublet III, ISX-B (I)		(I)		ISX-C, TFTR (F)	JT-60 (F)	TORE II (I)(F); T-15					

11. STABILITY CONTROL

Year	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
INTOR schedule: conceptual design engineering design production design fabrication, construction assembly engineering tests													
(R+D Adequate)													
- β limits and transport at high β with the aim of demonstrating $\langle\beta\rangle \gtrsim 6$ % at R/a $\simeq$ 4				I			F						
- Occurrence, early detection and avoidance of disruptions, including low-q operation, discharges with intense heating, and shut-down				I			F						
- Space and time dependence of energy deposition as well as transport during disruption				I			F						
- Position and shape control in large (noncircular) tokamaks in reactor-relevant conditions (divertor in JT-60)				I			F						
(R+D Inadequate)													
- Feedback control of kink modes and disruptions				I			F						
- Current profile control				I			F						

12. START-UP, BURN and SHUTDOWN CONTROL

Year

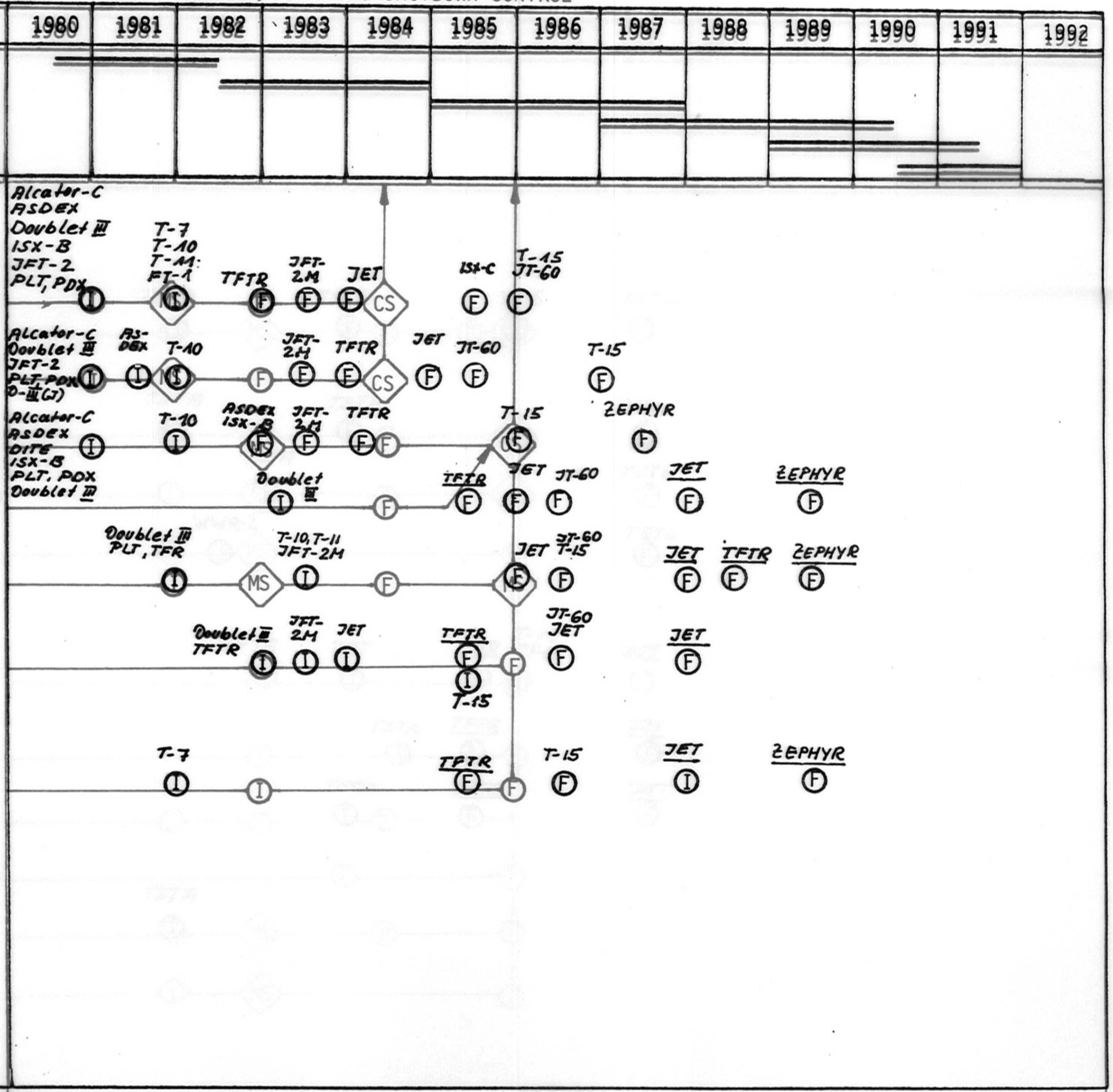
INTOR schedule: conceptual design
engineering design
production design
fabrication, construction
assembly
engineering tests

(R+D Adequate)

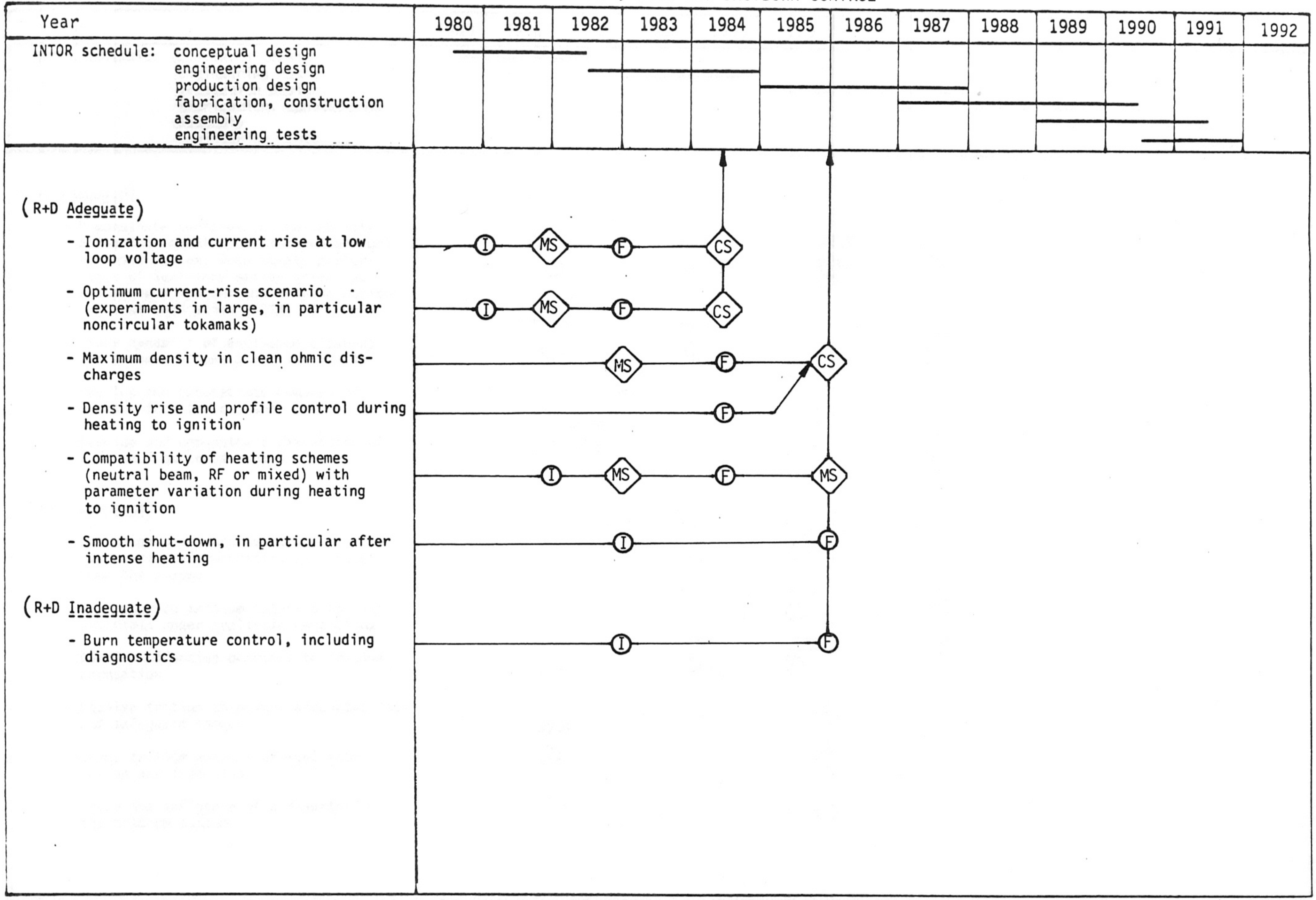
- Ionization and current rise at low loop voltage
- Optimum current-rise scenario (experiments in large, in particular noncircular tokamaks)
- Maximum density in clean ohmic discharges
- Density rise and profile control during heating to ignition
- Compatibility of heating schemes (neutral beam, RF or mixed) with parameter variation during heating to ignition
- Smooth shut-down, in particular after intense heating

(R+D Inadequate)

- Burn temperature control, including diagnostics



12. START-UP, BURN and SHUTDOWN CONTROL



13. TRITIUM

Year

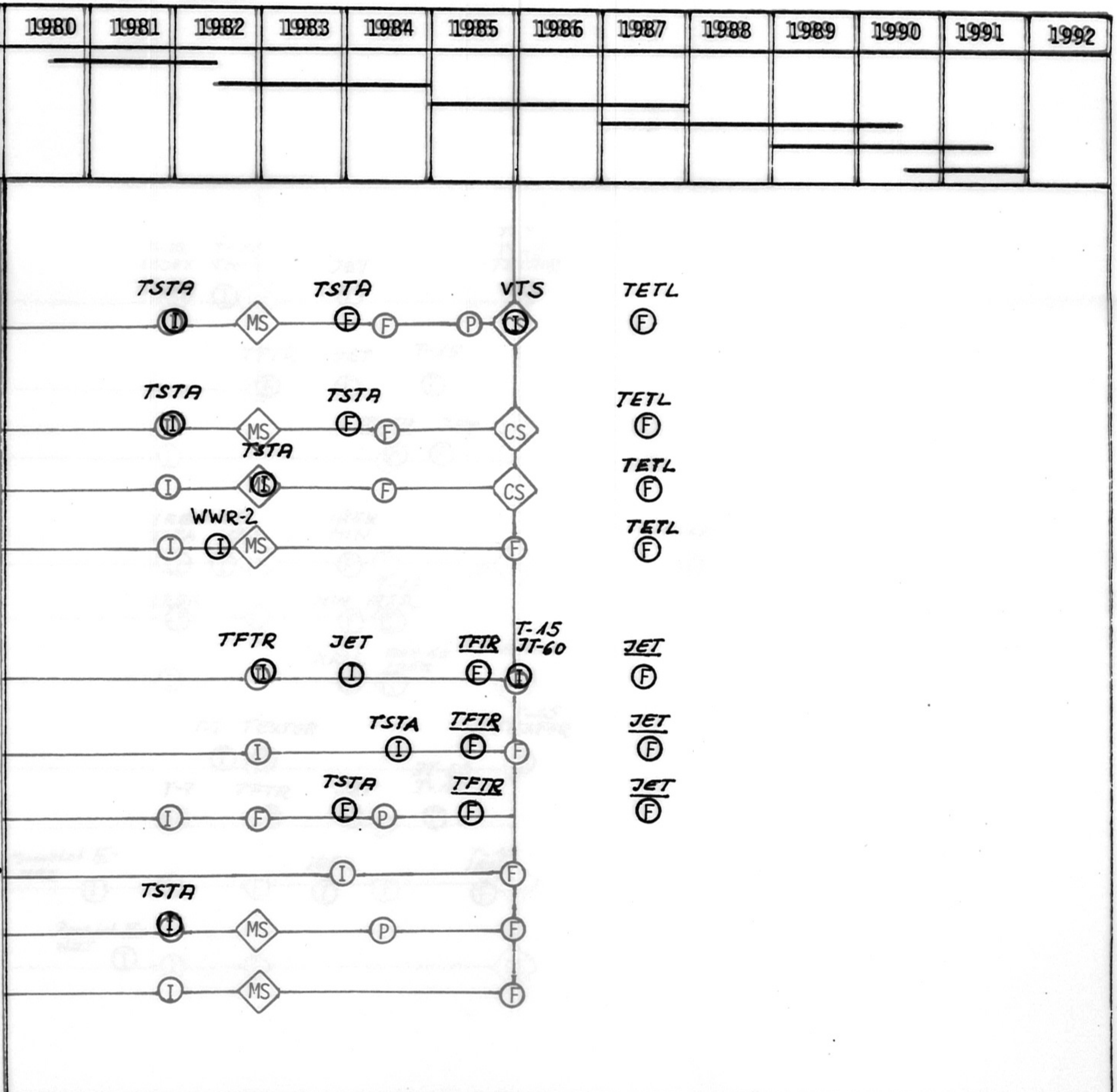
INTOR schedule:
- conceptual design
- engineering design
- production design
- fabrication, construction
- assembly
- engineering tests

(R+D Adequate)

- Demonstrate performance, reliability and maintainability of integrated fuel handling system. Demonstrate performance of auxiliary safety (clean-up and backup) systems and tritium monitoring instrumentation (TSTA, TETL, VTS)
- Study dynamics of enclosure clean-up operations following tritium spills
- Develop and demonstrate removal of tritium from the coolant
- Develop and demonstrate extraction of tritium from breeder materials

(R+D Inadequate)

- Determine concentration and chemical composition of impurities exhausted from the plasma
- Characterize tritium interaction with materials under realistic conditions
- Develop effective barriers to tritium permeation
- Resolve tritium shipping, accountability, and safeguard issues
- Study tritium aspects of fuel fabrication and injection
- Study the influence of a divertor on the tritium system



13. TRITIUM

Year

INTOR schedule: conceptual design
engineering design
production design
fabrication, construction
assembly
engineering tests

(R+D Adequate)

- Demonstrate performance, reliability and maintainability of integrated fuel handling system. Demonstrate performance of auxiliary safety (clean-up and backup) systems and tritium monitoring instrumentation (TSTA, TETL, VTS)
- Study dynamics of enclosure clean-up operations following tritium spills
- Develop and demonstrate removal of tritium from the coolant
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(R+D Inadequate)

- Determine concentration and chemical composition of impurities exhausted from the plasma
- Characterize tritium interaction with materials under realistic conditions
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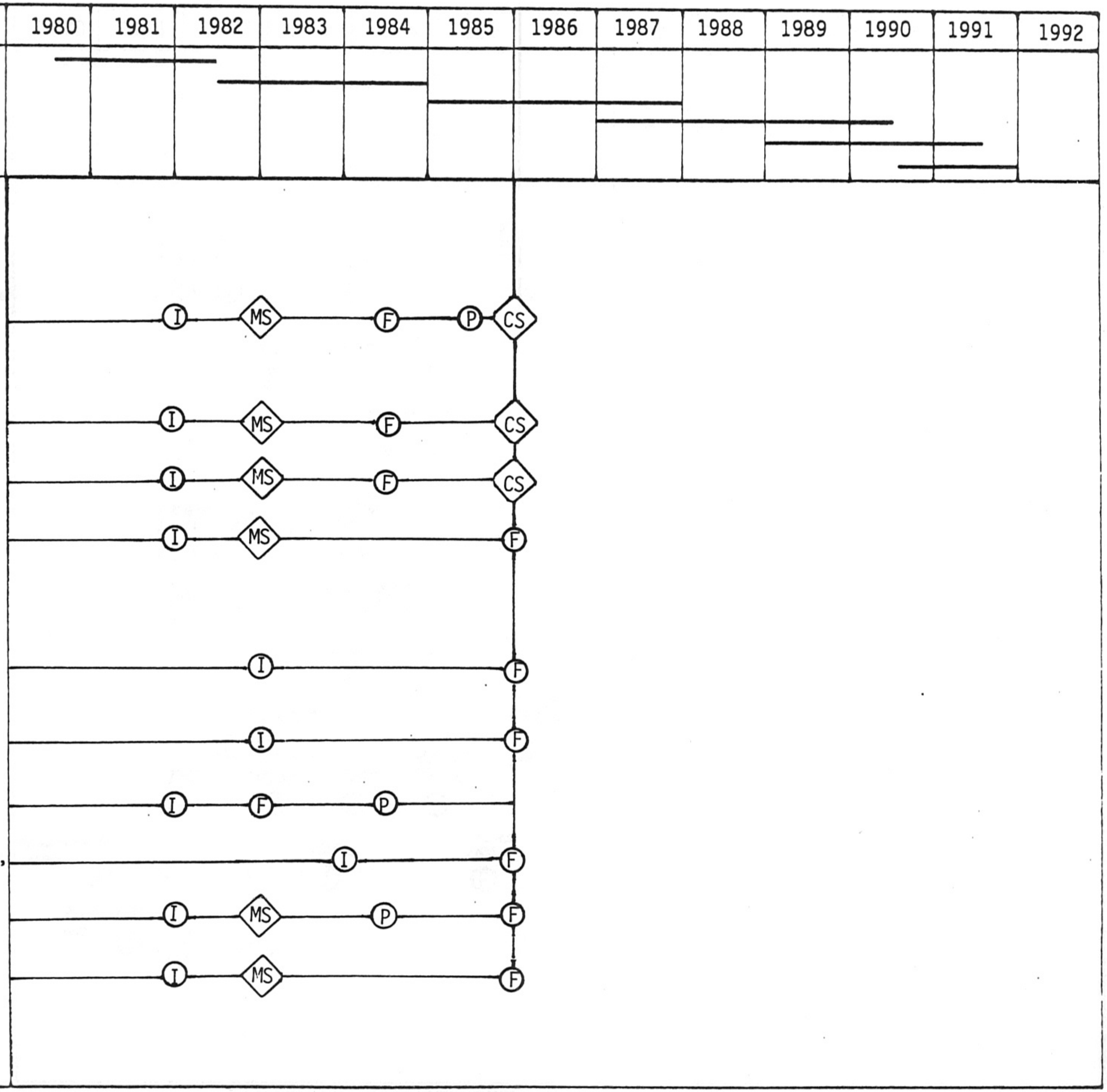
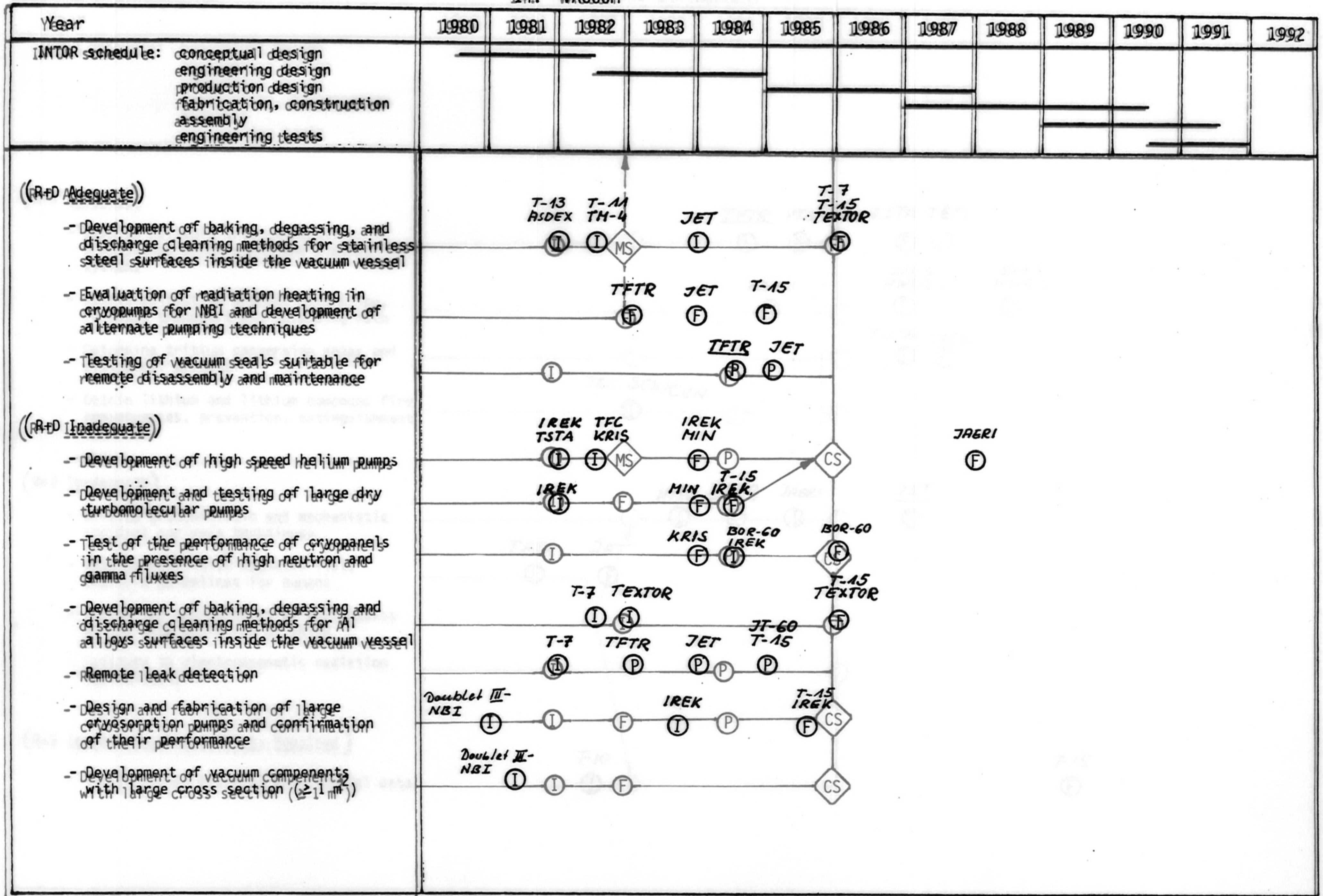
- Resolve tritium shipping, accountability, and safeguard issues
- Study tritium aspects of fuel fabrication and injection
- Study the influence of a divertor on the tritium system



14. VACUUM



Year
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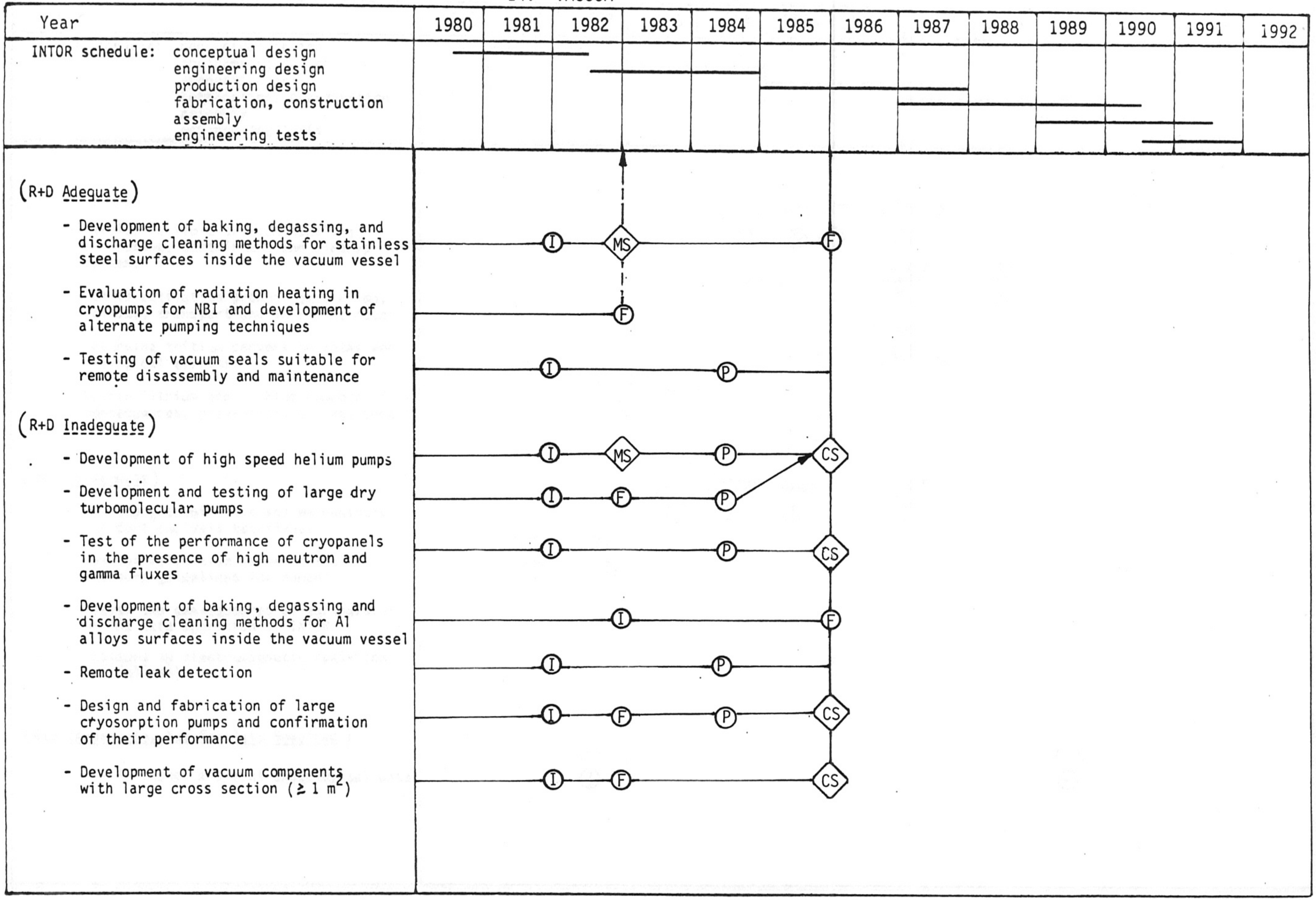
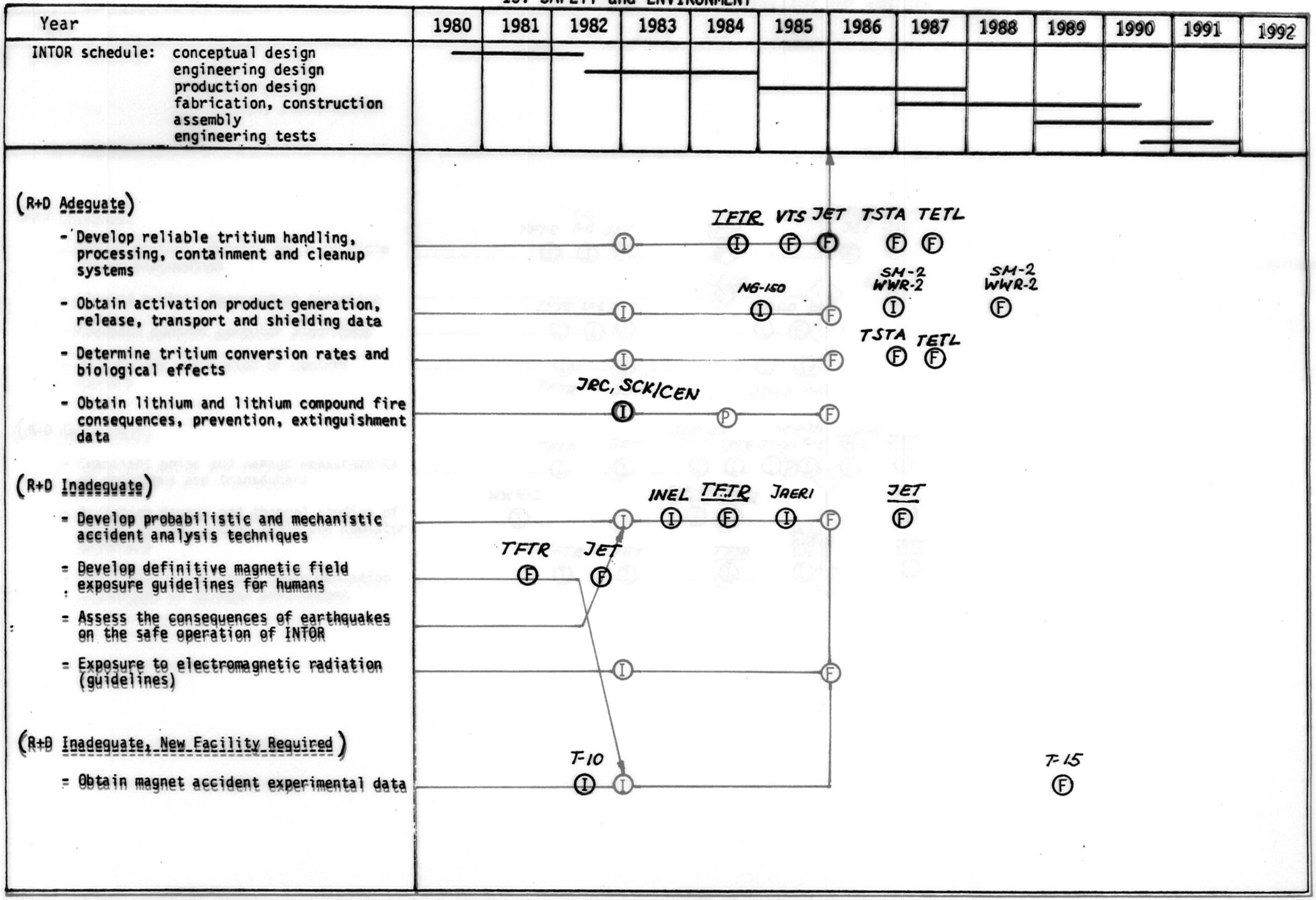
1990
1991
1992
INTOR schedule: conceptual design
engineering design
production design
fabrication, construction
assembly
engineering tests
(R+D Adequate)
- Development of baking, degassing, and discharge cleaning methods for stainless steel surfaces inside the vacuum vessel
T-13 ASDEX I
T-11 TH-4 I
MS
JET I
T-7 T-15 TEXTOR F
- Evaluation of radiation heating in cryopumps for NBI and development of alternate pumping techniques
TFTR F
JET F
T-15 F
- Testing of vacuum seals suitable for remote disassembly and maintenance
I
TFTR P
JET P
(R+D Inadequate)
- Development of high speed helium pumps
IREK TSTA I
TFC KRIS I
MS
IREK MIN F
P
CS
JAERI F
- Development and testing of large dry turbomolecular pumps
IREK I
F
MIN F
T-15 IREK F
- Test of the performance of cryopanels in the presence of high neutron and gamma fluxes
I
KRIS F
BOR-60 IREK I
BOR-60 F
CS
- Development of baking, degassing and discharge cleaning methods for Al alloys surfaces inside the vacuum vessel
T-7 I
TEXTOR I
T-15 TEXTOR F
- Remote leak detection
T-7 I
TFTR P
JET P
P
JT-60 T-15 P
- Design and fabrication of large cryosorption pumps and confirmation of their performance
Doublet III-NBI I
I
F
IREK I
P
T-15 IREK F
CS
- Development of vacuum compenents with large cross section (≥ 1 m²)
Doublet III-NBI I
I
F
CS

14. VACUUM

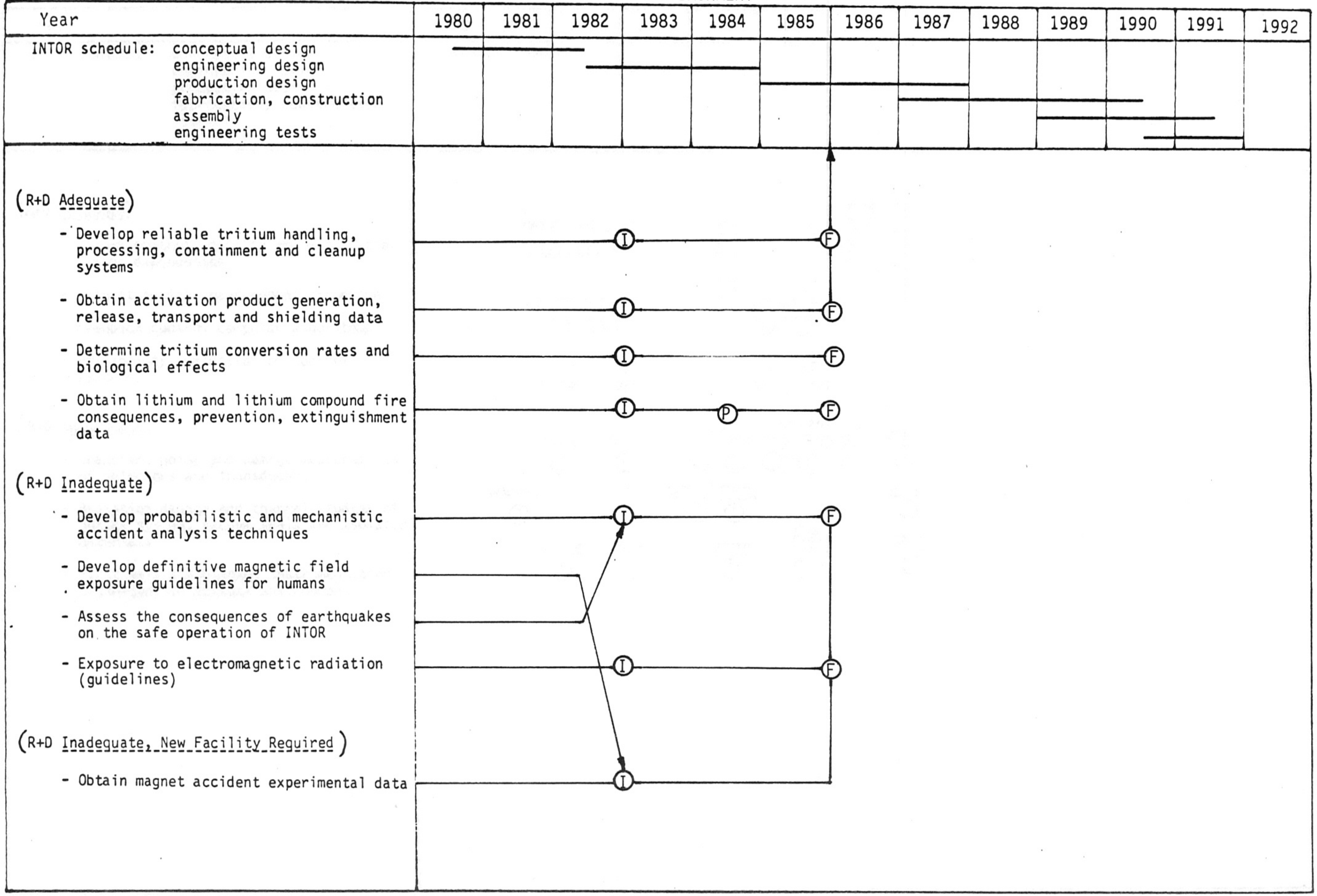


Year
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
INTOR schedule: conceptual design
engineering design
production design
fabrication, construction
assembly
engineering tests
(R+D Adequate)
- Development of baking, degassing, and discharge cleaning methods for stainless steel surfaces inside the vacuum vessel
- Evaluation of radiation heating in cryopumps for NBI and development of alternate pumping techniques
- Testing of vacuum seals suitable for remote disassembly and maintenance
(R+D Inadequate)
- Development of high speed helium pumps
- Development and testing of large dry turbomolecular pumps
- Test of the performance of cryopanels in the presence of high neutron and gamma fluxes
- Development of baking, degassing and discharge cleaning methods for Al alloys surfaces inside the vacuum vessel
- Remote leak detection
- Design and fabrication of large cryosorption pumps and confirmation of their performance
- Development of vacuum compenents with large cross section (≥ 1 m²)
I
MS
F
P
CS

15. SAFETY and ENVIRONMENT



15. SAFETY and ENVIRONMENT



16. DIAGNOSTICS, DATA ACQUISITION and CONTROL

Year

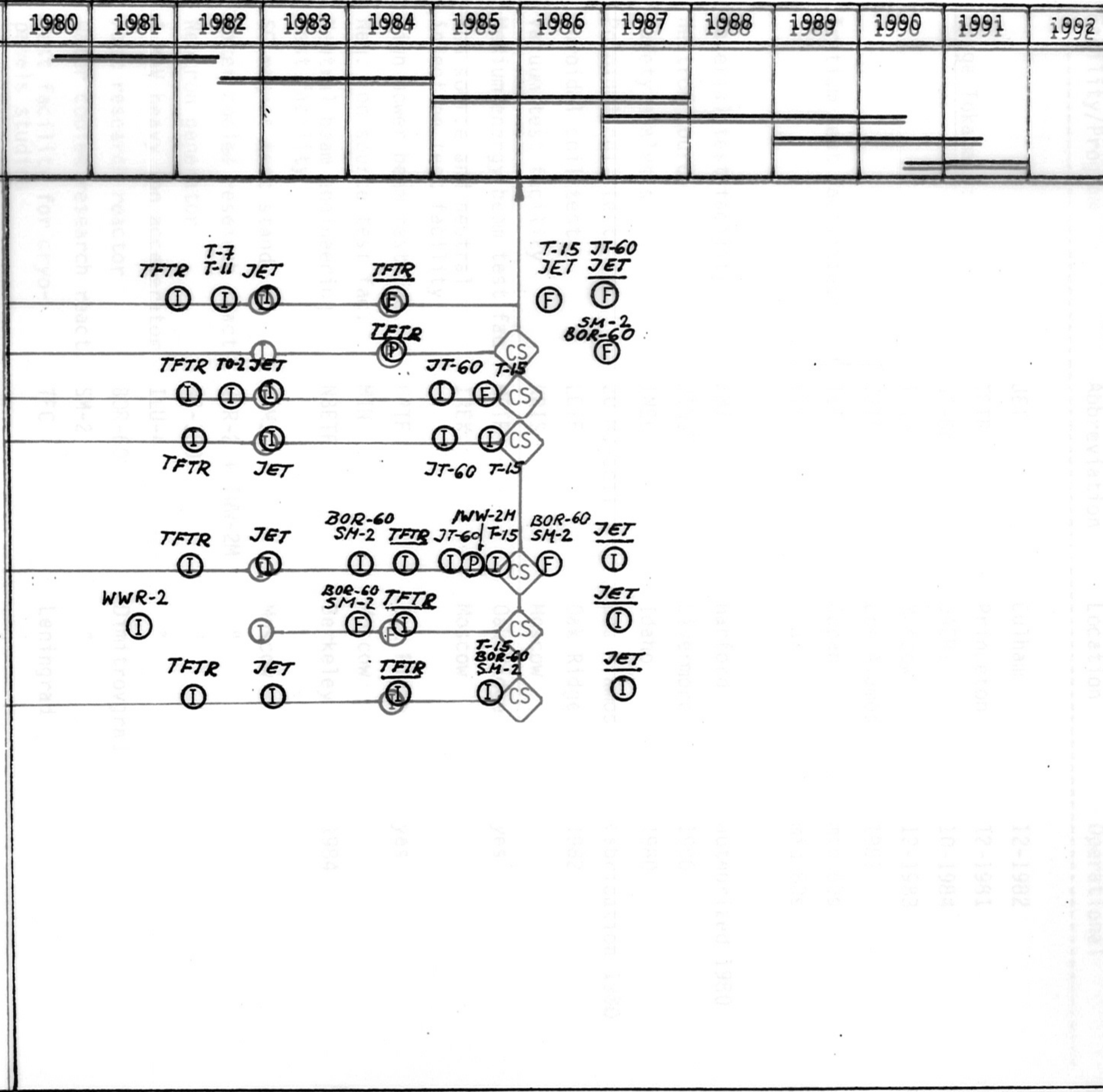
INTOR schedule: conceptual design
engineering design
production design
fabrication, construction
assembly
engineering tests

(R+D Adequate)

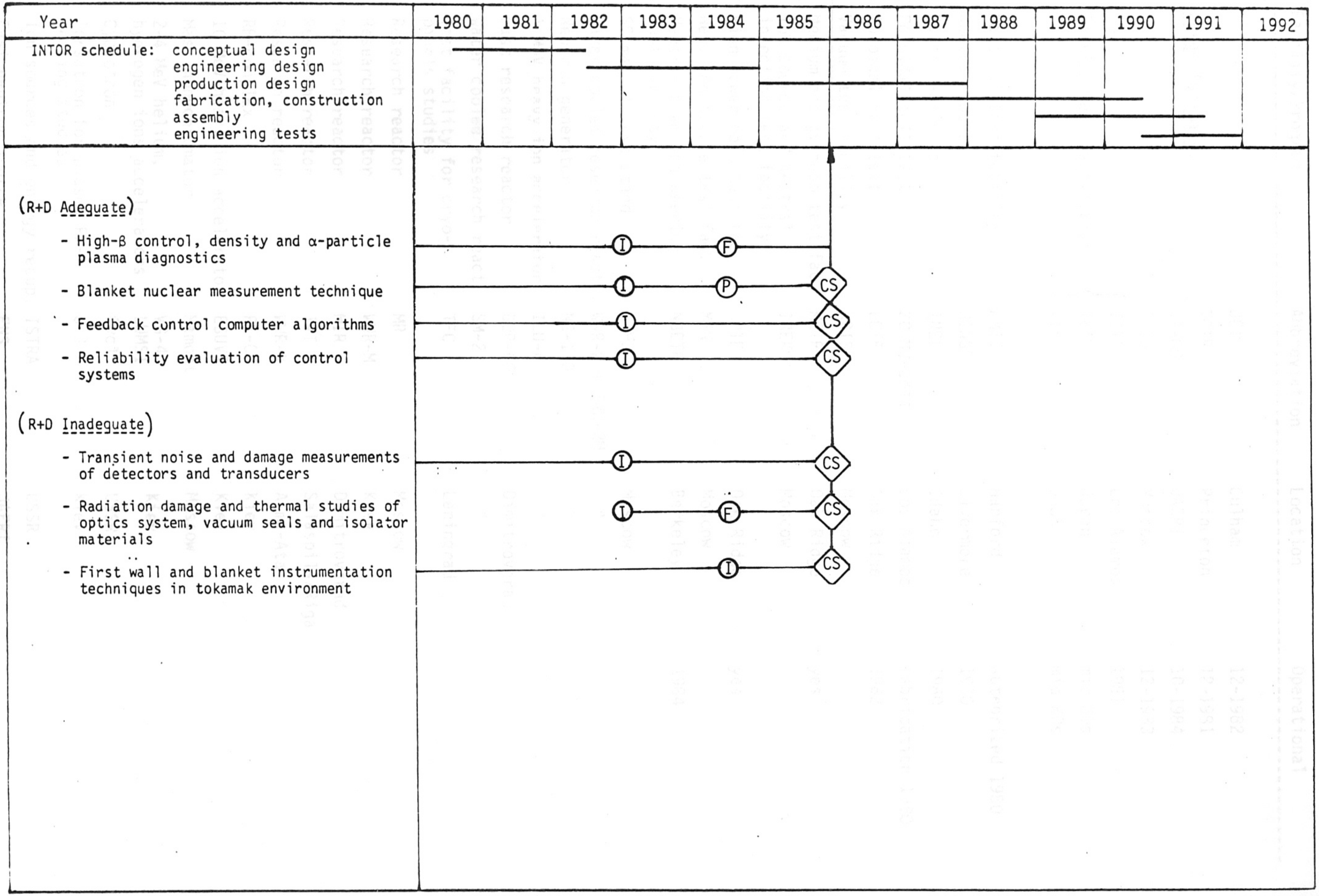
- High-β control, density and α-particle plasma diagnostics
- Blanket nuclear measurement technique
- Feedback control computer algorithms
- Reliability evaluation of control systems

(R+D Inadequate)

- Transient noise and damage measurements of detectors and transducers
- Radiation damage and thermal studies of optics system, vacuum seals and isolator materials
- First wall and blanket instrumentation techniques in tokamak environment



16. DIAGNOSTICS, DATA ACQUISITION and CONTROL



Facility/Program	Abbreviation	Location	Operational
Large Tokamaks:	JET	Culham	12-1982
	TFTR	Princeton	12-1981
	JT-60	JAERI	10-1984
	T-15	Moscow	12-1983
Tritium test facilities:	TSTA	Los Alamos	1981
	TETL	Japan	mid 80s
	VTS	USSR	mid 80s
Material test facility	FMIT	Hanford	authorized 1980
Neutron source	HINSF	Livermore	1980
Safety analysis	INEL	Idaho	1980
Poloidal coil test	20 MJ-coil	Los Alamos	fabrication 1980
Toroidal coil test	LCTF	Oak Ridge	1982
Vacuum test facility	KRIS	Moscow	
Medium energy beam test fac.	METF	Oak Ridge	yes
Ion source and neutral injection test facility	IREK	Moscow	
High power beam test fac.	HPTF	Oak Ridge	yes
Neg. ion source test fac.	MIN	Moscow	
Neutral beam engineering test facility	NBETF	Berkeley	1984
SC magnet test stand	SIMS	Moscow	
Water cooled research reacts.	WWR-2 + IWW-2M	"	
Neutron generator	NG-150	"	
1 MeV heavy ion accelerator	ILU-4	"	
Fast research reactor	BOR-60	Dimitrovgrad	
Water cooled research react.	SM-2	"	
Test facility for cryo-panels studies	TFC	Leningrad	
Research reactor	MR	Moscow	
Research reactor	WWR-M	Kiev	
Research reactor	MIR	Dimitrovgrad	
Research reactor	IRT	Salaspils/Riga	
Research reactor	WWR-K	Alma-Ata	
RF-complex	RF-C	Kiev	
10 MeV heavy ion accelerator	ESUVI	Kiev	
Mass-monochromator	Mamont	Moscow	
2-4 MeV helium, hydrogen ions accelerators	VG-4 LUMSI	Kiev	
Cyclotron	Cycl	USSR	
Torsatron for plasma RF-heating studies	U-3	Kiev	
Ion sources and energy recup.	ISTRA	USSR	
Fast neutron source	FNS	JAERI	

Facility/Programm	Abbreviation	Location	Operational
Present Tokamaks and Tokamaks under construction:	Doublet III (US/JAP Coop.)	San Diego	yes
	PLT	Princeton	"
	PDX	Princeton	"
	ISX-B	Oak Ridge	"
	Alcator-A	Cambridge	"
	Alcator-C	Cambridge	"
	JFT-2	Tokai-mura	"
	Tuman-3	Leningrad	"
	TO-2	Moscow	"
	TM-3	Moscow	"
	TM-4	Moscow	"
	T - 7	Moscow	"
	T - 10	Moscow	"
	T - 11	Moscow	"
	T - 13	Moscow	"
	FT-1	Leningrad	"
	R-05	Sukhumi	"
	ASDEX	Garching	"
	TEXTOR	Jülich	1982
	TFR	Fontenay-aux-Roses	yes
	DITE	Culham	"
	FT	Frascati	"
	Petula	Grenoble	"
	WEGA	Grenoble	"
	Ringboog/SPICA	Jutphaas	"
Planned Tokamaks:	TORE II	France	
	ISX-C	Oak Ridge	
	Doublet III Large Dee	San Diego	2-1984 or 6-1985
	TB-O	USSR	
	ZEPHYR	Garching	
Planned test facilities:	IREK II	USSR	
	MIN II	USSR	

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