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IFMIF
INTERNATIONAL FUSION MATERIALS IRRADIATION FACILITY
KEY ELEMENT TECHNOLOGY PHASE
TASK DESCRIPTION

August 2000

Fusion Neutron Laboratory

日本原子力研究所
Japan Atomic Energy Research Institute

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IFMIF
International Fusion Materials Irradiation Facility
Key Element Technology Phase
Task Description

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In 2000, a 3 year Key Element technology Phase (KEP) of the International Fusion Materials Irradiation Facility (IFMIF) has been initiated to reduce the key technology risk factors needed to achieve continuous wave (CW) beam with the desired current and energy and to reach the corresponding power handling capabilities in the liquid lithium target system. In the KEP, the IFMIF team (EU, Japan, Russian Federation, US) will perform required tasks. The contents of the tasks are described in the task description sheet. As the KEP tasks, the IFMIF team have proposed 27 tasks for Test Facilities, 12 tasks for Target, 26 tasks for Accelerator and 18 tasks for Design Integration. The task description by RF is not yet available. The task items and task descriptions may be added or revised with the progress of KEP activities. These task description sheets have been compiled in this report. After 3 years KEP, the results of the KEP tasks will be reviewed. Following the KEP, 3 years Engineering Validation Phase (EVP) will continue for IFMIF construction.

Keywords : IFMIF, Fusion Material, Neutron Source, Irradiation Facility, Task Description, Key Element Technology Phase

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※ This report was edited by members of Fusion Neutron Laboratory as follows;
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国際核融合材料照射施設 (IFMIF)計画における要素技術確証タスクの実施計画書

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核融合中性子工学研究室※

(2000 年 7 月 18 日受理)

国際核融合材料照射施設(IFMIF)概念設計活動、概念設計評価、段階的建設とコストの合理化を踏まえた再評価と再設計が行われたのを受けて、IEA 核融合調整委員会は IFMIF 活動が KEP に移行するのを了承した。本報告書は、2000 年から 2002 年の要素技術確証期間(KEP)において実施されるタスクの実施計画書を編集したものである。各タスクは、IFMIF 国際チーム（EU、日本、ロシア、米国）により行われる。KEP タスクとして、IFMIF 国際チームはテストセル系で 27 件、ターゲット系で 12 件、加速器系で 26 件、設計統合で 18 件をこれまでに提起した。ロシアの本タスク実施計画書は、現時点では未完成なため本報告書には掲載していない。KEP 活動の進展に伴い、タスク項目と内容は、今後、追加または変更されうる。本タスク実施計画書に従い、KEP での要素技術確証が実施される。その後、チェック＆レビューを実施し、次の３年間の工学実証に移行し、建設に備える予定である。

※本報告書は、核融合中性子工学研究室の以下のメンバーにより、編集された。
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Task Description

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An Activity of :
The International Energy Agency (IEA)
Implementing Agreement for a program of Research and Development
on Fusion Materials

Japan Atomic Energy Research Institute
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Preface

This report is the compilation of Task Description Sheets during Key Element technology Phase (KEP) of the International Fusion Materials Irradiation Facility (IFMIF). The mission of the IFMIF is to provide an accelerator-based D-Li neutron source to produce intense high energy neutrons (2 MW/m^2) and a sufficient irradiation volume (500 cm^3) for testing the candidate materials and components for fusion. The required deuteron (D) beam current is 250 mA at 40 MeV in the reference condition. The IFMIF activity is performed by the European Union, Japan, Russian Federation and United States of America under the auspices of the International Energy Agency (IEA) Implementing Agreement for a Program of Research and Development on Fusion Materials.

The IFMIF activity was performed as the Conceptual Design Activity (CDA) during 1995 – 1996, as the Conceptual Design Evaluation (CDE) during 1997 – 1998. After these design activities, reevaluation of the design and cost was performed with the proposal of staged construction and cost rationalization in response to the request from the 28th IEA Fusion Power Coordinating Committee (FPCC) meeting in January 1999. Two major ideas have been considered: 1) reduction of the total construction cost through elimination of the previously planned facility upgrade and 2) A facility deployment in 3 stages with increasing D beam current. As results, the total cost estimate for the IFMIF construction was reduced to 62 % of CDA estimate, and staged deployment consists of 3 stages (50 mA : 0.4 MW/m^2 @ 500 cm^3 - > 125 mA : 1 MW/m^2 -> 250 mA : 2 MW/m^2). After these works, the 29th FPCC required the IFMIF activity to proceed to KEP.

As activities in KEP from 2000 to 2002, the IFMIF international design team mainly performs following works.

1) Developments of key element technologies for long time, stable operation
2) Detailed design

As KEP tasks, the international design team have proposed 27 tasks for Test Facilities, 12 tasks for Target, 26 tasks for Accelerator and 18 tasks for Design Integration. These tasks have been compiled in this report. The task description by RF are not yet available.After a review of the KEP results, engineering validation of the Accelerator, the Target and the Test Facilities systems will be performed in the next 3 years called as Engineering Validation Phase (EVP). During the EVP, the final design of IFMIF will be performed. After the EVP, 3-staged construction of IFMIF in 15years (5years x 3stages) will be started.

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Acronyms and Definitions

- Aq: Pressure unit defined by water; 1 Aq = 1 mm H_2O
- CDA: Conceptual Design Activity
- CDE: Conceptual Design Evaluation
- CEA: Centre Europeen
- dpa: Displacements per Atom
- DTL: Drift Tube Linac
- ECU: European Currency Units
- EDC: Energy Dispersion Cavity
- EDI: Engineering Design and Inspection
- EMP: Electromagnetic Pump
- ENEA: Ente per le Nuove Technologie l'Energia e l'Ambiente
- EPFL: Ecole Polytechnique Federale de Lausanne)
- EU: European Union
- EVP: Engineering Validation Phase
- FMEA: Failure Modes and Effects Analysis
- FMIT: Fusion Materials Irradiation Test
- FPCC: Fusion Power Coordinating Committee
- fpy: Full Power Year
- FZK: Forschungszentrum Karlsruhe
- HEBT: High Energy Beam Transport
- I&C: Instrumentation and Controls
- ICRH: Ion Cyclotron Resonance Heating
- IEA: International Energy Agency
- ITER: International Thermonuclear Experimental Reactor
- ICF: IFMIF Currency Factor ; 1 ICF = 1 US$=105 Yen=0.807 ECU.
- JAERI: Japan Atomic Energy Research Institute
- KEP: Key Element technology Phase
- LANL: Los Alamos National Laboratory
- NPSH: Net Positive Suction Head
- ORNL: Oak Ridge National Laboratory
- PIE: Post Irradiation Examination
- RAM: Reliability, Availability and Maintainability
- RFQ: Radio Frequency Quadrupole.
- VTA: Vertical Test Assembly

1. Introduction

The International Fusion Materials Irradiation Facility (IFMIF) is an accelerator-based D-Li neutron source to produce intense high energy neutrons (2 MW/m^2) and a sufficient irradiation volume (500 cm^3) for testing the candidate materials and components for fusion. The required deuteron (D) beam current is 250 mA at 40 MeV in the reference condition.

The IFMIF activity is performed by the European Union, Japan, United States of America and Russian Federation under the auspices of the International Energy Agency (IEA) Implementing Agreement for a Program of Research and Development on Fusion Materials. After the IFMIF Conceptual Design Activity (CDA) during 1995 – 1996 and the Conceptual Design Evaluation (CDE) during 1997 – 1998, reevaluation of the design and cost was performed with the proposal of staged construction and cost rationalization in response to the request from the 28th IEA Fusion Power Coordinating Committee (FPCC) meeting in January 1999. Two major ideas have been considered: 1) reduction of the total construction cost through elimination of the previously planned facility upgrade and 2) A facility deployment in 3 stages with increasing D beam current. As results, the total cost estimate for the IFMIF construction was reduced to 62 % of CDA estimate, and staged deployment consists of 3 stages (50 mA : 0.4 MW/m^2 @ 500 cm3 - > 125 mA : 1 MW/m^2 -> 250 mA : 2 MW/m^2). After these works, the 29th FPCC required the IFMIF activity to proceed to Key Element technology Phase (KEP).

2. Outline of Task Description activity

As activities in KEP from 2000 to 2002, the IFMIF international design team mainly performs following works.

1) Developments of key element technologies for long time, stable operation
2) Detailed design

In March 2000, at the FZK Karlsruhe meeting, the IFMIF team agreed to prepare and publish the IFMIF Task Description Sheets to efficiently advance the mentioned developments and design. The task items and the sharing have been discussed at the Karlsruhe meeting for whole items, at the ENEA Frascati meeting for Design Integration items and through E-mail / Fax communications. The list of the selected KEP tasks are shown in Appendix-A. A Task ID is given to every task during KEP. These tasks are performed on voluntary base in US, EU, Russian Federation and Japan. Some Task ID, contents and sharing have been added or revised with the task proposals mainly by EU team for Test Facilities (Task ID : TFxx) and for Target (TG-xx), mainly by US and EU teams for Accelerator (AC-xx) and for Design Integration (DI-xx).

3. Brief summary

Until early July 2000, the international design team has proposed to perform 27 tasks for Test Facilities, 12 tasks for Target, 26 tasks for Accelerator and 18 tasks for DI, while some tasks may be added or revised in the future. Detailed descriptions of proposed tasks are shown in Appendix-B. The task description by RF is not yet available. According to the KEP list, Task ID is given to every Task. A Task ID includes US (United States), EU (European Union), RF (Russian Federation) or JP (Japan) as a performing team. Some tasks are proposed by more than one country to one Task ID (e.g. AC11-EU(Saclay), -EU(IAP) and -JP). They will perform different methods. (e.g. different types of ion sources for AC-11) The Task Description includes Institutes in Charge and Contact Persons to efficiently advance the task works by frequent communications, especially between relating tasks. (e.g. AC11s mentioned above) The Task Description includes also Need/Motivation and Brief Task Description to clear the works and to make efficient sharing. Furthermore, the Task Description includes Schedule and Task Deliverable to be utilized by other tasks or works in IFMIF, and to be checked & reviewed as KEP activities.

4. Following activities

According to this Task Description, the developments in KEP are to be performed until 2002 and the results are to be checked & reviewed. The task items and task descriptions may be added or revised with the progress of KEP activities.

Validations of the Accelerator, the Target and the Test Facilities as systems are performed in the next Engineering Validation Phase (EVP) from 2003. Also the final design of IFMIF is performed in EVP. The 3-staged construction of IFMIF in 15years (5years x 3stages) is started after EVP, and the 1st operation with 50 mA is started after the 1st stage of construction.

Acknowledgements

Appreciation is given to all members of the international IFMIF team on their contributions to this work. The IFMIF executive subcommittee has been highly impressed with dedication and enthusiasm of the IFMIF team. Also, appreciation is given to for the continued Interest of the IEA-FPCC.

Appendix-A

Detailed List of Development in KEP

Classification 1	Classification 2	Item	Necessity	Development Item / Method	KEP Task ID	KEP US	KEP EU	KEP RF	KEP JP	EVP
Test Facilities	Experimental Verification of Test Methods and Modules	High Flux Test Module (HFTM)	Experimental confirmation on test apparatus (structural integrity, temp.-control, fabrication)	Construction and fabrication of prototypic rigs, capsules & test module	TF11		X			X
				Testing of thermal hydraulic and instrumentation in He-loop	TF12		X			
		Medium Flux Test Module (MFTM) T Release	Detailed design of T-release test module, test structural integrity, temp.-control and gas piping	Fabrication of real size test module Experimental verification of concept He cooling						X
		Medium Flux Test Module (MFTM) Creep Fatigue	Confirm coolant concept, test instrumentation (e.g. Extensiometers, temp.-control)	Fabrication of prototype Experimental verification						X
	Neutron distribution	Spacial neutron distribution	Reduce present uncertanties by experimental verivication	Measurement of spacial distribution of Li(d,n) reaction by varying the incoming deuteron energy	TF21				X	
		Allowance of Asymmetric Irradiation Field	If another accelerator stops or unbalance of each current generates, asymmetry field is formed. Allowance should be investigated for irradiation facility.	From analysis of irradiation field, allowance of asymmetry is made clear in experiment of material test.	TF22				X	
		Optimisation, Qualification	Layout of suitable neutron multiplier/reflector	MCNP calculation for selection of proper geometry and material	TF23		X			X
				Design study, thermal hydraulics calculacions, verification of fabrication	TF24		X			
	Test Equipment	Vertical Test Assemblies (VTA)	Tests of exact positioning are required because space between assemblies is 1mm.	Design of test equipment, control system and sensor	TF31				X	
				Fabrication of test equipment Confirmation of running of control system and sensor						X
		Micro-tomography	Probably the only tool that allows verification of structural integrity of activated and assembled specimen capsules, rigs and modules	Design of teomographic equipment Prototype fabrication Generation of typical 3d-image recontractions	TF33		X			X
		T Laboratory and T Processing	Examination of tritium processing is needed.	Examination on Arrangement of Laboratory and processing method	TF34				X	X
		Arrangement of Test Cell System	Optimisation of arrangement of power cable, cooling water line and so on for various kind of irradiation materials is needed.	Examination of optimum arrangement	TF35				X	
		Transfer of Heavy Equipment	Equipment installing in test cell have to be set up and dismantled by remote handling.	Examination of universal robot system (URS)	TF36				X	
				Development of universal robot system (URS) Confirmation test by dummy equipment						X
		Operation in Off/Normal	Off/normal influences irradiation damage. So, the operation method should be determined in compliance with materials and irradiation parameters.	On the basis of experience on irradiation experiment, the condition of irradiation should be determined. If there is no data for operation method, the necessary data have to be taken.	TF38				X	
		Cooling Method by He	For accelerator beam-off times, temperature stability has to be verified experimentally in test module mock-ups.	Examination of response in temperature control	TF39				X	
	Revision for Cost Reduction	Optimisation of Staged Construction	Irradiation plan according to staged construction is needed.	Reviewing the plan of irradiation tests and post irradiation test	TF41				X	
		PIE Facility	PIE facility design for cost reduction is needed.	Reviewing the items of post irradiation test and the layout of PIE facility	TF42	X			X	

Test Facilities	Neutronics	Source Term of d-Li Reaction	The D-Li source term is of prime importance for the neutron yield, the neutron spectrum and the nuclear responses in the test cell.	Generation of complete nuclear data files for 6,7Li up to 50 MeV by calculation	TF51		X			
				Generation of nuclear data files for 6,7Li up to 18 MeV by experiments	TF52		X			
		Nuclear Data production, evaluation and processing	Nuclear data up to 50 MeV are needed for calculation of e.g. nuclear inventory, damage parameters, nuclear heating and design of shielding.	Sensitivity analysis and data evaluation for elements like Li, C, O	TF53				X	
				Data files evaluation for Z<6 isotopes with double differential cross section	TF54		X			
				Experiments for n+Fe between 2-30 MeV followed by benchmark calculations	TF55		X			
		Shielding analyses	Determination of dose rate in different areas	Evaluation of dose rates in operative and inaccessible areas Activation calculations of test modules Definition of radiological concerns based on calculated radioactive inventory	TF56		X			
		In-situ neutron / gamma monitors	Experimental monitoring of irradiation parameters	Set-up of accelerator based target station	TF57		X			
				Construction of sub-miniature fission chamber, tests on accelerator	TF58		X			
	User specific developments	Re-evaluation of Irradiation Parameters	For the reduced cost version all irradiation paramaters needs to be recalculated taking into account staging scenarios	Calculation of 3D contourplots of relevant parameters in reference materials based on cost reduced design	TF61		X			
		Review of Concept of Materials Test	To make maximum efficiency of irradiation test with limited volume and operation time	Reviewing test items to simulate materials in fusion condition Reviewing test methods and test devices	TF62				X	
		Development of Small Specimen Test Technology	The use of SSTT allows a very effective use of limited irradiation volumens and enhances significantly materials R&D	Fracture toughness specimens>: Optimization of specimen size	TF63				X	
				Development of bend bar specimens incl. test techniques; fracture analysis	TF64		X			
				Development and irradiation of various miniaturized specimens	TF65			X		

Classification 1	Classification 2	Item	Necessity	Development Item / Method	KEP Task ID	US	EU	RF	JP	EVP
Target	Stability of Li Flow	Stability of Li Jet	Li jet may be disturbed because of high-speed, broad jet and possible erosion/corrosion of reducer nozzle inner surface.	Examination of free surface behavior in water experiment under low pressure condition	TG11				X	
				Design of Li test Loop referring the JAERI and FMIT water jet experiments and simulation results	TG12		X	X	X	
				Remodelling of existing loop and verification of its performance	TG13				X	
				Fabrication of Li test loop and verification of the performance	TG14			X		X
		Cavitation	Cavitation should be avoided for flow stability and loop integrity.	Cavitation at a joint of back wall is examined in water experiment. (Current JAERI proposal does not include replaceable back wall)	TG15		X	X		
				Cavitation at EMP is examined in a small Li loop.	TG16		X		X	
	Damage and Corrosion by Li Flow	Behavior of Erosion/Corrosion	Data base for erosion/corrosion of pipe and target assembly materials under Li flow condition.	Measurement of erosion/corrosion in an existing loop	TG21				X	
				Li flow experiments for erosion/corrosion for the Li loop materials						X
		Inspection Method	Inspection method should be established.	Design of inspection method of damage and corrosion Verification of the method of damage and corrosion in Li test loop						X
	Li Purification	Diagnostic Method of Impurity in Li	On-line/off-line diagnostic and removal of impurities of T, 7Be and C,N,O	Design of both methods of impurity concentration measurement (On-line/off-line diagnostics) and impurity removal	TG31			X	X	
				Verification of the both method in Li test loop	TG32			X		X
	Li Vaporization	Li Vapour Effect on HEBT	Quantify Li accumulation rate on HEBT inner wall	Establishment of estimation methods of Li vapour towards HEBT based on Li loop experiments	TG41			X		X
	Li Safety	Li Leak, Li Fire	Events of Li leak and Li fire should be considered.	Collection and examination of existing data of Li reaction	TG51			X	X	
				Basic tests for Li fire in air contaminated Ar gas Analysis for behaviour of 7Be and T in the Li loop	TG52			X	X	X
	Loop Integrity	Transient Behaviour of Loops	Analyses of startup/shutdown procedures including beam trip	Numerical analyses by a computer code	TG61			X	X	
	Safety Analysis	Safety Analysis for Rationalized Design	Safety analyses should be performed again, because the number of target and the concept of reserved hot/cold traps have been changed.	FMEA, Dependent Failure and Accident Sequence analyses for the changed target system	TG71		X	X		
	Remote Handling	Setup Method of Target Assembly	Development of in-situ welding/cutting methods to mount/replace target assembly using a remote handling technique	Design remote handling devices	TG81		X		X	
				Manufacturing of remote handling devices Establishment of key methods such as a welding between different metals by remote handling						X

Classification 1	Classification 2	Item	Necessity	Development Item / Method	KEP Task ID	KEP US	KEP EU	KEP RF	KEP JP	EVP
Accelerator	Injector	Ion Source	Deuteron fraction : 85% Current stability : 1% Total beam current : 155mA Energy : 100keV Life time : 1000hours Emittance : 0.2π mm mrad	Estimation and verification of ECR, Multi-Cusp and Volume Type Beam orbit calculation Test of ion source (100hr in KEP, 1000hr in EVP) (Test with deuteron in EVP)	AC11		X		X	X
				Source analyses	AC12		X			
		Low Energy Beam Transport (LEBT)	Transmission : 90%	Suppression of beam divergence using space charge neutralisation in solenoid coil focusing	AC13		X		X	
				Suppression of fluctuation of current in pulse operation						X
				Beam analyses in RFQ matching conditions	AC14		X			
				Final layout	AC15		X			
	RF Source	Durability of RF Tube	1000hr continuous operation	Test in existing facility (1000hr)	AC21		X		X	
		Window, Circulator	Durability of windows and circulator	Development on the basis of plasma heating technology	AC22				X	
		Development Test Stand	Engineering verification of RF system	Fabrication of RF system for RFQ and DTL						X
	RFQ/DTL/HEBT	Beam Loss Estimation	Protection of discharge and beam collision in the wall of accelerator tube	Beam orbit calculation and bench mark test in existing accelerator	AC31		X		X	
		Cooling of Drift Tube	For high power accelerator	Examination of cooling method	AC32				X	
				Fabrication of model DTL, Test of cooling property						X
		Optimization of RFQ	Optimisation of electric field property in RFQ	Choise of RFQ structure	AC33		X			
				Fabrication of cold model of RFQ/DTL Measurement, optimization of electric field property	AC34		X		X	
		Optimization of DTL	Optimisation of electric field property in DTL	Choise of RFQ structure	AC35		X			
				Detailed DTL Design	AC36		X			
				Engineering evaluation of DTL at 5MeV	AC37	X				
		Matching Test of RFQ/DTL/HEBT	Optimisation of matching between each accelerat	Studies of RFQ/DTL maching	AC38		X			
				Fabrication and test of prototype						X
		Estimation of Activation	Maintenance method depends on activation of accelerator.	Estimation of activation and shielding effect from orbit calculation	AC39		X		X	
				Verification with experimental results						X
		Examination of S.C. Accelerator / Solid State AMP	Reduction of electric power and beam Loss To make the best use of independent cavity, 100kW AMP should be developed.	Examination of total system Cooperation with other accelerator development project (Neutron Spallation)						X
	Beam Diagnostics	Non-destructive Diagnostics of Beam	To accelerate large current beam without beam loss, indirect diagnostics of beam should be developed.	Development of sensor, signal processing and control	AC41		X			X

Classification 1	Classification 2	Item	Necessity	Development Item / Method	KEP Task ID	KEP US	KEP EU	KEP RF	KEP JP	EVP
Design Integration	Diagnostics for Safety and Stability on Operation	Diagnostics of Neutron Spatial Distribution	Monitor of target beam intensity	Target beam intensity measuring by neutron camera	DI11		X		X	
				Experiment on existing system						X
		Diagnostics of Target Temperature	To operate safely Li loop, the temperature of target is very important information.	Design of mirror arrangement to reduce neutron irradiation on camera	DI13				X	
				Experiment on existing system						X
	Estimation of Activation	Radiation Field on the Operation	Estimation of radiation in test cell is necessary for setting design condition of maintenance equipment.	Selection of element having large cross section from investigating material constituted building and equipment	DI21		X	X	X	
				Estimation of activation	DI22			X		X
	Stabilities of Target Jet and Assembly	Measurement of Jet Thickness	Monitor of reducer nozzle deformation by erosion/corrosion of nozzle inner wall by flowing Li and irradiation by neutron beam	Examination and design of measurement methods	DI31			X	X	
				Measurement test in Li test loop	DI32			X		X
		Measurement of Assembly Size and Location	Monitor of target assembly distortion around back wall by neutron-beam irradiation	Examination and design of measurement methods	DI33				X	
				Measurement test in Li test loop						X
	Conventional Facilities	Design of Room Space	Room space and handling lines should be arranged exactly.	Detailed design of buildings in KEP	DI41				X	
				Final design of buildings in EVP						X
		Design of Utility	Power and water supply from the outer side should be clarified.	Detailed design of utilities in KEP	DI43				X	
				Final design of utilities in EVP						X
	Central Control & Common Instruments	Design of C.C. & C.I.	Central control should be revised for rationalized IFMIF.	Detailed design of C.C. & C.I. in KEP	DI51				X	
				Final design of C.C. & C.I. in EVP						X
	IFMIF Total System	Consistency, Operation Flow	Consistency of IFMIF total system should be checked, including analysis of operation flow from startup to shutdown.	Check of consistency and analysis of operation flow	DI61	X			X	
				Review along with progress of design						X
	Radiation Shield	Evaluation of Radiation Shield	Specifications of shielding walls should be clarified for building design.	Verification of current design by computer code and data library	DI71				X	
				Review along with progress of design and calculation method						X
	RAM, Safety Assessment	RAM for Total IFMIF	RAM should be performed for 3 stages of IFMIF	RAM for 3 stages IFMIF with detailed design	DI81				X	
				RAM for 3 stages IFMIF with final design						X
		Safety Assessment for Total IFMIF	Safety assessment should be performed for 3 stages of IFMIF.	Safety analysis and assessment for IFMIF with detailed design	DI83		X		X	
				Safety analysis and assessment for IFMIF with final design						X
				Occupational Radiation Exposure evaluation of IFMIF	DI85		X			
	License, Schedule, Cost Estimation	Licences, Regulation depending the Site	Licences and regulations about radiation, nuclear fuel material, electromagnetic wave, dangerous material, high-pressure gas, earth quake and fire should be considered. Also the local condition of nature and public should be considered.	Examination and design in obedience to regulations with an assumption on site country.	DI91				X	
				Procedures for licences						X
		Schedule and Work Items in the period of IFMIF	Whole schedule and work items about construction, operation and decommission should be analysed.	Analysis of schedule and work items	DI93				X	
				Review of the analysis along with progress of IFMIF project						X
		Cost Estimation	Cost estimation should be performed along with progresses of design, KEP and EVP. Operation cost and cost in life cycle should be estimated.	Cost estimation with results of KEP and detailed design	DI95				X	
				Cost estimation with results of EVP and final design						X

Appendix-B

IFMIF-KEP

Task Description Sheets

Test Facilities
Target
Accelerator
Design Integration

Test Facilities

Task ID	Task Title
TF11-EU	He Cooled High Flux Test Module
TF12-EU	Test Module thermal hydraulic testing with He-loop
TF23-EU	Optimization of Neutron Moderator / Reflector
TF24-EU	Design of neutron moderator/reflector integrated in creep-fatigue test module
TF33-EU	Micro-tomography development for non-destructive analysis of devices
TF51-EU	Source term of D-Li Reaction ($E_d < 50$ MeV)
TF52-EU	Source term of D-Li Reaction ($E_d < 18$ MeV)
TF54-EU	Source term of D-Li Reaction ($Z < 6$ isotopes)
TF55-EU	Source term of D-Li Reaction (2 - 30 MeV n + Fe)
TF56-EU	Nuclear Safety & Shielding
TF57-EU(NPI)	On-line gamma monitors
TF57-EU(ENEA)	On-line gamma monitors
TF61-EU	Re-evaluation of Irradiation Parameters
TF64-EU	Small Specimen Test Technology
TF21-JP	Experimental study on neutron energy and spatial distribution of Li(d,n) reaction
TF22-JP	Analysis of Asymmetry in the Neutron Irradiation Field
TF31-JP	Vertical Test Assembles (Design of test equipment, control system and sensor)
TF34-JP	Tritium Laboratory and Tritium processing
TF35-JP	Arrangement of Test Cell System
TF36-JP	Transfer of Heavy Equipment (Examination of universal robot system (URS))
TF38-JP	Operation method in off/normal conditions of IFMIF
TF39-JP	Feasibility study on gas-cooled high flux test cell
TF41-JP	Optimization of Staged Construction
TF42-JP	PIE Facility
TF53-JP	Reliability Study of the Activation Cross Section Library
TF62-JP	Review of concept of material test in IFMIF
TF63-JP	Establishment of small specimen test technology for fracture toughness

Task ID : TF11-EU

Task Title : He Cooled High Flux Test Module

Facility : Test Facilities

Institutes in Charge : FZK (Germany)

Contact Persons : Prachai Jorajitra, Robert Ruprecht (IMF I of FZK)

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Need/Motivation :

Providing a test module for specimen temperatures up to 1000 °C is one of the most challenging requirements for the IFMIF Test Facilities. The successful development of a He-cooled test module would provide for any material a broad temperature window as well as flexible and very safe operating conditions.

Brief Task Description :

Based on the existing reference design of the high flux test module (HFTM), detailed thermal hydraulics calculations will be performed, taking into account also potential irradiation induced dimensional changes, decay heat and temperature gradients. Detailed design studies of specimen capsules, rigs and a reference test module will also be performed taking into account fabrication and handling issues. Finally, a mock-up of a test module will be fabricated that is equipped with a representative number of rigs and instrumented specimen capsules.

Schedule : June 2000 – December 2002

Jun. 2000 – Jun. 2001	Re-evaluation of the existing reference design, taking into account different loading scenarios typical for "reduced" (50-125 mA) and "full performance" (250 mA) irradiation phases. After that: (1) detailed thermal hydraulics calculations, (2) FE-optimized design of a test module mock-up that can be equipped with a representative number of rigs (3) assessment of fabrication technology using a reduced activation steel like F82H-mod or EUROFER97.
Jan. 2000 – Dec. 2001	Detailed thermal hydraulic calculations, taking into account nuclear decay heat, thermal cycling as well as beam-off times. Evaluation, of whether the nuclear decay heat could replace very complicated electrical heaters during beam-off periods. (2) FE-optimized design of 3 instrumented rigs and 24 dummy rigs. The instrumented rigs are equipped with capsules containing an adequate number of miniaturized specimens. (3) Assessment of manufacturing processes.
Jan. 2001 – Dec. 2002	(1) Construction and fabrication of one test module mock-up and an adequate number of specimens, instrumented capsules and rigs using a reduced activation ferritic/martensitic steel like F82H-mod or

EUROFER97. (2) Verification of assembling, disassembling, positioning. (3) Proper function of the instrumentation equipment.

Task Deliverables

No.	Description	Due Date
1	Detailed design of test module and verification of fabrication technology	2001/06
2	Detailed design of 3 instrumented rigs and 24 dummy rigs	2001/12
3	Fabricate specimens, instrumented capsules, rigs and test module	2002/12

Task ID : TF12-EU

Task Title : Test Module thermal hydraulic testing with He-loop

Facility : Test Facilities

Institutes in Charge : CRPP-EPFL (Switzerland)

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Need/Motivation :

The successful development of the helium cooled test modules is one of the main development objectives of the IFMIF Test Facilities, and would provide for any material a broad temperature window as well as flexible and very safe operating conditions. Once the specimen capsules, rigs and the test module fabricated in task TF11-EU will be available, it is foreseen to test them in the He-gas loop that has been successfully developed at the PIREX facility at PSI Switzerland.

Brief Task Description :

The objectives of the testing of the module are three fold: (i) to demonstrate the structural integrity of the module under cycling in high specimen and capsule temperatures, (ii) to verify the thermo-hydraulic calculations and (iii) to check the feasibility of fabrication with RAFM steels.

Schedule : June 2000 – December 2002

Jan. 2001 – Dec. 2001 Perform modifications at the existing loop to adjust pressure, throughput, electronics and to connect it to the test module; reprogramming of the measuring system and tests.

Jan. 2002 – Dec. 2002 Thermal-hydraulic testing of the module under different flow rates, pressures and temperatures. This deliverable and due date depend on the testing module being at PSI in due time.

Task Deliverables

No.	Description	Due Date
1	He-loop modifications	2001/12
2	Module testing and report	2002/12

Task ID : TF23-EU

Task Title : Optimization of Neutron Moderator / Reflector

Facility : Test Facilities

Institutes in Charge : FZK (Germany)

Contact Persons : Anton Möslang (IMF I of FZK)

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Need/Motivation :

The objective of this sub-task is to improve further the neutron spectrum and the irradiation conditions in the high and medium flux volume of the test cell. Although the general data like H, He and dpa production reflect already DEMO-relevant irradiation conditions in the high flux volume, there is reasonable hope to further improve the irradiation conditions by adapting also the spectral distribution of the primary knock-on atoms. This distribution depends strongly on the neutron spectral distribution. The latter can be modified by an additional neutron moderator/reflector module that might become part of an existing test module. It is expected that a successful development of such a module will also improve the irradiation conditions for in-situ tritium release experiments on breeder ceramics in the medium flux region.

Brief Task Description :

MCNP calculations will be performed based on the reference design, but with an additional module that serves as neutron moderator and reflector. Size, position, geometry and material of this module will be varied and the related neutron response will be determined and evaluated, in order to get a promising combination of module location, geometry and material. These results serves as input for the task TF24-EU (design integration of a neutron moderator into the creep-fatigue test module).

Schedule : June 2000 – December 2002

Jun. 2000 – Dec. 2000 MCNP calculations of key irradiation parameters for the selection of a proper moderator/reflector geometry, location and material. 3D-Calculation of nuclear heat deposition in the moderator.

Jan. 2001 – Dec. 2001 Impact of moderator/reflector on W(T) function and other relevant irradiation parameters in the high and medium flux position for iron

Task Deliverables

No.	Description	Due Date
1	MCNP-code based optimisation of neutron moderator/reflector	2000/12
2	Impact of moderator on W(T) function and irradiation parameters	2001/12

Task ID : TF24-EU

Task Title : Design of neutron moderator/reflector integrated in creep-fatigue test module

Facility : Test Facilities

Institutes in Charge : FZK (Germany)

Contact Persons : Anton Möslang (IMF I of FZK)

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Need/Motivation :

The proper integration of a neutron moderator/reflector immediately downstream the high flux test module requires a modification of the creep-fatigue test module or even its temporary replacement by integration of massive plates made of suitable material that is able to act as efficient neutron moderator. This moderator/reflector is necessary to increase the population of low energy neutrons for the irradiation of ceramic breeder materials in order to get fusion relevant tritium production rates in these materials and to optimize further the gas production to damage rates in other test modules.

Brief Task Description :

Based on the results (e.g. 3D-heat deposition, geometry, material) of MCNP calculations (task TF23-EU), thermal hydraulic calculations will be performed in conjunction with a design outline for a neutron moderator/reflector as part of an existing test module; the design outline includes He-gas coolant ducts and some instrumentation. In a second step a feasibility study is foreseen, if a refractory metal or Beryllium is proposed as moderator/reflector material; key joining techniques are experimentally verified. Finally a detailed design of the moderator/reflector component will be done as well as the design integration into an existing test module and VTA.

Schedule : June 2000 – December 2002

July 2000 – Dec. 2001 Thermal hydraulic calculations and design outline for a neutron moderator/reflector as part of an existing test module; outline of He-gas coolant and piping;

Jan. 2001 – Dec. 2002 Feasibility study if a refractory metal is proposed; experimental verification of necessary joining techniques; detailed design of moderator/reflector component; design integration into existing test module

Task Deliverables

No.	Description	Due Date
1	Thermal hydraulic calculations & design outline of neutron moderator	2001/12
2	Feasibility study & detailed design of this component	2002/12

Task ID : TF33-EU

Task Title : Micro-tomography development for non-destructive analysis of devices

Facility : Test Facilities

Institutes in Charge : NILPRP (Romania)

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Need/Motivation :

A non-destructive, powerful analysis of all safety relevant devices inside the highly activated test cell is urgently needed. The micro-tomography method developed in recent years within the nuclear community is the only known tool that could meet these requirements. This technique has the potential of monitoring voids, microcracks and flaws in a wide range of materials and densities. That is, it is able to assess the structural integrity of of activated and completely assembled rigs, test modules and the Li-target backwall.

Brief Task Description :

The existing micro-tomography devices must be further optimized and miniaturized in order to get even better special resolution and to become able for the detection of micro-cracks generated in test cell components. A qualified inspection of highly neutron loaded structural components during shut down phases and parameter input for lifetime prediction assessment would be possible. Main design constraints are: suitable for operation in test cell environment (remote handling capabilities), limited access angle, wide range of material densities and attenuation coefficients, very high space resolution requirements. Prototype fabrication of a microtomography facility suitable for operation in the IFMIF test cell environment and finally test on prototypes.

Schedule : June 2000 – December 2002

Jun. 2000 – Dec. 2000	Tomographic test measurements and conceptual design analysis of the micro-tomographic equipment for IFMIF test cell environment.
Jan. 2001 – Jun. 2001	Design of suitable micro-tomography equipment
Jul. 2001 – Dec. 2001	Evaluation of 2-D imaging detector for the application in in-situ radiography/neutronography of the He cooled high-flux test module
Jan. 2001 – Jun. 2002	Prototype fabrication of micro-tomography system
Jul. 2002 – Dec. 2002	Design of a consistent data base of the 3-D image reconstructions

Task Deliverables

No.	Description	Due Date
1	Design analysis	2000/12
2	Design of suitable micrography equipment	2001/06
3	Evaluation of 2D imaging detector	2001/12
4	Prototype fabrication of micro-tomography system	2002/06
5	3D imaging reconstructions of specimen capsules, rigs, etc.	2002/12

Task ID : TF51-EU

Task Title : Source term of D-Li Reaction (E_d < 50 MeV)

Facility : Test Facilities

Institutes in Charge : FZK (Germany)

Contact Persons : Ulrich von Möllendorff (IRS of FZK), Ulrich Fischer (IKET of FZK)

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Need/Motivation :

The D-Li neutron source term is of prime importance for calculating the neutron yield, the neutron spectrum and the nuclear responses in the test cell. The present neutron yield uncertainty of ±20% runs through all neutronic answers. Complete nuclear data files are prepared for deuteron energies up to 50 MeV based on a full data *evaluation* for the double-differential cross-sections of the ^{6,7}Li(d,xn) reactions.

Brief Task Description :

The objective of this sub-task is to provide the required data in terms of a full data evaluation of the double-differential ^{6,7}Li(d,xn) reaction cross-sections using state-of-the-art nuclear models and computational procedures. Nuclear data evaluation is performed in co-operation with INPE Obninsk, Russian Federation. A newly developed method based on diffraction theory, a modified intranuclear cascade model as well as standard evaluation techniques is employed to describe the emission of particles through the d + ^{6,7}Li – reactions. Numerical calculations for the double differential cross-sections of the ^{6,7}Li(d,xn) reactions are performed with the DISCA/3D code of INPE Obninsk which makes use of the new evaluation method. The resulting nuclear data files are prepared in standard ENDF-6 format and processed for use with an updated version of the McDeLi Monte Carlo code.

Schedule : June 2000 – December 2002

Jul. 2000 – Dec. 2001 Data files for the ^{6}Li(d,xn) reactions with double differential cross-sections in ENDF-6 format for deuteron energies up to 50 MeV.

Jan. 2002 – Dec. 2002 Data files for the ^{7}Li(d,xn) reactions with double differential cross-sections in ENDF-6 format for deuteron energies up to 50 MeV.

Task Deliverables

No.	Description	Due Date
1	Data files for the ^{6}Li(d,xn) reactions with double differential cross-sections	2001/12
2	Data files for the ^{7}Li(d,xn) reactions with double differential cross-sections	2002/12

Task ID : TF52-EU

Task Title : Source term of D-Li Reaction (E_d < 18 MeV)

Facility : Test Facilities

Institutes in Charge : IPP NPI in Rez (Czech)

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Need/Motivation :

The D-Li neutron source term is of prime importance for calculating the neutron yield, the neutron spectrum and the nuclear responses in the test cell. The present neutron yield uncertainty of ±20% runs through all neutronic answers. Accelerator based measurements will be performed to provide *experimental* data on the Li(d,xn) reaction.

Brief Task Description :

The research program is intended to provide accurate data concerning the yield observables of the Li(d,xn) reaction. Measurements will be performed employing the currently upgraded cyclotron-based Fast Neutron Facility (FNF) of the Nuclear Physics Institute (NPI) to validate the Li(d,xn) cross-section evaluation recently produced by FZK/INPE Obninsk. Part of the experimental data (thick-target yield) will also be utilized for benchmarking the semi-empirical McDeLi model. As a first step of the task the data at the deuteron energy of 18 MeV will be obtained. The work will be performed in close contact with nuclear data specialists at FZK (task TF51-EU).

Schedule : June 2000 – December 2002

Jul. 2000 – Dec. 2000 Upgrade of the NPI FNF target station for measurements of the neutron cross-section of the deuteron reaction on a Li-target in an open-geometry arrangement.

Jan. 2001 – Jun. 2001 The differential and the total spectral yield of neutrons from the Li(d,xn) reaction ≤18 MeV deuteron energy will be measured in the angular range 0°-150°.

Aug. 2001 – Dec. 2001 The differential yield results will be used for comparison with and possibly improvement of the Li(d,xn) evaluated nuclear data files. The thick-target yield data will be used, in addition, to benchmark McDeLi model calculations.

Task Deliverables

No.	Description	Due Date
1	Target station upgrade	2000/12
2	Differential yield data acquisition	2001/06
3	Comparison with evaluated-data based calculations; benchmark of McDeLi	2001/12

Task ID : TF54-EU

Task Title : Source term of D-Li Reaction (Z < 6 isotopes)

Facility : Test Facilities

Institutes in Charge : FZK (Germany)

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Need/Motivation :

In the IFMIF Test Cell there will be a considerable amount of neutrons produced above 20 MeV. Neutron nuclear data files for energies above 20 MeV are lacking. They need to be developed and processed for use with the calculational tools available for IFMIF design analyses. This includes neutron cross section data for collided spectrum calculations and important nuclear responses like dpa, nuclear heating, gas production, and others. Nuclear data files for transport calculations are prepared for the nuclides Li-6, Li-7 and Be-9 up to 150 MeV neutron incidence energy. The focus of the evaluation effort will be on lightmass nuclides which are primarily important for the intermediate flux region of the IFMIF test cell. Activation cross-section data are prepared for nuclides with Z < 6 up to 150 MeV neutron incidence energy to complete the existing IEAF activation library in the low mass region.

Brief Task Description :

Nuclear data evaluation is performed in co-operation with INPE Obninsk, Russian Federation. A newly developed method based on diffraction theory, a modified intranuclear cascade model as well as standard evaluation techniques is employed to describe the emission of particles through the n + ^{6,7}Li and n + ^{9}Be reactions. The double differential cross-sections are calculated with the help of the DISCA/3D code which makes use of the new evaluation method. Whenever available, use is made of cross-section data measurements in the evaluation. The resulting nuclear data files are prepared in ENDF-6 format to allow the processing with standard computational tools.

Schedule : June 2000 – December 2002

Jun. 2000 – Dec. 2001 Data files for the n+^{6,7}Li reactions with double differential cross-sections

Jan. 2001 – Dec. 2002 Activation data files for nuclides with Z<6 for neutron energies <150 MeV.

Jan. 2002 – Dec. 2002 Data file for the n + 9Be reaction with double differential cross-sections.

Task Deliverables

No.	Description	Due Date
1	Data files for the n+^{6}Li(d,xn) reactions	2000/12
2	Activation data files for nuclides with Z<6	2001/12
3	Data file for the n + ^{9}Be reaction	2002/12

Task ID : TF55-EU

Task Title : Source term of D-Li Reaction (2 - 30 MeV n + Fe)

Facility : Test Facilities

Institutes in Charge : IPP NPI in Rez (Czech)

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Need/Motivation :

In the IFMIF Test Cell there will be a considerable amount of neutrons produced above 20 MeV. Neutron nuclear data files for energies above 20 MeV are lacking. They need to be developed and processed for use with the calculational tools available for IFMIF design analyses. This includes neutron cross section data for collided spectrum calculations and important nuclear responses like dpa, nuclear heating, gas production , and others. The only way to validate the data and tools for IFMIF neutron flux calculations is by benchmarking them against *experiments* with a neutron beam having a IFMIF-like energy distribution.

Brief Task Description :

Benchmark tests will be performed at NPI FNF to validate the neutron transport data files produced within the IFMIF work. As a first step, the transport of neutrons through an iron slab will be measured in an open geometry employing a white neutron spectrum ranging from 2 MeV to 30 MeV. In the second step, a collimated neutron beam will be employed for measuring the angle-dependent characteristics of neutron transport. The results will be used to benchmark MCNP calculations performed at FZK Karlsruhe using the IFMIF evaluated neutron transport data files.

Schedule : June 2000 – March 2002

Dec. 2000 – Jun. 2001 The spectral flux of fast neutrons penetrating the and emerging from the iron slab will be measured in the irradiation experiment, performed in an open geometry with a white IFMIF-like primary neutron spectrum.

Aug. 2001 – Dec. 2001 The experimental results will be used to benchmark the evaluated nuclear data files produced within the IFMIF work by comparison with calculations. The results will be presented in a final report jointly with FZK.

Task Deliverables

No.	Description	Due Date
1	Iron slab benchmark experiment	2001/06
2	Benchmark test of MCNP calculations, final report	2001/12

Task ID : TF56-EU

Task Title : Nuclear Safety & Shielding

Facility : Test Facilities

Institutes in Charge : ENEA (Italy)

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Need/Motivation :

The primary safety hazard associated with the test cell is besides the lithium inventory the radioactivity. As a result of the cost reduced IFMIF design, a complete re-evaluation of the shielding and activation calculations is necessary due to the significant design changes that have been made.

Brief Task Description :

The objectives of this subtask is to perform: (i) The estimation of the dose rate (gamma and neutron) in the operative areas of the IFMIF Test Facilities, especially those where the direct irradiation from the activated test assemblies may be remarkable, to verify the maximum allowable limit of 10 μSv/h. The level of radiation in inaccessible areas will be also assessed as well at the end of an irradiation cycle. (ii) The neutron induced gamma activation of test modules and specimens will be calculated to assess shielding requirements for the entire Test Facilities Complex. Furthermore, the material damages will be assessed as well, namely those in VTAs and specimens.

Schedule : June 2000 – March 2002

Jun. 2000 – Apr. 2001	Estimation of the dose rate in operative areas and in inaccessible areas. A geometric model of the test cell facilities will be defined and the 3-D Monte Carlo MCNP code will be used to perform neutron and gamma transport analysis
May 2001 – Dec. 2001	Activation calculations of test modules and specimens. The neutron induced gamma activation of test modules and specimens will be calculated by the ANITA 4-M code.
Jan. 2002 – Jun. 2002	Definition of Radiological concerns related to PIE, tritium & glove box labs.
Dec. 2002	Final report.

Task Deliverables

No.	Description	Due Date
1	Evaluation of dose rate in operative and inaccessible areas	2001/04
2	Activation calculations of the test modules and specimens	2001/12
3	Definition of radiological concerns based on calculated rad. inventory	2002/06
4	Final report	2002/12

Task ID : TF57-EU(NPI)

Task Title : On-line gamma monitors

Facility : Test Facilities

Institutes in Charge : IPP NPI in Rez (Czech)

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Need/Motivation :

The importance of the task is to provide reliable methods to measure the gamma/neutron field in the test cell and test assembly. (a) Activation Foils: This is a dosimetric method largely used in fission reactors. Its application to IFMIF requires to improve the available dosimetry database for high energy neutrons. (b) Real-Time Neutron/Gamma Detectors: The option of using real-time detectors for spatial and time-resolved flux monitoring will be examined by means of a survey of the present status of in-core reactor monitoring instrumentation (microfission chambers and self-powered detectors) in EU/US nuclear sites. An assessment of these detectors for their application to IFMIF (where sensitivity to neutrons up to 50 MeV is required) will be provided.

Brief Task Description :

The proposed program aims at the test of prototype on-line neutron monitors for IFMIF in an IFMIF-like neutron field provided by the upgrade of the NPI cyclotron-based Fast Neutron Facility (FNF). In parallel, integral tests on activation foils selected for IFMIF neutron dosimetry will be also performed. All this work will be performed in close contact with ENEA-Frascati (Italy) which will provide prototype on-line neutron monitors and activation foils.

Schedule : June 2000 – March 2002

Jul. 2000 – Dec. 2000	Exploration of suitability of NPI cyclotron-based Fast Neutron Facility (FNF) to simulate an IFMIF-like neutron field; selection of the most suitable reaction, upgrade of the cyclotron target station.
Oct. 2000 – May 2001	Design of high power neutron station.
May 2001 – Sep. 2001	Experimental validation of the dosimetry foil package (multifoil activation).
Oct. 2001 – May 2002	Final tests on cyclotron of IFMIF neutron monitors (sub-miniaturized fission chambers and activation foils) ; Final report.

Task Deliverables

No.	Description	Due Date
1	Search for IFMIF-like neutron source reaction	2000/12
2	Design of high power station	2001/05
3	Preliminary neutron spectrum measurements	2001/09
4	Final experiments, both on fission chambers and activation foils	2002/03

Task ID : TF57-EU(ENEA)

Task Title : On-line gamma monitors

Facility : Test Facilities

Institutes in Charge : ENEA (Italy)

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Need/Motivation :

The importance of the task is to provide reliable methods to measure the gamma/neutron field in the test cell and test assembly. (a) Activation Foils: This is a dosimetric method largely used in fission reactors. Its application to IFMIF requires to improve the available dosimetry database for high energy neutrons. (b) Real-Time Neutron/Gamma Detectors: The proposed programm aims at the realization of prototype on-line neutron monitors for IFMIF in conjunction with irradiation tests performed on NPI cyclotron facility (another task TF57-EU).

Brief Task Description :

(a) After completion of on-going EFDA contract for the definition of the final characteristics of sub-miniaturized fission chambers monitors for IFMIF, the construction of a prototype monitor will be performed by CEA. Photo-fission effects should be also evaluated. As a final step of the work, a test campaign of the prototype IFMIF neutron on-line monitor and of the activation foils will be performed in the upgraded NPI Fast Neutron Facilities. (b) Various dosimetry foils (Co, Au, Mn, Rh, Lu, Y and Zr) will be positioned close to the target and irradiated; the gamma activity from the samples will be subsequently counted in HPGe detectors. After corrections, the measured saturated activities will be used for spectrum unfolding and cross section optimization. Spectra measured with scintillators will be used as reference spectra. Prior checking of deconvolution codes' performance at high neutron energy is required.

Schedule : June 2000 – March 2002

Mar. 2001 – Sep. 2001	Sub-miniaturized fission chamber prototype construction and relevant report.
Nov. 2001 – Nov. 2002	Analyses of the measurements of tests performed at NPI (CR) on activation foils and sub-miniaturized chamber prototypes.

Task Deliverables

No.	Description	Due Date
1	Sub-miniaturized fission chamber prototype construction and report	2001/09
2	Analyses of irradiations on activation foils and sub-miniaturized chamber prototypes.	2002/11

Task ID : TF61-EU

Task Title : Re-evaluation of Irradiation Parameters

Facility : Test Facilities

Institutes in Charge : FZK (Germany)

Contact Persons : Anton Möslang (IMF I of FZK)

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Need/Motivation :

Because (i) significant design changes have been performed as consequence of the cost reduced IFMIF version, (ii) a neutron moderator/degrader is foreseen, and (iii) a staged approach is seriously considered, complete re-evaluation of all irradiation parameters in reference materials throughout the test cell is necessary. That is, 3D contour-plots will be calculated of relevant parameters like irradiation volume, total neutron flux, hydrogen and helium gas transmutation products, displacement damage, gas to damage ratios, nuclear and gamma heating throughout all test regions for the reduced cost design.

Brief Task Description :

The irradiation parameters and engineering responses are calculated by use of the Monte Carlo neutron and photon transport code MCNP. Geometrical models have to be developed to meet the new cost reduced IFMIF test cell and test module design either for 50 mA (2 MW) or 125 mA (5 MW) beam power.

Schedule : June 2000 – December 2002

Jun. 2000 – Dec. 2000	Irradiation parameters for the 50 mA (2 MW) on a 4 cm x 5 cm target
Jan. 2001 – Dec. 2001	Set of irradiation parameters for 50mA with 20 cm2 area, but varying aspect ratios; Set of irradiation parameters for 125mA target on a 10 cm x 5 cm target.
Jan. 2002 – Dec. 2002	Irradiation parameters for 50, 125 and 250 mA current, using reference beam footprints for different primary candidate materials.

Task Deliverables

No.	Description	Due Date
1	Irradiation parameters for the 50 mA stage on a 4cm x 5 cm target.	2000/12
2	Irradiation parameters for 50 mA, 125 mA for various beam footprints	2001/12
3	Irradiation parameters for 50, 125 and 250 mA for different materials	2002/12

Task ID : TF64-EU

Task Title : Small Specimen Test Technology

Facility : Test Facilities

Institutes in Charge : CRPP-EPFL (Switzerland)

Contact Persons : Philippe Spätig (CRPP-EPFL)

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Need/Motivation :

Activities in that field are essential in order to fully utilize the available irradiation volume and to qualify all miniaturized specimens. One of the most challenging issues regarding the development of miniaturized specimens is the possibility to get reliable fracture toughness measures from small specimens. The efforts will be concentrated on fracture specimens of F82H ferritic/martensitic steels, such as mini bend bars and Charpy as well as compact tension, from which effective fracture toughness is measured.

Brief Task Description :

The possibility of performing the mechanical testing, SEM observations and fracture reconstruction using confocal microscopy with active materials will be demonstrated. The effect of irradiation and irradiation conditions on the fracture toughness-temperature curve will be determined. The specimens which will be used are already under irradiation in Budapest (KFKI) and Petten.

Schedule : June 2000 – December 2002

Jun. 2000 – Sep. 2001	Machining and precracking of subsized bend bars and Charpy specimens. Development of the corresponding bend fixtures, clevises and load train including a system to set up active specimens (mini compact and bend bar) by remote handling in a testing machine. - Mechanical testing of fracture specimens.
Oct. 2001 – Sep. 2002	Preparation of active specimens for SEM and confocal microscopy observations after testing. SEM observations of fractures surfaces & confocal microscopy - fracture reconstruction
Oct. 2002 – Dec. 2002	Final report

Task Deliverables

No.	Description	Due Date
1	Machining and testing of subsized specimen, development of tools	2001/09
2	Preparation of active specimens followed by microstructural analyses	2002/09
3	Final report	2002/12

Task ID : TF21-JP

Task Title : Experimental study on neutron energy and spatial distribution of Li(d,n) reaction

Facility : Test Facilities

Institutes in Charge : Tohoku University (Japan)

Contact Persons : Mamoru Baba (Tohoku University)

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Need/Motivation :

For the design of test cell, energy spectrum and spatial distribution of neutrons produced by Li(d,n) reaction is needed. Systematic experiments designed for obtaining energy spectrum and its angular distribution using an existing accelerator is necessary.

Brief Task Description :

Using the AVF cycrotron and its supporting facilities, (1) energy spectrum and its angular distribution of D-Li neutrons will be systematically measured as a function of the incident deuterium ion energy, (2) energy spectrum and its distribution at the test cell will be estimated, and (3) radioisotopes produced with the D-Li reaction will be investigated.

Schedule : April 2000 – September 2002

Jun. 2000 – Mar. 2001 Design of target chamber and specimen holder
Setup of neutron detector
Spectrum detection by TOF with 20 and 25 MeV D

Apr. 2001 – Mar. 2002 Spectrum detection by TOF with 30, 35 and 40 MeV D
Identification of RI produced by the D irradiation by activation analysis

Apr. 2002 – Sep. 2002 Analysis of neutron energy spectrum and its spatial distribution.
Database construction of spectrum, distribution and RI production

Task Deliverables

No.	Description	Due Date
1	Neutron spectrum with 20 and 25 MeV D	2001/03
2	Neutron spectrum with 30, 35 and 40 MeV D	2002/03
3	Database of neutron spectrum and distribution and byproduct RI	2002/09

Task ID : TF22-JP

Task Title : Analysis of Asymmetry in the Neutron Irradiation Field

Facility : Test Facilities

Institutes in Charge : JAERI (Japan)

Contact Persons : Masayoshi Sugimoto (JAERI)

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Need/Motivation :

The neutron irradiation field of IFMIF is required to be uniform with flux gradient less than 10%/cm, which is based on the small specimen size. However, the 40-MeV deuterons interact with lithium and generate neutrons with forward peaking distribution, so that the beam footprint is large (20 cm width by 5 cm height) to cover the specimen size (~cm). Furthermore, two deuteron beams enter into a lithium target with 20-deg opening angle, and the beam intensity of each beam may be varied independently depending on the operating conditions, such as beam failure and planned beam-off. As one of two accelerators is operated at the first- and second-stage of the staged construction plan, the asymmetry of the irradiation field needs to be examined and the allowance level should be determined.

Brief Task Description :

The beam distribution on the target surface provided by the accelerator team is used to calculate the neutron field distribution inside the test assembly by using Monte Carlo code. The factors affecting the results like the balance of intensity and the position shift of two beams, the thickness fluctuation of liquid lithium flow, distortion of the target backwall and test assembly, etc. are evaluated and the criteria of the allowance of each effect are deduced. An idea to moderate the neutron flux gradient using reflecting materials in the test assembly is also examined.

Schedule : June 2000 – March 2002

Jun. 2000 – Mar. 2001	Setup of code/library and test calculations
Apr. 2001 – Mar. 2002	Analysis of asymmetry of irradiation field using realistic beam / target / test assembly conditions

Task Deliverables

No.	Description	Due Date
1	Test calculations using idealized conditions	2001/03
2	Analysis of asymmetry using realistic conditions	2002/03

Task ID : TF31-JP

Task Title : Vertical Test Assembles (Design of test equipment, control system and sensor)

Facility : Test Facilities

Institutes in Charge : JAERI (Japan)

Contact Persons : Toshiaki Yutani (JAERI)

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Need/Motivation :

The Vertical Test Assemblies (VTAs) are heavy (>5 tons), because they have the concrete shielding arranged in a stair-step. These VTAs must be positioned to ensure that the test modules are accurately aligned (±1mm) relative to the neutron source (Target Assembly) and each other. Satisfying this requirement requires the remote handling system and control system to handle accurately the heavy weight and the sensor to measure the position of target assembly and test modules. The proposed remote handling system is the Universal Robot system based on the gantry type crane with combined manipulator system. This system may handle VTAs accurately. However, the test modules may not be accurately aligned. If the concrete shielding is not fabricated accurately, VTAs will be inclined after setting up. And also the distances between target assembly and test module and between test modules will be changed by the bowing of test modules due to the differences of temperature and swelling rate during irradiation. Therefore, the structures of VTAs need to be modified.

Brief Task Description :

The structure of Vertical Test Assemblies (especially VTA1) is modified to ensure the accurate alignment of test module to target assembly and the constant distance between test module and target assembly. This task is performed in conjunction with the design of universal robot system and target assembly. The design of control system and sensor is involved in this task.

Schedule : April 2000 – September 2002
Apr. 2000 – Mar. 2001 Conceptual design of modified VTA1 structure
Apr. 2001 – Sep. 2002 More detailed design of VTA1 and sensor, etc

Task Deliverables

No.	Description	Due Date
1	Design of Vertical Test Assembly	2002/09
2	Design of control system and sensor	2002/09

Task ID : TF34-JP

Task Title : Tritium Laboratory and Tritium processing

Facility : Test Facilities

Institutes in Charge : JAERI (Japan)

Contact Persons : Toshiaki Yutani (JAERI)

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Need/Motivation :

The tritium Laboratory is constructed at the first stage. It has two functions. One is a disassembly of test module containing tritium, maintenance of target assembly and post irradiation examination of tritium contaminated or containing specimens, and another is a processing and temporary storage of tritium contaminated or containing materials produced in test cell and PIE laboratories. Therefore, this laboratory is composed of the tritium handling hot cells, tritium glove boxes and tritium processing systems. However, their layouts are not optimized. Also, the tritium processing method must be examined in detail.

Brief Task Description :

This task is performed with the next procedure.

(1) Examination of requirements to tritium laboratory

(2) Design of tritium handling hot cells, tritium glove boxes, tritium processing systems and tritium laboratory equipments

(3) The examinations of arrangement

Schedule : April 2000 – September 2002

Apr. 2000 – Mar. 2001 Examination of requirements

Apr. 2001 – Sep. 2002 Design and evaluation

Task Deliverables

No.	Description	Due Date
1	Examination of requirements	2001/03
2	Examination of tritium processing method	2002/09
3	Examination of tritium laboratory arrangement	2002/09

Task ID : TF35-JP

Task Title : Arrangement of Test Cell System

Facility : Test Facilities

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The test equipments such a VTA are equipped with various signal lines, power cables, and coolant lines. These systems need to be connected to their control systems with an optimum arrangement. Also, the coolant pipes, instrumentation equipment, vacuum pumping and emergency systems for test cell must be arranged in an optimized manner.

Brief Task Description :

This task involves the examination of arrangement for test cell, access cell test cell technology rooms and test module handling cell, and the examination of irradiation material's flow from test cell to post irradiation examination laboratories.

Schedule : April 2000 – September 2002
Apr. 2000 – Sep. 2002 Examination and evaluation

Task Deliverables

No.	Description	Due Date
1	Examination of optimum arrangement for test cell system	2002/09
2	Examination of optimum arrangement for test cell, access cell, etc.	2002/09
3	Examination of irradiation material's flow	2002/09

Task ID : TF36-JP

Task Title : Transfer of Heavy Equipment (Examination of universal robot system (URS))

Facility : Test Facilities

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The requirements to the remote handling system in the access cell are as follows.

(4) Routine VTAs removal and reloading operation
(5) Removal and exact insertion of shielding plug, VIT and removal test cell cover
(6) Routine VTAs assemble and disassemble operation
(7) Replacement of target assembly
(8) Any maintenance operation in the access cell and the test cell including cleaning of Li contamination

To satisfy those requirements, the remote handling system required to handle heavy load (up to xx tons) with high precision of 1 mm, and to be equipped with various multiple-purpose modular articulated robot systems. The proposed remote handling system of IFMIF is composed of large and small universal robot systems, a test module transporter and a rig transporter, etc. Both universal Robot systems are based on the gantry type crane with combined manipulator system. Above requirement will be satisfied by the large universal robot system in the access cell.

Brief Task Description :

The design of the proposed remote handling system involving large universal robot system is performed to make their specification. This task is performed in conjunction with the design of VTAs and target assembly.

Schedule : April 2000 – September 2002
Apr. 2000 – Mar. 2001 Examination of detailed requirements and handling procedures
Apr. 2001 – Sep. 2002 Design and evaluation

Task Deliverables

No.	Description	Due Date
1	Examination of requirements and handling procedures	2001/03
2	Examination of universal robot system	2002/09

Task ID : TF38-JP

Task Title : Operation method in off/normal conditions of IFMIF

Facility : Test Facilities

Institutes in Charge : JAERI (Japan)

Contact Persons : Toshiaki Yutani, Hiroo Nakamura (JAERI)

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Need/Motivation :

IFMIF operation in off/normal conditions influences the behavior of irradiation damage of specimens. So, the IFMIF operation method should be determined in compliance with kinds of materials and irradiation condition.

Brief Task Description :

On the basis of research on irradiation damage and experience in the existing irradiation experiment, the condition of irradiation in off/normal will be determined.

(1) Review of the existing experiment in off/normal conditions.
(2) Evaluation of effect of off/normal conditions on irradiation damage.
(3) Determination of off/normal conditions in IFMIF

Schedule : April 2000 – September 2002

Jun. 2000 – Mar. 2001	Review of the existing experiment in off/normal conditions and evaluation of effect of off/normal conditions on irradiation damage. Determine preliminary condition in off/normal.
Apr. 2001 – Mar. 2002	Revise conditions in off/normal based on existing irradiation experiment.
Apr. 2002 – Sep. 2002	Determine final condition in off/normal.

Task Deliverables

No.	Description	Due Date
1	Preliminary condition in off/normal	2001/03
2	Revised condition in off/normal	2002/03
3	Final condition in off/normal	2002/09

Task ID : TF39-JP

Task Title : Feasibility study on gas-cooled high flux test cell

Facility : Test Facilities

Institutes in Charge : Kyushu University (Japan)

Contact Persons : Akihiko Shimizu (Kyushu University)

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Need/Motivation :

Gas-cooled system is one of the candidate type of high flux position of the test cell. It is necessary to demonstrate spatial homogeneity and controllability of temperature in an mock-up under varying gamma heating rate.

Brief Task Description :

Mock-up of gas-cooled test cell in which gamma-heating is simulated by electric heater will be fabricated. The temperature distribution and response to the change of the heating rate is measured using a number of TCs installed into the mock-up.

Schedule : April 2000 – September 2002

Jun. 2000 – Mar. 2001	Design and fabrication of a mock-up. Fabrication of a gas-loop.
Apr. 2001 – Mar. 2002	Temperature control capability test in steady and varying heating condition.
Apr. 2002 – Sep. 2002	Modification of the mock-up to enhance the homogeneity and controllability of temperature.

Task Deliverables

No.	Description	Due Date
1	Temperature homogeneity and controllability of a mock-up test cell	2002/03
2	Effects of modification to the cell structure on the temperature	2002/09

Task ID : TF41-JP

Task Title : Optimization of Staged Construction

Facility : Test Facilities

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The original plan of irradiation tests and post irradiation tests has been made on the 250mA operation of the accelerators. However, the review of the plan is necessary, because the facility is expected to be constructed dividing into 3 stages (50mA->125mA->250mA).

Brief Task Description :

An examination for the size of deuteron beam spot and the review of the plan of irradiation tests and post irradiation tests of each stage are performed.

Schedule : April 2000 – September 2002
Apr. 2000 – Sep. 2002 Examination and review

Task Deliverables

No.	Description	Due Date
1	Examination for the size of deuteron beam	2002/09
2	Review of the plan of irradiation tests and post irradiation tests	2002/09

Task ID : TF42-JP

Task Title : PIE Facility

Facility : Test Facilities

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The PIE facilities are constructed in the 2nd stage to reduce the construction cost, except for the tritium laboratory that is constructed in the 1st stage. And the plan of irradiation tests and post irradiation tests will be reviewed according to staged construction. Therefore, the review for the items of post irradiation tests and the layout of PIE facilities is necessary.

Brief Task Description :

The review for the items of post irradiation tests and the layout of PIE facilities is performed according to the review for the plan of irradiation tests and post irradiation tests.

Schedule : April 2000 – September 2002
Apr. 2000 – Sep. 2002 Review

Task Deliverables

No.	Description	Due Date
1	Review for the items of post irradiation tests and the layout of PIE facilities	2002/09

Task ID : TF53-JP

Task Title : Reliability Study of the Activation Cross Section Library

Facility : Test Facilities

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The accuracy of the neutron nuclear data library at 14 ~ 50 MeV energy range and the charged particle reaction data library up to 40 MeV is a key issue for estimating the radioactivity and the nuclear heating during and after the irradiation test. The fundamental tools to calculate such parameters are already obtained, however, their accuracy is not fully checked yet.

Brief Task Description :

The newly compiled neutron data library, JENDL-3.2 High Energy File, is used mainly to analyze the induced radioactivity and nuclear heating inside the test assembly, test cell wall, concrete shield, etc., by using Monte Carlo code. The incident neutron flux is supplied by the other task, TF22-JP, to take into account the realistic beam and target arrangement. The evaluation of some important elements, Li, C, and O, are continued to satisfy the accuracy requirement for the activity/heating of specific materials. Such requirements are identified through the activity of other tasks, TF31-JP, TF34-JP and TF35-JP.

Schedule : June 2000 – March 2002

Jun. 2000 – Mar. 2001	Setup of code/library and perform test calculations
Apr. 2001 – Mar. 2002	Sensitivity analysis of calculation method/library data for the realistic beam/target/test assembly conditions and comparison with the required accuracy for radioactivity/heat production

Task Deliverables

No.	Description	Due Date
1	Test calculations using a new data library	2001/03
2	Analysis of sensitivity using realistic conditions and check of accuracy	2002/03

Task ID : TF62-JP

Task Title : Review of concept of material test in IFMIF

Facility : Test Facilities

Institutes in Charge : JAERI (Japan)

Contact Persons : Toshiaki Yutani, Hiroo Nakamura (JAERI)

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Need/Motivation :

To make maximum efficiency of irradiation test with limited volume and operation time, review of concept of material test on test item, test method and test device is necessary.

Brief Task Description :

(1) Review of the test items to simulate in fusion condition.
(2) Review of test methods.
(3) Review of test deivces.

Schedule : April 2000 – September 2002

Jun. 2000 – Mar. 2001 Preliminary review of test items, methods and deices.
Apr. 2001 – Mar. 2002 Interim review of test items, methods and deices.
Apr. 2002 – Sep. 2002 Final review of test items, methods and deices.

Task Deliverables

No.	Description	Due Date
1	Preliminary review of test items, methods and deices.	2001/03
2	Interim review of test items, methods and deices.	2002/03
3	Final review of test items, methods and deices.	2002/09

Task ID : TF63-JP

Task Title : Establishment of small specimen test technology for fracture toughness

Facility : Test Facilities

Institutes in Charge : Kyoto University and Tohoku University (Japan)

Contact Persons : Akihiko Kimura (Kyoto Univ.), Hiroaki Kurishita (Tohoku Univ.)

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Need/Motivation :

For efficient use of the limited irradiation volume, optimization of specimen size test procedure and test matrix is necessary. Especially the fracture toughness test procedure and specimen matrix should be determined.

Brief Task Description :

Systematic investigation will be carried out on the effect of specimen size, pre-cracking condition, deformation speed and test environments on the fracture toughness derived with pre-cracked bend bar or DCT specimens. Also examined will be other new techniques to evaluate fracture toughness.

Schedule : April 2000 – September 2002

Jun. 2000 – Mar. 2001	Set up of test machine. Size and test speed effect at room temperature
Apr. 2001 – Mar. 2002	Set up of high temperature test chamber. Size, test speed and environment effects at high temperature. Investigation of other techniques for fracture toughness evaluation.
Apr. 2002 – Sep. 2002	Optimization of the specimen size and determination of the test matrix for the irradiation test

Task Deliverables

No.	Description	Due Date
1	Size, precracking and test speed effect on fracture toughness data at RT	2001/03
2	Size, test speed and environment effects at high temperature Investigation of other technique for fracture toughness evaluation	20020/3
3	Optimization of the specimen size and determination of the test matrix for the irradiation test	2002/09

Target

Task ID	Task Title
TG11-EU	Water experiments at the joint of the replaceable back plate
TG12-EU	Jet Flow Stability Analysis
TG15-EU	Support to Japanese test for the cavitation conditions at EMP and at the joint of replaceable black plate
TG22-EU, TG31-EU	Lithium corrosion and chemistry
TG61-EU, TG71-EU	Lithium target safety analysis and thermal transient analysis of target lithium loop
TG82-EU	Detailed design, fabrication and remote handling test of the removable backplate
TG11-JP	Examination of free surface behavior under low pressure
TG12-JP	Design of Li test loop mockup
TG13-JP, TG16-JP, TG21-JP	Free surface flow study of liquid lithium
TG31-JP	Detection and control of impurities in molten Li
TG61-JP	Numerical analyses for transient behavior of Li loop
TG81-JP	Design of remote handling devices

Task ID : TG11-EU

Task Title : Water experiments at the joint of the replaceable back plate
Facility : Target

Institutes in Charge : ENEA (Italy)

Contact Persons : Gianni Dell'Orco (ENEA Brasimone)

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Need/Motivation :

The reference IFMIF design is based on the concept of a replaceable back plate. This solution was chosen firstly for its capability to allow for a significant reduction of the target substitution time, i.e. for an increase of the duty factor. Once more, due to the small dimension of the replaceable back plate with respect to the whole target structure, the use of a replaceable back wall reduces strongly the disposal of irradiated material. At the same time, it implies the presence of a joint in the nozzle inlet region. This discontinuity is surely influencing the jet stability, particularly with respect to the jet surface stability. Objective of the envisaged measurements is to investigate the jet stability in the presence of a replaceable back wall.

Brief Task Description :

The mock-up, properly assembled on a frame, will be host in a special glove box provided with the cooling and electrical feedthroughs, the inert gas and vacuum system. The mock-up water supply loop will be derived from the CEF 1-2 thermal hydraulic facility of Brasimone. The water loop main parameters (water temperatures, pressures, flows etc.) will be measured by using a proper data acquisition system.

- Test Facilities used:

The tests will be performed in a glove box apparatus hydraulically connected to the CEF 1-2 facility of ENEA Brasimone. This thermal hydraulic facility, already used for the ITER Breeding Blanket Beryllium-Wall Interaction small-scale tests and for the ITER Divertor Cassette Body Prototype thermal-hydraulic tests, consists of two demineralized water closed circuits organised in two independent or twin loops. The main features of the testing apparatus are :

glove box dimension (ø x l)	… mm x … mm;
water inlet temperature	140 °C;
water flow rate	2 x 70 kg/s;
water inlet pressure	2.5 Mpa

Schedule :

- Jul. 2001	Design of water experiment and related mock-up
- Dec. 2001	Mock-up fabrication
- Dec. 2001	Testing apparatus modification and preparation
- Dec. 2002	Report on the water test

Task Deliverables

No.	Description	Due Date
1	Design of water experiment and related mock-up	2001/07
2	Mock-up fabrication	2001/12
3	Testing apparatus modification and preparation	2001/12
4	Report on the water test	2002/12

Task ID : TG12-EU

Task Title : Jet Flow Stability Analysis

Facility : Target

Institutes in Charge : ENEA (Italy)

Contact Persons : Silvio Cevolani (ENEA Bologna)

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Need/Motivation :

The reduction in the IFMIF cost is partially obtained by means of changes in parameters influencing the liquid lithium jet behaviour, such as the beam power distribution and the static pressure in the loop. Objective of this subtask is to define the thermal-hydraulic conditions of the liquid lithium jet for the present design requirements. The work will be performed by means of the code RIGEL, developed in ENEA in the frame of the IFMIF-CDA and already used during that preliminary design phase. The results of the activity will give the main parameters for the definition of the jet stability tests.

Brief Task Description :

The task will start with the review of the Target design parameter basing on the new IFMIF requirements. This phase will include also the preparation of the RIGEL code input data. Then thermal hydraulic analysis of the Li Jet will be using the RIGEL code. Final results will be expressed in terms of temperature and velocity distribution of the Jet; evaluation of the evaporation rate at the free surface, pressure distribution in the Jet, no boiling conditions. All these results will be used for the updating of the target design.

Schedule :

- Jul. 2001	Target design parameter review Target design parameter review basing on the new IFMIF requirements including the preparation of the RIGEL code input data
- Dec. 2001	Preliminary evaluations with the RIGEL code
- Dec. 2002	Final results Final results in terms of temperature and velocity distribution of the Jet; evaluation of the evaporation rate at the free surface, pressure distribution in the Jet, no boiling conditions. All these results will be used for the updating of the target design.

Task Deliverables

No.	Description	Due Date
1	Target design parameter review	2001/07
2	Preliminary evaluations with the RIGEL code	2001/12
3	Final results	2002/12

Task ID : TG15-EU

Task Title : Support to Japanese test for the cavitation conditions at EMP and at the joint of replaceable black plate

Facility : Target

Institutes in Charge : ENEA (Italy)

Contact Persons : Silvio Cevolani (ENEA Bologna)

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Need/Motivation :

The presence in the reference IFMIF design of a replaceable back plate calls for the investigation of the discontinuity effect on the jet stability. Objective of this subtask is to define the general similarity conditions for the experiments. Once more, one of the major factors of the Li loop cost reduction plan, is to reduce the Li loop height, thus the depth of underground Li loop building.

The height reduction decreases static pressure on every plan inside the Li loop, consequently increases the cavitation risk on every Li loop component. Cavitation must be avoided because it is a source of damages and jet instability. Primary pump, flow straightener and nozzle were considered in the old and more conservative work conditions. It is necessary reconsider the new conditions and repeats some study performed in 1998. In this frame, JAERI has planned some cavitation test in small Li loop. CASBA noise detection technique and ENEA specialist will support this test. The results will give an evaluation of actual cavitation risk and the new requirements for experiments in dynamic simulation.

Brief Task Description :

JAERI has planned some cavitation test in small Li loop. CASBA noise detection technique and ENEA specialist will support this test. The results will give an evaluation of actual cavitation risk and the new requirements for experiments in dynamic simulation

Schedule :

- Jul. 2001	Design parameter review of the replaceable back plate and of the Li cooling loop
- Dec. 2002	Test and final results Support of ENEA specialist to the JAERI cavitation test in small Li loop through the ENEA CASBA noise detection technique and result analysis

Task Deliverables

No.	Description	Due Date
1	Design parameter review	2001/07
2	Test and final results	2002/12

Task ID : TG22-EU, TG31-EU

Task Title : Lithium corrosion and chemistry

Facility : Target

Institutes in Charge : ENEA (Italy)

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Need/Motivation :

The construction of the IFMIF loop and target requires the development of suitable systems and materials able to operate in flowing Li. Even if the envisaged operating temperatures within the target and in the loop are relatively low, both the effect of corrosion/erosion and liquid metal chemistry have to be controlled and assessed.
In fact, as in the case of the sodium, the lithium corrosion is strongly influenced by the presence of non-metallic impurities into the liquid metal. Those impurities, especially N and C, are able to form Li- compounds which can increase the corrosion effects on steels. This phenomenon, in addition to the elemental dissolution, can create problem for the structural materials.
Aims of the present task are the :
- Development of a Li purification strategy, including monitoring and removal systems;
- Evaluation of the corrosion rate of different materials (namely steels) in conditions relevant for the IFMIF loop and target.

Brief Task Description :

Two kinds of impurities could be present in the lithium flowing through the IFMIF target. A first group, including N, H, C and O, can affect both the corrosion behaviour of the structural materials and the loop operational condition (deposits, plugs). A second group of impurities is related with elements generated by nuclear reactions in the target. In this case, the generation of Tritium and Beryllium could be a crucial point for the safety of the system.

The action of ENEA is manly focused on the development and the conceptual design of the purification system and impurity monitoring systems for the IFMIF loop. More in detail, the following techniques could be considered:
- electrochemical sensors for N, C and H;
- resistivity meter for N;
- diffusion carbon meter;
- analytical techniques

Among the possible techniques, ENEA will investigate the use of electrochemical sensors for N and evaluate different systems for C (for instance, diffusion systems). The possibility of coupling a "permeation method " with mass spectrometry for H isotopes determination will be also investigated (using H and D).

At the same time, possible methods that could be used for the removal of such impurities from the liquid metal will be investigated. Among them, two systems will be

investigated in detail:
a) the use of cold trap
b) the use of hot trap

In parallel to these studies, some investigations on the behaviour of steels (namely austenitic and martensitic) in flowing Li could be done. Particular attention will be given to investigation of new materials more resistant to Li corrosion. These tests will be conducted in a small special Li loop available in Brasimone and in glove-boxes. However, the existing loop needs a deep remaking.

The activities described above will be performed in close co-operation with the University of Nottingham which has large experience in Alkali Liquid Metals and monitoring systems.

Schedule :

Basic tests of Cold trap, Hot Trap and on-line monitoring

- Dec. 2000	Selection of the most promising on-line monitoring methods (for N, C, H/D) for the successive development. Preparation of the specifications for those meters and beginning the tests for N meters in stagnant Li. Intermediate report.
- Dec. 2001	Development of meters and conclusion of tests in stagnant conditions. Development of hot and cold trap systems and first tests. Intermediate report.
- Dec. 2002	Final tests in dynamic loop with impurities control for the metres and the traps. Final report.

Lithium corrosion tests for the loop components and back wall materials

- Dec. 2000	Modification of the existing loop for the new experiments. Specifications preparation, test section design and components purchase. Intermediate Report
- Dec. 2001	Loop re-adaptation and compatibility tests beginning. Intermediate Report
- Dec. 2002	Conclusion of the tests. Final report

Analysis for the behaviour of some impurities in the primary loop

- Dec. 2001	The main impurities will be evaluated and a strategy for trapping will be defined. This analysis will concern mainly C, N, O but also the presence of radioactive and dangerous elements (T, Be). Conclusion and final report.

Task Deliverables

No.	Description	Due Date
1	Intermediate report on Impurities monitoring and control	2000/12
2	Intermediate report on corrosion	2000/12
3	Intermediate report on Impurities monitoring and control	2001/12
4	Intermediate report on corrosion	2001/12
5	Final report on impurities characterisation	2001/12
6	Final report on Impurities monitoring and control	2002/12
7	Final report on corrosion	2002/12
8	Final report on impurities characterisation	2002/12

Task ID : TG61-EU, TG71-EU

Task Title : Lithium target safety analysis and thermal transient analysis of target lithium loop

Facility : Target

Institutes in Charge : ENEA (Italy)

Contact Persons : Luciano Burgazzi (ENEA Bologna)

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Need/Motivation :

The evaluation of the risk associated with the IFMIF Target operation requires the identification and description of the possible system failure modes and the evaluation of their consequences. A preliminary safety analysis was made in the CDA phase. As some important modifications have been brought up to the Target, a new "safety analysis" activity finalised: 1) to verify if the design improvement meet the safety goals; 2) to identify the transient and accident sequences that could lead to dangerous situation for the Target and for the environment; 3) to analyse these sequences. This analysis will be conducted on the latest version of the design.

Brief Task Description :

ENEA will perform a review of hazard analysis for the Target oriented towards detailing, on a component-by-component basis, all possible failure modes and identifying their effects. Also the effects of the supporting and surrounding subsystem or system malfunctions will be analysed. ENEA will perform also the preliminary dependent failure analysis, that allows to identify the failure that can defeat the redundancy or diversity employed in the design to improve the availability of the subsystem plant functions.

We underline the probabilistic internal events analysis and the preliminary environmental impact analysis are included in the design integration activities.

ENEA will carry out an analysis of the lithium loop transients and accidents. A Lithium target loop model will be developed, using the ATHENA code

Schedule :

- Mar. 2002 LiTarget safety analysis review
  - Review of hazard analysis for the Target oriented towards detailing, on a component-by-component basis, all possible failure modes and identifying their effects. Also the effects of the supporting and surrounding subsystem or system malfunctions will be analysed.
  - Preliminary dependent failure analysis, that allows to identify the failure that can defeat the redundancy or diversity employed in the design to improve the availability of the subsystem plant functions.
  - (The probabilistic internal events analysis and the preliminary environmental impact analysis are included in the design integration

activities).

- Dec. 2002 Thermal transient analysis of target lithium loop
  - Analysis of the lithium loop transients and accidents. A Lithium target loop model will be developed, using the ATHENA code.

Task Deliverables

No.	Description	Due Date
1	Li Target safety analysis review	2002/03
2	Transient and accident analysis of Target Lithium loop	2002/12

Task ID : TG82-EU

Task Title : Detailed design, fabrication and remote handling test of the removable backplate
Facility : Target

Institutes in Charge : ENEA (Italy)

Contact Persons : Carlo Damiani (ENEA Brasimone)

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Need/Motivation :

The reference IFMIF design is based on the concept of a replaceable back plate. This solution was chosen firstly for its capability to allow for a significant reduction of the target substitution time, i.e. for an increase of the duty factor. Once more, due to the small dimension of the replaceable back plate with respect to the whole target structure, the use of a replaceable back wall reduces strongly the disposal of irradiated material.
For the IFMIF-CDA, ENEA proposed a back plate design based on the so called Bayonet concept. The main advantages of such a solution are concerned with the design simplicity and with the possibility to change the back plate without removing the VTA (Vertical Test Assembly).

Objective of this activity is to realise a removable back plate sample and to test the bayonet back plate remote handling.

Brief Task Description :

- A conceptual RH design and general test specification will be defined
- A detailed design of a target assembly with a back plate easily removable will be developed following by the construction of the and construction
- Then a detailed test specification will be developed as well as the shop drawings of the test section with particular indication of the key tolerances and of the functional gaps.
- Test campaign aimed at the verification and improvement of the mock-up of the back will be executed.
- Finally, the design will be reviewed basing on the test results.

Schedule :

- Jun. 2001	Conceptual RH design and general test specification
- Dec. 2001	Detailed design and construction of the target assembly with a back plate easily removable
- Dec. 2001	Detailed test specification including the shop drawings of the test section with particular indication of the key tolerances and of the functional gaps
- Dec. 2002	Test campaign aimed at the verification and improvement of the design. Final report including the review of the design

Task Deliverables

No.	Description	Due Date
1	Conceptual RH design and general test specification	2001/06
2	Design and fabrication of the replaceable back plate mock-up	2001/12
3	Detailed test specification including the shop drawings of the test section with particular indication of the key tolerances and of the functional gaps	2001/12
4	Test campaign aimed at the verification and improvement of the design. Final report including the review of the design	2002/12

Task ID : TG11-JP

Task Title : Examination of free surface behavior under low pressure

Facility : Target

Institutes in Charge : JAERI (Japan)

Contact Persons : Hideo Nakamura, Hiroo Nakamura, Mizuho Ida (JAERI)

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Need/Motivation :

The liquid Li of IFMIF Target flows in high-speed up to 20m/s. Furthermore, the free surface of Li Target is broad with width 260mm and length 350mm. The stability of Li jet influences the neutron field and the integrity of Target system. The behavior of free surface influences the stability of high-speed broad jet under high vacuum condition.

Brief Task Description :

The free surface behavior mentioned above is simulated in water experiment under low pressure. The experiment is performed in JAERI using a horizontal water experiment equipment, which makes a water jet with 100mm-wide free surface. The experiment equipment has been remodeled to deal with a free surface under low pressure condition. Waves on the free surface are observed using high-speed camera under various conditions of jet velocity. Also the length and amplitude of surface wave are measured.

Schedule : April 2000 – September 2000

Apr. 2000	Setup of experiment equipment
May 2000 – Sep. 2001	Experiment
Jul. 2000 – Mar. 2002	Analysis of measured data
Apr. 2002 – Dec. 2002	Summary

Task Deliverables

No.	Description	Due Date
1	Performance test of remodeled water experiment equipment	2001/09
2	Examination of free surface behavior under atmospheric pressure	2002/03
3	Examination of free surface behavior under low pressure	2002/12

Task Number : TG12-JP

Task Title : Design of Li test loop mockup

Facility : Target

Institutes in Charge : JAERI (Japan)

Contact Persons : Hiroo Nakamura, Mizuho Ida (JAERI)

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Need/Motivation :

A stable lithium jet is the most critical requirements of target performance. Jet stability depends on several factors including the flow straightener, nozzle, diffuser, backwall/nozzle transition, jet length, interaction with surrounding medium, and temperature. Extensive testing of FMIT target prototypes were conducted project using lithium working fluid. Similar testing of IFMIF target will be needed because of significant differences in target design and overall integration operation of the IFMIF target system.

Brief Task Description :

Based on the water jet and the lithium loop experiment, design of the lithium loop mockup will be conducted. Validated simulation model by the water and lithium experiments will be applied to the analysis of the lithium flow. Thermal and structural analysis will de also done. Diagnostics of Li temperature, surface waves and evaporation will be designed for the mockup loop. Transient behavior of the lithium loop will be done.

Schedule : April 2001 – March 2003
Apr. 2001 – Mar. 2002 Conceptual design of mockup
Apr. 2002 – Dec. 2002 Deatiled design

No.	Description	Due Date
1	Conceptual design of mockup	2002/03
2	Deatiled design	2002/12

Task ID : TG13-JP, TG16-JP, TG21-JP

Task Title : Free surface flow study of liquid lithium

Facility : Target

Institutes in Charge : Osaka University (Japan)

Contact Persons : Hiroshi Horiike (Osaka University)

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Need/Motivation :

Stability of Li jet is crucial for the target. Using the existing loop, it should be demonstrated that cavitation can be avoided.

Brief Task Description :

A Li jet test section will be installed into the existing Li loop at Osaka University. Stability of the jet surface and influence of nozzle erosion on the stability will be investigated.

Schedule : April 2000 – September 2002

Jun. 2000 – Mar. 2001	Cavitation at EMP will be investigated in reduced pressure. Design of the Li jet test section.
Apr. 2001 – Mar. 2002	Fabrication and installation of the jet test section into the loop. Stability of the jet and its dependence on the nozzle structure will be examined. Nozzle lifetime will be estimated.
Apr. 2002 – Sep. 2002	Removal of the test section.

Task Deliverables

No.	Description	Due Date
1	Cavitation at EMP	2001/03
2	Stability of the jet and its dependence of the nozzle structure. Nozzle lifetime by erosion.	2002/03

Task ID : TG31-JP

Task Title : Detection and control of impurities in molten Li

Facility : Target

Institutes in Charge : University of Tokyo and Tokyo Institute of Technology (Japan)

Contact Persons : Satoru Tanaka (U. Tokyo), Minoru Takahashi (TIT)

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Need/Motivation :

Development of monitoring and control technology of non-metallic impurities in Li is important for reducing corrosion and T inventory in the target system.

Brief Task Description :

Scavenging O, N and C impurities in Li using Ti, Zr, Y or their alloys with V will be investigated by immersion into a Li pot. Optimization of the getter materials and their operation conditions will be investigated. Also examined will be an application of solid electrolyte to in-situ monitoring of H impurities using an existing Li loop.

Schedule : April 2000 – September 2002

Jun. 2000 – Mar. 2001	Immersion test using Ti, Zr and Y Installation of solid electrolyte into the existing loop
Apr. 2001 – Mar. 2002	Immersion test using various V-Ti-Zr-Y alloys In-situ monitoring of H level in the existing Li loop.
Apr. 2002 – Sep. 2002	Optimization and designing of the impurity monitoring and control procedure.

Task Deliverables

No.	Description	Due Date
1	Characterization and optimization of impurity getter	2002/03
2	In-situ H monitoring capability using solid electrolyte in the existing Li loop	2002/03
3	Design of impurity monitoring and control procedure	2002/09

Task ID : TG61-JP

Task Title : Numerical analyses for transient behavior of Li loop

Facility : Target

Institutes in Charge : JAERI (Japan)

Contact Persons : Mizuho Ida, Hiroo Nakamura, Hideo Nakamura (JAERI)

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Need/Motivation :

In the IFMIF Li target, most of the deuteron beam power changes to heat and the average temperature of Li increases from 250°C to 285°C in case of 10MW beam power and 20m/s flow velocity. This heat is removed by the target heat removal system, which consists of the primary Li loop, the secondary organic loop, the tertiary water loop and cooling tower. The secondary organic loop with alkyl diphenyls is provided to avoid direct contact of Li and water.

For the integrity of Li loop, the Li temperature should be enough high to keep smooth flow not only in constant operations but also in transient conditions. The startup and shutdown of Li loop are scheduled transient conditions, when the Li is circulated without beam heating. Furthermore, there will be unexpected beam trip of IFMIF accelerator(s). In a long time of beam trip, full operation of heat removal system will cause too large decrease of Li temperature to keep flow. Therefore, transient behaviors of Li and control methods of Li temperature should be examined.

Brief Task Description :

The transient temperatures and flow rates are simulated by using a reactor transient code RETRAN. While the original RETRAN deal only water as fluid, it has been modified in JAERI to deal with Li and the mentioned organic oil. At first, transient behaviors are examined in case of no control at startup, shutdown, one beam trip and two beam trips. Transient behavior of the Li loop and the organic oil loop are simulated. At the next, control methods by changing flow rates at EMP and organic pump or heating at heaters are examined to keep the Li temperature within suitable range.

Schedule : April 2000 – December 2002

Apr. 2000 – Mar. 2001 Examination of transient behaviors with no control
Apr. 2001 – Sep. 2002 Examination of control methods
Oct. 2002 – Dec. 2002 Summary

Task Deliverables

No.	Description	Due Date
1	Transient behaviors with no control at beam trip	2001/09
2	Control methods at beam trip and startup/shutdown	2002/12

Task Number : TG81-JP

Task Title : Design of remote handling devices

Facility : Target

Institutes in Charge : JAERI(Japan)

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Need/Motivation :

The IFMIF test cell is significantly activated in the intense neutron field. Under this condition, cutting and welding operations are required at the 2 junction parts between a target assembly and inlet piping / outlet piping of Li loop. These parts are lip sealed to avoid Li leak. Also the mount and replace operation are required for a target assembly, which weighs about 600kg. Therefore, remote handling devices with mentioned functions should be developed.

Brief Task Description :

Remote handling devices for IFMIF target should have the mentioned functions (cutting, welding, mounting/replacing a 600kg assembly) and the whole of remote handling operation should be completed within 2 weeks. The remote handling devices are designed by JAERI in cooperation with industries. Note that the remote handling devices for target are attached to Universal Robot System (URS) for Test Facilities. Therefore, at first, boundary conditions between the target assembly and the others, required functions and specifications are examined and clarified. Also similar remote handling devices in activated facilities are researched. At the next, the remote handling devises for target are designed.

Note that the fabrication and the verification of remote handling devices are performed in another task in EVP.

Schedule : April 2000 – December 2002

Apr. 2000 – Mar. 2001	Examination and clarification of boundary condition, required function and required specification
Apr. 2000 – Mar. 2001	Research of similar devices
Apr. 2001 – Dec. 2002	Design of remote handling devices

Task Deliverables

No.	Description	Due Date
1	Boundary condition and requirements for remote handling devices	2001/09
2	Design of remote handling devices	2002/12

Accelerator

Task ID	Task Title
AC37-US	Engineering Evaluation of the Drift Tube at 5 MeV
AC11-EU(Saclay)	Very long test of ion source
AC12-EU(Saclay)	Source analyses
AC13-EU(Saclay)	Beam compensation measurement
AC14-EU(Saclay)	Beam analyses in the RFQ matching conditions
AC15-EU(Saclay)	Final layout of the LEBT
AC21-EU(Saclay)	Radio Frequency system
AC33-EU(Saclay)	Choice of RFQ structure
AC34-EU(Saclay)	Optimization of electric field property in RFQ on cold model
AC36-EU(Saclay)	Detailed DTL design
AC38-EU(Saclay)	Matching from the RFQ to the DTL
AC41-EU(Saclay)	Diagnostics for high power beam
AC11-EU(IAP)	Long run test of ion source
AC12-EU(IAP)	Source analysis
AC13-EU(IAP)	Low energy beam transport (LEBT)
AC33-EU(IAP)	Choice of RFQ structure, development of 4 rod RFQ
AC35-EU(IAP)	Choice of DTL structure, investigation of CH-DTL
AC41-EU(IAP)	Diagnostics for high power beam
AC11-JP	Test of ECR and Multi-Cusp Type Ion Sources
AC13-JP	Test of Low Energy Beam Transport
AC21-JP	RF Power Tube Durability Test
AC22-JP	Test of RF Window
AC31-JP	Estimation of Beam Loss at Various Operating Conditions
AC32-JP	Examination of Drift Tube Cooling Scheme
AC34-JP	Examination of Beam Matching to RFQ
AC39-JP	Activation of Accelerator System Components

Task ID : AC37-US

Task Title : Engineering Evaluation of the Drift Tube at 5 MeV

Facility : Accelerator

Institutes in Charge : Advanced Energy Systems, Inc. (US)

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Need/Motivation :

A critical aspect of the decision to reduce the transition energy of the RFQ to the DTL is the engineering limitation imposed by the first drift tube. The physical packaging of the required electromagnetic quadrupole inside a drift tube designed to withstand CW power load can be problematic. This conceptual design will determine if this can be done for 125 mA of D+ at 5 MeV.

Brief Task Description :

Using PARMILA data for the physics design of the IFMIF DTL at 5 MeV, AES will develop a concept for the electromagnetic quadrupole and it's packaging in the first drift tube. This work will include determining the power losses on the drift tube and performing the transient and steady state thermal/RF analysis to confirm adequate performance. This task will result in a pre-conceptual design with analytical back-up.

Schedule : May 2000 – September 2000

May 2000	Receive PARMILA from JAERI for starting point
May 2000 – Aug. 2000	Perform design and analysis iteration
Aug. 2000	Conduct initial review with Accelerator Design Team
Sep. 2000	Prepare final documentation

Task Deliverables

No.	Description	Due Date
1	Interim Design presentation	2000/08
2	Final documentation	2000/09

Task ID : AC11-EU(Saclay)

Task Title : Very long test of ion source

Facility : Accelerator

Institutes in Charge : CEA-Saclay (France)

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Need/Motivation :

The injector system has a high impact in terms of reaching the required performance and RAM goals for IFMIF. No sources to date have been operated CW for more than 100 hours at output levels approaching the IFMIF requirements (140 mA, D^+). Lifetimes suitable to the overall plant availability and reliability goals must be demonstrated.

Brief Task Description :

The task consists in running the ECR source for more than 4 weeks, CW. The injector system (source and Low Energy Beam Transport) must demonstrate reliability commensurate the maintenance schedule of the accelerators. Low to very low spark rates have to be shown, as well as reliability in terms of source performances. Current has to be recorded and stabilized, as well as other important source parameters (beam noise, species fraction, beam emittance...). The source will be run in a proton mode to avoid activation of the test stand.

Schedule : September 2000 – September 2001

Apr.–Sep. 2000	Setup and development of experiment equipment
Oct.–Nov. 2000	Development of control and command system suitable to this task
Feb.–Mar. 2001	4 weeks run
Apr. 2001	Summary

Task Deliverables

No.	Description	Due Date
1	Performance test of the injector in the experiment conditions	2000/11
2	Long run results	2001/04

Task ID : AC12-EU(Saclay)

Task Title : Source analyses.

Facility : Accelerator

Institutes in Charge : CEA-Saclay (France)

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Need/Motivation :

The injector must deliver 140 mA, CW, in D^+ to the RFQ matching point. The IFMIF goals require also very good beam quality in conjunction with the above extreme performance. Individual requirements could be achieved, but the overall performance still needs to be reached. Development of the source for the IFMIF accelerators is then a multi-path effort that will take advantage of the ongoing programs in injector around the world.

Brief Task Description :

The task consists in analyzing the source performance, and develops the necessary engineering. The source parameters that need to be verified are the total extracted D^+ beam current at the IFMIF extraction energy, the beam emittance, beam noise, pulse and CW operation. It is a continuous work that influences the following accelerator parameters choice and could lead to a cost saving (ex: if the emittance is decreased in the RFQ, the total RFQ length could be reduced, leading to a lower power consumption in the copper)

Schedule : April 2000 – December 2001
Apr. 2000 – Dec. 2001 Development of experiment equipments
Apr. 2000 – Dec. 2001 Analyzes of the beam parameters

Task Deliverables

No.	Description	Due Date
1	Source analyses	2001/12

Task ID : AC13-EU(Saclay)

Task Title : Beam compensation measurement

Facility : Accelerator

Institutes in Charge : CEA-Saclay (France)

Contact Persons : Jean-Michel Lagniel, Robin Ferdinand (CEA-Saclay)

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Need/Motivation :

The injector must deliver 140 mA, CW, in D^+ to the RFQ matching point. The IFMIF goals require also very good beam quality in conjunction with the above extreme performance. The Low Energy Beam Transport (LEBT) from the source to the RFQ is achieved with a beam under space charge compensation. The matching into the RFQ supposes to suddenly increase the focusing of the beam. It is therefore extremely important to understand the beam transport and the processes involved in the matching to the RFQ.

Brief Task Description :

The task consists in analyzing the space charge compensation processes. The behavior as a function of different parameters (beam current, beam fluctuation, beam size) and in presence of source of electrons (losses on the wall, heavy particles as a background gas) has to be checked. It should lead to a better understanding of how to transport such a high power, low energy beam. According to other high power RFQs, a big effect is expected at the RFQ matching point and is not fully understood. It has to be mastered.

Schedule : May 2000 – December 2001

Apr. 2000 – Dec. 2001 Development of experiment equipments

Apr. 2000 – Dec. 2001 Analyzes of the space charge compensation

Task Deliverables

No.	Description	Due Date
1	Beam space charge compensation measurement	2001/12
2	Beam analyses in the RFQ matching conditions	2001/12

Task ID : AC14-EU(Saclay)

Task Title : Beam analyses in the RFQ matching conditions.

Facility : Accelerator

Institutes in Charge : CEA-Saclay (France)

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Need/Motivation :

The injector must deliver 140 mA, CW, in D^+ to the RFQ matching point. The IFMIF goals require also very good beam quality in conjunction with the above extreme performance. The matching into the RFQ supposes to suddenly increase the focussing of the beam. It is therefore extremely important to understand the beam transport and the processes involved in the matching to the RFQ.

Brief Task Description :

The experience back from CW RFQ shows problems in the matching of the beam into the RFQ. The task consists in understanding the difference between theoretical design and real beam. It should lead to a better knowledge of how to transport and matched such a high power, low energy beam. The problem resides in the power density (15 kW in a few millimeter diameter).

Schedule : May 2000 – December 2002
May 2000 – Dec. 2001 Developing the tools
May 2000 – Dec. 2001 Beam analyses.

Task Deliverables

No.	Description	Due Date
1	Tools for 20 kW beams.	2001/12
2	Matching of the IFMIF beam from the LEBT into the RFQ.	2002/12

Task ID : AC15-EU(Saclay)

Task Title : Final layout of the LEBT.

Facility : Accelerator

Institutes in Charge : CEA-Saclay (France)

Contact Persons : Jean-Michel Lagniel, Robin Ferdinand (CEA-Saclay)

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Need/Motivation :

The injector must deliver 140 mA, CW, in D^+ to the RFQ matching point. The IFMIF goals require also very good beam quality in conjunction with the above extreme performance.

Brief Task Description :

The Low Energy Beam Transport (LEBT) will have to be designed taking into account the best transmission possible, without any beam characteristics degradation. The knowledge acquired with the previous tasks and other experiment will be used.

Schedule : May 2000 – December 2002
May 2000 – Jun. 2002 Data compiling
Jun. 2000 – Dec. 2002 Final LEBT.

Task Deliverables

No.	Description	Due Date
1	Acquisition and compilation of LEBT data.	2001/12
2	Final LEBT design	2002/12

Task ID : AC21-EU(Saclay)

Task Title : Radio Frequency system

Facility : Accelerator

Institutes in Charge : CEA-Saclay (France)

Contact Persons : Jean-Michel Lagniel, Robin Ferdinand (CEA-Saclay)

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Need/Motivation :

Development and testing of a 1 MW rf system is identified as the highest impact development item. Existing operating experience is for short period of time (1-8 hours). No test stand fully capable of 100-1000 hours is available in the world. The rf amplifier power baseline of 1 MW insures that a competitive bid could be obtained from two manufacturers. Accomplishing a full-scale test of the first system would allow the remaining large procurement to be on a fixed-price basis.

Brief Task Description :

The task consists in collecting information on the THOMSON Diacrode progress. A choice between different rf sources could be proposed. The main task remains the rf test and requires an upgrade of existing test stand (see comment). All the above items can be done using the current 200 MHz – 1 MW diacrode, knowing that a higher frequency is generally harder to develop. This existing diacrode could achieve the requirement without spending the amount of money in buying a non-existing 175 MHz diacrode.

Schedule : Mai 2000 – December 2002
May 2000–Dec. 2002 Collecting information about the diacrode
May 2000–Dec. 2002 Long test.

Task Deliverables

No.	Description	Due Date
1	Collection of Diacrode progress	2002/12
2	Long test run in IFMIF conditions	2002/12

Comment :

It is necessary to launch an addition activity for this long run

Task ID : AC33-EU(Saclay)

Task Title : Choice of RFQ structure

Facility : Accelerator

Institutes in Charge : CEA-Saclay (France)

Contact Persons : Jean-Michel Lagniel, Robin Ferdinand (CEA-Saclay)

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Need/Motivation :

The IFMIF RFQ is design to accelerate the 140 mA D^+ beam produced by the source. The input energy is 100 keV. The output energy is 5 MeV. It is important to verify that fundamental technical difficulties will not arise in case of IFMIF RFQ.

Brief Task Description:

In spite of already existing 4-vanes, CW, high current RFQ's, 4-rods RFQ could be a back-up solution for IFMIF. However, power consumption in the copper is said to lead to undesirable effects on such structure. It has to be verified with full 3-d calculations and collecting information on existing high duty cycle RFQ's. Beam dynamics will be performed. The construction and test of existing CW RFQ will be used as engineering basis to fix the IFMIF RFQ basic design.

Schedule: June 2000 – June 2001
Jun. 2000–Jun. 2001 RFQ design.
Jun. 2000–Jun. 2001 3D calculation of the IFMIF RFQ structure.

Task Deliverables

No.	Description	Due Date
1	Add on RFQ design	2001/06
2	Comparisons between 4-vanes vs 4-rod RFQ.	2001/06

Task ID : AC34-EU(Saclay)

Task Title : Optimization of electric field property in RFQ on cold model

Facility : Accelerator

Institutes in Charge : CEA-Saclay (France)

Contact Persons : Jean-Michel Lagniel, Robin Ferdinand (CEA-Saclay)

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Need/Motivation :

The IFMIF RFQ is design to accelerate the 140 mA D^+ beam produced by the source. The input energy is 100 keV. The output energy is 5 MeV. The length of such accelerator complicates the rf tuning of the cavity. Moreover, the design of IFMIF RFQ is optimized for a highly space charged beam and implied non-constant vane voltage and mean vane aperture which complicates the rf tuning. A method has to be developed.

Brief Task Description:

RFQs are powerful accelerators to both accelerate and bunch beams. Nevertheless, the IFMIF beam power and RFQ design complicates the RF tuning of the RFQ. The task will consist in the elaboration of the tuning method and tools for the IFMIF RFQ RF tuning.

Schedule: June 2000 – December 2002
Jun. 2000 – Jun. 2002 Work of cold model
Jun. 2002 – Dec. 2002 Development of a RF tuning method

Task Deliverables

No.	Description	Due Date
1	Results on cold model	2002/06
2	Tuning method of the IFMIF 4-Vanes RFQ.	2002/12

Task ID: AC36-EU(Saclay)

Task Title: Detailed DTL design.

Facility: Accelerator

Institutes in Charge : CEA-Saclay (France)

Contact Persons : Jean-Michel Lagniel, Robin Ferdinand (CEA-Saclay)

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Need/Motivation:

The DTL is the main part of the accelerator. Many uncertainties on the drift tubes and quadrupoles have to be verified. A fixed DTL design has to be provided. Halo formation is an expected process leading to strong structure activation (DTL + High energy beam transfer line). Studies should provide a way to avoid or channel this halo formation.

Brief Task Description:

DTL beam dynamics will be performed taking into account the simulation of the RFQ output beam. The drift tubes are the delicate point of DTL accelerators.

Multiparticles simulations from the source to the target will be carried out. The performed error studies will include field errors, misalignments, sensitivity to beam fluctuations, beam losses.

The formation process will be checked for the IFMIF design using both calculations and the experimental results gained.

Schedule: June 2000 – June 2002

Jun. 2000 – Jun. 2001 DTL design (dynamics)
Jun. 2000 – Jun. 2001 Drift tube and quadrupoles analyses
Jun. 2001 – Jun. 2002 Multiparticles simulations from source to target.

Task Deliverables

No.	Description	Due Date
1	Detailed DTL design	2001/06
2	Drift tubes analyses	2002/06
3	Multiparticles simulations	2002/06

Task ID : AC38-EU(Saclay)

Task Title : Matching from the RFQ to the DTL.

Facility : Accelerator

Institutes in Charge : CEA-Saclay (France)

Contact Persons : Jean-Michel Lagniel, Robin Ferdinand (CEA-Saclay)

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Need/Motivation :

The IFMIF RFQ is design to accelerate the 140 mA D^+ beam produced by the source. The input energy is 100 keV. The output energy is 5 MeV. Transitions between accelerators are known to be a sensitive point. It is therefore more difficult with the IFMIF beam power and structure possible activation.

Brief Task Description :

The high space charge at the RFQ output energy, as well as the beam power, makes the RFQ-DTL transition difficult. A scaling from existing design parameters will be done.

Schedule : June 2000 – December 2002

Jun. 2000 – Dec. 2002 Studies of RFQ DTL matching line.

Task Deliverables

No.	Description	Due Date
1	RFQ-DTL matching	2002/12

Task ID: AC41-EU(Saclay)

Task Title: Diagnostics for high power beam.

Facility: Accelerator

Institutes in Charge : CEA-Saclay (France)

Contact Persons : Jean-Michel Lagniel, Robin Ferdinand (CEA-Saclay)

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Need/Motivation:

IFMIF beam represents about 15 kW between the source and the RFQ, 625 kW before the DTL and 5 MW in the HEBT. The relatively low energy (40 MeV) means that this power is deposited in any interceptive diagnostics. New kind of diagnostics has to be developed.

Brief Task Description:

The task consists in developing new kinds of diagnostics to analyze the beam during the transport. Different approaches can be imagined, but they all need to be checked on a high power beam.

Schedule: May 2000 – December 2002

Mai 2000–Dec. 2002 Developing and testing of the diagnostics

Task Deliverables

No.	Description	Due Date
1	Development of the diagnostics.	2002/12

Task ID : AC11-EU(IAP)

Task Title : Long run test of ion source

Facility : Accelerator

Institutes in Charge : IAP, J.W.Goethe-Universitaet Frankfurt am Main (Germany)

Contact Persons : Horst Klein, Klaus Volk (IAP, Frankfurt)

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Need/Motivation :

The ion source must deliver a 140 mA D+ beam in cw operation with high availability and stability. This has to be demonstrated in a long term operation, up to now no source coming close to the IFMIF requirements has been operated longer than 100 hours .

Brief Task Description :

The volume source under development in Frankfurt for IFMIF shall be operated in a long term run. Source parameters like beam current, source noise, cathode performance have to be recorded and stable extraction and transport of the beam have to be shown. The optimum cathode arrangement has to be investigated. The source will be operated with protons to avoid activation.

Schedule : September 2000 – December 2001

May 2000 – Mar. 2001	Layout and setup of test experiment and control devices, development of beam measurement equipment
Mar. – June 2001	volume source test
Jul. – Aug. 2001	writing of test report

Task Deliverables

No.	Description	Due Date
1	Experimental test set-up	2001/03
2	Long run results	2001/08

Task ID : AC12-EU(IAP)

Task Title : Source analysis

Facility : Accelerator

Institutes in Charge : IAP, J.W.Goethe-Universitaet Frankfurt am Main (Germany)

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Need/Motivation :

The injector must deliver a 140 mA D+ beam at 100 keV in cw operation to the RFQ matching point. A very high beam stability as well as low beam emittance is favourable for high transmission. Consequently, detailed investigations of the beam quality and the plasma of the ion source have to be performed in order to improve the performance of our ion source.

Brief Task Description :

With the help of 127x cylinder spectrometer the ion energy distribution will be measured. The source will be optimized for a low ion temperature and a small energy spread. With the knowledge of the ion temperature we will estimate the beam emittance. In a second step it is essential to check the beam emittance at high currents with our slid-grit emittance measurement device.

Schedule : May 2000 – December 2001
May 2000 – Dec. 2001 Plasma investigations, emittance measurements

Task Deliverables

No.	Description	Due Date
1	Plasma investigations	2000/12
2	Emittance measurement	2001/12

Task ID : AC13-EU(IAP, Frankfurt)

Task Title : Low energy beam transport (LEBT)

Facility : Accelerator

Institutes in Charge : IAP, J.W.Goethe-Universitaet Frankfurt am Main (Germany)

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Need/Motivation :

Beam transport in the IFMIF LEBT is dominated by the space charge forces. Beam transmission of more than 90% is necessary to deliver a 140 mA D+ beam at the RFQ entrance starting with 155 mA from the ion source. Emittance growth has to be minimized to avoid particle losses and activation along the accelerator. Space charge compensation is very helpful when using a magnetic LEBT. Therefore a detailed analysis of the space charge compensation process is necessary to understand beam propagation and particle losses in order to get a proper final layout of the LEBT. In addition the matching into the RFQ is strongly influenced by decompensation effects and must be understood.

Brief Task Description :

A LEBT system consisting of two solenoids will be used to analyze the space charge compensation process, the transmission and emittance growth as a function of beam current, beam size, current fluctuations and residual gas pressure as most important factors. The behaviour of beam current, emittance and compensation is studied and measured between source exit and RFQ entrance.

Schedule : May 2000 – June 2002

May 2000 – Jun. 2002 Compensation measurements, development of equipment analysis of results, writing-up

Task Deliverables

No.	Description	Due Date
1	Definition of RFQ matching conditions	2001/12
2	Concept of final layout of LEBT	2002/06

Task ID : AC33-EU(IAP)

Task Title : Choice of RFQ structure, development of 4 rod RFQ

Facility : Accelerator

Institutes in Charge : IAP, J.W.Goethe-Universitaet Frankfurt am Main (Germany)

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Need/Motivation :

A critical aspect of IFMIF is the choice of an RF structure to drive the quadrupole electrodes with the high electrode voltage and required flat voltage distribution. This needs a thoroughly design with respect to power load, structure cooling and alignment and tuning properties for a cw resonator. 4-rod-RFQs are operated in different laboratories successfully with high currents and high duty cycles, but up to now not with full IFMIF specifications. The capability of the 4-rod-structure for the envisaged IFMIF parameters is investigated.

Brief Task Description :

The 4-rod structure developed in Frankfurt for high duty factor operation will be adapted for IFMIF needs. Beam dynamics layout with respect to small emittance and high transmission will be done. Technical design of a short 4-rod-RFQ to demonstrate the required cw operation capability are planned together with experimental verification.

Schedule : May 2000 – December 2002
May 2000–May 2001 Beam dynamics studies
May 2000–Dec. 2002 RF model studies, cw tests

Task Deliverables

No.	Description	Due Date
1	Beam dynamics design of 4-rod-RFQ for IFMIF needs	2001/06
2	Report on sructure development and cw test	2001/06
3	Optimization of 4-rod cw structure properties	2002/12

Task ID : AC35-EU(IAP)

Task Title : Choice of DTL structure, investigation of CH-DTL

Facility : Accelerator

Institutes in Charge : IAP, J.W.Goethe-Universitaet Frankfurt am Main (Germany)

Contact Persons : Ulrich Ratzinger, Horst Deitinghoff (IAP, Frankfurt)

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Need/Motivation :

The IFMIF beam parameters A/q = 2, Wout= 20 MeV/u, cw operation fit very well to the capabilities of an H-type-DTL. First numerical calculations with proton beams have shown, that also the needed high beam current is within the range of this structure. During the past two decades the tools were developed and applied successfully, which make H-structures a real candidate for this application. Moreover, superconducting H-DTL versions become feasible as the magnetic quadrupoles are positioned outside of the cavities. The CH-structure (H210-mode) is proposed for the investigation with respect to IFMIF requirements.

Brief Task Description :

Beam dynamics studies and numerical simulations with LORASR and PARMILA will result in an optimized drift tube array with known operating frequency , number of cavities, total linac length. Normalconducting as well as superconducting versions with IFMIF relevant parameters have to be designed. RF models are investigated to study mechanical as well as RF aspects in detail.

Schedule : May 2000 – December 2002
May 2000 – Dec. 2001 Beam dynamics studies
Oct. 2000 – Dec. 2002 RF model studies

Task Deliverables

No.	Description	Due Date
1	Beam dynamics design of CH-DTL for IFMIF needs	2001/12
2	Results of RF and mechanical tests	2002/06

Task ID : AC41-EU(IAP, Frankfurt)

Task Title : Diagnostics for high power beam

Facility : Accelerator

Institutes in Charge : IAP, J.W.Goethe-Universitaet Frankfurt am Main (Germany)

Contact Persons : Horst Klein, Jurgen Pozimski, Klaus Volk (IAP, Frankfurt)

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Need/Motivation :

The IFMIF beam is a high power beam of D+ ions in cw operation. The power deposition and possible activation are major concerns. Existing and new beam diagnostic devices have to be investigated and further developed.

Brief Task Description :

Emittance measurement devices, optical diagnostics with a CCD camera and other non-destructive methods have to be analyzed and tested. Main field of testing will be the LEBT section and the RFQ output.

Schedule : May 2000 – December 2002

May 2000–Dec. 2002 Development and testing of diagnostic devices

Task Deliverables

No.	Description	Due Date
1	Development of diagnostics	2002/12

Task ID : AC11-JP

Task Title : Test of ECR and Multi-Cusp Type Ion Sources

Facility : Accelerator

Institutes in Charge : JAERI (Japan)

Contact Persons : Yoshikazu Okumura, Kazuhiro Watanabe, Masaki Taniguchi (JAERI)

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Need/Motivation :

The ion source of IFMIF is required to produce the 100keV/155mA deuterium ion beam continuously with a low beam emittance of 0.2_mm.mrad and a high deuterium fraction of more than 85%. To avoid the neutron production, the performance test of the ion source is to be conducted with hydrogen. The required availability is 99 % with the average lifetime longer than 300 hours, which is extended up to 1000 hours as a goal.

There are two candidates for the ion source: a multi-cusp type source and an ECR type source. Although the injector represents a critical element of the IFMIF accelerator facility, the ultimate choice of technology for the system has little effect on the overall system. Physical space, power, cooling, safety, and other interface requirements will be very similar for any of the technologies considered. In the KEP stage, both of two ion source types are tested and validate their performances, and the best technology is selected for the long-run test in the next EVP stage.

The target of the test is to demonstrate the steady-state operation of deuteron ion source at 140mA/100keV, however, it is necessary to enhance the radiation shielding to carry out such a test. So the target of the KEP stage is substituted by hydrogen ion extraction at 220mA/100keV with a good beam emittance.

Brief Task Description :

Two types of the ion sources, a multi-cusp ion source and an ECR ion source, are to be tested in the same test facility in JAERI (ITS-2M Test Stand) at 60keV to compare the ion source performances; e.g. efficiency, beam emittance, proton ratio, current stability, life time, gas flow rate, etc. Full performance of the ion source is to be demonstrated using JAERI NIAS Test Stand at 100 keV with long pulse operation. Long life cathode will be utilized for the multi-cusp source for the long pulse operation.

Schedule : April 2000 – March 2002

Apr. 2000 – Sep. 2000	Design of the Ion Source
Oct. 2000 – Jan. 2001	Test of the Multi-Cusp Ion Source with W Filament
Feb. 2001 – Sep. 2001	Test of the ECR Type Ion Source
Oct. 2001 – Mar. 2002	Long Pulse Test

Task Deliverables

No.	Description	Due Date
1	Performance test of the multi-cusp ion source	2001/01
2	Performance test of the ECR ion source	2001/09
3	Long pulse operation of the ion source	2002/03

Task ID : AC13-JP

Task Title : Test of Low Energy Beam Transport

Facility : Accelerator

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The IFMIF LEBT is required to have a capability to transport the 155mA deuteron beam with a good transmission higher than 90% and a minimized emittance growth. The space charge expansion effect becomes very strong when the beam current exceeds several tens of milli-ampere, and the non-linear effect might be expected for the high current ion beam of 155mA D+.

There are two candidates to suppress the beam expansion: a magnetic and an electrostatic focusing methods. In the KEP stage, if necessary, both of two LEBT types are tested using the same ion source assembly and validate their performances, and the best technology is selected for the long-run test in the next EVP stage.

Brief Task Description :

The LEBT system using solenoid coils is to be tested in ITS-2M test stand with a 60keV/200mA H+ ion beam, whose space charge is higher than the 155mA/100keV D+ ion beam. The beam emittance is measured at the entrance and the exit of the LEBT system. In case the emittance growth exceeds a permissible value, the electrostatic LEBT system is to be tested.

Schedule : April 2000 – March 2002
Apr. 2000 – Sept. 2000 Design of the LEBT
Oct. 2000 – Mar. 2001 Test of the LEBT using solenoid coils
Apr. 2001 – Mar. 2002 Test of the LEBT using electrostatic lens (if required)

Task Deliverables

No.	Description	Due Date
1	Test of the LEBT (intermediate report)	2001/3
2	Test of the LEBT (final report)	2002/3

Task ID : AC21-JP

Task Title : RF Power Tube Durability Test

Facility : Accelerator

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The RF system of IFMIF accelerator is required to provide 175 MHz cw power for 125 mA beam acceleration using RFQ and DTL. Each module generates 1MW power and consists of high-power final amplifier tube and associated driver amplifiers and power supplies. The required lifetime is 10,000 hours and a long-run test around 1,000 hours is necessary to design and construct the prototype module used in the next engineering phase.

Brief Task Description :

The 200 MHz, 1MW cw power tube is achieved by Thomson diacrode and has been tested for 8 hours. We seek for the procedure to perform the long run test over 100 hours to verify the performance of this tube under the collaborative work among every party. When such process is succeeded, a specialist of this field will be assigned to attend for the witness of tests. The design change of the power source module required for 175 MHz frequency is separately performed to apply the tube to IFMIF accelerator.

Schedule : June 2000 – December 2002

Jun. 2000 – Dec. 2002 RF power tube long run test

Jun. 2000 – Dec. 2002 Design change for 175 MHz

Task Deliverables

No.	Description	Due Date
1	Verification test of RF power generation over 100 hrs	2002/12
2	Design of power source module system for 175 MHz	2002/12

Task ID : AC22-JP

Task Title : Test of RF Window

Facility : Accelerator

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The RF system of IFMIF is required to provide 175 MHz cw power to RFQ and DTL. The system consists of a number of 1MW power module which generate and transport the RF power through the coaxial line. Each coaxial line has 4 (RFQ) or 2 (DTL) antenna drives, which separate the gas-pressurized condition in the coaxial line and the vacuum condition in linac by using RF window. Each window needs to be operated at 500 kW max. cw power. The required lifetime is 20,000 hours and a long-run test around 1,000 hours is necessary to proceed to the next EVP stage.

Brief Task Description :

Design study of a 175 MHz / 500 kW cw window is carried out, and an experimental equipment is designed to test the required capability (RF field and RF loss) of the windows without a high power RF source. The window and experimental equipment are fabricated to examine the RF and thermal properties of the window in a short-run test (less than an hour). A long-run test (over 1000 hours) is performed after some modifications of the window and experimental equipment.

Schedule : June 2000 – December 2002

Jun. 2000 – Mar. 2001	Design study of window and the experimental equipment
Apr. 2001 – Oct. 2001	Design and Fabrication of the window and the experimental equipment
Nov. 2001 – Mar. 2002	Short-run test and summary
Apr. 2002 – Dec. 2002	Modification and Long-run test

Task Deliverables

No.	Description	Due Date
1	Design of RF window for 500 kW CW at 175 MHz	2001/03
2	Data of the RF and thermal properties of window	2002/03
3	Data of 1000 hour operation corresponding to 500 kW transmission	2002/12

Task ID : AC31-JP

Task Title : Estimation of Beam Loss at Various Operating Conditions

Facility : Accelerator

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The 125 mA deuteron beam is highly active to produce neutrons and radioactivity even if a small fraction of the beam is lost. The beam loss criteria for DTL in the conceptual design is 3 _ A/m but is required to reduce to 3 nA/m as a goal to achieve the hands-on maintenance and the availability of the facility. The similar criteria should be applied for HEBT. The most beam loss events are not distributed uniformly but located near the positions of magnetic field elements, like quadrupoles in drift tubes/transport line, dipoles and octupoles in HEBT. Such loss events are caused by the accumulation of various effects at the upstream line. The accurate estimation of the beam loss using the end-to-end beam dynamics simulation is critical to verify the validity of the loss criteria and the resulting availability requirement.

Brief Task Description :

The various operation modes of IFMIF accelerator are patterned according to the beam conditions, the accelerator equipment conditions, and the interface conditions. The beam dynamics simulation is carried out for each operating pattern and the model to express the results is developed. The sensitivity of the fluctuations of the various conditions to the beam loss events is evaluated and the permissible levels are deduced. The similar methodology is applied to the existing accelerator for checking its validity.

Schedule : April 2000 – December 2002
Jun. 2000 – Oct. 2000 Operation mode definition
Nov. 2000 – Oct. 2001 Beam dynamics simulation / code development
Nov. 2001 – Apr. 2002 Model analysis

Task Deliverables

No.	Description	Due Date
1	Estimation of beam loss at various operating conditions	2002/04

Task ID : AC32-JP

Task Title : Examination of Drift Tube Cooling Scheme

Facility : Accelerator

Institutes in Charge : JAERI (Japan)

Contact Persons : Masayoshi Sugimoto, Yoshikazu Okumura (JAERI)

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Need/Motivation :

The drift tubes in Alvarez linac are assembled and positioned aligned to the beam axis and the magnetic field axis needs to coincide to the axis. At the high-power cw operating condition, the generated heat inside the drift tubes are removed efficiently to keep such an alignment. The typical drift tube assembly is fabricated and the cooling scheme is necessary to be tested.

Brief Task Description :

The 175MHz drift tube model is fabricated and assembled in the dummy vacuum chamber to simulate the tank shell. The heat source is used to simulate the heat generation and the water cooling test is performed. The temperature is monitored inside the assembly and compared with the calculations.

Schedule : April 2001 – December 2002
Apr. 2001 – Mar. 2001 Design of experimental test stand
Apr. 2002 – Sep. 2002 DT fabrication and cooling tests

Task Deliverables

No.	Description	Due Date
1	Design of 175 MHz drift tube model	2001/03
2	Experimental verification of drift tube cooling scheme	2002/09

Task ID : AC34-JP

Task Title : Examination of Beam Matching to RFQ

Facility : Accelerator

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The 175 MHz IFMIF RFQ accelerates a 125 mA deuteron beam injected at 0.1 MeV and the output energy is 5 - 8 MeV which depends on the optimization / trade-off of the technology and economy. The coupled cavity technique developed at APT/LEDA project of LANL is employed to achieve such high output energy. The coupled cavity RFQ frequency investigated before is 350 MHz at LANL and Saclay, but little study has been carried out for 175 MHz RFQ. It is important to verify that the fundamental technical difficulty does not arise in case of IFMIF RFQ. The optimization of the exact shape for the 175 MHz RFQ is necessary to be performed and the result must be compared with low power model experiments.

Brief Task Description :

A design for the cold model of 175 MHz cw RFQ is carried out and the model is constructed to investigate the fabrication method and to test the field pattern in the cavity. The measured field pattern is compared with the electromagnetic field calculation, and the key issues to improve the performance are made clear.

Schedule : June 2000 – December 2002

Jun. 2000 – Mar. 2001 Design of cold model
Apr. 2001 – Mar. 2002 Fabrication of cold model
Apr. 2002 – Dec. 2002 Measurements

Task Deliverables

No.	Description	Due Date
1	Physics and Engineering Designs of RFQ Cold Model	2001/09
2	Measurement and Analysis of RFQ Cold Model	2002/12

Task ID : AC39-JP

Task Title : Activation of Accelerator System Components

Facility : Accelerator

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The exact estimation of radioactivity induced by the deuteron beam and the neutron generated by lost beam is essential to allow hands-on maintenance after a reasonable cool down time. The estimation is strongly affected by the beam loss model, so that this task is correlated with a task AC31-JP to provide the beam loss estimation in a realistic accelerator and transport system. The task focuses on the uncertainties in the nuclear data library and the material selection to reduce the long-life activity. As a reversal action, it is meaningful to deduce the allowed beam loss and activity levels as a function of acceptable cool down time.

Brief Task Description :

JAERI has completed a compilation of the new nuclear data files, JENDL-3.2 High Energy File and charged particle induced activation file. These libraries are used to check the induced radioactivity along the IFMIF accelerator system based on the beam loss pattern obtained from the task AC31-JP. The results are compared with the other data libraries to estimate the uncertainties of the activation. The effect of the materials choice and volume of the components are also examined and optimized. The amount of beam loss allowed for the specified cool down scenario is estimated. Some experimental checks are necessary before to use the library extensively.

Schedule : June 2000 –December 2002

Jun. 2000 – Mar. 2001 Setup of library check its validity
Apr. 2001 – Dec. 2001 Case studies independent of exact beam loss patterns
Jan. 2002 – Aug. 2002 Combined calculation using the beam loss estimation

Task Deliverables

No.	Description	Due Date
1	Activity analyses for typical beam loss pattern	2001/12
2	Estimation of realistic activity and allowable beam loss level	2002/08

Design Integration

Task ID	Task Title
DI61-US	Design Integration of Key Element Technology Phase Achievements
DI83-EU	Safety analysis and assessment
DI85-EU	Safety analysis and assessment.
DI11-JP	Diagnostics of Spatial Distribution of Neutron
DI13-JP	Infrared Camera for Diagnostics of Target Temperature
DI21-JP	Selection of elements having large cross section for activation
DI31-JP	Examination and design of measurement methods for Li jet thickness
DI33-JP	Examination and design of measurement methods for target assembly size and location
DI41-JP	Detailed design of buildings
DI43-JP	Detailed design of utilities
DI51-JP	Detailed design of central control and common instruments
DI61-JP	Check of consistency and analysis of operation flow for IFMIF total system
DI71-JP	Verification of current design of radiation shielding
DI81-JP	RAM analysis for 3 stages IFMIF with detailed design
DI83-JP	Safety assessment for 3 stages IFMIF with detailed design
DI91-JP	Examination of licences and regulations and consequent facility design
DI93-JP	Analysis of whole schedule and work items of IFMIF
DI95-JP	Cost estimation with results of KEP and detailed design

Task ID : DI61-US

Task Title : Design Integration of Key Element Technology Phase Achievements.

Facility : Design Integration

Institutes in Charge : Advanced Energy Systems, Inc. (US)

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Need/Motivation :

As Key Element Technology Phase progresses, it is necessary to monitor this progress and evaluate the effects of the KEP achievements on the overall system cost reduction and system reliability and availability improvements.

Brief Task Description :

The task consists in tracking the advances in Key Elements Technology developments and their integration into the overall system design by means of integrated system cost, reliability and availability models.

Schedule : May 2000 – December 2002
May 2000 – Dec. 2002 Integration of KEP developments into the system design

Task Deliverables

No.	Description	Due Date
1	Integration of KEP developments	2002/12

Task ID : DI83-EU

Task Title : Safety analysis and assessment

Facility : Design Integration

Institutes in Charge : ENEA (Italy)

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Need/Motivation :

A preliminary safety analysis aimed at studying the event accident sequences that could lead to dangerous situation for the facilities and for the environment was made in the CDA phase. As some important modifications have been brought up to the plant facilities, a new "system analysis" activity finalised: 1) to verify if the design improvement meet the safety goals and the availability, reliability and maintainability requirements; 2) to monitor and to evaluate the enhancement of plant safety and 3) to identify possible safety gaps. This analysis will be conducted on the latest version of the design. FMEA, Fault Tree and Event Tree, supported by engineering judgement (if necessary), will be the principal methods to be applied. Some major potential hazard of the IFMIF will be studied extensively.

This activity may also used for the preparation of the documents required for the preliminary safety report.

Brief Task Description :

ENEA will perform a review of hazard analysis for the Accelerator and Test Cell Facilities oriented towards detailing, on a component-by-component basis, all possible failure modes and identifying their effects. Also the effects of the supporting and surrounding subsystem or system malfunctions will be analysed.

Furthermore, ENEA will carry out a preliminary dependent failure analysis finalised to identify the failure that can defeat the redundancy or diversity employed in the design to improve the availability of the subsystem plant functions. For some major accident, which can lead to the damage of the plant or/and cause environment hazard, ENEA will perform a probabilistic internal events analysis and a preliminary environmental impact analysis.

Schedule :

- Mar. 2002 — Review of hazard analysis for the Accelerator and Test Cell Facilities oriented towards detailing, on a component-by-component basis, all possible failure modes and identifying their effects.
- Dec. 2002 — Preliminary dependent failure analysis finalised to identify the failure that can defeat the redundancy or diversity employed in the design to improve the availability of the subsystem plant functions. For some major accident, which can lead to the damage of the plant or/and cause environment hazard, a probabilistic internal events analysis and a preliminary environmental impact analysis will be performed.

Task Deliverables

No.	Description	Due Date
1	Review of Accelerator and Test Cell FMEA	2002/03
2	Plant safety analysis	2002/12

Task ID : DI85-EU

Task Title : Safety analysis and assessment.

Occupational Radiation Exposure evaluation of the entire facility

Facility : Design Integration

Institutes in Charge : ENEA (Italy)

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Need/Motivation :

The IFMIF facility has to be operated with a reduced Occupational Radiation Exposure (ORE). Safety requirements have to be fixed for the overall station dose and for single operations on systems and subsystems according international standards and ALARA process. The respect of such requirements have to be verified by the assessment of design solutions both during the design development, in order to assist designers in fixing right choosing, and when final design will be frozen, in order to achieve consensus by licensing authorities.

Brief Task Description :

Safety requirements for Occupational Radiation Exposure (ORE) have to be fixed for the overall station dose and for single operations on systems and subsystems. International radiation protection norms have to be considered in fixing such requirements. The compliance with such requirements and, with the ALARA process have to be verified both during design developing, in order to assist designers in fixing right choosing, and at the final design frizzing, in order to achieve consensus by licensing authorities.

A preliminary assessment of the Occupational Radiation Exposure (ORE) were performed, by evaluating both the dose rates and the estimated times of operation in the areas where the radiological risk is concentrated. Preliminary results gave alerting values on the related ORE issues. So that, a more detailed assessment have to be performed in order to give right indication to designers for shielding, maintenance procedures, remote handling needs.

An investigation on international radiation protection norms will precede the detailed ORE evaluation in order to fix the related safety requirements. The ORE evaluation will be performed on the base of results coming from works on “Shielding and nuclear inventory” (defining contact doses for components and dose rates for IFMIF plant zones), as well as from the works on “Design studies” (defining plant layout, maintenance and operating procedures, remote handling solutions). Maintenance, in-service inspection and operating actions will be taken into account evaluating the overall facility dose. Suggestion to get compliance with the ALARA process will be individuated where it will need.

Schedule :

- Dec. 2001 Occupational dose requirements for IFMIF facility
  - Investigation on international radiation protection norms.

- Report on requirements related to Occupational Radiation Exposure for IFMIF facility.

- Dec. 2002 ORE evaluation for IFMIF facility
  - Analysis of data related to dose rates and estimated times of operation
  - Detailed assessment of ORE
  - Report on Occupational Radiation Exposure for IFMIF facility and suggestion for design improvements related to ORE issues.

Task Deliverables

No.	Description	Due Date
1	Occupational dose requirements for IFMIF facility	2001/12
2	ORE evaluation for IFMIF facility	2002/12

Task ID : DI11-JP

Task Title : Diagnostics of Spatial Distribution of Neutron

Facility : Design Integration

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The target beam intensity measuring by neutron monitor is one of most important beam diagnostic techniques. The neutron monitors of the gamma thermometer and activation wire were proposed at the CDE phase. The gamma thermometer detector is composed of stainless needle, thermocouple and copper board. A compact multi-channel on-line gamma thermometer detector, with a size of about 210 mm (wide), 86 mm (high) and 15 mm (depth) measures neutron flux uniformity of $\pm 5\%$/cm at the period of "target on test". The activation wire detector can measure neutron profile without stopping IFMIF operation.

Brief Task Description :

The gamma thermometer detector cannot be installed at the same time as the test equipment of test cell. Also, the activation wire detector needs to be incorporated to the test equipment. Therefore, the examination of method that combines these detectors to the test equipment of test cell is performed.

Schedule : April 2000 – September 2002

Apr. 2001 – Sep. 2002 Examination and design

Task Deliverables

No.	Description	Due Date
1	Examination and design of neutron detector	2002/09

Task ID : DI13-JP

Task Title : Infrared Camera for Diagnostics of Target Temperature

Facility : Design Integration

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

An infrared camera is proposed as deuteron ion beam measurement and monitor instrument on a target for not only footprint but also surface temperature. The measurement of beam position is important from points of estimating the neutron flux position and checking the state of beam operation. The conclusions at the CDE phase are as follows. The horizontal distribution of surface temperature on target can be measured by a space resolution of about 5 mm. In order to realize the space resolution of 1 mm, it is necessary to take in the technique of chopping and data processing. However the perpendicular beam position measurement is hard, because the perpendicular (flow direction) surface temperature has no clear boundary.

Brief Task Description :

In order to reduce neutron irradiation on infrared camera, an infrared light from the target needs to be reflected by a mirror and to be led to the camera. Therefore, the design of optical path and mirror arrangement is performed.

Schedule : April 2000 – September 2002
Apr. 2001 – Sep. 2002 Design

Task Deliverables

No.	Description	Due Date
1	Design of optical path for infrared camera	2002/09
2	Design of mirror arrangement	2002/09

Task ID : DI21-JP

Task Title : Selection of elements having large cross section for activation

Facility : Design Integration

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

Estimation of radiation in test cell is necessary for setting design condition of maintenance equipment. This condition also influences the construction cost of IFMIF.

Brief Task Description :

In KEP, elements having large cross section are selected among materials constituting buildings and maintenance equipment with activation data.

Schedule : April 2000 – December 2002
Apr. 2000 – Dec. 2002 Selection of elements having large cross section for activation

Task Deliverables

No.	Description	Due Date
1	Selection of elements having large cross section for activation	2002/12

Task ID : DI31-JP

Task Title : Examination and design of measurement methods for Li jet thickness

Facility : Design Integration

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The reducer nozzle of target assembly would be deformed by intense neutron irradiation. The inner surface of nozzle would suffer erosion / corrosion by flowing Li including impurities. Under these conditions, the Li jet thickness and behavior of surface wave would change. Significant change of jet thickness and significant surface wave affect an irradiation field and a target integrity. Therefore the jet thickness should be monitored during operation.

Brief Task Description :

Measuring methods of jet thickness and surface wave is examined. The jet thickness with range 19-25 mm is measured with accuracy 0.1 mm. The amplitude of surface wave is measured with accuracy 0.1 mm. The measuring equipment should function well under the condition of intense neutron field and heat radiation from Li surface with temperature range 250-330 °C through the vacuum condition 10^{-3} Pa. With the consideration of these conditions, measuring devices are examined. Other way is an examination of equipment arrangement to avoid the severe condition. After these examinations, the design of the measuring equipment and its arrangement is performed.

Schedule : April 2000 – December 2002
Apr. 2000 – Sep. 2001 Examination of the measuring methods and arrangement
Oct. 2001 – Sep. 2002 Design of the measuring methods and arrangement
Oct. 2002 – Dec. 2002 Summary

Task Deliverables

No.	Description	Due Date
1	Examination of the measuring methods and arrangement	2001/09
2	Design of the measuring methods and arrangement	2002/09

Task ID : DI33-JP

Task Title : Examination and design of measurement methods for target assembly size and location

Facility : Design Integration

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The target assembly, especially parts around back wall, would be deformed by intense neutron irradiation. This distortion affects a neutron irradiation field and a target integrity. With the monitoring of distortion, replace period of target assembly or back wall would be predicted. An accurate prediction would increase the availability and decrease the operating cost of IFMIF. Therefore the measurement methods for target assembly size and location should be monitored during operation.

Brief Task Description :

Measuring methods of target assembly size and location is examined. They are measured with accuracy 0.1 mm. The measuring equipment should function well under the condition of intense neutron field and heat radiation from target assembly with temperature about 250 °C under the vacuum condition 10^{-3} Pa in the test cell. With the consideration of these conditions, measuring devices are examined. Other way is an examination of equipment arrangement to avoid the severe condition. After these examinations, the design of the measuring equipment and its arrangement is performed.

Schedule : April 2000 – December 2002

Apr. 2000 – Sep. 2001 Examination of the measuring methods and arrangement
Oct. 2001 – Sep. 2002 Design of the measuring methods and arrangement
Oct. 2002 – Dec. 2002 Summary

Task Deliverables

No.	Description	Due Date
1	Examination of the measuring methods and arrangement	2001/09
2	Design of the measuring methods and arrangement	2002/09

Task ID : DI41-JP

Task Title : Detailed design of buildings

Facility : Design Integration

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The required room spaces and handling lines for activated, heavy or other objects would be clarified along with progress of design for the accelerator, target, test facilities and others. Therefore, the design of room space should be revised in KEP.

Brief Task Description :

According to the revised design of accelerator, target, test facilities and others in KEP, the room spaces and arrangement and handling lines are revised and drawn as 2D- and 3D-CAD figures.

Schedule : April 2000 – December 2002
Apr. 2000 – Sep. 2002 Detailed design of buildings
Oct. 2002 – Dec. 2002 CAD drawings

Task Deliverables

No.	Description	Due Date
1	Detailed design of buildings and CAD drawings	2002/12

Task ID : DI43-JP

Task Title : Detailed design of utilities

Facility : Design Integration

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The required specifications of electric power, water for cooling, gas circulation for ventilation, vacuum condition and others would be clarified along with progress of design for the accelerator, target, test facilities and others. Furthermore, the condition of power and water supply from the outer side of IFMIF site depends on the site location and country. Therefore, the design of these utilities should be revised in KEP.

Brief Task Description :

According to the revised design of accelerator, target, test facilities and others in KEP, the utilities are revised adding an assumption of site location and country.

Schedule : April 2000 – December 2002
Apr. 2000 – Mar. 2002 Design of required utilities
Apr. 2002 – Dec. 2002 Design with an assumption of site location and country

Task Deliverables

No.	Description	Due Date
1	Detailed design of utilities	2002/12

Task ID : DI51-JP

Task Title : Detailed design of central control and common instruments

Facility : Design Integration

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

For the rationalized IFMIF, the cost of central control and common instruments are reduced mainly with the reduced number of target and test cell from 2 set to 1 set. Furthermore, C.C. & C.I. is extended along with staged construction of IFMIF. The design of C.C. & C.I. should be examined and revised with mentioned condition.

Brief Task Description :

Detailed design of C.C. & C.I. is performed for rationalized and staged IFMIF.

Schedule : April 2000 – December 2002

Apr. 2000 – Mar. 2002 Design of C.C. & C.I. for rationalized IFMIF

Apr. 2002 – Dec. 2002 Design of C.C. & C.I. for staged IFMIF

Task Deliverables

No.	Description	Due Date
1	Detailed design of central control and common instruments	2002/12

Task ID : DI61-JP

Task Title : Check of consistency and analysis of operation flow for IFMIF total system

Facility : Design Integration

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

IFMIF project should be advanced keeping the consistency among accelerator, target, test facilities and others. Also IFMIF operation flow from startup to shutdown should be considered.

Brief Task Description :

This task is performed along with the advantage of IFMIF design work. In KEP, the consistency is checked and kept, and the operation flow is analyzed for the detailed design of IFMIF.

Schedule : April 2000 – December 2002

Apr. 2000 – Sep. 2002 Consistency check for detailed design of IFMIF

Apr. 2002 – Dec. 2002 Analysis of the operation flow for detailed design of IFMIF

Task Deliverables

No.	Description	Due Date
1	Consistency check for detailed design of IFMIF	2002/12
2	Analysis of the operation flow for detailed design of IFMIF	2002/12

Task ID : DI71-JP

Task Title : Verification of current design of radiation shielding

Facility : Design Integration

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

The maximum wall thickness for radiation shielding is 2.5 m in CDA design. The specifications of shielding walls should be clarified for the building design and construction cost. Especially, the weight of shielding plugs on test cell influence the required specification of the Universal Robot System (URS) in the Access Cell.

Brief Task Description :

The propriety of wall thickness in CDA design is verified by a computer code MCNP with data libraries which would be improved.

Schedule : April 2000 – December 2002

Apr. 2000 – Mar. 2002 Preparation and adjustment of computer code and data libraries
Apr. 2002 – Sep. 2002 Calculation for radiation shielding
Oct. 2002 – Dec. 2002 Summary

Task Deliverables

No.	Description	Due Date
1	Verification of current design of radiation shielding	2002/12

Task ID : DI81-JP

Task Title : RAM analysis for 3 stages IFMIF with detailed design

Facility : Design Integration

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

IFMIF performances such as Reliability, Availability and Maintainability are changed with the rationalization and staged construction of IFMIF. Therefore RAM analysis should be performed again for the 1st, the 2nd and the 3rd sages of rationalized IFMIF.

Brief Task Description :

The mean time between failure (MTBF) and mean time to repair (MTTR) data are acquired from existing similar facilities of accelerator, liquid metal loop, irradiation and others. Based on these data, 3 sets of RAM analyses are performed for the 1st, the 2nd and the 3rd stages of IFMIF detailed design in KEP.

Schedule : April 2000 – December 2002

Apr. 2000 – Mar. 2002 Data acquisition from existing facilities

Apr. 2002 – Dec. 2002 3 sets of RAM analyses for IFMIF detailed design

Task Deliverables

No.	Description	Due Date
1	RAM analysis for 3 stages IFMIF with detailed design	2002/12

Task ID : DI83-JP

Task Title : Safety assessment for 3 stages IFMIF with detailed design

Facility : Design Integration

Institutes in Charge : JAERI (Japan)

Contact Persons : Hiroshi Takeuchi, Mizuho Ida (JAERI)

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Need/Motivation :

IFMIF safety is changed with the rationalization and staged construction of IFMIF. Therefore RAM analysis should be performed again for the 1st, the 2nd and the 3rd sages of rationalized IFMIF.

Brief Task Description :

The data for safety are acquired from existing facilities in the point view of large current beam, large capacity liquid Li loop, very intense 14 MeV neutrons. Based on the data, 3 sets of safety assessments with analysis method such as failure mode and effect analysis (FMEA) are performed for the 1st, the 2nd and the 3rd stages of IFMIF detailed design in KEP.

Schedule : April 2000 – December 2002

Apr. 2000 – Mar. 2002 Data acquisition from existing facilities

Apr. 2002 – Dec. 2002 3 sets of safety analyses for IFMIF detailed design

Task Deliverables

No.	Description	Due Date
1	Safety assessment for 3 stages IFMIF with detailed design	2002/12

Task ID : DI91-JP

Task Title : Examination of licences and regulations and consequent facility design

Facility : Design Integration

Institutes in Charge : JAERI (Japan)

Contact Persons : Hiroshi Takeuchi, Mizuho Ida (JAERI)

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Need/Motivation :

Licences and regulations about radiation, nuclear fuel material, electromagnetic wave, dangerous material, high-pressure gas, earth quake and fire should be considered, because these restrictions affect the IFMIF design. Also the local condition of nature and public should be considered

Brief Task Description :

With an assumption on site country and location, licences, regulations and other restrictions are examined. With these restriction conditions, check and adjustment are performed to detailed design of accelerator, target, test facilities and others.

Schedule : April 2000 – December 2002

Apr. 2000 – Mar. 2002 Examination of licences, regulations and other restrictions

Apr. 2002 – Dec. 2002 Check and adjustment of IFMIF detailed design

Task Deliverables

No.	Description	Due Date
1	Examination of licences, regulations and other restrictions	2002/03
2	Check and adjustment of IFMIF detailed design	2002/12

Task ID : DI93-JP

Task Title : Analysis of whole schedule and work items of IFMIF

Facility : Design Integration

Institutes in Charge : JAERI (Japan)

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Need/Motivation :

Whole schedule and work items about construction, operation and decommission should be analyzed for efficient use of IFMIF resources such as talent, time, budget and IFMIF itself.

Brief Task Description :

The analysis of schedule and work items are performed with IFMIF detailed design in KEP.

Schedule : April 2000 – December 2002

Apr. 2000 – Dec. 2002 Analysis of whole schedule and work items of IFMIF

Task Deliverables

No.	Description	Due Date
1	Analysis of whole schedule and work items of IFMIF	2002/12

Task ID : DI95-JP

Task Title : Cost estimation with results of KEP and detailed design

Facility : Design Integration

Institutes in Charge : JAERI (Japan)

Contact Persons : Hiroshi Takeuchi, Mizuho Ida (JAERI)

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Need/Motivation :

Cost estimation should be performed along with progresses of design work and KEP activities, because the estimated cost would be changed. Furthermore, the operation cost and cost in life cycle should be estimated.

Brief Task Description :

The construction, operation cost and cost in life cycle are estimated with IFMIF detailed design and results of KEP activities.

Schedule : April 2000 – December 2002

Apr. 2000 – Dec. 2002 Cost estimation with results of KEP and detailed design

Task Deliverables

No.	Description	Due Date
1	Cost estimation with results of KEP and detailed design	2002/12

国際単位系 (SI) と換算表

表 1　SI 基本単位および補助単位

量	名　称	記　号
長　さ	メートル	m
質　量	キログラム	kg
時　間	秒	s
電　流	アンペア	A
熱力学温度	ケルビン	K
物質量	モル	mol
光　度	カンデラ	cd
平面角	ラジアン	rad
立体角	ステラジアン	sr

表 2　SI と併用される単位

名　称	記　号
分，時，日	min, h, d
度，分，秒	°, ′, ″
リットル	l, L
トン	t
電子ボルト	eV
原子質量単位	u

1 eV $=1.60218\times10^{-19}$ J
1 u $=1.66054\times10^{-27}$ kg

表 5　SI 接頭語

倍数	接頭語	記　号
10^{18}	エクサ	E
10^{15}	ペタ	P
10^{12}	テラ	T
10^{9}	ギガ	G
10^{6}	メガ	M
10^{3}	キロ	k
10^{2}	ヘクト	h
10^{1}	デカ	da
10^{-1}	デシ	d
10^{-2}	センチ	c
10^{-3}	ミリ	m
10^{-6}	マイクロ	μ
10^{-9}	ナノ	n
10^{-12}	ピコ	p
10^{-15}	フェムト	f
10^{-18}	アト	a

表 3　固有の名称をもつ SI 組立単位

量	名　称	記号	他の SI 単位による表現
周波数	ヘルツ	Hz	s^{-1}
力	ニュートン	N	$m\cdot kg/s^2$
圧力，応力	パスカル	Pa	N/m^2
エネルギー，仕事，熱量	ジュール	J	N·m
工率，放射束	ワット	W	J/s
電気量，電荷	クーロン	C	A·s
電位，電圧，起電力	ボルト	V	W/A
静電容量	ファラド	F	C/V
電気抵抗	オーム	Ω	V/A
コンダクタンス	ジーメンス	S	A/V
磁束	ウェーバ	Wb	V·s
磁束密度	テスラ	T	Wb/m^2
インダクタンス	ヘンリー	H	Wb/A
セルシウス温度	セルシウス度	℃	
光束	ルーメン	lm	cd·sr
照度	ルクス	lx	lm/m^2
放射能	ベクレル	Bq	s^{-1}
吸収線量	グレイ	Gy	J/kg
線量当量	シーベルト	Sv	J/kg

表 4　SI と共に暫定的に維持される単位

名　称	記　号
オングストローム	Å
バーン	b
バール	bar
ガル	Gal
キュリー	Ci
レントゲン	R
ラド	rad
レム	rem

1 Å $=0.1$ nm $=10^{-10}$ m
1 b $=100$ $fm^2=10^{-28}$ m^2
1 bar $=0.1$ MPa $=10^5$ Pa
1 Gal $=1$ $cm/s^2=10^{-2}$ m/s^2
1 Ci $=3.7\times10^{10}$ Bq
1 R $=2.58\times10^{-4}$ C/kg
1 rad $=1$ cGy $=10^{-2}$ Gy
1 rem $=1$ cSv $=10^{-2}$ Sv

（注）

1. 表1－5は「国際単位系」第5版，国[illegible]度量衡局 1985年刊行による。ただし，1 e[illegible]および1 uの値はCODATAの1986年推[illegible]値によった。
2. 表4には海里，ノット，アール，ヘク[illegible]ールも含まれているが日常の単位なので[illegible]こでは省略した。
3. bar は，JISでは流体の圧力を表わす[illegible]合に限り表2のカテゴリーに分類されて[illegible]る。
4. EC閣僚理事会指令では bar，barn お[illegible]び「血圧の単位」mmHgを表2のカテゴ[illegible]ーに入れている。

換　算　表

力	N(=10^5dyn)	kgf	lbf
	1	0.101972	0.224809
	9.80665	1	2.20462
	4.44822	0.453592	1

粘　度　1 Pa·s(N·s/m^2) = 10 P(ポアズ)(g/(cm·s))

動粘度　1 m^2/s = 10^4St(ストークス)(cm^2/s)

圧力	MPa(=10 bar)	kgf/cm^2	atm	mmHg(Torr)	lbf/in^2(psi)
	1	10.1972	9.86923	7.50062×10^3	145.038
	0.0980665	1	0.967841	735.559	14.2233
	0.101325	1.03323	1	760	14.6959
	1.33322×10^{-4}	1.35951×10^{-3}	1.31579×10^{-3}	1	1.93368×10^{-2}
	6.89476×10^{-3}	7.03070×10^{-2}	6.80460×10^{-2}	51.7149	1

エネルギー・仕事・熱量	J(=10^7erg)	kgf·m	kW·h	cal(計量法)	Btu	ft·lbf	eV
	1	0.101972	2.77778×10^{-7}	0.238889	9.47813×10^{-4}	0.737562	6.24150×10^{18}
	9.80665	1	2.72407×10^{-6}	2.34270	9.29487×10^{-3}	7.23301	6.12082×10^{19}
	3.6×10^{6}	3.67098×10^{5}	1	8.59999×10^{5}	3412.13	2.65522×10^{6}	2.24694×10^{25}
	4.18605	0.426858	1.16279×10^{-6}	1	3.96759×10^{-3}	3.08747	2.61272×10^{19}
	1055.06	107.586	2.93072×10^{-4}	252.042	1	778.172	6.58515×10^{21}
	1.35582	0.138255	3.76616×10^{-7}	0.323890	1.28506×10^{-3}	1	8.46233×10^{18}
	1.60218×10^{-19}	1.63377×10^{-20}	4.45050×10^{-26}	3.82743×10^{-20}	1.51857×10^{-22}	1.18171×10^{-19}	1

1 cal = 4.18605 J (計量法)
　= 4.184 J (熱化学)
　= 4.1855 J (15 °C)
　= 4.1868 J (国際蒸気表[illegible]

仕事率　1 PS (仏馬力)
　= 75 kgf·m/s
　= 735.499 W

放射能	Bq	Ci
	1	2.70270×10^{-11}
	3.7×10^{10}	1

吸収線量	Gy	rad
	1	100
	0.01	1

照射線量	C/kg	R
	1	3876
	2.58×10^{-4}	1

線量当量	Sv	rem
	1	100
	0.01	1

(86年12月26日現在)