FP7 SPIRAL 2 Preparatory Phase

WP 6.3 Task "Beam Dump"

1st Meeting
Madrid (CIEMAT) December 5th 2008

M I N U T E S

DATE:	05/12/08	OBJECT:	Minutes of the 1st WP 6.3 Task "Beam Dump" Meeting
N/REF:			
PREPARED BY:	T. Junquera	LOCATION:	Madrid, Spain

INSTITUTION:	GANIL	CNRS	CIEMAT U. Madrid	SOREQ	U. Huelva
PRESENT:	P. Bertrand J. Sauret	T. Junquera L. Perrot E. Schibler	B. Brañas A. Ibarra D. Iglesias C. Oliver J. Gomez Palomino J. Sanz M. Garcia A. Mayoral D. Lopez F. Ogando P. Sauvan	D. Berkovits	I. Martel
EXCUSED:					
DIFFUSION:	To all participants				

N°	TOPIC	SPEAKER
1	Status of the SP2 Driver Accelerator Construction • Project schedule: main milestones following recent decisions and signature of contracts for Phase 1 buildings: Contract for Buildings phase 1: 06/10/2008 Buildings Construction (begins): 31/03/2010 Buildings contract reception : 15/02/2012 First beams (commissioning, first experiments): march 2012 Phase 2 Contract for Buildings : October 2009	T. Junquera

- Linac tunnel underground: beam axis level -7.5 m
- New design of High Energy Lines. Location of the Beam Dump
- Progress in the construction of the Injector, SC Linac and HE lines

ESFRI: Spiral 2 PP Last News

- SPIRAL2 PP Grant Agreement signed by the European Commission on November 14th, 2008.

- The prefinancing will be probably paid within the following weeks; it should be in any case before the end of the year.

- Accession Form will be sent to all beneficiaries for signature and have to be sent back to GANIL before December 10th, 2008.

- SPIRAL2 PP General Assembly and Management Board meeting during the SPIRAL2 Week January 26-29, 2009 in Caen

WP 6.3 Task "Beam Dump"

Milestones:

- 1st: goals, partners contributions and responsibility (month 8)
  ⇒ after 1st Meeting (January/Feb. 2009)
- 2nd: material choice, activation calculations, sample tests, thermo-mechanical aspects (month 17) ⇒ September 2009 ?
- 3rd : Design report (month 20) ⇒ December 2009 ?
- 4th : Proposal for construction (month 24) ⇒ June 2010 ?

Activities:

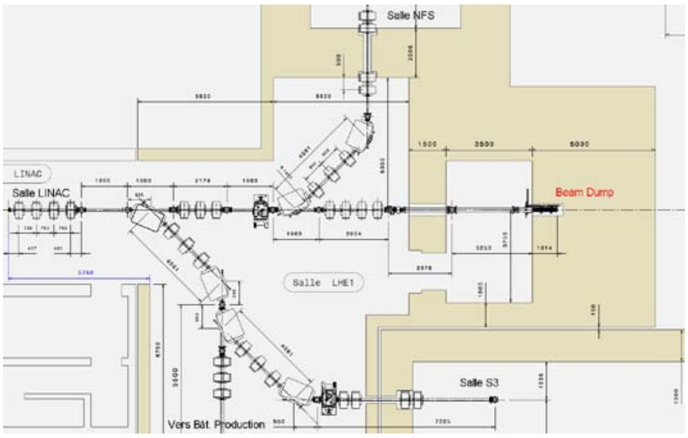
- Beam dynamics calculation of the High Energy Beam line
- Proposal of Beam diagnostics associated to the B.D.
- Thermo-mechanical calculations (conical shapes, plates, ...)
- Materials activation (calculations, sample tests)
- Preliminary Safety Report for Spiral (operation modes of the beam dump and the maximum beam power for deuteron beam)

Next meetings

Meetings	Date	Place
WP6 (all tasks)	June 12th, 2008	Giens EURORIB 08
Task 6.3 (Beam dump)	June, july 08 05/12/08	Madrid
All Tasks (proposal)	Spiral 2 Week January 26-29	Caen
Task 6.1 (BLM) Task 6.4 (beam diagnostics)	June, july 08 1st Q 2009 ?	Bucharest
WP6 (all tasks)	Autumn 2008 1st Qr 2009 ?	Tel Aviv SOREQ

2 High Energy Beam Line Studies for SPIRAL2 project and Beam Dump — Luc Perrot

- Available beams at SPIRAL2
- New scheme of the HE lines (October/November 2008). Final position of the Beam Dump.



- Proposal for installation of Beam Diagnostics in the straight line: Profilers, BPM, Intensity, Energy measurements
- Study of the Transport section (telescopic mesh), length 5.9m with 3 quads
- Beam matching using the last 4 quadrupoles for beam waist in X-Y few 30cm after last Q and beam-size of 14mm at 1 RMS at BD entrance
- Beam envelopes, beam emittance, power deposition on the Beam Dump walls (see E. Schibler presentation)
- Study of errors in quadupoles & beam alignment
- Study of beam losses in case of quadrupole failure

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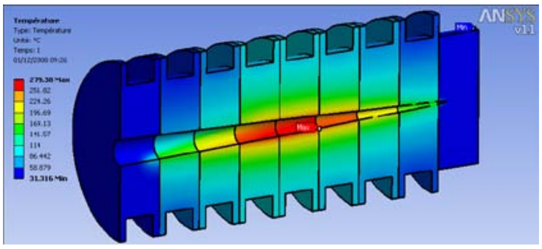
<u>Spiral 2 Beam Dump Mechanical and Thermal aspects</u>

Presentation of a new design for the Spiral 2 Beam Dump based on 20 independently cooled copper cylinders:

- Cylindrical blocks of copper with a conical opening
- 10 kW / block → ~20 blocks (max. thermal power 200 KW)
- Thickness: 50 mm, total length ~1 m
- External radius 65 mm
- Cooling system
- Brazed copper pipes, Øint = 4 mm
- Assembled by welded flanges or direct welding



<u>Material Study (mechanical and thermal aspects)</u>

- Cu OFHC (Copper Oxygen Free High Conductivity) Cu > 99.99% (P < 0.0003%)

- Glipcop® LoX (Copper alloy with submicroscopic particles of Al_2O_3 (0.15% Al). Low Oxygen. Good high temperature strength

<u>Beam penetration:</u> Bragg peak for Deuterons/protons and Heavy ions

<u>Cooling studies</u> : Pressurized water 8 bars. Pipes (Øint 4 mm – Øext 6 mm). Thermal transfer coefficients.

<u>Mechanical calculations</u>

<u>Transients</u> :

- Pulsed mode
- Delay to detect problem and stop beam ~ 100 ms

<u>Over-focalized beam:</u> thermal effects

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<td>Emilie Schibler</td>
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4	<u>NUCLEAR SAFETY AND RADIATION PROTECTION IN SPIRAL 2 FACILITY</u>	Josiane Sauret

<u>NUCLEAR SAFETY AND RADIATION PROTECTION IN SPIRAL 2 FACILITY</u>

- Administrative licensing procedure and time schedule
  - Phase 1 (accelerator, HE lines, stable beams)
  - Phase 2: RIB production

A global safety report (DAM report) leading to <u>a single ministerial decree with steps</u> : a single licensing procedure will be leaded (only 1 public inquiry). The decree will mention that <u>phase 2 will be submitted to the authorization</u> of nuclear safety authority

DAM report includes :

► Preliminary Safety Report : two level of details according to phase 1 or 2
► Operating domain of the whole facility and associated dimensioning
► Impact on environment : release of radioactive effluents
(normal operation and accidental situations)

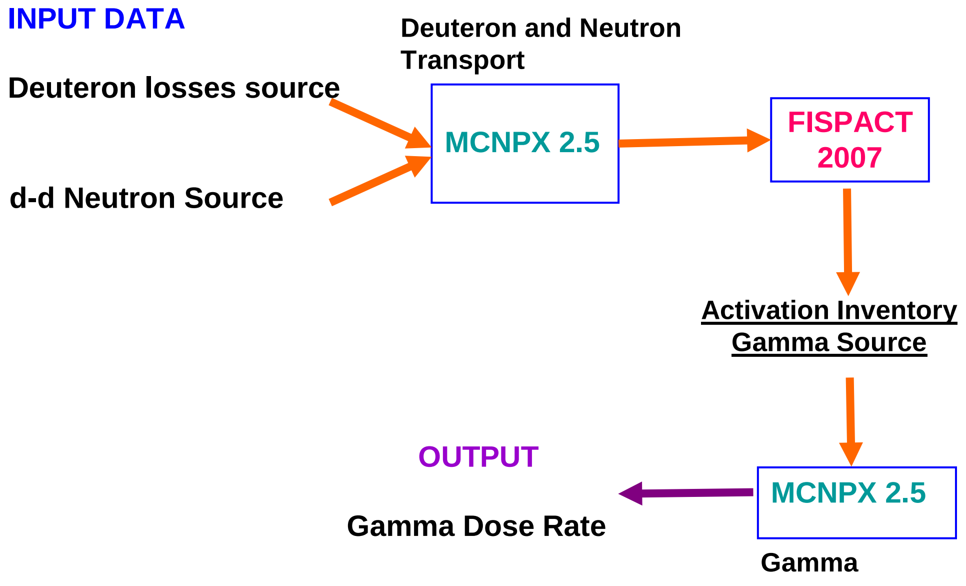
- Safety and radioprotection objectives

	Workers	People/Environment
Normal operation	ALARA < 2mSv/year (0 internal exposure)	ALARA < 10 µSv/year
Incidental situation	< 10 mSv/year	< 10 µSv/incident
Major incident	< 20 mSv/incident	< 100 µSv/incident
Major accident	Variable according to situation and potential impact	< 1 mSv/accident

- Different risks and safety/radioprotection requirements

EXTERNAL EXPOSURE TO IONISING RADIATIONS
INTERNAL EXPOSURE TO IONISING RADIATIONS
NON NUCLEAR RISKS (EXTERNAL AGRESSIONS, FIRE, System Failures, …)

- Activation and dose rate calculations:



Input data : deuteron energy 40 MeV – Beam intensity = 5 m
beam losses below 1 Watt/m
modelling of LINAG equipments

Hypothesis : 3 months irradiation ; 1 month cooling

- On-going experimental program

Radioactive ion implantation and equipment activation
► experiments on SPIRAL 1 at GANIL (Caen)

Transfer of contamination to the pumping system
► experiments on SPIRAL 1 (GANIL) and ILL (Grenoble)

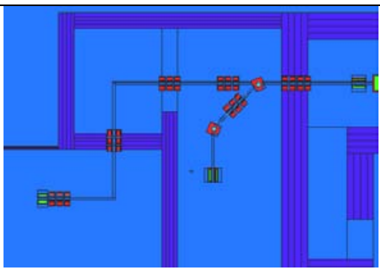
Thermal releases of radioactive ions (samples Cu, Ti, Al, W….)
► experiments at ISOLDE (CERN) and ILL (Grenoble)

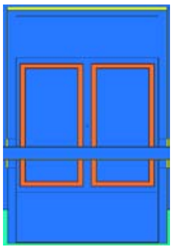
Cryotraps system efficiency
► experiment planned in 2009 on prototype (ALTO-Orsay)

Neutron production with 40 MeV deuterons
► Measurements for different convertors
(march to september 2008) Physics Department in Jyvaskyla (Finland)
Graphite, heavy water, light water

SPIRAL 2 Phase 1 : Activation, dose rate, dose

Modelling of accelerator components:

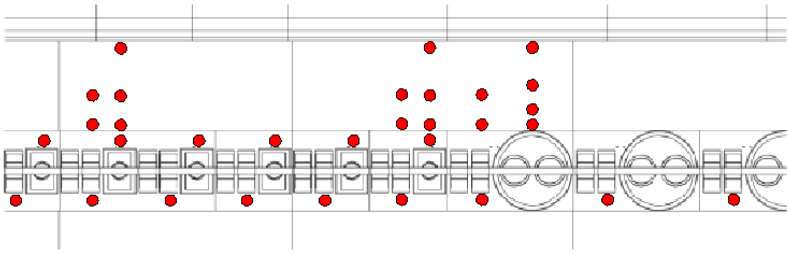




Input :

- 3 runs of 3 months / year – 20 years
- Beam losses 0.2 W / cryomodule et 1 W / Qpoles
- Chamber in steel 316 L
- Dose rate at different time and different positions

Dose rate map :



Collective dose (H.mSv per year) for different cooling time

	0 seconde	1 jour	7 jours	1 mois
LBE	0.1	0	0	0
RFQ	0	0	0	0
LME	0.2	0	0	0
CMA	0.6	0.3	0.3	0.2
CMB 1-4	0.7	0.4	0.3	0.3
CMB 5-7	0.8	0.4	0.3	0.3
LHE	**7.8**	**4.6**	**3.3**	**3.2**
Maintenance	7.3	4.9	4.4	3.1
total	17.4	10.8	8.7	7.1

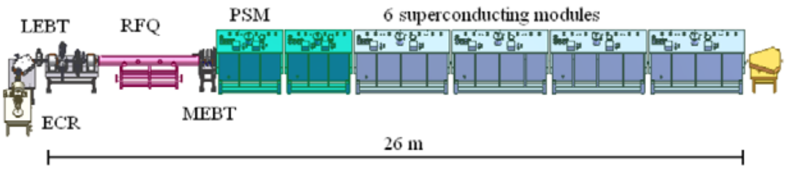
- Comparison between proton and deuteron activation
- Comparison between steel (316 L) and Aluminum (5083) from dose rate point of view.

5

The SARAF CW 40 MeV Proton/Deuteron Accelerator

Dan Berkovits

- Accelerator Basic Characteristics

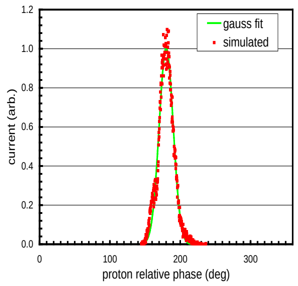


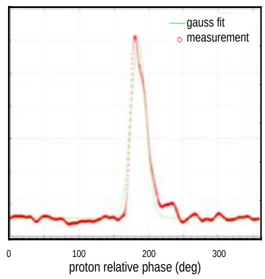
- Set up for Phase I beam characterization: Injector, first cryomodule, diagnostics test plate, beam dump

- LEBT emittance measurements: protons, H2+, deuterons between 0.04 and 5 mA. Deuterons emittance results: 0.1 π.mm.mrad at 5 mA(with collimator), 0.25 π.mm.mrad at max. current 6.1 mA

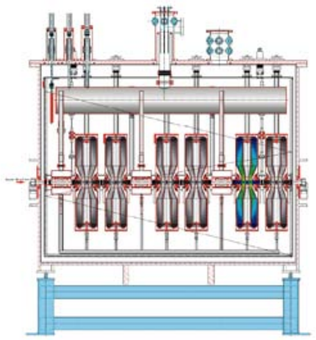
- RFQ commissioning results: protons 1.5 MeV, 4 mA, transversal emmittance 0.25 π.mm.mrad at 4 mA, longitudinal emmittance 30 π·keV·deg/u at 3 mA, transmission 65 à 80 % decreasing with beam intensity between 4 mA and 0.5 mA, required RF power 62 KW for protons, 248 KW for deuterons

- Present improvements program of the RFQ structure
- Beam diagnostics: energy measurements using BPM with TOF techniques
- Bunch profiles measurements: using Wire Scanner
- Bunch length measurements: using Fast Faraday Cup



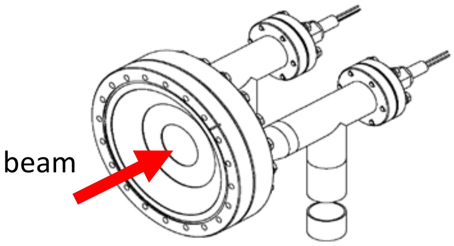


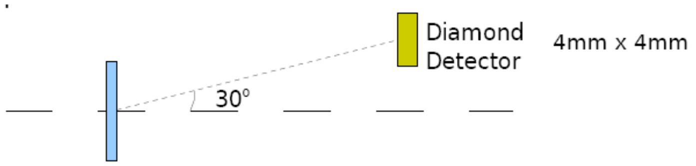
- Prototype SC Module (PSM): 6 HWR and 3 superconducting solenoids



Results : 0.7 < Vcav < 1.14 MV per cavity
LLRF : Generator Driven and Tuning loop
Stability: amplitude 0.5 % , phase ± 0.3°

- Beam dynamics simulations at SARAF:

	Analysis of Phase I (1 Cryomodule) commissioning results Optimization of the design of Phase II (+ 5 cryomodules) Phase II beam losses down to 1 nA envelope Effect of errors in production, assembly, alignment and operation on beam energy, quality and loss Residual activation from beam loss: at 40 MeV, a beam loss value of 0.4 nA/m at 40 MeV in ^{56}Fe generates 2 mRem/hr after a 1 year irradiation <u>SARAF < 10 MeV, 20 kW deuterons moveable beam dump for commissioning</u> • Able to dump <10 MeV protons or deuterons and 20 kW for short periods during beam commissioning • Able to moderate prompt radiation (0.1 mrem/h behind 1.5 m concrete shield) and residual activity (2 mrem/h, 4 hours after shutdown and 30 cm away) • Protect the superconducting cavities from residual gasses and dirt (10-8 mbar at cryomodule exit) • Moveable <u>Residual activity calculation</u> Basic parameters for the calculations: 40 µA 8 MeV deuterons 2 month continues beam Heavy metal composition: HM1 = 95% W, 3.5% Ni, 1.5% Fe HM2 = 97% W, 2% Ni, 1% Fe Natural abundance: 56Fe-92%, 58Ni-68%, 60Ni-26% Measured cross sections + ALICE  Performed calculations (see details in presentation): Radiation rate from HM Dose rate from HM: 30 cm from dump several hours after shutdown Dose rate behind local lead shield Primary radiation conclusions: • Replace dump each time it reaches the hands-on criterion spear dumps • Local shielding of 6 cm lead is recommended for 140 h/y hands-on maintenance (for Phase-I 5.2 MeV shielding is not required) Secondary neutrons induced residual activity: on Beam Dump, on Air Conditioning pipes, on Vacuum pumps, on Concrete walls (24Na)	

	<u>Heat removing design:</u> Micro-channel cooling system Tested with 20 keV electrons 10 kWatt 750 Watt/cm^2 <u>First results with up to 6 kW protons </u>(1.5 MeV, 4 mA) Beam dump current calibration B.D. Temperature and Vacuum pressure Beam shape on beam dump extracted from measured emittance 6.45 m upstream <u>2nd and 3rd generation BD: </u>under development <u>Summary</u> • 20 kW heat removal, based on 6 kW proton beam and extrapolation, is possible • The main challenge today is keeping the vacuum criterion at the exit of the cryomodule • Prompt radiation, residual activation and local shielding still need to be measured and studied	
6	<u>Beam Diagnostics: Diamond and Silicon Detectors</u> - Single Crystal Diamond (SDD) are excellent detectors for timing and spectroscopy applications, with an energy resolution comparable to that of a silicon detector. Currently used in different experimental setups (Agata, DINEX, …) and proposed for the future facilities (GASPARD in Spiral 2, HYDE in FAIR, FAZIA) - SDD are good candidates as beam diagnostics for the tuning procedures of the SC Linac in the Spiral 2 project. Measurement of beam energy and bunch length could be very interesting applications for the monitoring of the HE beam lines. - Test must be performed in December at CNA Tandem machine (Sevilla), where timing performance will be studied.  	Ismael Martel

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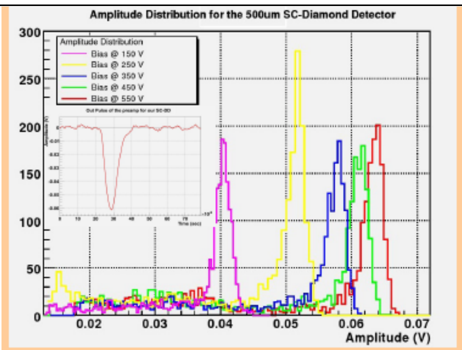
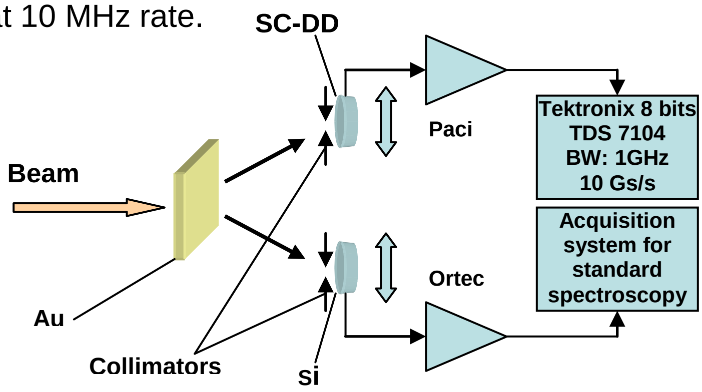


Figure 2. Amplitude distribution obtained for different bias voltages
Inset shows the shape of a pulse at bias of 550 V.

- Within the Spiral 2 PP program a new test is foreseen in February 2009 at the IPN Orsay Tandem. Different beams will be available, protons/deuterons up to 25 MeV, C up to 70 MeV, O up to 90 MeV. A pulsing system is also available, delivering bunches of < 2ns at 10 MHz rate.



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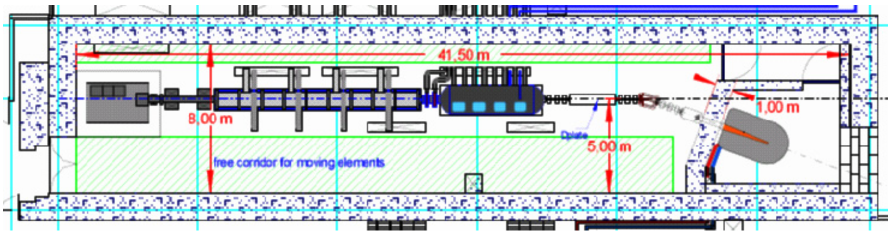
<u>Beam dump for IFMIF-EVEDA Accelerator. Project Status</u>

- IFMIF-EVEDA present status: The EVEDA phase (Engineering Validation and Engineering Design – 2007-2013) of the IFMIF project includes the manufacturing and tests of a prototype accelerator (1:1) with 9 MeV final energy. Composed of an Ion source, RFQ, HWR cryomodule, transport line and Beam Dump.



- BEAM DUMP MISSION: to stop the beam at the exit of the accelerator during commissioning (1st RFQ, 2nd whole accelerator) and accelerator tests

- It must stop **deuteron and H2+ beams** with energies 5 MeV & **9 MeV. DC and pulsed** (5 Hz, 0.1% duty cycle) operation
- It will be designed for a maximum continuous beam power of
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<td>Beatriz Brañas</td>
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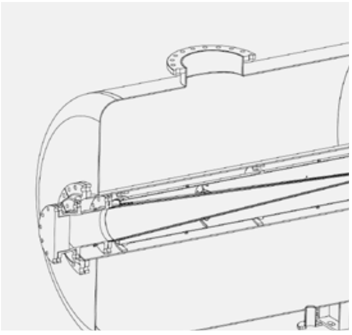
125 mA x 9 MeV= **1.12 MW**

Beam dump reference design:

- Material: copper
- Conical geometry with D=30 cm, L=250 cm
- Cylindrical scraper with L~50 cm and D=30 cm
- Cooling system: Axial flow through annular channel of varying width in counter-beam direction. 10 kg/s, Tin=20 ºC, p=6 bar, v<5 m/s (presently under revision)



- Range of 9 MeV deuterons inside candidate materials:
  It is not possible to install a vacuum window in front of the BD→
  The beam dump must operate in vacuum (p ~10-5 mbar)

Heat deposition can be considered as a surface source

- To reduce as much as possible the power density at the beam dump : **Increase beam size, defocus** or sweep the beam (raster scan)
- To obtain a manageable power density at the beam stop, the beam coming from the accelerator output will be defocused. For that purpose three quadrupoles are included in the HEBT line in front of the BD.
- A maximum rms size of 42 mm and a divergence of 15 mm/m at the beam dump entrance can be achieved
- Thermal Management: optimization of the Beam Dump geometry (shape and dimensions)
- Power deposition calculation: using TraceWin

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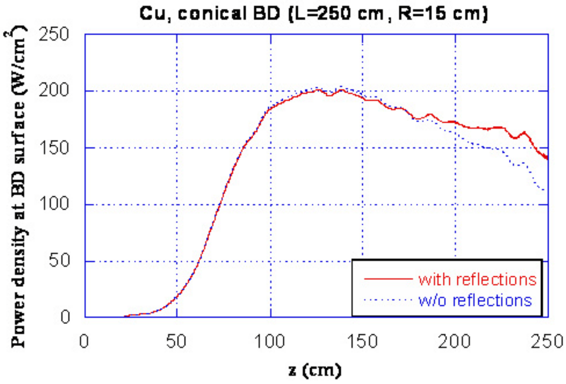
<td>

- The effect of particle backscattering on the power deposition curve has also been estimated
- <u>Cooling System</u>: Stationary 1D Heat Transfer analysis, coolant channel geometry is chosen, temperature velocity and pressure profile, pressure requirements, heat transmission coefficient estimation.
- <u>Conclusions and remarks</u>: A liquid water cooling system is appropriate for the IFMIF-EVEDA beam dump. Maximum temperatures at material-coolant interphase around 100 ºC. The water must be pressurized (pout around 4 bar). The h estimations, cross checked with CFD calculations, give values around 20000 W/m2K. Temperature gradients inside the material are independent on cooling. Thus, thermal stresses depend very little on cooling system design. Total mechanical stresses are affected by the cooling system design mainly because of the coolant pressure load on the material

- <u>On-going Work :</u> Fabricability issues, Beam Dump instrumentation, maintenance issues (only during commissioning with H2+), replacement strategy in case of failure. Effect of deuteron radiation on material.</td>
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<td><u>Thermo-mechanical analysis of the IFMIF/EVEDAc beam dump</u>

<u>Beam parameters:</u> TraceWin calculations

<u>Thermal load :</u> A house-made code let us compute 2D and 3D beam power density deposition

<u>Geometries:</u> Different geometries have been studied: Cone, plates, divided plates, cone with cylindrical scraper.

<u>Material's Properties:</u> High conductivity, low termal expansion, low elastic modules, high yield strength

<u>Computational Models – FEM</u>: 2D solid axis-symmetric elements and</td>
<td>Fernando Arranz</td>
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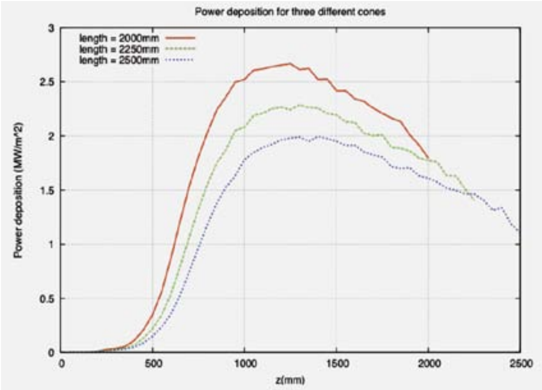
3D shell elements



<u>Reference Design</u> – Geometry: Cone

- Increase in beam divergence to diminish maximum power deposition → cylindrical scraper
- Parameters: Cone length = 2500mm, Cylindrical scraper ≈ 500 mm, Initial inner diameter = 300mm, Wall thickness = 3,5 to 5 mm
- Material: OFE-Copper [Cu 101; UNS Nº C10200]

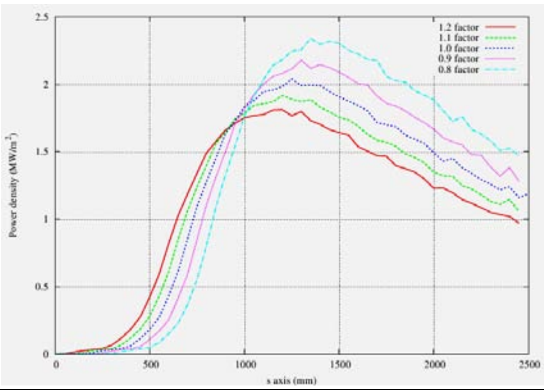
<u>Linear static análisis:</u> Temperatures, Tmax = 152ºC, Thermal stress intensity, Q = 29 MPa, Pressure stress intensity (6 bar), Pm1 = 26 MPa, Weight stress, Pm2 < 1 MPa

<u>ASME verification of stresses :</u> Maximum allowable stress intensity of OFE-Cu value at 149ºC => Sm =34,5 MPa

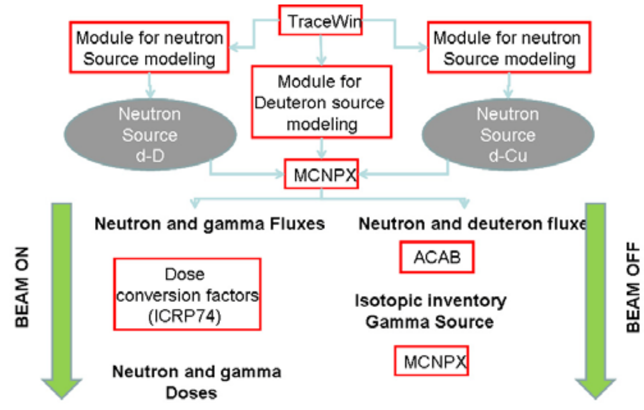
<u>Fatigue análisis:</u> cyclic power, continuous power

<u>Buckling análisis</u>

<u>Sensitivity análisis:</u> Beam Divergence



<u>Other effects to be analyzed :</u> Progressive deformation , Thermal creep**:** probably negligible as temperatures are relatively low, Irradiation creep and swelling: on going

9	<u>IFMIF/EVEDA RADIOPROTECTION STUDIES FOR THE DESIGN OF THE BEAM DUMP</u> Work within the frame of Spanish participation in EVEDA/IFMIF Accelerator System Group. <u>Radioprotection and Safety</u> : Two European home-teams involved for the EVEDA phase: CEA (France) and UNED/Inst. Nuclear Fusion/CIEMAT (Spain). Two radioprotection requirements For the present design of both building and BD cartridge: 1.- Are the dose rates outside the accelerator vault during accelerator operation below the required levels for workers? (limit 12.5 μSv/h)? 2.- Is man-access for maintenance inside the accelerator vault feasible during beam- off phases? THE MAIN ISSUES FOR THE PROPOSE TASK: 1.Develop a computational methodology able to make predictions with enough accuracy. Special attention is paid to the treatment of the neutron source, coming from both d-D and d-Cu interactions. 2.The neutron source for the BD is evaluated, and the d-D and d-Cu contributions compared. **3.** Analyze the possibility of a BD local shielding able to fulfil the two mentioned radioprotection requirements. Methodology:  - Module for d-D Source modeling - Module for d-Cu Source modeling	Javier Sanz

- Excitation functions: MCNPX&TALYS vs Experimental data
- Total neutron production XS: MCNPX models vs TALYS+Avrig
- Total neutron production XS: TALYS options

NEUTRON SOURCE EVALUATION:

- Concentration profile of implanted deuterium
- d-D vs d-Cu contributions

After **24 hours** of irradiation the neutron yield can be considered **constant**

The neutron production from **d-D can be neglected** for BD shielding design

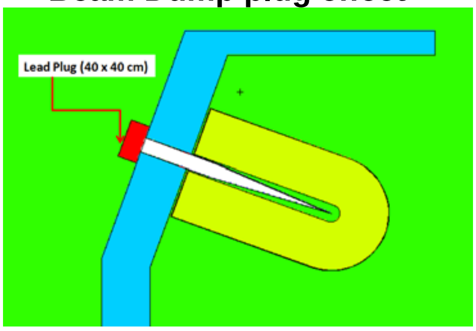
<u>Dose rates on beam-on</u> phase outside accelerator vault: compliance with targeted values

The 1.5 m concrete thickness fulfill with the dose limit

Additional small shielding is needed whenTalys / MCNPX correction factor is applied

<u>Dose rates during beam-off phase</u> in the accelerator room

Beam Dump plug effect



- Lead cylindrical plug: 40 cm thickness, 40 cm radius.
- Dose rates decreases 4 order of magnitude in the beam line area.
- Resulting dose rates one order of magnitud higher than 12.5 µSv/h.
- Deuteron activation only. Zn65 main contributor, one hour cooling (92%), one day cooling (98%)

<u>Dose rates in the hot point</u>**:** irradiation time effect

- Irradiation up to 1 week allows manual maintenance with the plug configuration
- One month irradiation (plug configuration): 15.5 µSv/h (1 day cooling time).
- Dose rates due to neutron induced activation almost negligible for irradiation time higher than 1 month. (2.17 % for 1 month,

	4.65 % for 1 week, 7 % for 1 day). **CONCLUSIONS AND ONGOING WORK:** Designing of a local shielding for the Cu cartridge; radioprotection response ? Comprehensive methodology proposal. d-D and d-Cu neutron source. - Able to address radioprotection analyses on both BD and accelerator elements - potential of MCNPX for BD applications? MCNPX/INCL4 with a module for deuteron source modelling and a renormalization factor of ~2.5 is a helpful starting point approach for preliminary BD applications (not necessary to deal with the d-D neutron source) <u>Base line shielding design</u>: - dose rates outside the vault: good perspectives to fulfil the 12.5 μSv/h requirement - beam-off phase: adding a plug at the BD entrance seems to be a feasible solution to fulfil dose requirements for hands-on maintenance in the beam line accelerator area	
10	**<u>General Conclusions of the Meeting</u>** URGENT: To establish the Beam Dump description in the Safety report for Spiral 2, we need: - In 3 month: a preliminary description of operational modes, beam power, material, activation, maintenance, etc. - In One year: more detailed description and final configuration. In the frame of the Spiral 2 PP (WP 6.3), we can propose the following activities: 1. Quick comparison of activation calculations between GANIL and UNED using different methodologies. Initiating this task by giving the neutron flux description in the material or materials of interest and the irradiation schedule. Deuteron and proton induced activation, if necessary for methodology reliability purposes, will be also computed in the material or materials selected taken as inputs the corresponding flux descriptions and irradiation time. 2. Meeting in Caen (with UNED) end of January during the Spiral 2 Week. 3. Experimental validation with samples: list of materials, program of irradiations, analysis methods, facilities, …	all

	4. Interaction with SC cavities vacuum: sputtering calculations by CIEMAT 5. Beam diagnostics associated to Beam Dump operation: CIEMAT is considering fluorescence on residual gas (Kr or Xe) 6. Interlocks for BD machine protection: temperature, water cooling, etc.	