SANDA WP2

New nuclear data measurements for energy and non-energy applications

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Structure of SANDA

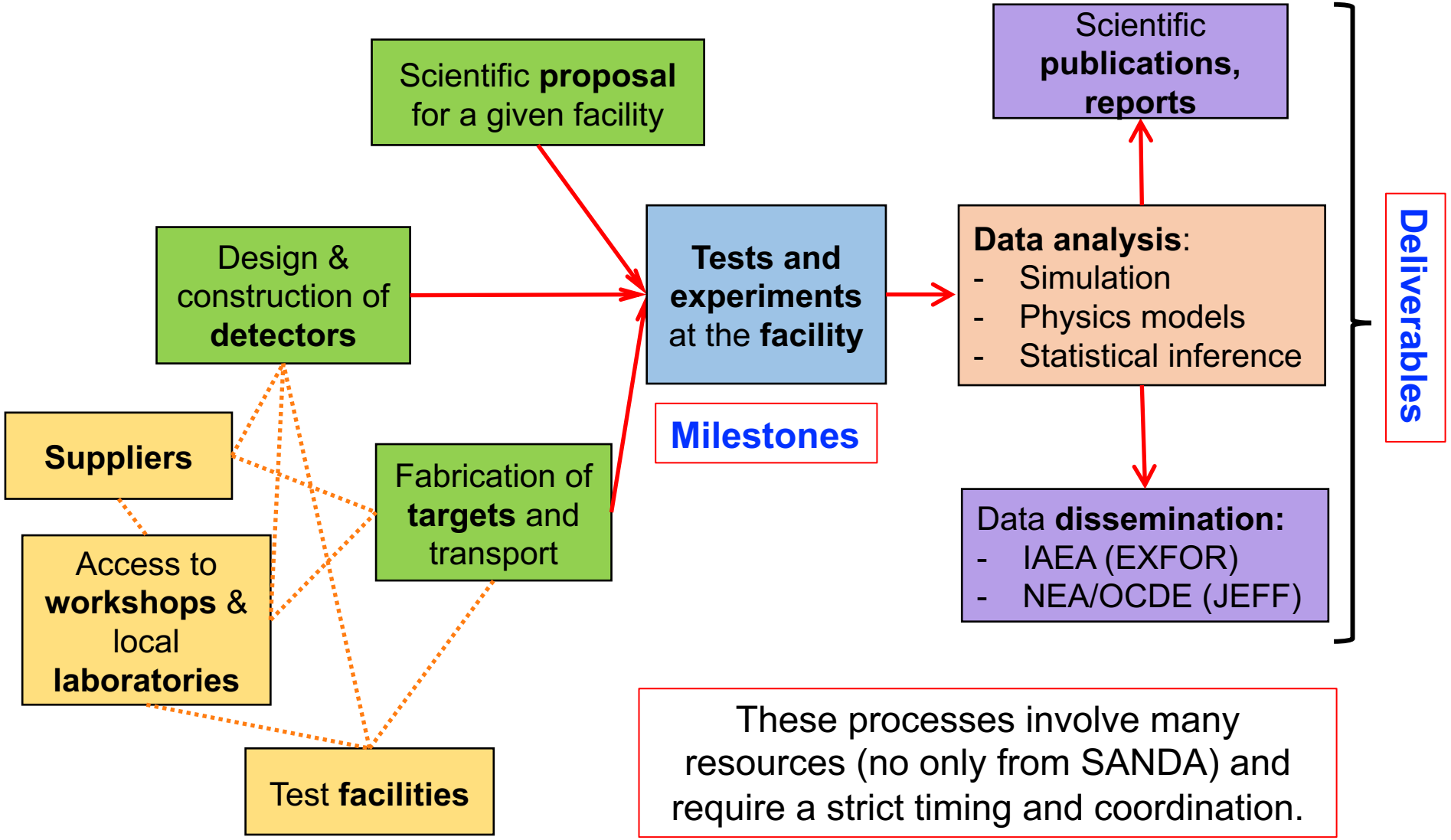
WP2 "**New nuclear data measurements for energy and non-energy applications**" is the largest WP (in PMs) in SANDA.

WP Number[9]	WP Title	Lead beneficiary[10]	Person-months[11]	Start month[12]	End month[13]
WP1	Developments of new innovative detector devices	5 - CNRS	80.80	1	48
WP2	New nuclear data measurements for energy and non-energy applications	1 - CIEMAT	213.00	1	48
WP3	Target Preparation for Improvement of Nuclear Data Measurements	21 - PSI	66.20	1	48
WP4	Nuclear data evaluation and uncertainties	21 - PSI	173.20	1	48
WP5	Nuclear data validation and integral experiments	3 - CEA	69.20	1	48
WP6	Management, ND research coordination at EU level and Education and Training	1 - CIEMAT	27.40	1	48
		Total	629.80		

List of participants

Work package number	WP2 **23 institutions / 213 PMs**			Lead beneficiary		CIEMAT	
Work package title	New nuclear data measurements for energy and non-energy applications						
Participant number	1	3	5	6	7	8	10
Short name of participant	*CIEMAT*	CEA	CNRS	CSIC	CVREZ	ENEA	IFIN-HH
Person-months per participant	14.3	7.1	21	14.4	11.7	15	11.2
Participant number	11	12	13	15	17	18	20
Short name of participant	IRSN	IST	JRC	JYU	NPI	NPL	NTUA
Person-months per participant	1.5	4	17.2	5	17.3	2.3	6
Participant number	22	23	27	29	30	31	33
Short name of participant	PTB	SCK	ULODZ	UMANCH	UOI	UPC	USC
Person-months per participant	4	2.2	12	10	6	1.8	10
Participant number	34	35					
Short name of participant	USE	UU					
Person-months per participant	10	9					
Start month	1			End month	48		

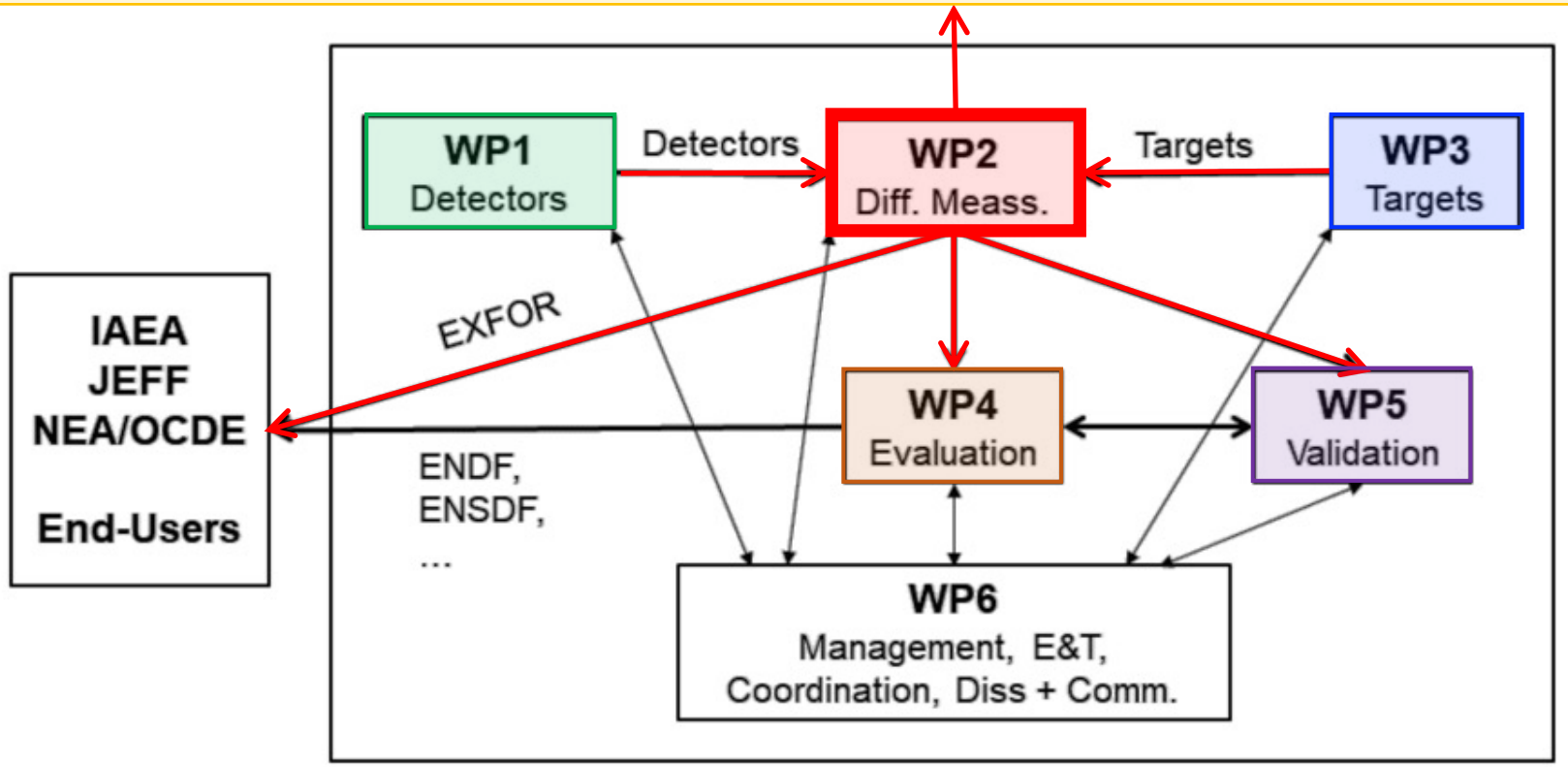
The complexity of a (nuclear data) experiment



These processes involve many resources (no only from SANDA) and require a strict timing and coordination.

WP2 links to other WPs

ARIEL H2020 project: education and training of young researchers + scientific visits



It depends on the development of detectors in **WP1**, the delivery of targets from **WP3** and on the proper operation of different facilities: **n_TOF** (CERN), **NFS** (France), **nELBE** (Germany), **JYFL** (Finland), **accelerators and experimental reactors**. It produces some data for **WP4** (evaluation) and also for **WP5** (validation).

WP2 scientific program

The tasks of this work package are accurate measurements of:

- **Task 1**. Neutron-induced fission and charge particle production cross sections.
- **Task 2**. Neutron capture cross sections.
- **Task 3**. Total, neutron elastic and inelastic scattering and neutron multiplication cross sections.
- **Task 4**. Decay data (β-delayed γ-rays and neutrons).
- **Task 5**. Fission yields.
- **Task 6**. Nuclear data for non-energy applications (medical, standards…).

WP2 Tasks

Task 2.1: Neutron induced fission and charged particle production cross sections

Task coordinator: ***UMANCH****, partners:* ~~***CNRS/CENBG***~~***, CNRS/LPCC, CVREZ, NPI-CAS, NTUA, UOI, UU***

2.1.1: Neutron induced fission cross sections: ^{230}Th(n,f), ^{241}Am(n,f) and ^{239}Pu(n,f) cross section at the n_TOF EAR2, nubar(EN) of ^{235}U(n,f) at JRC-Geel

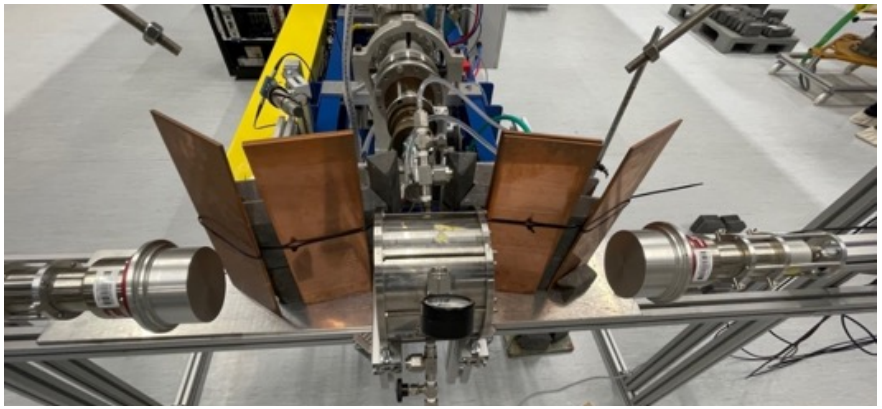
2.1.2: Neutron induced charged particle production cross sections: ^{nat}C(n,lchp) reaction at NFS, ^{16}O(n,a)^{13}C, (n,lchp) at NPI-CAS and prompt fission neutron spectra with activation measurements at CVREZ.

2.1.1: Neutron induced fission cross sections

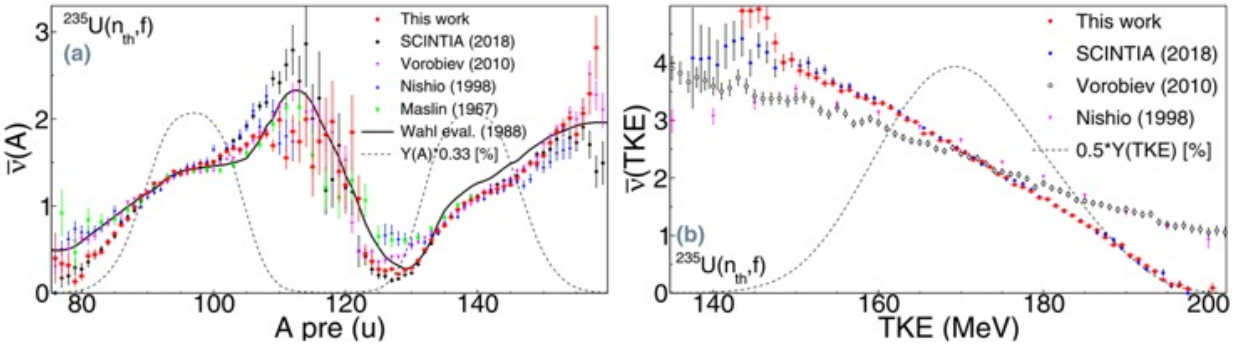
Measurements of ^{239}Pu(n,f) and γ-ray production completed at ILL and n_TOF with the STEFF spectrometer. The analysis is ongoing.

Measurements of ^{241}Am(n,f) and ^{230}Th(n,f) at n_TOF EAR1 and EAR2, completed on time. Supported by ARIEL.

MS15 and MS16 achieved. Contribution to D 2.1 expected on time.



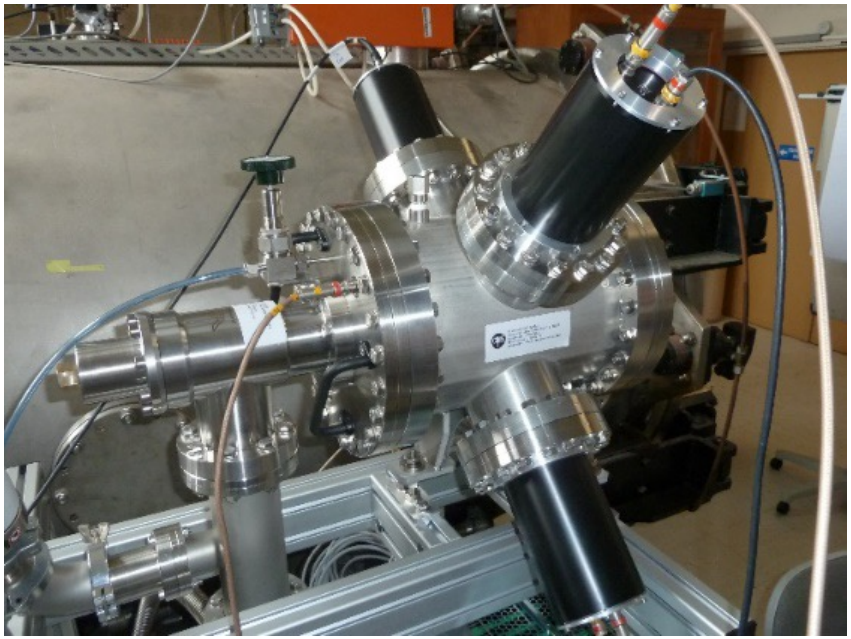
Measurements of nubar(A) and nubar(TKE) at the JRC / MONNET facility with neutron detectors and fission fragment detectors.

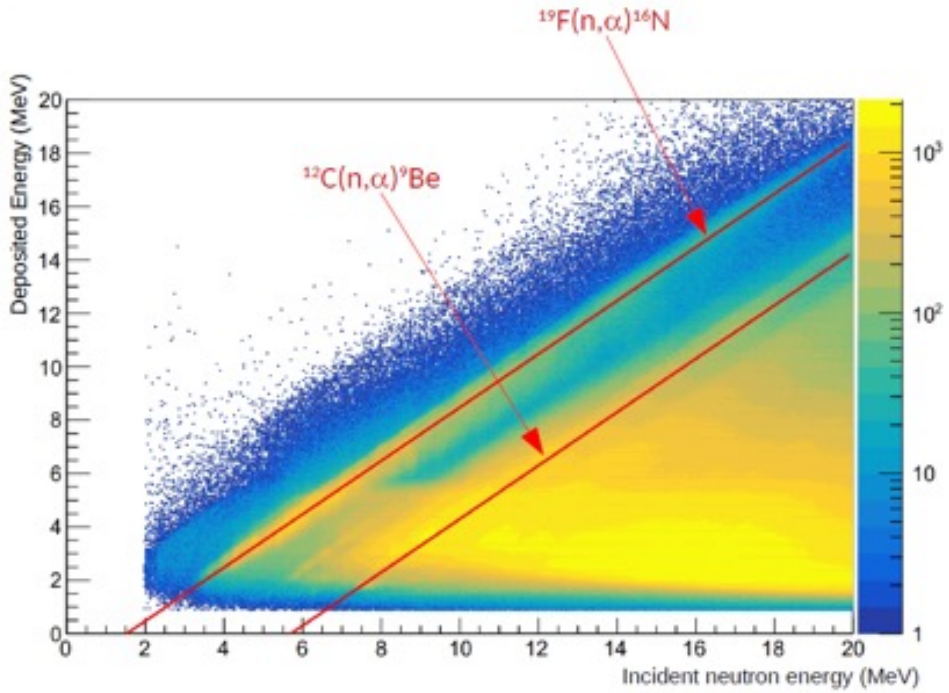


MS12 achieved with delay (problems at NFS). Contribution to D 2.1 expected on time.

2.1.2: Neutron induced charged particle production cross sections.

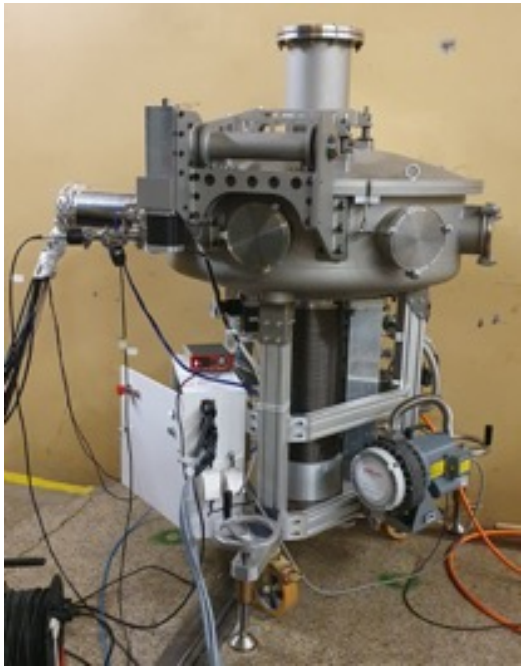
^{16}O(n,α) measurements at nELBE (delayed until early 2023), GELINA (done) and NFS (carried out in October 2021). SCALP detector based on an ionisation chamber filled with CF_4 scintillating gas + optical readout and low amounts of CO_2. Analysis of the data is ongoing. Supported by ARIEL.

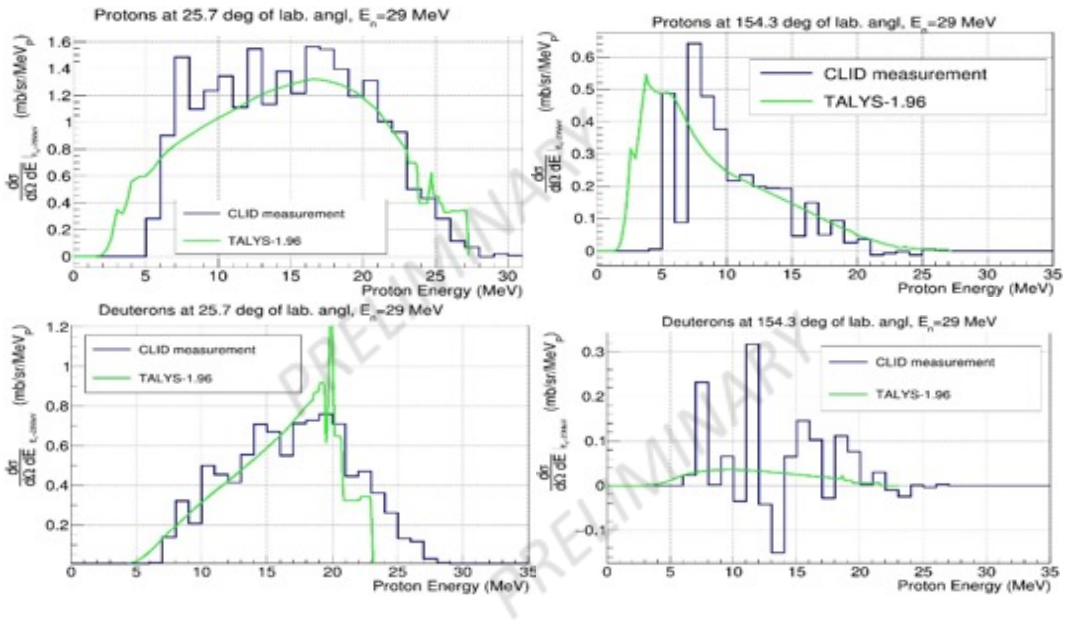




MS18 achieved.
Contribution to D 2.2 expected on time.

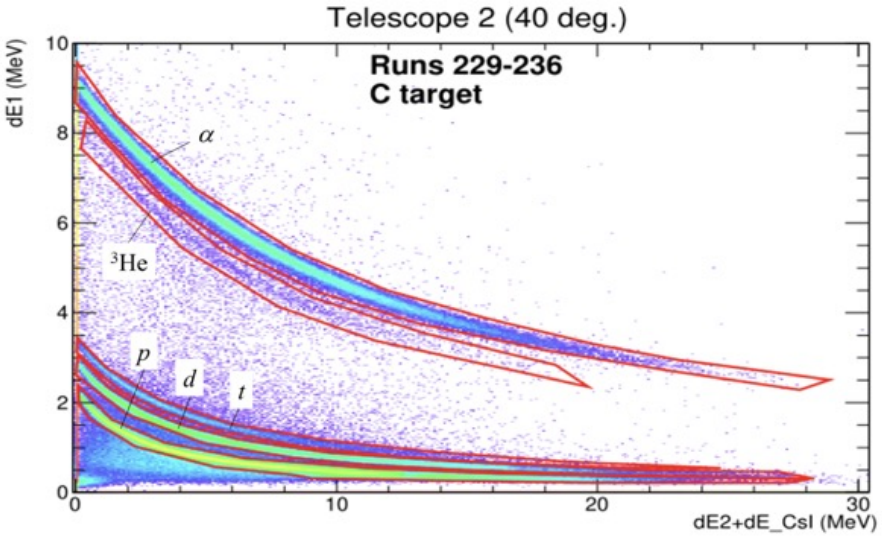
New detection setup at NPI CAS for the measurement of light ion particles (p, d, t, ^{3}He, α) produced in the **^{13}C(n, lchp)** reactions induced by fast neutrons + TOF technique. All but one experiment have been carried out and the data analysis is ongoing. One further experiment in 2023.

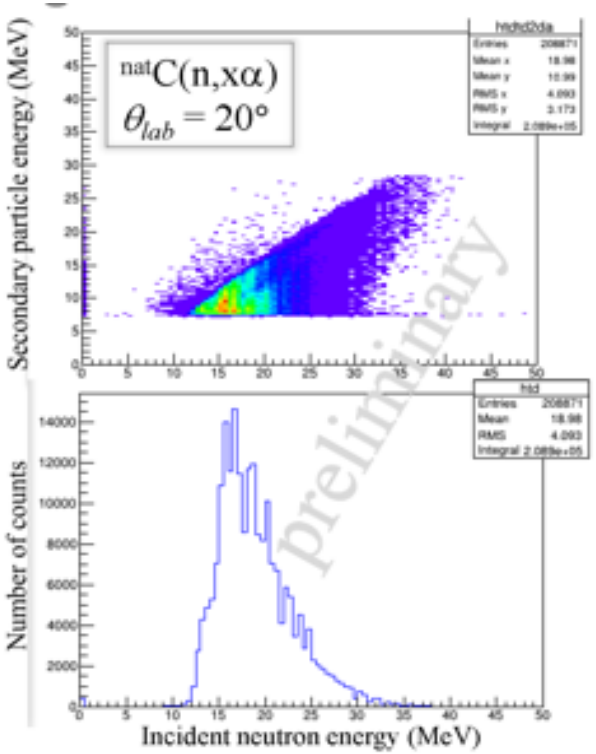




MS20 achieved. Contribution to D 2.2 expected on time.
Mitja Majerle at NPI/CAS is now leaving NPI and Martin Ansorge will be in charge.

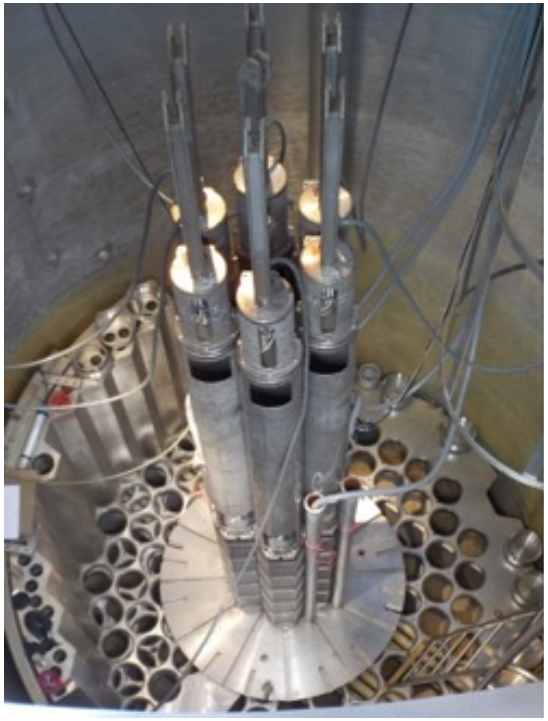
^{nat}C(n,lchp) reaction at NFS with the Medley (silicon + CsI telescopes) setup from 1 MeV up to 40 MeV, approximately. 1st experiment successful but interrupted due to a problem with the rotating neutron converter (NFS neutron source). New experiment in October 2022 for completing the statistics. Analysis of the first data have started. Supported by ARIEL.

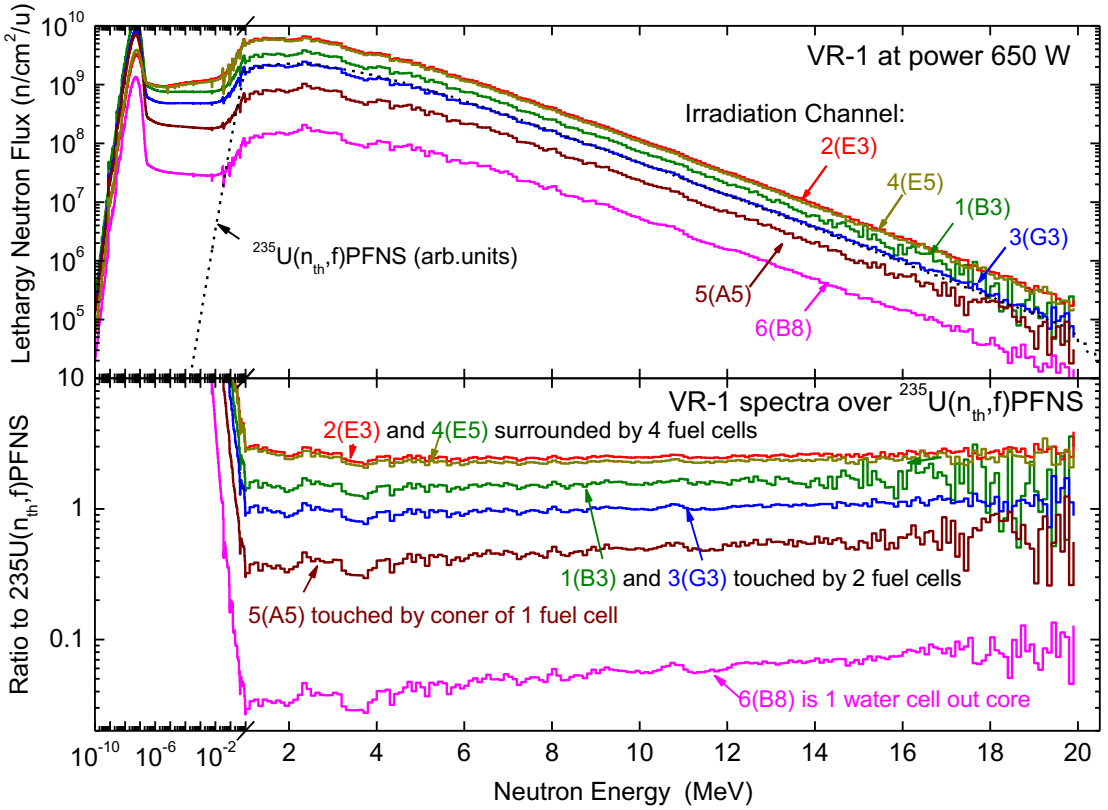




MS19 expected on time.
Contribution to D2.2 expected on time.

Activation measurements at CVREZ in 3 experimental reactors: zero power LR-0 and VR-1 and 15 MW LVR-15. Isotopes studied: ^{54}Fe, Fe, Y, Mo, Au, V, Ti, Cu, Nb and ^{14}N. Information on prompt fission neutron spectra based on ratios of well known Spectrum Averaged Cross Sections (SACS). **Work has been completed**.



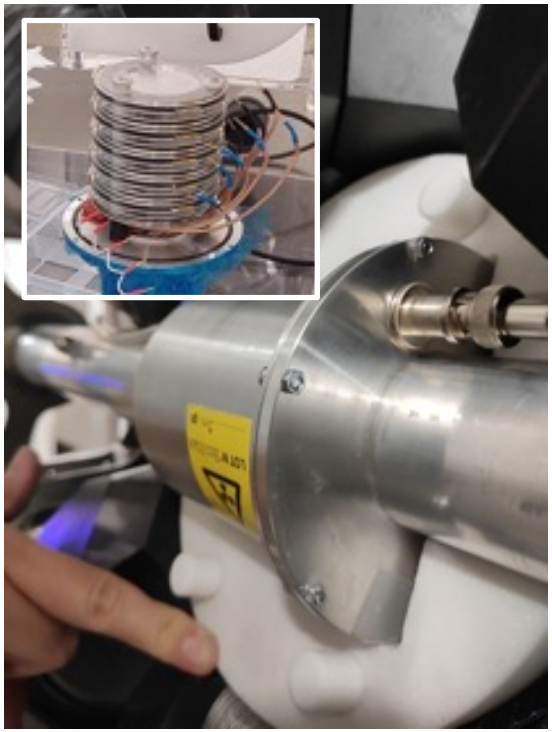


MS11 achieved with delay.
Results have been published.

Task 2.2: Neutron capture cross sections

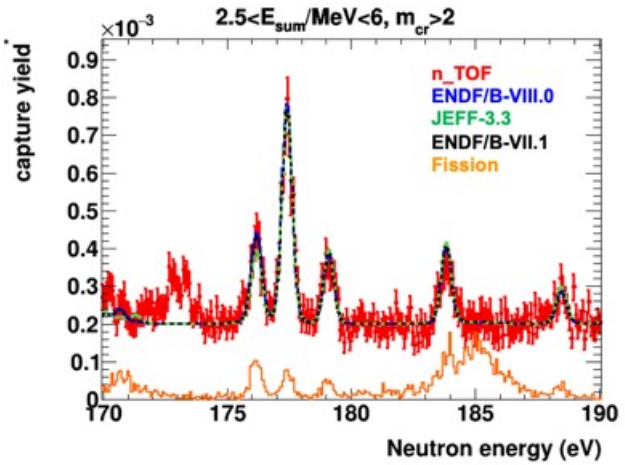
Task coordinator: ***ENEA****, partners:* ***CIEMAT, JRC, ULODZ, IRSN***

2.2.1. Capture measurements of fissile isotopes: ^{239}Pu(n,γ) at GELINA and n_TOF EAR1. Measurement at n_TOF EAR1 with the Total Absorption Calorimeter and a **new fast ionisation chamber** (2 MBq/mg). **High quality targets** have been produced at the **JRC-Geel target laboratory (WP3)**. ARIEL and EUFRAT support.

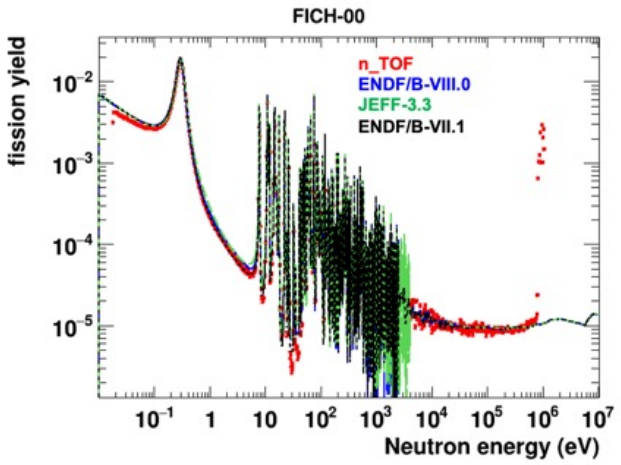


Experiment at GELINA not done due to accelerator problems. The experiment at n_TOF has been carried out from September till mid of November. The analysis of the **excellent data** has started.

Capture



Fission



MS21 achieved.
Contribution to D2.3 will be delayed 8 months

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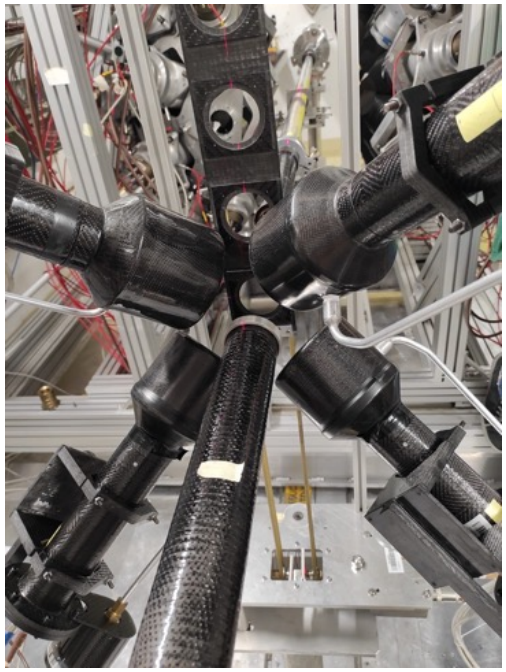
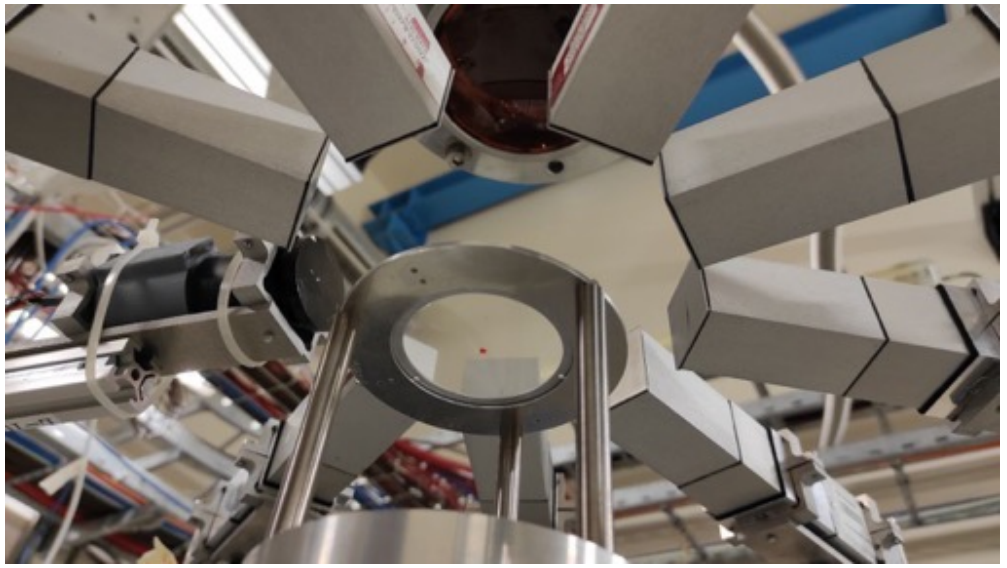
2.2.2. Capture measurement of stable isotopes: ^{92,94,95}Mo(n, γ) at n_TOF EAR1.

Combined capture (n_TOF EAR1 and EAR2) and transmission (GELINA) measurements of ^{92,94,95}Mo samples. Two experiments were carried out in September – October 2022 and the data analysis has just started. First samples were not according to specifications and new ones needed to be ordered for a second experiment.



C_6D_6 detectors in EAR1.



sTED detectors developed by CIEMAT for EAR2 (WP1).

MS21 achieved with delay.
Contribution to D2.3 will be delayed 8 months.

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Task 2.3: Neutron elastic and inelastic scattering and neutron multiplication cross sections

Task coordinator: ***IFIN-HH****, partners:* ***CNRS/IPHC, JRC***

^{14}N(n,n'γ) cross section using GAINS at GELINA . Started with delay and is going on right now. 6 to 12 months delayed data analysis.

$^{35\text{-}37}$Cl(n,n'γ) at GELINA. Experiment will take place during the 1st half of 2023. Delayed.

^{239}Pu(n,xn'γ) with GRAPhEME. First beam in April 2022 and continuation during fall 2022. 6 to 12 months delay in the data analysis.

^{233}U(n,xn'γ) with GRAPhEME. Experiment done and data analysis completed. Conference paper presented.

Several experiments at GELINA had delays (9 months to 1 year) due to the COVID pandemic and issues with the accelerator. The delays have to be propagated into the data analysis time.

MS23 will be delayed 6 months.
D2.4 will be delayed 12 months.

^{238}U(n,xn'γ) with GRAPhEME. The experiment has been done, compared with theory, published and data were disseminated.

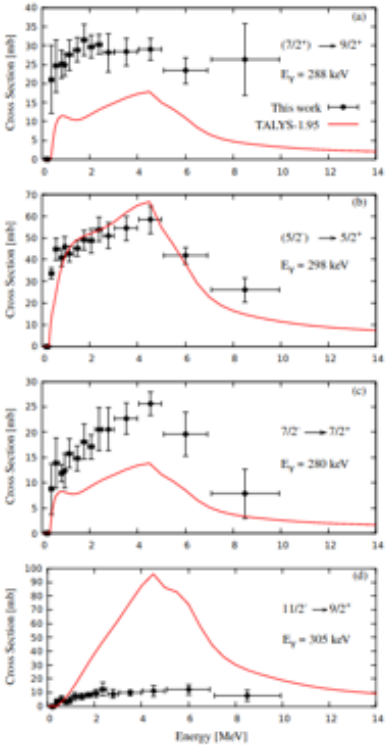
^{209m,g}Bi(n,γ) at JPARC (Japan) with the participation of JRC-Geel and SCK. The data analysis will be completed during the first half of 2023.

^{209}Bi(n, γ) at GELINA with total energy detectors. The experiment was carried out in 2020. Due to problems with the accelerator, a new measurement for increasing the statistics is needed in 2023. Capture yields will be available in December 2023.

^{209}Bi(n,tot) at GELINA. The experiment and data analysis have been completed and data + a detailed report are being prepared for EXFOR.

^{206,208,nat}Pb transmission measurements carried out in May 2022. Analysis is in progress.

^{233}U(n,xn'γ)



MS24 will be delayed 8 months.
D2.5 will be delayed 12 months.

Task 2.4: Decay data measurements

Task coordinator: ***CSIC****, partners:* ***CEA/LNHB, CNRS/Subatech, CSIC, JRC, SCK, UPC***

2.4.1. Beta decay measurements with TAGs: Nb, Y, Sr isotopes.

^{96,96m}**Y** isomers (8+ and 0-) measured at IGISIOL (Jyväskylä) and separated with the use of the Penning trap. Data have been analysed and published.

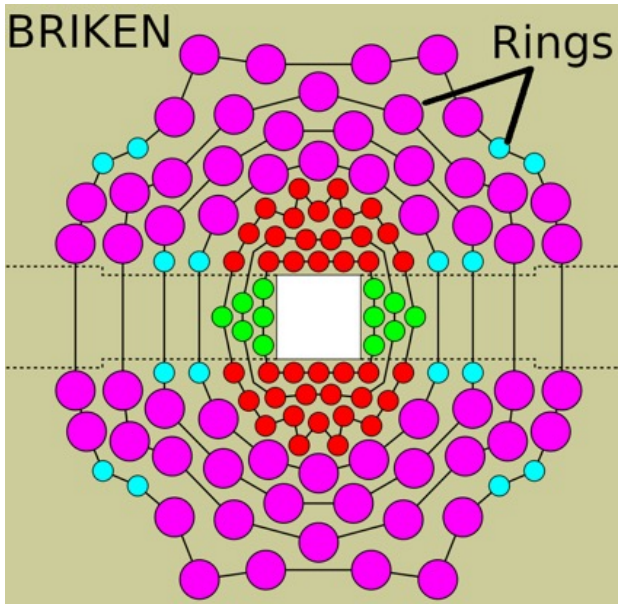
^{100,100m}**N** and ^{102,102m}**Nb** have been measured, analysed and published.

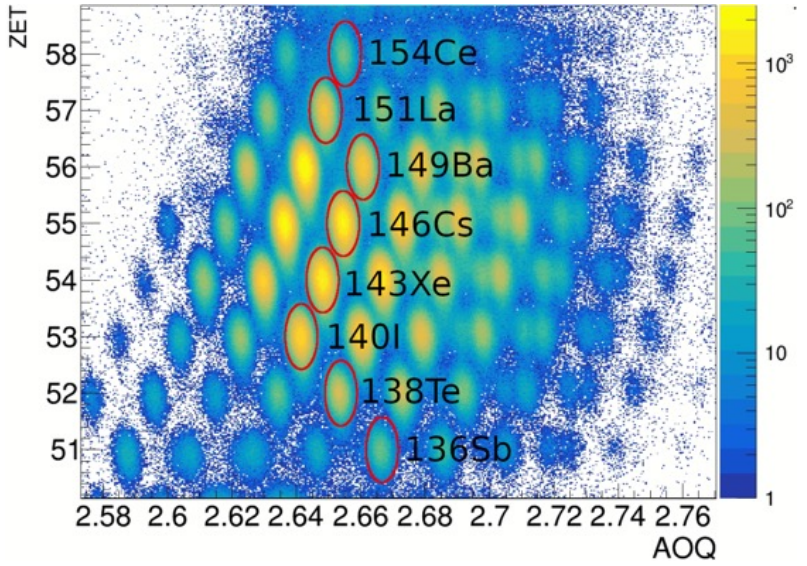
^{98}**Sr** (together with additional Y and Nb isotopes) has been measured in September 2022 (scheduled for 2020 but was not feasible due to COVID and problems with the JYFL cyclotrons) and will be analysed until the end of the project.

MS25 to be achieved.
Delay of 6 to 12 months.

2.4.2. Beta delayed neutron measurements: ^{78}Ni, rare earth peak and A=100 at RIKEN.

World largest neutron long counter BRIKEN has been used in a long-lasting (2016 to 2021) experimental campaign at RIKEN for the measurement of β-delayed neutron emission probabilities of neutron-rich isotopes. Experiment has been completed and analysis is in progress.





MS25 delayed 2 months.
D2.6 delayed 6 months.

2.4.3. Measurement of half-lives and gamma-ray emission probabilities of beta emitters: ^{106}Ru, ^{153}Sm, ^{166}Ho, ^{186}Re, ^{212}Pb, ^{225}Ac and ^{223}Ra

Measurements at a new facility (ionisation chamber + sample changer) for the determination of half-lives with uncertainties of 0.1%.
γ-ray emission probabilities are being measured with the BOLUX bolometer.

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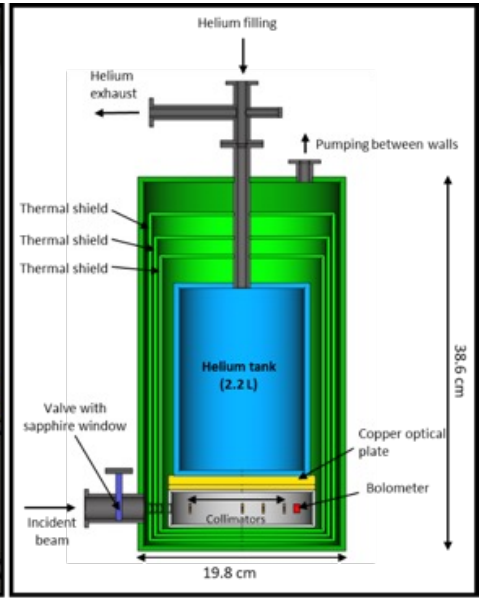


b

BOLUX is being calibrated and the facility for half-live measurements is being commissioned. No measurements have been reported.

MS3 achieved with 12 months delay.
D1.3 submitted.

D2.15 will be delayed 3 months. No experimental contribution will be possible due to reduction of staff but a report will be written on time with evaluations and recommendations of priorities.

Task 2.5: Fission yields measurements

Task coordinator: ***UU****, partners:* ***CEA/IRFU, CNRS/LPSC, UJY, USC***

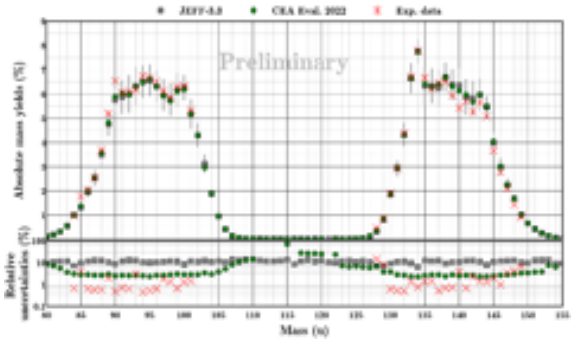
2.5.1. Fission yield studies in (n,f) reactions: ^{235}U(n,f) and ^{238}U(p,f) with various instruments and techniques.

2.5.1.1 Fission yield measurements at NFS

The experiment at ILL was impossible due to mechanical incompatibilities and has been replaced by one at NFS. Calibration experiment at GANIL coupled to VAMOS. The experiment at NFS is planned for November and December 2022.

MS13. Delay of 4 months

2.5.1.1 Fission yield measurements at LOHENGRIN



Preliminary results of the a measurement in May 2021. Prototype of the new TOF line tested in July 2021 with insufficient time resolution. New test with MCP in fall 2022.

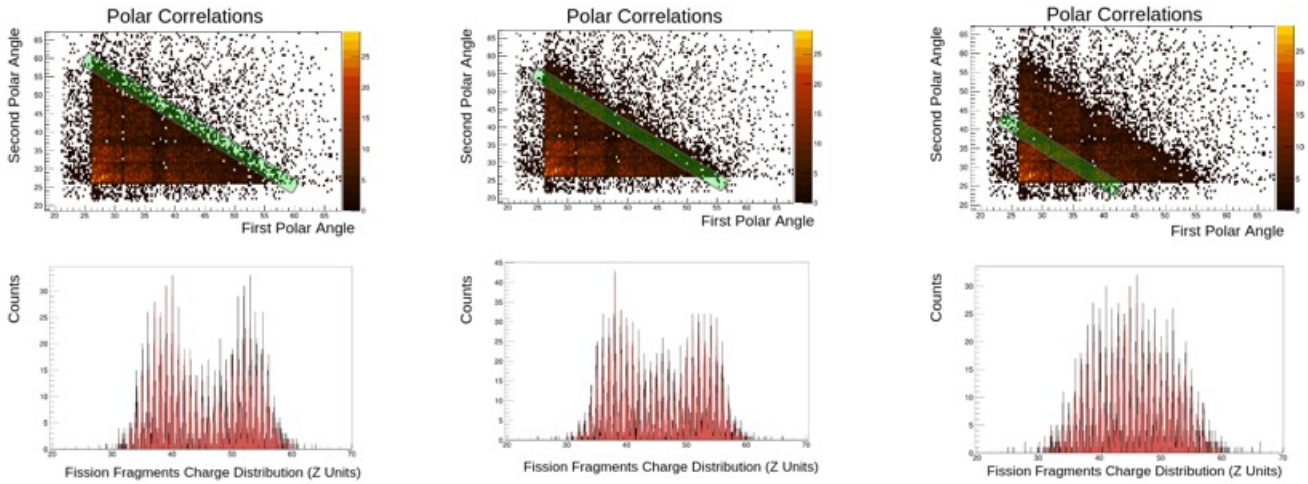
D2.12 is delayed 12 months

2.5.1.1 Fission yield measurements with the PI-ICR technique at IGISOL

Counting of the fission ions with a high resolution Penning trap and MR-TOF. Development of the PI-ICR. Proposal accepted in 2021 and experiment scheduled for early 2023. Severe delay due to extended maintenance break of the JYFL-ACCLAB cyclotrons and the technical problems with the helium gas purification system.

D2.8 is delayed 12 months

2.5.2. Fission yield studies in inverse kinematics: ^{238}U(p,2p) reaction studies at FAIR.



MS14 is achieved. D2.14 completed with 4 months delay

Task 2.6: New measurements for non-energy applications

Task coordinator: ***USE****, partners:* ***IST, NPL, PTB***

2.6.1. Spectrum averaged cross sections for dosimetry: ^{252}Cf spectrum-averaged activation measurements of ^{117}Sn(n,inl), ^{117m}Sn and ^{60}Ni(n,p).

^{117}Sn(n,n')^{117m}Sn measurement completed and data analysis is completed. New setup and new ^{252}Cf source for reducing the uncertainties.

D2.9 has been submitted ahead of schedule.

2.6.2. Measurement of cross sections relevant for hadron therapy: DDX for C(n, lcp x)

First experiment in May 2022. Problems with the electronics due to RF noise. New experiment with improved electronics in November 2022 (D1.8 is delayed). A new scattering chamber will have to be designed and built. The experiment can not take place before 2023 (submission of the proposal). Supported by ARIEL.

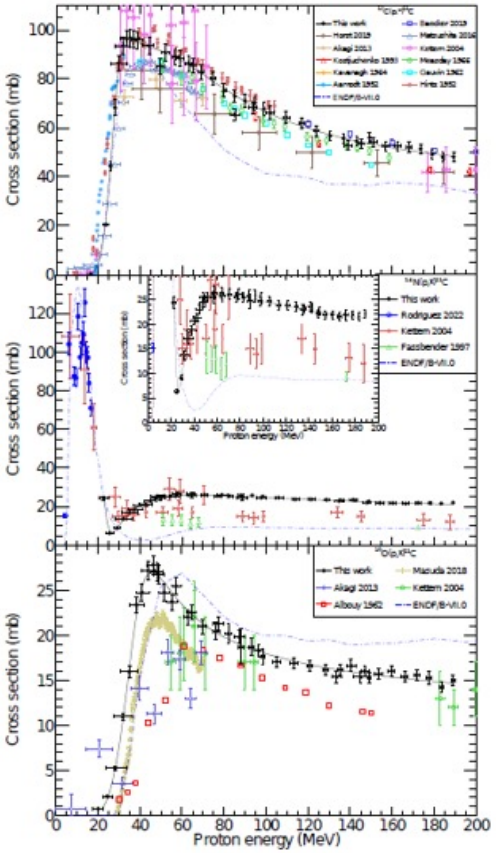
D2.10 has a delay of 12 months.

2.6.3. Measurement of beta+ emitters: production of ^{11}C, ^{13}N and ^{15}O, ^{10}C, ^{29}P, ^{38m}K with high energy protons (~200 MeV)

$^{14}N(p,\alpha)^{11}C$, $^{12}C(p,\gamma)^{13}N$, $^{16}O(p,\alpha)^{13}N$ and $^{16}O(p,3p3n)^{11}C$ measurements were carried out at the CNA (Seville, Spain) at the 18 MeV cyclotron. Innovative technique combining a PET scanner (β+ emitters) and a stack of samples. Results have analysed and published.

Complementary measurements in 2021 on **$^{12}C(p,x)^{11}C$, $^{14}N(p,x)^{11}C$, $^{14}N(p,x)^{13}N$, $^{14}N(p,\gamma)^{15}O$, $^{16}O(p,x)^{11}C$, $^{16}O(p,x)^{13}N$ and $^{16}O(p,x)^{15}O$** up to 200 MeV up to 200 MeV at the WPE proton therapy centre in Essen. Data ave been published.

$^{12}C(p,n)^{12}N$, $^{31}P(p,p2n)^{29}P$ and $^{40}Ca(p,2pn)^{38m}K$ measured at the Heidelberg proton therapy center (HIT) in 2021.



Supported by ARIEL.

D2.11 has been submitted wit 6 months delay.

Data management

The data management plan as described in the DoA is still valid.

Although most of the data to be stored is to be produced by the end of the project, there are several examples of data that are already being submitted to the international repositories.

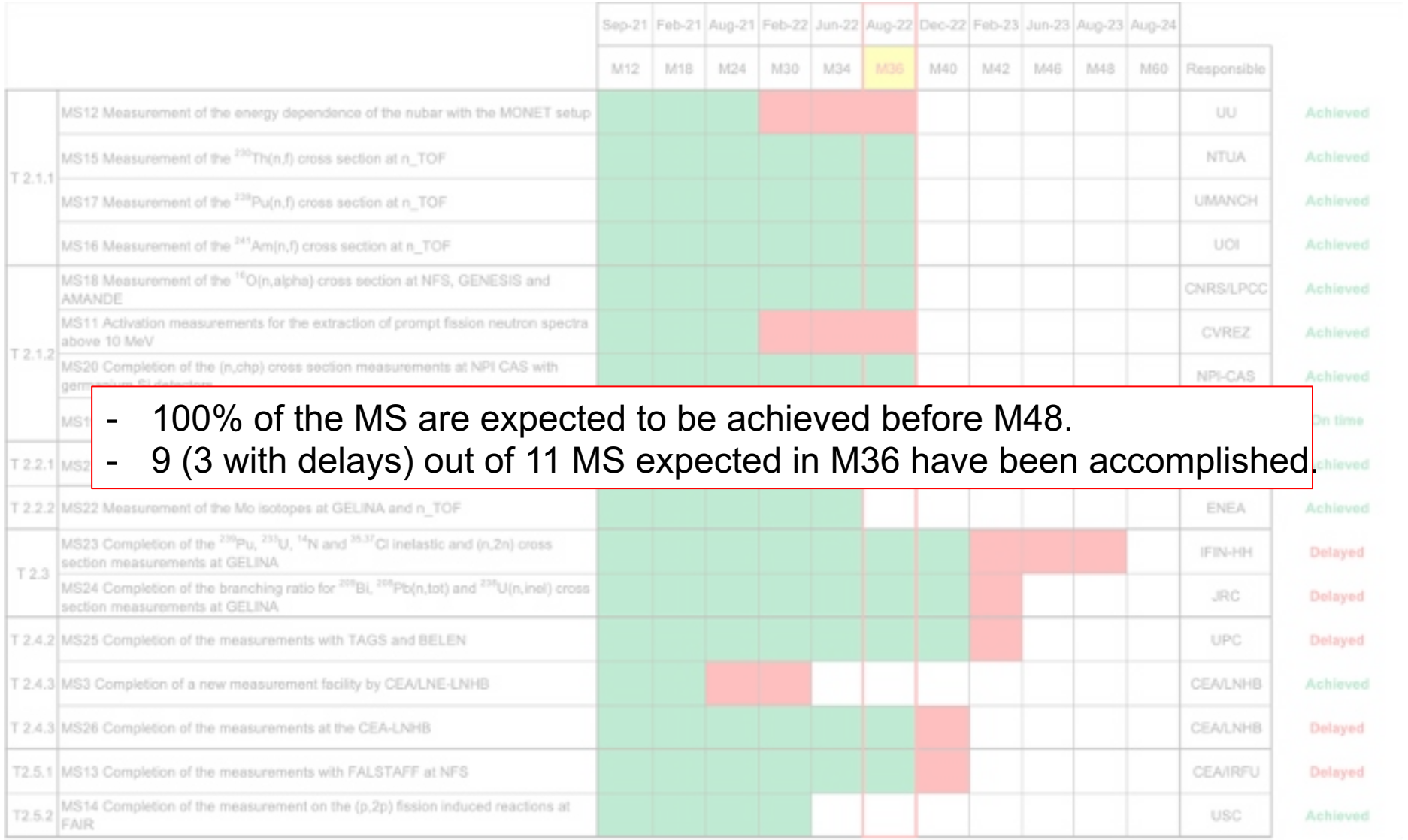
Examples of experimental data are:

- The nubar(A) data obtained in task 2.1 had been reported in EXFOR.
- 18 ^{238}U(n,n'g) cross sections from task 2.3 have been transmitted to EXFOR (entry number 22795).
- ^{117}Sn(n,n')^{117m}Sn data from task 2.6 has also been published to EXFOR.
- A report to submit ^{209}Bi(n,tot) data from task 2.3 to the EXFOR library is also in preparation
- The ^{241}Am(n,f) experimental data from task 2.1 will be submitted to the EXFOR data-base within the next 6 months, as soon as it is published.
- The ^{230}Th(n,f) experimental data from task 2.1 will be published to the EXFOR data-base as soon as it is published in a few months.

Milestones

		Sep-21	Feb-21	Aug-21	Feb-22	Jun-22	Aug-22	Dec-22	Feb-23	Jun-23	Aug-23	Aug-24		
		M12	M18	M24	M30	M34	M36	M40	M42	M46	M48	M60	Responsible	
T 2.1.1	MS12 Measurement of the energy dependence of the nubar with the MONET setup												UU	Achieved
	MS15 Measurement of the ^{230}Th(n,f) cross section at n_TOF												NTUA	Achieved
	MS17 Measurement of the ^{239}Pu(n,f) cross section at n_TOF												UMANCH	Achieved
	MS16 Measurement of the ^{241}Am(n,f) cross section at n_TOF												UOI	Achieved
T 2.1.2	MS18 Measurement of the ^{16}O(n,alpha) cross section at NFS, GENESIS and AMANDE												CNRS/LPCC	Achieved
	MS11 Activation measurements for the extraction of prompt fission neutron spectra above 10 MeV												CVREZ	Achieved
	MS20 Completion of the (n,chp) cross section measurements at NPI CAS with germanium Si detectors												NPI-CAS	Achieved
	MS19 Measurement of the ^{natC}(n,lchp) at NFS												UU	On time
T 2.2.1	MS21 Measurement of the ^{239}Pu(n,g) at n_TOF												CIEMAT	Achieved
T 2.2.2	MS22 Measurement of the Mo isotopes at GELINA and n_TOF												ENEA	Achieved
T 2.3	MS23 Completion of the ^{239}Pu, ^{233}U, ^{14}N and ^{35,37}Cl inelastic and (n,2n) cross section measurements at GELINA												IFIN-HH	Delayed
	MS24 Completion of the branching ratio for ^{209}Bi, ^{208}Pb(n,tot) and ^{238}U(n,inel) cross section measurements at GELINA												JRC	Delayed
T 2.4.2	MS25 Completion of the measurements with TAGS and BELEN												UPC	Delayed
T 2.4.3	MS3 Completion of a new measurement facility by CEA/LNE-LNHB												CEA/LNHB	Achieved
T 2.4.3	MS26 Completion of the measurements at the CEA-LNHB												CEA/LNHB	Delayed
T2.5.1	MS13 Completion of the measurements with FALSTAFF at NFS												CEA/IRFU	Delayed
T2.5.2	MS14 Completion of the measurement on the (p,2p) fission induced reactions at FAIR												USC	Achieved

Milestones



		Sep-21	Feb-21	Aug-21	Feb-22	Jun-22	Aug-22	Dec-22	Feb-23	Jun-23	Aug-23	Aug-24		
		M12	M18	M24	M30	M34	M36	M40	M42	M46	M48	M60	Responsible	
T 2.1.1	MS12 Measurement of the energy dependence of the nubar with the MONET setup												UU	Achieved
	MS15 Measurement of the ^{230}Th(n,f) cross section at n_TOF												NTUA	Achieved
	MS17 Measurement of the ^{239}Pu(n,f) cross section at n_TOF												UMANCH	Achieved
	MS16 Measurement of the ^{241}Am(n,f) cross section at n_TOF												UOI	Achieved
T 2.1.2	MS18 Measurement of the ^{16}O(n,alpha) cross section at NFS, GENESIS and AMANDE												CNRS/LPCC	Achieved
	MS11 Activation measurements for the extraction of prompt fission neutron spectra above 10 MeV												CVREZ	Achieved
	MS20 Completion of the (n,chp) cross section measurements at NPI CAS with germanium Bi detectors												NPI-CAS	Achieved
	MS1													On time
T 2.2.1	MS2													Achieved
T 2.2.2	MS22 Measurement of the Mo isotopes at GELINA and n_TOF												ENEA	Achieved
T 2.3	MS23 Completion of the ^{239}Pu, ^{233}U, ^{14}N and ^{35,37}Cl inelastic and (n,2n) cross section measurements at GELINA												IFIN-HH	Delayed
	MS24 Completion of the branching ratio for ^{209}Bi, ^{208}Pb(n,tot) and ^{238}U(n,inel) cross section measurements at GELINA												JRC	Delayed
T 2.4.2	MS25 Completion of the measurements with TAGS and BELEN												UPC	Delayed
T 2.4.3	MS3 Completion of a new measurement facility by CEA/LNE-LNHB												CEA/LNHB	Achieved
T 2.4.3	MS26 Completion of the measurements at the CEA-LNHB												CEA/LNHB	Delayed
T2.5.1	MS13 Completion of the measurements with FALSTAFF at NFS												CEA/IRFU	Delayed
T2.5.2	MS14 Completion of the measurement on the (p,2p) fission induced reactions at FAIR												USC	Achieved

- 100% of the MS are expected to be achieved before M48.
- 9 (3 with delays) out of 11 MS expected in M36 have been accomplished.

Deliverables

		Sep-21	Aug-21	Feb-22	Jun-22	Aug-22	Dec-22	Feb-23	Apr-23	Jun-23	Aug-23	Aug-24		
		M12	M24	M30	M34	M36	M40	M42	M44	M46	M48	M60	Responsible	
T 2.1.1	D2.1 Report on the (n,f) Measurements												UMANCH	Expected on time
T 2.1.2	D2.2 Report on (n,chp)												CNRS/LPCC	Expected on time
T 2.2	D2.3 Report on the ^{239}Pu(n,g), ^{94,95}Mo(n,g) cross section measurements at n_TOF and GELINA												ENEA	Delayed (8 months)
T 2.3	D2.4 Report on the ^{239}Pu, ^{233}U, ^{14}N and ^{35,37}Clinelastic cross sectionmeasurements at GELINA												IFIN-HH	Delayed (12 months)
	D2.5 Report on the measurements of the branching ratio for ^{209}Bi, ^{208}Pb(n,tot) and ^{238}U(n,inel) cross sections at GELINA												JRC	Delayed (12 months)
T 2.4.1	D2.6 Report of the decay data measurements performed with DTAS and BELEN												CSIC	Delayed (6 moths)
T 2.4.2	D2.7 Report on on the development of a new technique for obtaining low resolution information on the beta delayed neutron energies with BELEN-like detectors.												UPC	Submitted
T 2.4.3	D2.15 Report on the of half-live and gamma-ray emission probabilities of beta emitters measurement												JRC/SCK	Delayed (3 moths)
T 2.5.1	D2.8 Report on the method based on the PI-ICR technique for general fission product yield studies at JYFL												JYU	Not submitted (12 months)
	D2.12 Report on the fission yield studies with the LOHENGRIN spectrometer at ILL												CNRS/LPSC	Not submitted (12 months)
	D.2.13 Report on fission yield studies with FALSTAFF at NFS.												CEA/IRFU	Expected on time
T2.5.2	D.2.14 Report on fission yield studies in inverse kinematics at FAIR												USC	Submitted
T 2.6.1	D.2.9, Report on the spectrum averaged cross sections for dosimetry (NPL)												NPL	Submitted
T 2.6.2	D.2.10 Report on the measurement of double-differential charged-particle emission cross sections at the CERN n_TOF facility in the neutron energy range from 20 MeV to 200 MeV.												PTB	Delayed (12 months)
T 2.6.3	D.2.11 Report on the production cross sections of beta+ emitters used for range verification in proton therapy.												USE	Submitted

Deliverables

		Sep-21	Aug-21	Feb-22	Jun-22	Aug-22	Dec-22	Feb-23	Apr-23	Jun-23	Aug-23	Aug-24		
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T 2.4.1	D2.[illegible]													[illegible]oths)
T 2.4.2	D2.[illegible]													[illegible]d
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- 3 out of 5 Deliverables expected in M36 have been submitted.
- 80% of the Deliverables are expected to be submitted by M48.
- 3 of 15 deliverables require a 12 month extension for being completed.

Summary and conclusions

The COVID pandemic and the subsequent international scenario has introduced many difficulties:

- Limited access to the laboratories for doing measurements due to COVID.
- Travel restrictions limited scientific visits and experiments.
- Technical problems after restarting different facilities.
- Reduced access to workshops.
- Difficulties with suppliers.
- Difficulties in the production of targets.
- Problems at the facilities after restarting complex systems that were shut-down over a long period.

Despite these problems, huge (and in many cases additional) efforts were made for achieving the project goals. Large amount of results have been achieved:

- 100% of the MS are expected to be achieved before M48.
- 9 (3 with delays) out of 11 MS expected in M36 have been accomplished.
- 3 out of 5 Deliverables expected in M36 have been submitted.
- 80% of the Deliverables are expected to be submitted by M48.
- 3 of 15 deliverables require a 12 month extension for being completed.

Summary and conclusions (II)

However, several deliverables will not be completed at the end of the project.

The WP2 activities would benefit from a 12 month extension of SANDA since all of the activities will be completed by then.