4 YEARS OF OPERATION WITH THE CYCLOTRON C70 ARRONAX

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Abstract

The Cyclone C70 of Arronax is a multi-particles cyclotron based in Nantes, France. Arronax has been running a regular program for radioisotopes production based on protons at the intensity of the order of 100 μA simultaneously in two beamlines and at the same time has ensured a wide variety of beams with various characteristics and particles for an extended R & D program for experimental users.

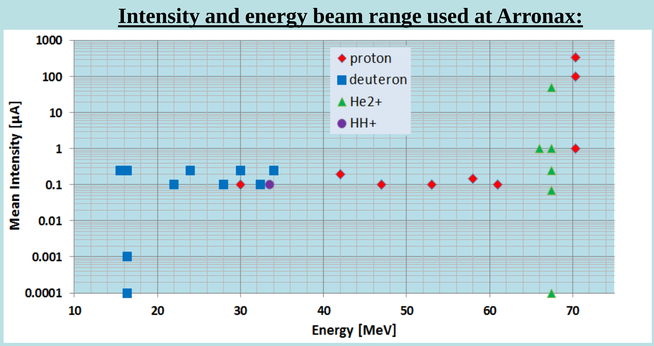
The facility, the machine and operations that are performed at Arronax as well as the difficulties with the runs and solutions that have been applied are here presented.

C70 ARRONAX STATUS

ARRONAX, an acronym for "Accelerator for Research in Radiochemistry and Oncology at Nantes Atlantique", is located in Nantes, France.

- March 2010: Irradiations at low current started for radiochemical studies and process optimisations.
- October 2010: Full specifications (24H in a row at 750µA for protons on beam dumps
- 2011: Start of the hands-on phase, with an extensive program on optimisation of the beams and exploration of beam parameters for the users.
- In the first half of 2011 a library of more than 50 beam settings has been established.
- 2013: Increase of beamtime and intensity on targets for radio-isotopes production
- 2014: continuation of operation at high intensity and low intensity with stabilisation of the beam settings.

Intensity and energy beam range used at Arronax:



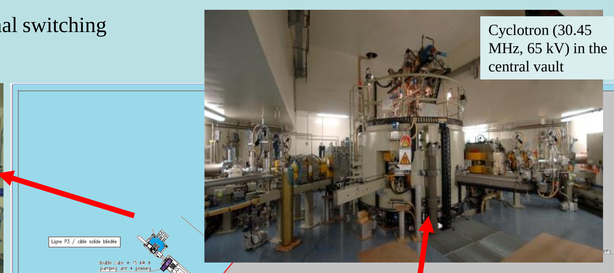
C70 ARRONAX

•Five vaults each houses a single end-station [1,2], and one vault has three, i.e. 8 beamlines in total are in use at ARRONAX.

•The 6th vault is equipped with an additional switching magnet leading to three more beamlines

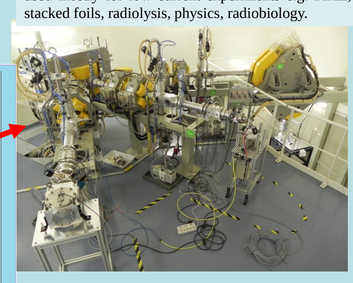
Preparation for high intensity irradiations

New reception room for neutron activated samples

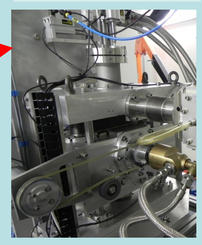


Cyclotron (30.45 MHz, 65 kV) in the central vault

3 beamlines in 6th vault with a top-bottom capability, used mostly for low current experiments e.g. PIXE, stacked foils, radiolysis, physics, radiobiology.



Alpha degrader mechanical details



alpha degrader: The water cooled carbon target lowered.

Machine Status and Operation

The cyclotron has accumulated:

✓ over the first 9 months of 2014, 2500 hours RF equivalent time.

High intensity runs in dual-mode are reguarly performed:

✓ Average intensity on each target of 100 eµA for radioisotope production.

✓ Several runs have been performed at 350 eµA for more than 22 on the neutron activator .

✓ A run up to 150 µA on target has been performed

The **yearly RF equivalent time** of the cyclotron has been increased from 2011 to 2014 mostly due to extension of the daily schedule. It is expected that 2014 will reach 3000h.

year	RF equivalent time [h]
2011	1000
2012	1700
2013	3000
sep. 2014	2530

Transmissions from the injection to the end-of-line have been increased and are in 2014 for high intensity runs of the order of:

- 43% for protons
- 37% for deuterons
- 10% for other particles

Losses are mainly at:

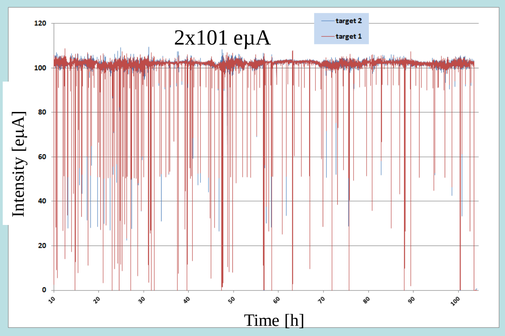
✓ The beginning of the acceleration in the cyclotron (for radius < 200 mm) and injection

✓ Specific locations in the beamlines

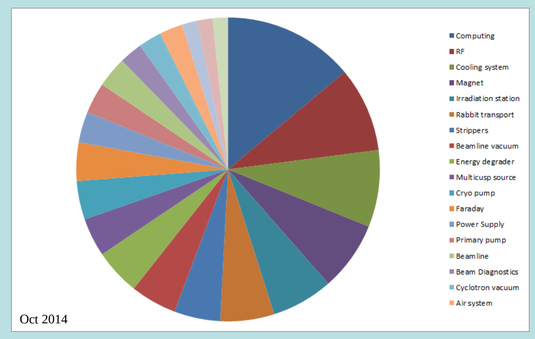
✓ And within the machine through neutral current (H^0)

Operations

Regular runs with high intensity beams on target:



Breakdown/interventions in 2014:



Dual mode operation:

✓ Here stable run over 98 hours

✓ <I>=101.5 eµA, $\sigma_{<i>}$=5.4 eµA

✓ Breakdowns = 1.8% of the overall time

✓ Vacuum in the center of the machine =4x10^7 mbar

✓ Neutral current (H^0) = 9eµA in 2014 (18µA in 2012)

Breakdown in 2014:

✓ Several types of breakdowns occurred during beam operations

✓ The most recurrent ones are computing and RF.

- ✓ A new computing system is planned
- ✓ Modification of RF filter and specific data follow-up

Operational challenges at high intensity:

- Dealing with rapid dissymmetric beams which implies peak intensity potentially destructive for the targets:
  - Time reactivity reducion control system (from 3s to 1 s).
  - Increase of the data analysis capacities
  - Systematic control from operators (also for beam breakdowns)
- Destruction of gaskets along the beamline
  - protection with carbon rings + studies of Beam Loss monitors for later use

Operation at low intensity

Deuterons and alpha particles have been extensively used in the vault for basic researches:

Deuterons:
- From 50 nA to 1.2 eµA
- 16.4 MeV up to 34 MeV

Alpha:
- 18.4 MeV/n
- Few pA up to 1.2 eµA

The upper limit for the intensity being constrained by safety issues on the beamline exit window made of kapton and the need to keep low background activation in the vault.

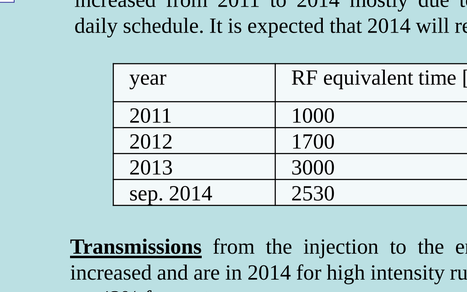
Technique used for low intensity

In 2011:
- source at a low stable level
- Quadrupole triplet

Since 2012: Adaptation to ease the tune
- Source and solenoid in injection to blow up the envelope

The users at the end of the beamlines requires stable beam after their access to the vault within a limited time.

Several checks have been performed simulating the users experimental access condition. Here these conditions, in accordance with safety, require the source to be switched-off while the beamline magnets are let on.
Intensity from the source follow a specific pattern (peak, drop and ramp-up) before stabilisation which occurs after several tens of minutes.



1st 35 min. of source run, afterwards the intensity drops exponentially as the filaments degrade.

The present strategy to ensure that the beam intensity is according to the users requirements is based on adaptation of the source and solenoid parameters by the operators. It is foreseen that modification of the access scenarios is required to further assure stable beam within 10 min.

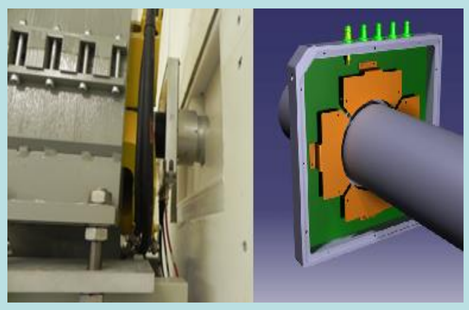
Machine and Beamline Adaptation

Beam loss monitors (BLM): Air ionisation chamber around the beampipe [3].

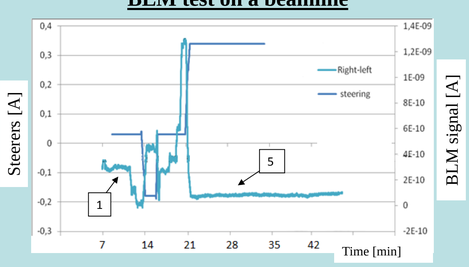
✓ Preliminary goal: check mechanical suitability around several beampipes, electronics, and the chain of data measurements.

✓ Final Goal: Check losses

labview-based code for data analysis from BLM.



BLM test on a beamline



BLM signal while steering the beam. For condition, 1 and 5, the beam is centered on target but less signal is detected on the BLM in 5.

Alpha pulsing [2,4]

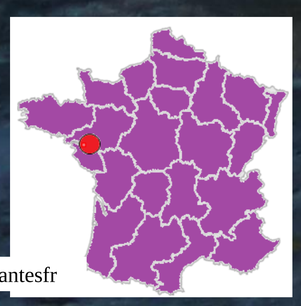
Alpha pulsing is based on a deflector located in the injection. A new electronic control equipment is being devised for deflector to allow bunches to be sent to the target in trains.

Other modification:

- To accommodate high power beams temperature and conductivity measurements in the water and on beam pipe have been added specifically for runs at 150 uA and above

CONCLUSION

The cyclotron C70 Arronax has increased beam time and intensity on targets for isotope production and neutron activation. At the same time, beams have been optimised to offer a wider range of energy for user requirements. The yearly RF equivalent beamtime has increased in 2013 and 2014 to reach 2530h at the end of septembre 2014. It is expected that 3000 h will be obtained at the end of the year.
Further, various upgrades are being performed on the beamlines, the irradiation stations, and the cyclotron environments.



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REFERENCES

[1] J. Martino, “ARRONAX, a 70 MeV cyclotron for Radiochemistry and Nuclear Medicine,” Proc. 18th Conf. on Cyclotrons and their Applications, Catania 2007.
[2] F. Poirier et al, “The C70 ARRONAX and Beam Line Status”, IPAC11-WEPS069, Sept. 2011 and references therein.
[3] F. Poirier et al, “The C70 ARRONAX in the hands-on phase”, IPAC12-MOPPD024, May 2012
[4] F. Poirier et al, “On-Going Operations with the Cyclotron C70 ARRONAX”, CYC2013-MOPPT010, Sept. 2013

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