Calculation of Water Activity in Point 7

SC/RP

J. Vollaire, M. Brugger, S. Roesler

joachim.vollaire@cern.ch

Production of radioactive nuclei in water

Production on Oxygen atom (H_2O)

	Half Life	Decay modes and energy
^{3}H	12.35 y	100 % β^-, E_{ave}= 5.68x10^{-3}MeV
^{7}Be	53.3 d	89.7 % β^+, Electron capture 10.3 % γ, E_{ave}= 0.4776 MeV
^{11}C	20.4 m	99.8 % β^+, E_{ave}= 3.86x10^{-1}MeV
^{14}C	5730 y	100 % β^+, E_{ave}= 4.95x10^{-2}MeV
^{13}N	9.97 m	99.8 % β^+, E_{ave}= 4.92x10^{-1}MeV
^{14}O	71 s	99.9 % β^+, E_{max}= 1.81 MeV 0.6 % β^+, E_{max}= 4.12 MeV 99 % γ, E = 2.312 MeV
^{15}O	122 s	99.9 % β^+, E_{ave}= 7.35x10^{-1}MeV

- Trace elements can lead to the production of other nuclei as ^{24}Na

- Most critical nuclei are ^{3}H and ^{7}Be

- ^{7}Be has a specific behaviour (filters)

Release of radioactive water / CERN policy

To consider effluents as radioactive two conditions must be fulfilled :

1. The specific activity (Bq/Kg) exceeds 1 % of the exemption limit
2. The absolute activity released exceeds 100 times the absolute exemption limit LE_{abs} expressed in Bq

For mixture :

$$\sum_i \frac{A_i}{L_i} \leq 1$$

Based on Swiss Legislation but could be accepted by french authorities for the LHC operation (INB)

	Specific activity (Bq/kg)	Absolute activity (Bq)
^{3}H	$6.0x10^{03}$	$6.0x10^{07}$
^{7}Be	$3.0x10^{03}$	$3.0x10^{07}$

Exemption limit (LE) :

^{3}H : $6x10^{5}$ Bq/kg

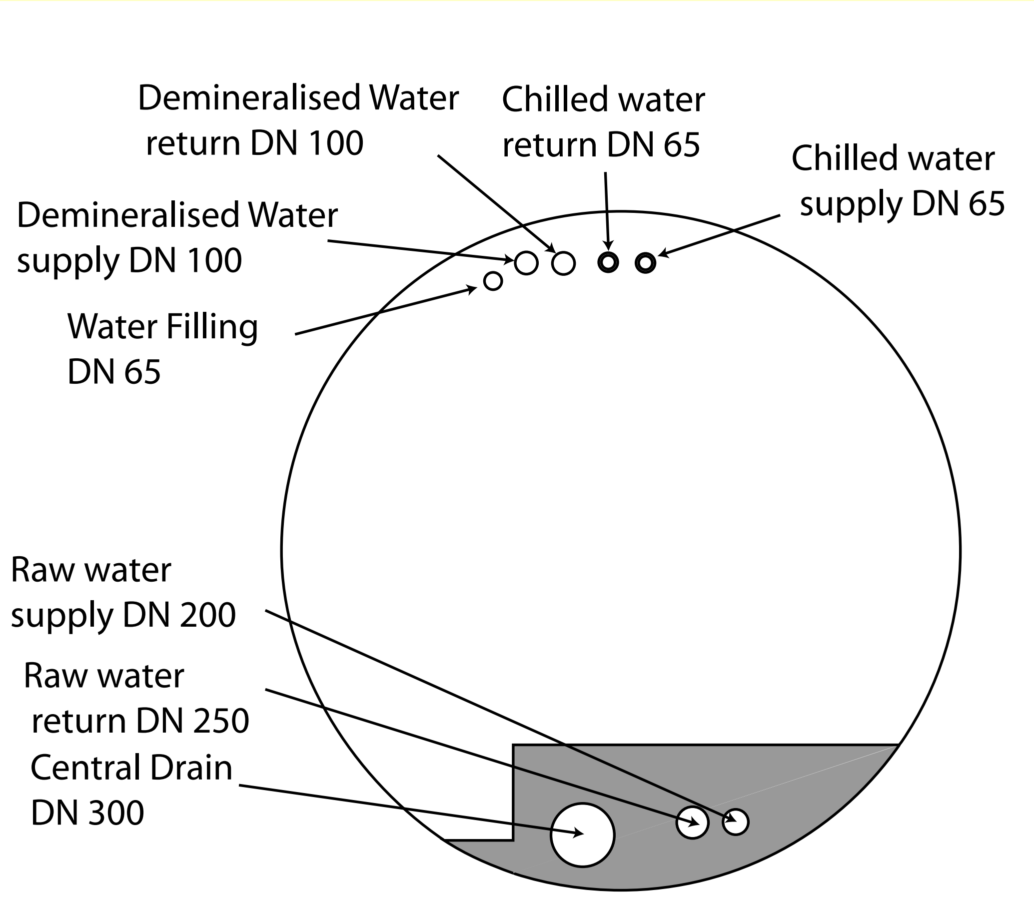
^{7}Be : $4x10^{5}$ Bq/kg

In any case in Points 6,7 and 8 authorisation from the environmental section is required due to the low flow rate of the receiving streams

Authorising releases of radioactive water into the environment, P. Vojtyla (EDMS 342244)

Different water pipe in the tunnel in Point 7

Tunnel Cross Section in Point 7



- Demineralised water circuit (supply and return)
- Chilled water circuit (supply and return)
- Water Filling pipe
- Raw water supply pipe
- Raw water reject pipe
- Drain pipe

The presentation will focus on
- Circuits Description
- Activity calculation
- Release scheme

FLUKA used for the calculations

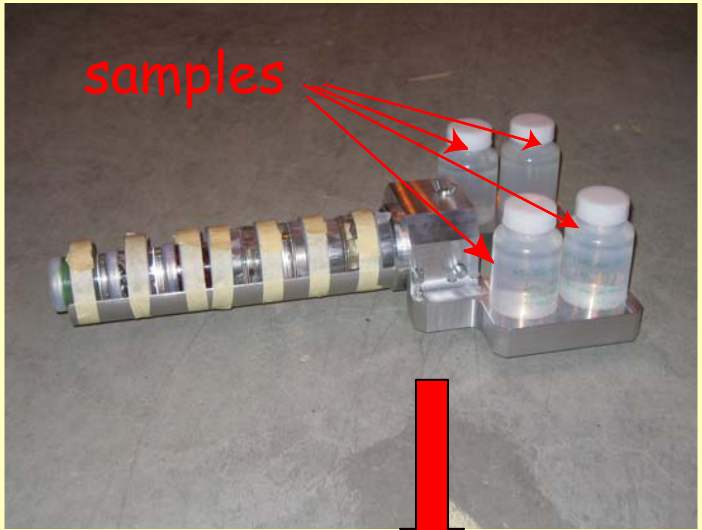
Water benchmark experiment at CERF

Validity of FLUKA for water activation calculation in the LHC ?

SPS secondary pulsed beam, 120 GeV
(1/3 protons, 2/3 pions, 1.5 % kaons)

Irradiation of water sample

1. Treated Water
2. Demineralised water
3. Infiltration water
4. Raw Water



Detailed Chemical Analysis

Gamma spectroscopy measurement using a Germanium detector and ^{3}H activity determination with a liquid scintillation counter

Simulation of the experimental setup

Beam characteristics measurement

Comparison FLUKA / experiment

Results from the chemical analysis

	PA3	Appoint	Deconc.	Distilled
H	1.12E+01	1.12E+01	1.12E+01	1.12E+01
O	8.88E+01	8.88E+01	8.88E+01	8.88E+01
C	4.08E-03	1.16E-02	1.14E-02	
N	5.90E-05			
SiO_2	2.52E-04	3.76E-04	2.02E-04	
Si	1.18E-04			
Ca	6.90E-03	3.77E-03	7.13E-03	
Mg	5.20E-04	5.70E-04	1.10E-03	
Sr	1.80E-05			
Na	2.13E-04	8.31E-04	1.67E-03	
K	4.60E-05	1.56E-04	3.15E-04	
Li	2.00E-03			
Fe	2.00E-06	2.80E-05	1.14E-04	
Zn	1.00E-06	4.00E-06	2.48E-04	
Cl	1.00E-04	7.50E-04	2.96E-03	
SO_4	1.08E-03	4.09E-03	7.78E-03	
F	2.60E-05			

Exact composition taken into account in the FLUKA calculation

Different traces element composition for the different samples

Nuclei production on trace elements can be benchmarked

Results of the benchmark experiment

	Ratio Measurement / Simulation		
	^{24}Na	^{3}H	^{7}Be
Treated Water	1.16(9.8%)	2.45(4.1%)	1.00(9.8%)
Demineralised	-	2.49(4.1%)	-
Raw water	1.15(15%)	2.52(4.1%)	1.10(15%)
Infiltration	1.02(38%)	2.69(4.1%)	1.09(9.8%)
Average	1.11(23%)	2.54(4.1%)	1.07(8.1%)

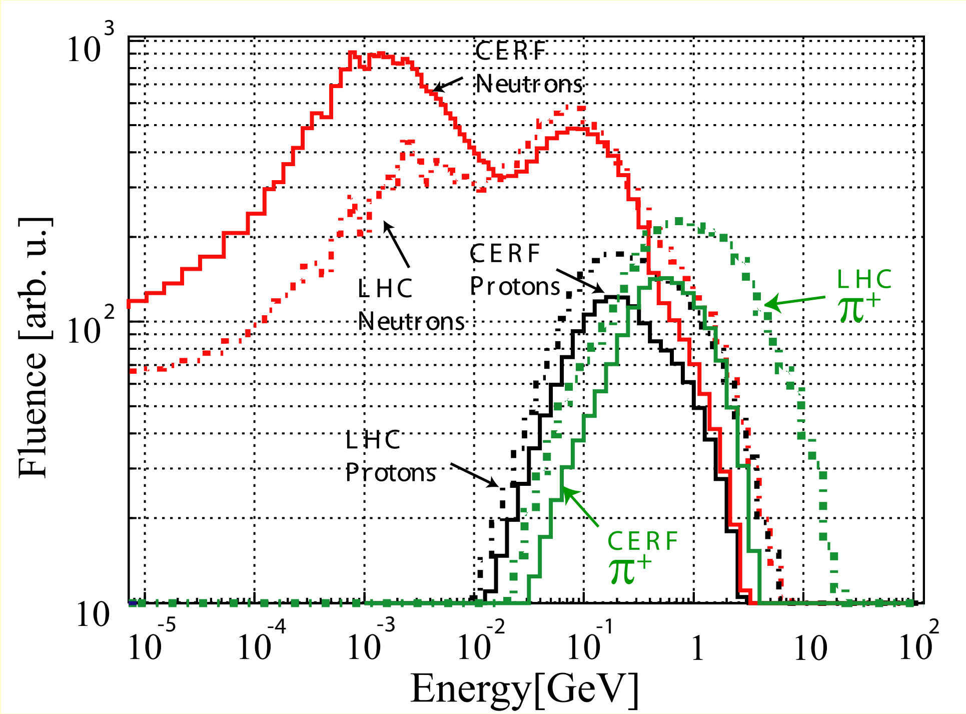
- FLUKA underestimates the ^{3}H production

- Excellent agreement for ^{24}Na and ^{7}Be

Are those results valid for LHC calculation ?

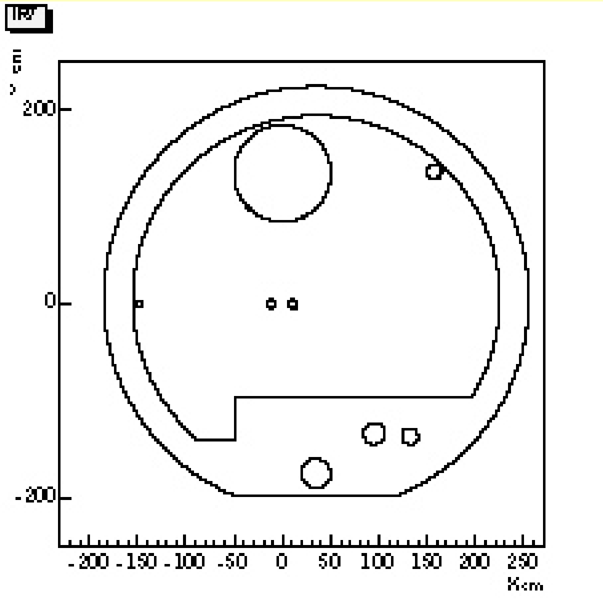
Simulated fluence in a water bottle and in one of the LHC water pipe

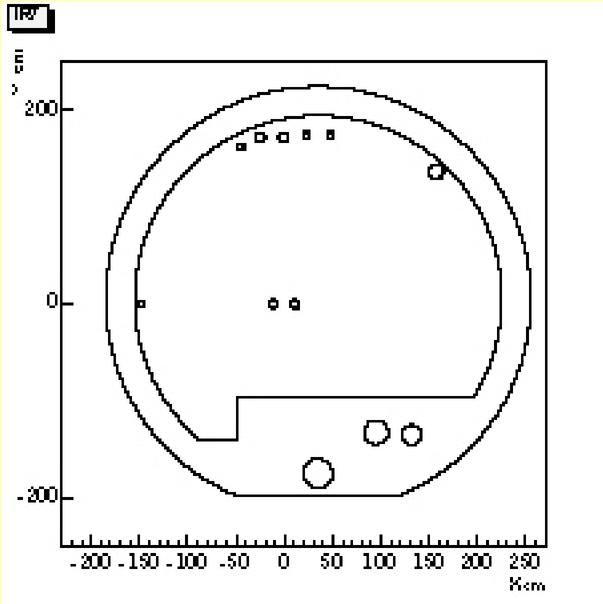
correction factor will be applied to LHC calculation for ^{3}H



Calculation of residual nuclei production with FLUKA

FLUKA geometry used for air activation (M.Brugger)



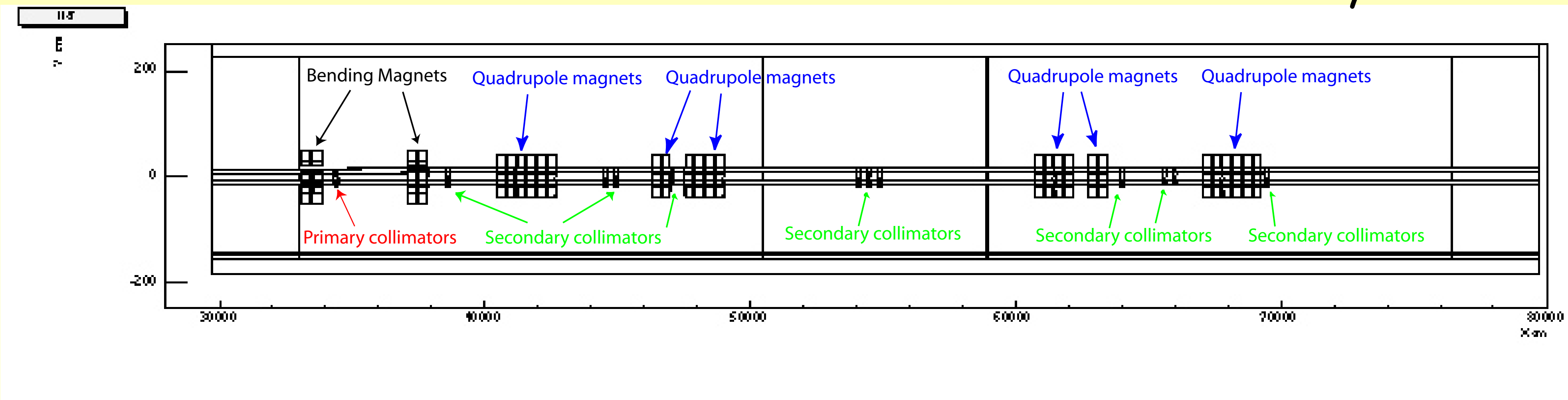


Small changes

- Air duct removed
- New pipe locations

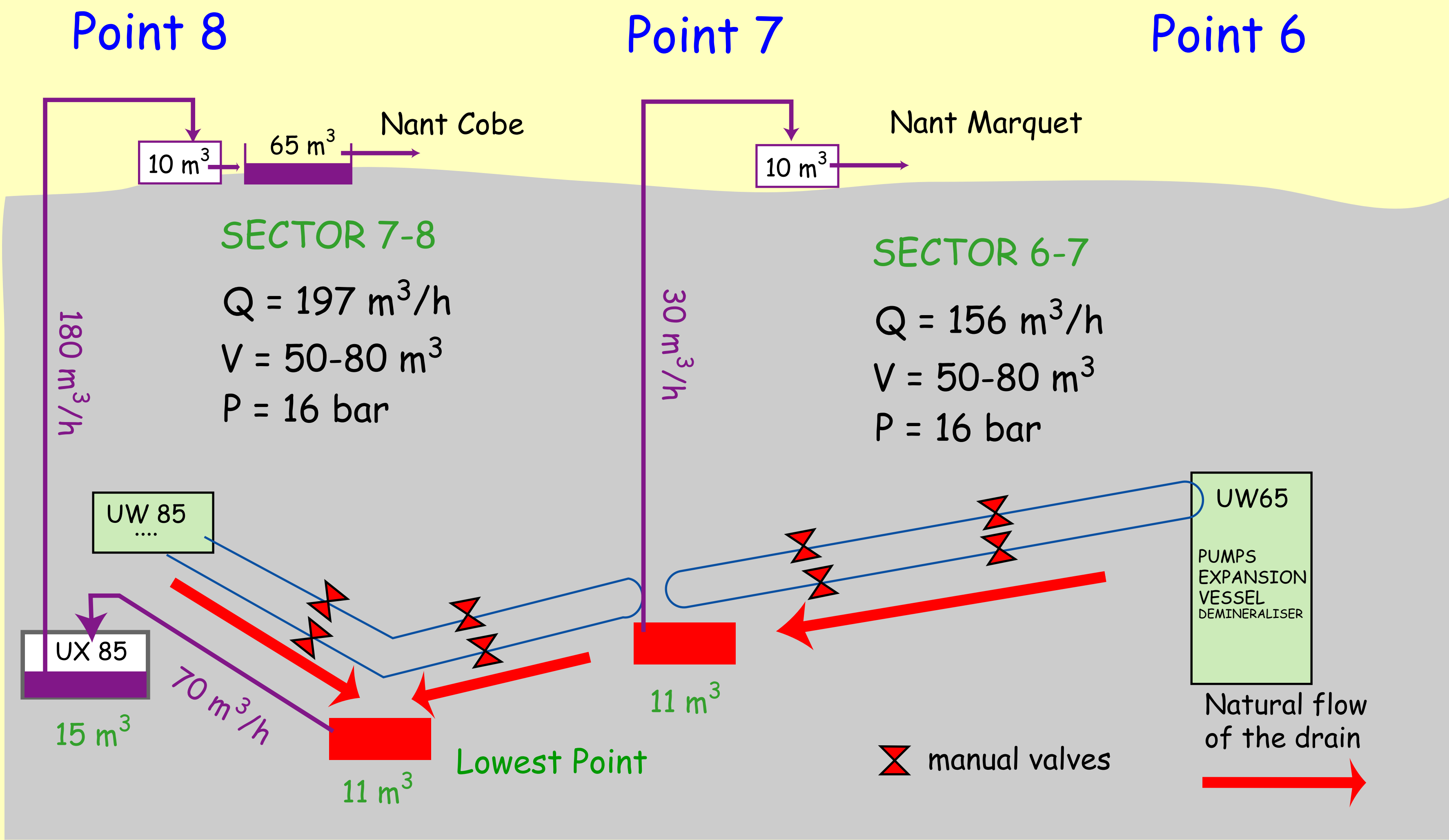
Characteristics

- 2x2 Bending magnets
- 2x12 Quadrupoles magnets
- 1x3 Primary collimators
- 1x11 Secondary collimators



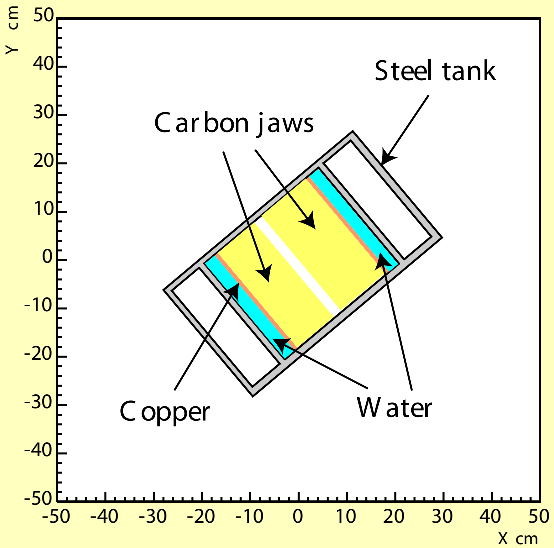
The Demineralised Water Circuit

- Two different circuits supply Point 7 with demineralised water
- Used to cool several equipments such as collimator, warm magnets....
- To empty the DW circuits the central drain is used (oil in Point 7&8)

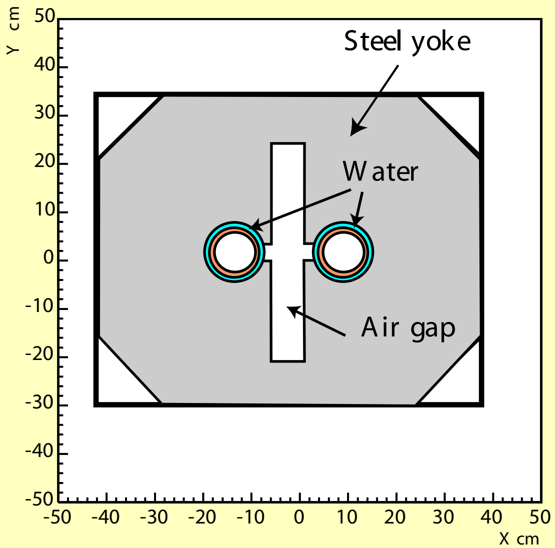


Equipments cooled with demineralised water

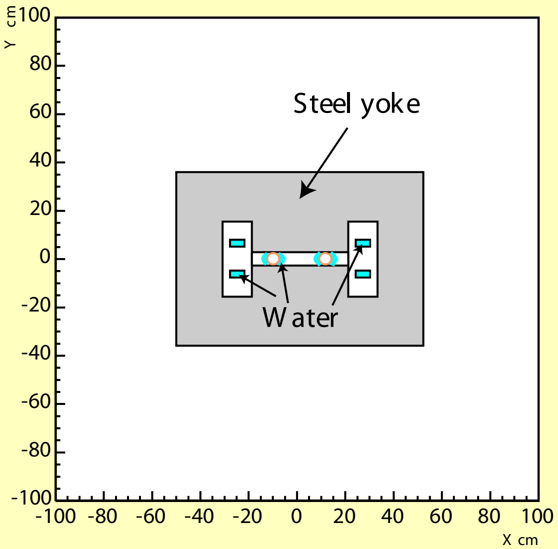
- Water present in the pipe (2xDN100) and used to cool equipments
- Each device are connected to the supply and return pipes (in the simulation)



Collimator



Quadrupole



Dipole

(Collimation project web site)

- The demineralised water is closed to the beam, radioactive nuclei are produced in the main pipes and in the equipments

The Demineralised Water Circuit

- Simulation length equal to 500 m, particle which are able to induce radioactive nuclei are transported within the length of the simulation

	Real Volume	Simulated Volume	Flexible hose Volume
Collimator	1 ℓ	1.5 ℓ	3.9 ℓ
Quadrupole	30 ℓ	20 ℓ	3.3 ℓ
Dipole	20 ℓ	30 ℓ	3.4 ℓ
Entire circuit	50 m^3	4000 ℓ	

Individual connections

500 m

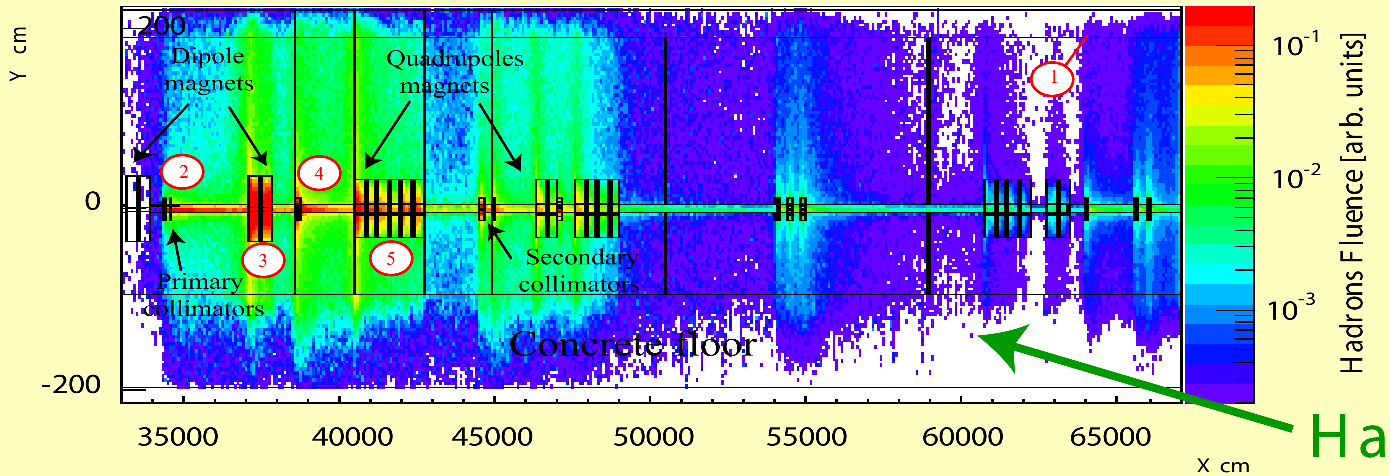
volumes are indicated for one module

Radioactive nuclei production per lost protons and per volume units

→ Normalisation to the real volume

Some results for ^{3}H and ^{7}Be production

	^{3}H nuclei/ℓ/p	^{7}Be nuclei/ℓ/p	^{3}H nuclei/p	^{7}Be nuclei/p
Supply Pipe (1)	1.6×10^{-04}	2.5×10^{-05}	6.3×10^{-01}	9.7×10^{-02}
3rd Primary(2)	1.4×10^{-01}	2.6×10^{-02}	2.9×10^{-02}	5.1×10^{-02}
1st Dipoles(3)	1.7×10^{-01}	2.1×10^{-02}	9.8×10^{-01}	1.2×10^{-01}
1st Secondary(4)	4.9×10^{-01}	7.0×10^{-02}	4.9×10^{-02}	7.0×10^{-02}
1st Quadrupole(5)	1.6×10^{-02}	2.2×10^{-03}	4.8×10^{-03}	6.7×10^{-02}



Hadrons fluence map

- Supply and return pipes do not have the main contribution
- Activation occurs in the equipment

Activity calculatin for ^{3}H and ^{7}Be

Production of radioactive nuclei per lost protons

	^{3}H nuclei/p	^{7}Be nuclei/p
Main Pipes	1.3	0.20
All Collimators	1.3	0.17
All Dipoles	1.9	0.24
All Quadrupoles	2.0	0.30
Total	6.4	0.90

- ^{7}Be concentration is close to saturation
- ^{7}Be will be caught in the ions exchangers
- ^{3}H concentration will double if the water is used for two years

Activity Calculation

$$A_i = Y_i \frac{N_p}{t_{irr}} \left(1 - \exp(-\lambda_i t_{irr})\right)$$

Y_i *nuclei per lost protons*

N_p *protons lost during the time* t_{irr}

λ_i *decay constant of nuclei i*

Losses	Ultimate	3.0×10^{16} p/beam
	Nominal	1.9×10^{16} p/beam

Irradiation 180 days

Specific Activity

$$a_i = \frac{A_i}{V}$$

Activity of ^3H and ^7Be

Swiss legislation :

	Specific activity (kBq/kg)	Absolute activity (MBq)
^3H	6.0	60
^7Be	3.0	30

two conditions must be fulfilled at the same time to consider water as radioactive

Ultimate Losses and one year of operation

Tritium activity*	^7Be activity*
$A_i = 676 \pm 7$ MBq	$A_i = 3150 \pm 7$ MBq
$a_i = 6.76 \pm 0.07$ kBq/ℓ	$a_i = 31.5 \pm 0.5$ kBq/ℓ

Production Yield corresponding to phase 1 collimator !

Total volume of the circuit = 2 x 50 m^3

Nominal Losses and one year of operation

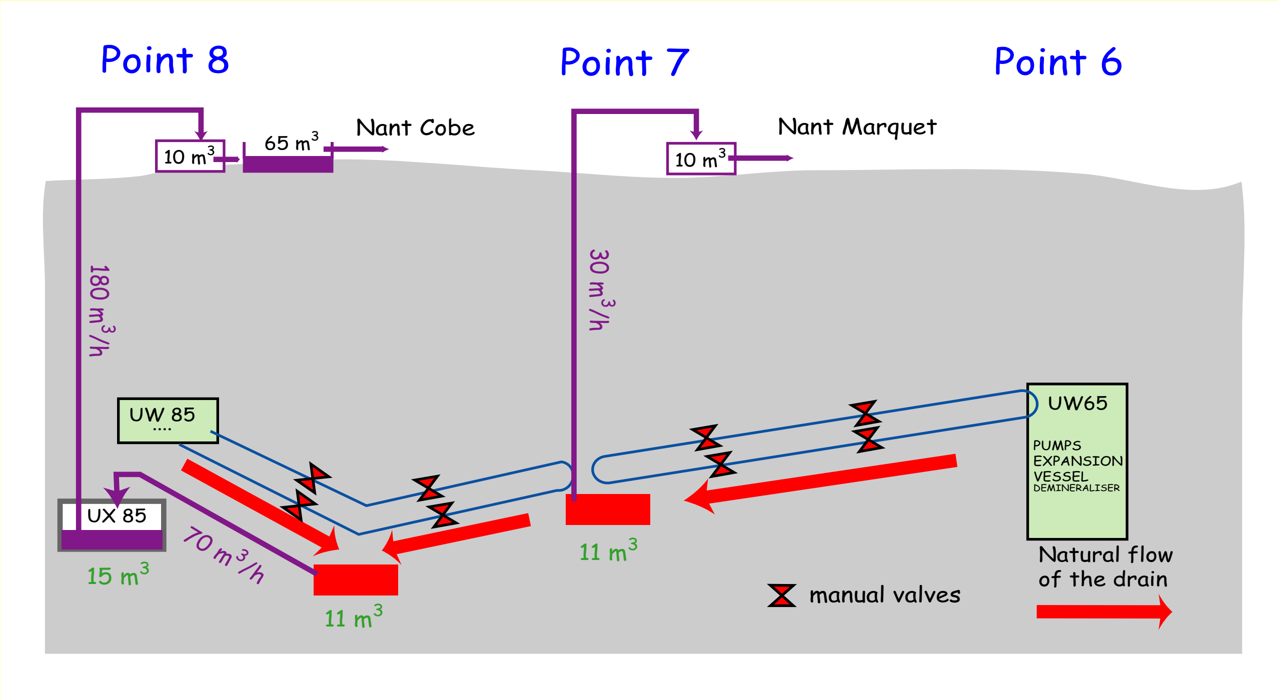
Tritium activity*	^7Be activity*
$A_i = 428 \pm 4$ MBq	$A_i = 2000 \pm 3$ MBq
$a_i = 4.28 \pm 0.04$ kBq/ℓ	$a_i = 20.0 \pm 0.3$ kBq/ℓ

^7Be concentration calculated without taking into account the effect of the filters

* Statistical uncertainty

What to do with this water ?

- Possibility to take samples in the UW cavern an purge the circuit before the activity level becomes critical (CERN detection limit of the order of a few Bq/ℓ)
- Water can only be brought back to the surface after being mixed with the so called clean water (lot of hydrocarbons)
- Partly open decantation basin at the surface for hydrocarbons/water separation / other solutions being discussed (truck, no big stream...)

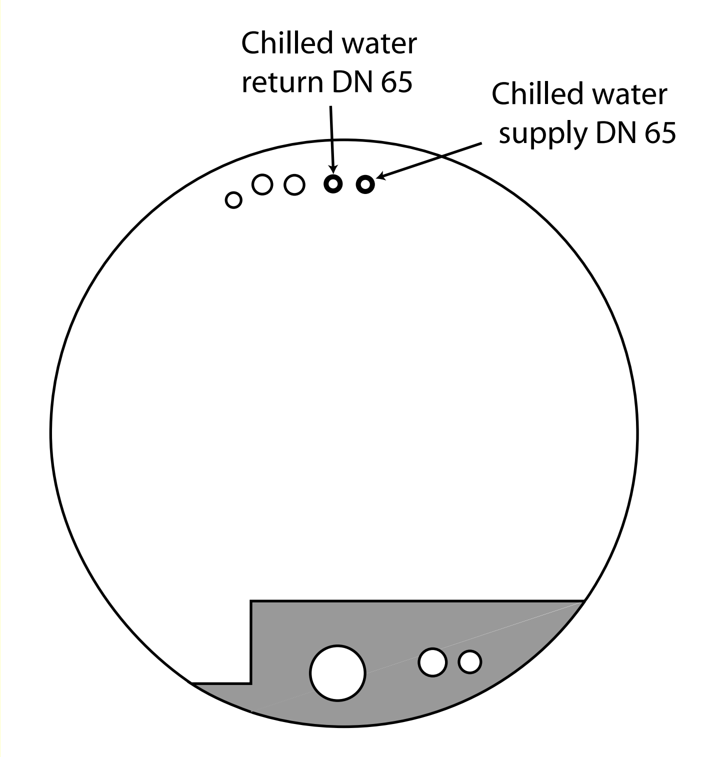


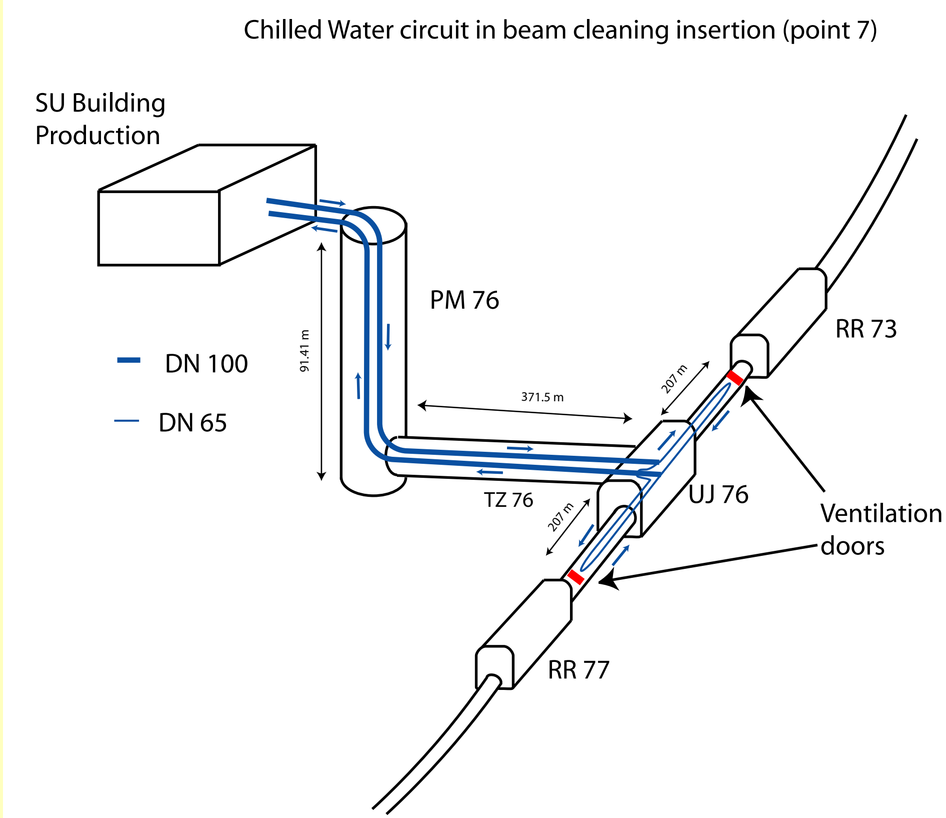
A few pictures





Chilled Water Circuit





- Closed circuit used to cool ventilation convectors
- Dilution at the surface : big tank of 30 m^3 + other circuits used for air handling ➡ 60 m^3
- Radioactive water expected in the surface buildings
- Circuit equipped with filter ➡ Should catch ^7Be

Chilled Water Circuit

Radioactive nuclei production

^{3}H : Supply + Return pipes

0.56 nuclei/p

^{7}Be : Supply + Return pipes

0.079 nuclei/p

circuit volume is 10+50 m^3

Chilled and mixed water Engineering Specifications

LHC Project Document No.
LHC-FG-ES-0001 rev 1.0

Page 16 of 22

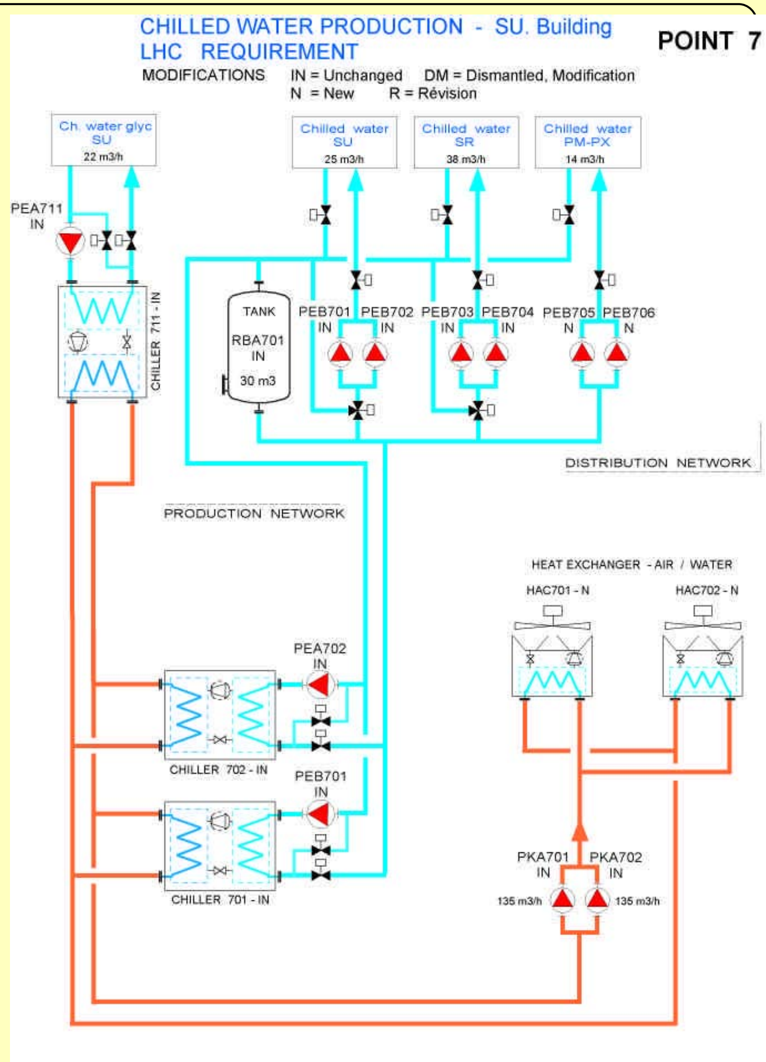


Figure 13. Production and distribution of chilled water at LHC point 7

Nominal Losses and one year of operation

Tritium activity*	^{7}Be activity*
$A_i = 37 \pm 1$ MBq	$A_i = 174 \pm 9$ MBq
$a_i = 0.62 \pm 0.01$ kBq/ℓ	$a_i = 2.9 \pm 0.1$ kBq/ℓ

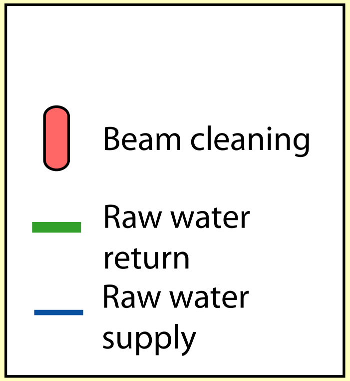
Ultimate Losses and one year of operation

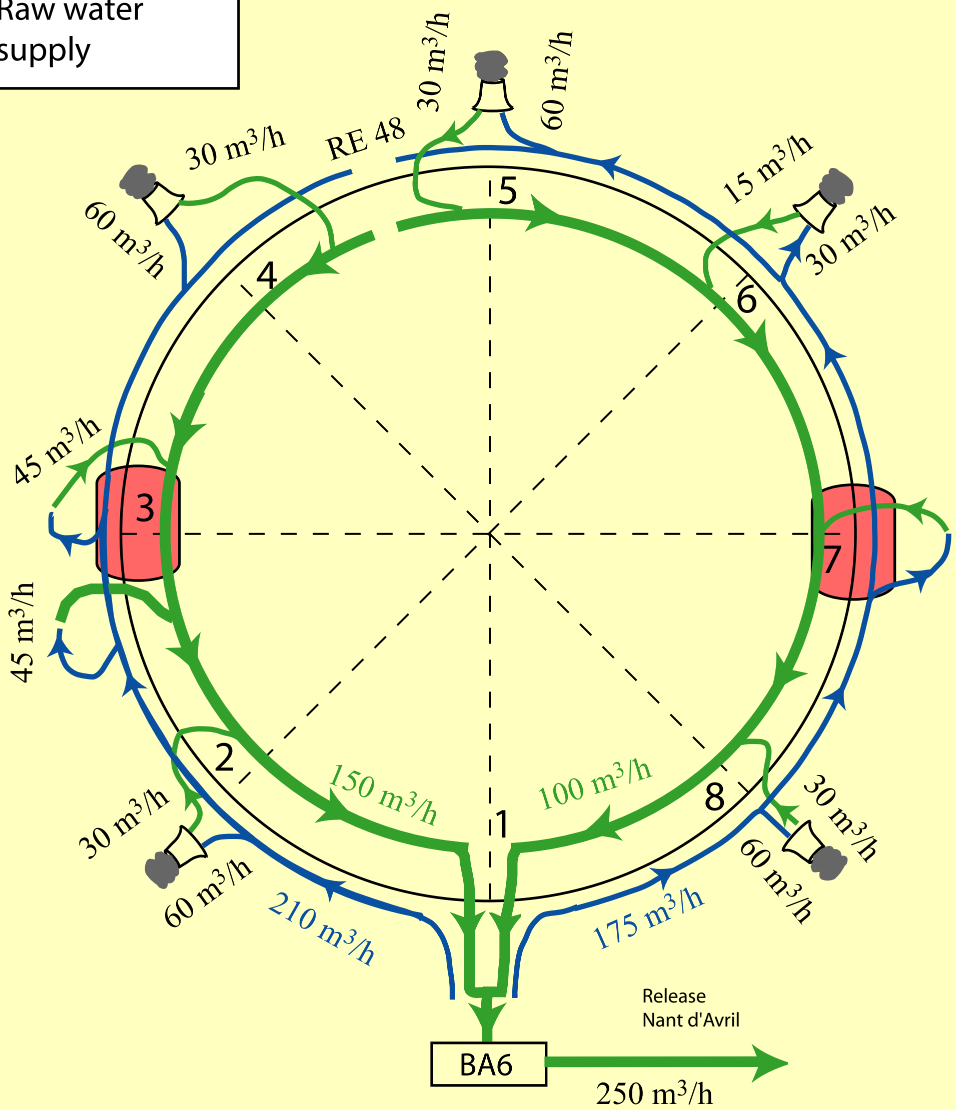
Tritium activity*	^{7}Be activity*
$A_i = 59 \pm 2$ MBq	$A_i = 275 \pm 13$ MBq
$a_i = 0.98 \pm 0.02$ kBq/ℓ	$a_i = 4.6 \pm 0.2$ kBq/ℓ

^{3}H : 6 kBq/ℓ ^{7}Be : 4 kBq/ℓ

Specific activity

Raw Water Circuit





- Open circuit, the water flows once in the collimator area
- Reject pipe collects water from the cooling towers
- Two circuits join in Point 1 before the release in the Nant d'Avril
- Estimate of the flow rate gives the time of irradiation in the collimator area

Raw Water Circuit Activity

- Pipes located in the concrete (shielding)

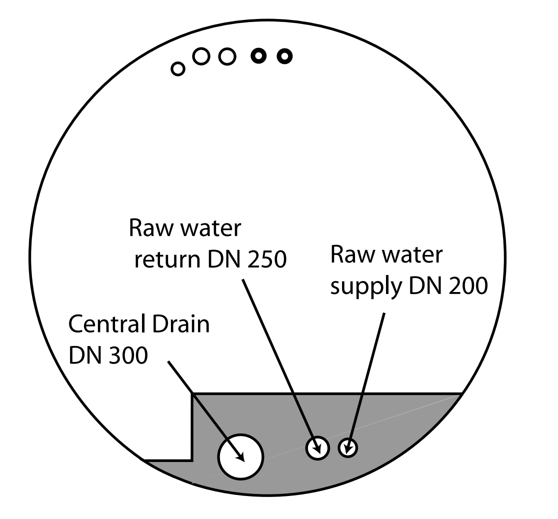
Production of radioactive nuclei

^{3}H supply pipe : 0.5 nuclei/proton

^{3}H Return pipe : 0.2 nuclei/proton

^{7}Be supply pipe : 0.08 nuclei/proton

^{7}Be return pipe : 0.03 nuclei/proton



Rejected in the Nant d'Avril in 180 days

98 MBq of ^{3}H

1290 MBq of ^{7}Be

Specific activity in several locations

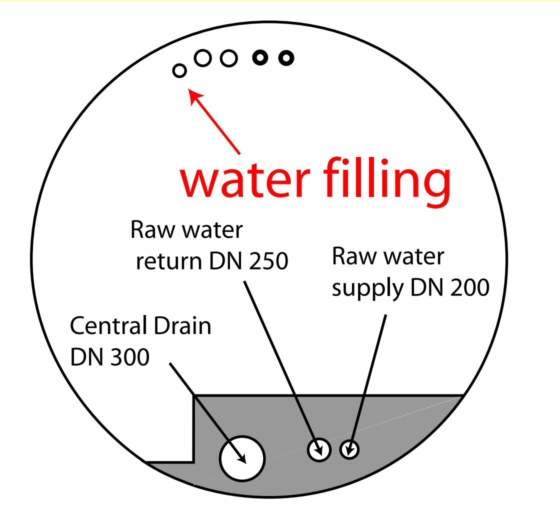
	^{3}H (kBq/ℓ)	^{7}Be (kBq/ℓ)
Supply Pipe		
Before IR7	3.96×10^{-6}	5.70×10^{-5}
Point 7	1.06×10^{-4}	1.40×10^{-3}
End of IR7	1.64×10^{-4}	2.16×10^{-3}
Reject Pipe		
Before IR7	1.71×10^{-4}	2.26×10^{-3}
Point 7 (1)	2.87×10^{-4}	3.78×10^{-3}
Point 7 (2)	2.22×10^{-4}	3.93×10^{-3}
End of IR7	3.38×10^{-4}	4.46×10^{-3}
Nant d'Avril	1.09×10^{-4}	1.44×10^{-3}

- Contribution from beam-gas interactions before the collimators section
- Junction with the second circuit in Point 1 before release

^{3}H : 6 kBq/ℓ ^{7}Be : 4 kBq/ℓ

Water Filling Pipe

- This pipe is used to supply the demineralised water circuits in each octant with demineralised water produced in Point 1
- It is hard to evaluate the flow rate in the pipe and thus the time spend by water in the collimator area. However the total activity produced can be estimated



Nominal Losses and one year of operation

Tritium activity	^{7}Be activity
$A_i = 17 \pm 1$ MBq	$A_i = 76 \pm 5$ MBq

Ultimate Losses and one year of operation

Tritium activity	^{7}Be activity
$A_i = 31 \pm 1$ MBq	$A_i = 143 \pm 9$ MBq

^{3}H : 0.3 nuclei produced per lost protons in the collimators

^{7}Be : 0.04 nuclei produced per lost protons in the collimators

Synthesis of tritium concentration and releases

The specific and total activity calculated correspond to losses for the ultimate intensity of the accelerator

Release Point	Specific activity kBq/l	Estimated volume	Total activity (MBq)	Comments
Nant d'Avril (BA6)	1.09×10^{-4}	$\approx 250\ m^3/h$	98	Raw water circuit including the two half rings with contribution from collimators in point 3 and 7. The average flow in BA6 is supposed to be equal to $250 m^3/h$
Nant Marquet (Pt7)	7	$\approx 50\ m^3$	338	The activation results from 180 days of operation of the accelerator, it is then assumed that the water is replaced. The water must be mixed with other drainage water before it can be pumped-up to the surface
Nant Marquet (Pt7)	1	$\approx 60\ m^3$	59	This is the activity reached after 180 days of operation for the water of this circuits which also flows in surface buildings
Nant de cobe (Pt8)	7	$\approx 50\ m^3$	338	The activation results from 180 days of operation of the accelerator, it is then assumed that the water is replaced. The water must be mixed with other drainage water before it can be pumped-up to the surface

Perspectives

- Updated layout : flexible, long primary collimators, absorbers (water cooled ?)

Conclusions

- The activity in the demineralised water circuit may reach values close to legal limits (if the principles of the Swiss legislation is accepted by French authorities)

- There are no big streams in Point 7 and in Point 8 to receive those large amount of water → hard to estimate the effect of this release

- The tritium activity in the water is several hundred times higher than the activity of rain water (few Bq/l)