Calculation of Water Activity in Point 7

SC/RP

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Production of radioactive nuclei in water

Production on Oxygen atom (H₂O)

<table>
<thead>
<tr>
<th>nucleus</th>
<th>Half Life</th>
<th>Decay modes and energy</th>
</tr>
</thead>
<tbody>
<tr>
<td>³H</td>
<td>12.35 y</td>
<td>100 % β⁻, $E_{\text{ave}} = 5.68 \times 10^{-3}$ MeV</td>
</tr>
<tr>
<td>⁷Be</td>
<td>53.3 d</td>
<td>89.7 % β⁺, Electron capture</td>
</tr>
<tr>
<td></td>
<td></td>
<td>10.3 % γ, $E_{\text{ave}} = 0.4776$ MeV</td>
</tr>
<tr>
<td>¹¹C</td>
<td>20.4 m</td>
<td>99.8 % β⁺, $E_{\text{ave}} = 3.86 \times 10^{-1}$ MeV</td>
</tr>
<tr>
<td>¹⁴C</td>
<td>5730 y</td>
<td>100 % β⁺, $E_{\text{ave}} = 4.95 \times 10^{-2}$ MeV</td>
</tr>
<tr>
<td>¹³N</td>
<td>9.97 m</td>
<td>99.8 % β⁺, $E_{\text{ave}} = 4.92 \times 10^{-1}$ MeV</td>
</tr>
<tr>
<td>¹⁴O</td>
<td>71 s</td>
<td>99.9 % β⁺, $E_{\text{max}} = 1.81$ MeV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.6 % β⁺, $E_{\text{max}} = 4.12$ MeV</td>
</tr>
<tr>
<td></td>
<td></td>
<td>99 % γ, $E = 2.312$ MeV</td>
</tr>
<tr>
<td>¹⁵O</td>
<td>122 s</td>
<td>99.9 % β⁺, $E_{\text{ave}} = 7.35 \times 10^{-1}$ MeV</td>
</tr>
</tbody>
</table>

- Most critical nuclei are $^3$H and $^7$Be
- $^7$Be has a specific behaviour (filters)

- Trace elements can lead to the production of other nuclei as $^{24}$Na
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 \( \text{LE}_{abs} \) 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).

<table>
<thead>
<tr>
<th></th>
<th>Specific activity (Bq/kg)</th>
<th>Absolute activity (Bq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(^3\text{H} )</td>
<td>6.0x10(^{03})</td>
<td>6.0x10(^{07})</td>
</tr>
<tr>
<td>(^7\text{Be} )</td>
<td>3.0x10(^{03})</td>
<td>3.0x10(^{07})</td>
</tr>
</tbody>
</table>

Exemption limit (LE):

\(^3\text{H} : 6x10^5 \text{ Bq/kg}\)

\(^7\text{Be} : 4x10^5 \text{ Bq/kg}\)

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

- 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

Simulation of the experimental setup

Beam characteristics measurement

Detailed Chemical Analysis

Comparison FLUKA / experiment

Gamma spectroscopy measurement using a Germanium detector and \(^3\)H activity determination with a liquid scintillation counter

samples
copper target
Results from the chemical analysis

<table>
<thead>
<tr>
<th></th>
<th>PA3</th>
<th>Appoint</th>
<th>Deconc.</th>
<th>Distilled</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>1.12E+01</td>
<td>1.12E+01</td>
<td>1.12E+01</td>
<td>1.12E+01</td>
</tr>
<tr>
<td>O</td>
<td>8.88E+01</td>
<td>8.88E+01</td>
<td>8.88E+01</td>
<td>8.88E+01</td>
</tr>
<tr>
<td>C</td>
<td>4.08E-03</td>
<td>1.16E-02</td>
<td>1.14E-02</td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>5.90E-05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiO₂</td>
<td>2.52E-04</td>
<td>3.76E-04</td>
<td>2.02E-04</td>
<td></td>
</tr>
<tr>
<td>Si</td>
<td>1.18E-04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ca</td>
<td>6.90E-03</td>
<td>3.77E-03</td>
<td>7.13E-03</td>
<td></td>
</tr>
<tr>
<td>Mg</td>
<td>5.20E-04</td>
<td>5.70E-04</td>
<td>1.10E-03</td>
<td></td>
</tr>
<tr>
<td>Sr</td>
<td>1.80E-05</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Na</td>
<td>2.13E-04</td>
<td>8.31E-04</td>
<td>1.67E-03</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>4.60E-05</td>
<td>1.56E-04</td>
<td>3.15E-04</td>
<td></td>
</tr>
<tr>
<td>Li</td>
<td>2.00E-03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Fe</td>
<td>2.00E-06</td>
<td>2.80E-05</td>
<td>1.14E-04</td>
<td></td>
</tr>
<tr>
<td>Zn</td>
<td>1.00E-06</td>
<td>4.00E-06</td>
<td>2.48E-04</td>
<td></td>
</tr>
<tr>
<td>Cl</td>
<td>1.00E-04</td>
<td>7.50E-04</td>
<td>2.96E-03</td>
<td></td>
</tr>
<tr>
<td>SO₄</td>
<td>1.08E-03</td>
<td>4.09E-03</td>
<td>7.78E-03</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>2.60E-05</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>Ratio (Measurement / Simulation)</th>
<th>24Na</th>
<th>3H</th>
<th>7Be</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treated Water</td>
<td>1.16 (9.8%)</td>
<td>2.45 (4.1%)</td>
<td>1.00 (9.8%)</td>
<td></td>
</tr>
<tr>
<td>Demineralised</td>
<td>-</td>
<td>2.49 (4.1%)</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Raw water</td>
<td>1.15 (15%)</td>
<td>2.52 (4.1%)</td>
<td>1.10 (15%)</td>
<td></td>
</tr>
<tr>
<td>Infiltration</td>
<td>1.02 (38%)</td>
<td>2.69 (4.1%)</td>
<td>1.09 (9.8%)</td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>1.11 (23%)</td>
<td>2.54 (4.1%)</td>
<td>1.07 (8.1%)</td>
<td></td>
</tr>
</tbody>
</table>

- FLUKA underestimates the 3H production
- Excellent agreement for 24Na and 7Be

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 3H
Calculation of residual nuclei production with FLUKA

FLUKA geometry used for air activation (M. Brugger)

- Air duct removed
- New pipe locations

Small changes

Characteristics
- 2×2 Bending magnets
- 2×12 Quadrupoles magnets
- 1×3 Primary collimators
- 1×11 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)

Point 8

- SECTOR 7-8
  - \( Q = 197 \, \text{m}^3/\text{h} \)
  - \( V = 50-80 \, \text{m}^3 \)
  - \( P = 16 \, \text{bar} \)

Point 7

- SECTOR 6-7
  - \( Q = 156 \, \text{m}^3/\text{h} \)
  - \( V = 50-80 \, \text{m}^3 \)
  - \( P = 16 \, \text{bar} \)

Point 6

- \( \text{UX 85} \)
  - \( 10 \, \text{m}^3 \)
  - \( 65 \, \text{m}^3 \)
  - \( 10 \, \text{m}^3 \)

- \( \text{UW 85} \)
  - \( 15 \, \text{m}^3 \)
  - \( 70 \, \text{m}^3/\text{h} \)

- \( \text{UW65} \)
  - \( 11 \, \text{m}^3 \)

- \( \text{Natural flow of the drain} \)

- 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)

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

(Collimation project web site)
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

<table>
<thead>
<tr>
<th>Collimator</th>
<th>Real Volume (ℓ)</th>
<th>Simulated Volume (ℓ)</th>
<th>Flexible hose Volume (ℓ)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quadrupole</td>
<td>30 ℓ</td>
<td>20 ℓ</td>
<td>3.3 ℓ</td>
</tr>
<tr>
<td>Dipole</td>
<td>20 ℓ</td>
<td>30 ℓ</td>
<td>3.4 ℓ</td>
</tr>
<tr>
<td>Entire circuit</td>
<td>50 m³</td>
<td>4000 ℓ</td>
<td></td>
</tr>
</tbody>
</table>

Individual connections

Radioactive nuclei production per lost protons and per volume units

Normalisation to the real volume

500 m
Some results for $^3$H and $^7$Be production

<table>
<thead>
<tr>
<th></th>
<th>$^3$H nuclei/l/p</th>
<th>$^7$Be nuclei/l/p</th>
<th>$^3$H nuclei/p</th>
<th>$^7$Be nuclei/p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Supply Pipe (1)</td>
<td>1.6x10^{-04}</td>
<td>2.5x10^{-05}</td>
<td>6.3x10^{-01}</td>
<td>9.7x10^{-02}</td>
</tr>
<tr>
<td>3rd Primary (2)</td>
<td>1.4x10^{-01}</td>
<td>2.6x10^{-02}</td>
<td>2.9x10^{-02}</td>
<td>5.1x10^{-02}</td>
</tr>
<tr>
<td>1st Dipoles (3)</td>
<td>1.7x10^{-01}</td>
<td>2.1x10^{-02}</td>
<td>9.8x10^{-01}</td>
<td>1.2x10^{-01}</td>
</tr>
<tr>
<td>1st Secondary (4)</td>
<td>4.9x10^{-01}</td>
<td>7.0x10^{-02}</td>
<td>4.9x10^{-02}</td>
<td>7.0x10^{-02}</td>
</tr>
<tr>
<td>1st Quadrupole (5)</td>
<td>1.6x10^{-02}</td>
<td>2.2x10^{-03}</td>
<td>4.8x10^{-03}</td>
<td>6.7x10^{-02}</td>
</tr>
</tbody>
</table>

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

Hadrons fluence map
Activity calculation for $^3$H and $^7$Be

Production of radioactive nuclei per lost protons

<table>
<thead>
<tr>
<th></th>
<th>$^3$H nuclei/p</th>
<th>$^7$Be nuclei/p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Pipes</td>
<td>1.3</td>
<td>0.20</td>
</tr>
<tr>
<td>All Collimators</td>
<td>1.3</td>
<td>0.17</td>
</tr>
<tr>
<td>All Dipoles</td>
<td>1.9</td>
<td>0.24</td>
</tr>
<tr>
<td>All Quadrupoles</td>
<td>2.0</td>
<td>0.30</td>
</tr>
<tr>
<td>Total</td>
<td>6.4</td>
<td>0.90</td>
</tr>
</tbody>
</table>

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 $t_{irr}$
$\lambda_i$ decay constant of nuclei $i$

Losses

<table>
<thead>
<tr>
<th>Ultimate</th>
<th>Nominal</th>
</tr>
</thead>
<tbody>
<tr>
<td>$3.0 \times 10^{16}$ p/beam</td>
<td>$1.9 \times 10^{16}$ p/beam</td>
</tr>
</tbody>
</table>

Irradiation 180 days

Specific Activity

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

- $^7$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 of $^3$H and $^7$Be

<table>
<thead>
<tr>
<th></th>
<th>Specific activity (kBq/kg)</th>
<th>Absolute activity (MBq)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^3$H</td>
<td>6.0</td>
<td>60</td>
</tr>
<tr>
<td>$^7$Be</td>
<td>3.0</td>
<td>30</td>
</tr>
</tbody>
</table>

Swiss legislation:

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

Ultimate Losses and one year of operation:
- Tritium activity: $A_i = 428 \pm 4$ MBq, $a_i = 4.28 \pm 0.04$ kBq/l
- $^7$Be activity: $A_i = 2000 \pm 3$ MBq, $a_i = 20.0 \pm 0.3$ kBq/l

Nominal Losses and one year of operation:
- Tritium activity: $A_i = 676 \pm 7$ MBq, $a_i = 6.76 \pm 0.07$ kBq/l
- $^7$Be activity: $A_i = 3150 \pm 7$ MBq, $a_i = 31.5 \pm 0.5$ kBq/l

Production Yield corresponding to phase 1 collimator!

Total volume of the circuit = $2 \times 50$ m$^3$

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

*Statistical uncertainty

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

LHC Collimation Working Group
What to do with this water?

- Possibility to take samples in the UW cavern and 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 m³ + other circuits used for air handling ➔ 60 m³
- 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

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

Specific activity

$^3$H : 6 kBq/l  $^7$Be : 4 kBq/l
- 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**

³H supply pipe: 0.5 nuclei/proton

³H Return pipe: 0.2 nuclei/proton

⁷Be supply pipe: 0.08 nuclei/proton

⁷Be return pipe: 0.03 nuclei/proton

<table>
<thead>
<tr>
<th>Specific activity in several locations</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Supply Pipe</td>
</tr>
<tr>
<td>Before IR7</td>
</tr>
<tr>
<td>Point 7</td>
</tr>
<tr>
<td>End of IR7</td>
</tr>
<tr>
<td>Reject Pipe</td>
</tr>
<tr>
<td>Before IR7</td>
</tr>
<tr>
<td>Point 7 (1)</td>
</tr>
<tr>
<td>Point 7 (2)</td>
</tr>
<tr>
<td>End of IR7</td>
</tr>
<tr>
<td>Nant d'Avril</td>
</tr>
</tbody>
</table>

Rejected in the Nant d'Avril in 180 days

- 98 MBq of ³H
- 1290 MBq of ⁷Be

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

³H : 6 kBq/ℓ  
⁷Be : 4 kBq/ℓ
- 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 spent by water in the collimator area. However, the total activity produced can be estimated.

**Nominal Losses and one year of operation**

<table>
<thead>
<tr>
<th>Tritium activity</th>
<th>$^7$Be activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_i = 17 \pm 1 \text{ MBq}$</td>
<td>$A_i = 76 \pm 5 \text{ MBq}$</td>
</tr>
</tbody>
</table>

**Ultimate Losses and one year of operation**

<table>
<thead>
<tr>
<th>Tritium activity</th>
<th>$^7$Be activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A_i = 31 \pm 1 \text{ MBq}$</td>
<td>$A_i = 143 \pm 9 \text{ MBq}$</td>
</tr>
</tbody>
</table>

$^3$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.

<table>
<thead>
<tr>
<th>Release Point</th>
<th>Specific activity kBq/l</th>
<th>Estimated volume</th>
<th>Total activity (MBq)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nant d'Avril (BA6)</td>
<td>1.09x10^{-4}</td>
<td>≈ 250 m³/h</td>
<td>98</td>
<td>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 m³/h</td>
</tr>
<tr>
<td>Nant Marquet (Pt7)</td>
<td>7</td>
<td>≈ 50 m³</td>
<td>338</td>
<td>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</td>
</tr>
<tr>
<td>Nant Marquet (Pt7)</td>
<td>1</td>
<td>≈ 60 m³</td>
<td>59</td>
<td>This is the activity reached after 180 days of operation for the water of this circuits which also flows in surface buildings</td>
</tr>
<tr>
<td>Nant de cobe (Pt8)</td>
<td>7</td>
<td>≈ 50 m³</td>
<td>338</td>
<td>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</td>
</tr>
</tbody>
</table>
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)