Dismantling cyclotron
Application of international REX to Belgian situation

F. Schmitz, C. Mommaert
Content

• Introduction.

• International REX.
  – Dismantling of a SCX MC 40/Argonne cyclotron;
  – Dismantling of a Cyclone-30 in Australia;
  – Dismantling of a self-shielded cyclotron;
  – Second hand market.

• Bunker.

• Discussion.

• Conclusion.
Number of cyclotrons world-wide

2002 : 246 cyclotrons.
2006 : 262 cyclotrons registred, 350 believed to be set up.
Since then +/- 50 machines are believed to be set up per year.
2015 : +/- 800 accelerators ?

References :
IAEA Tecdoc-1007.
IAEA-Directory of cyclotrons used for radionuclide production in member states 2002.
IAEA-Directory of cyclotrons used for radionuclide production in member states 2006.
# Introduction - situation in Belgium

<table>
<thead>
<tr>
<th>Localisation</th>
<th>Type of cyclotron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bebig (Seneffe)</td>
<td>Cyclone-14+, Cyclone14+ (IBA)</td>
</tr>
<tr>
<td>UCL (LLN)</td>
<td>Cyclone-30 (IBA), <strong>Cyclone-44 and 100</strong> (LLN)</td>
</tr>
<tr>
<td>Erasme (Brussel)</td>
<td>Cyclone-30 (IBA)</td>
</tr>
<tr>
<td>Ulg (Liège)</td>
<td>Cyclone-18/9 (IBA), <strong>CGR MeV</strong> (GE)</td>
</tr>
<tr>
<td>VUB (Brussel)</td>
<td><strong>CGR MeV</strong> (GE)/Cyclone-18 (under installation) (IBA)</td>
</tr>
<tr>
<td>KUL (Leuven)</td>
<td>Cyclone-18/9 (IBA)</td>
</tr>
<tr>
<td>UG (Gent)</td>
<td>Cyclone-18/9 (IBA), <strong>CGR MeV</strong> (GE)</td>
</tr>
<tr>
<td>UZA (Antwerpen)</td>
<td><strong>RDS 111</strong> (Siemens)</td>
</tr>
<tr>
<td>Onsf (Fleurus)</td>
<td>Cyclone-30 (IBA), <strong>CGR MeV</strong> (GE)</td>
</tr>
<tr>
<td>IRE-Elit (Fleurus)</td>
<td>Cyclone-AE (IBA)</td>
</tr>
<tr>
<td>St Luc (Woluwe)</td>
<td>Cyclone-18/9 (IBA)</td>
</tr>
</tbody>
</table>
Dismantling of the Scanditronix MC40 of Hammersmith: strategy

- [https://www.youtube.com/watch?v=LI5Synde5fCI](https://www.youtube.com/watch?v=LI5Synde5fCI)

- Scanditronix MC 40 v.s. CGR MeV.
  - Multiparticles (p/d/alpha/...);
  - Mix of activities (regular RI production/R&D/physics/...);
  - Complex layout (Cyclotron bunker/switching magnets/beam line/...);
  - Year of installation SCX MC 40: 1986, Gent: 1977 (upgrade 1982), VUB: 1983, ...
Dismantling of the Scanditronix MC40 of Hammersmith : a few comments

- MC 40 of Birmingham University was transferred in 2002-2004 from Minneapolis (MN, U.S.A).
- In 2009, Birmingham acquired most parts from the decommissioned Hammersmith MC 40.
- Removal of peripherals and annex equipment first.

- «70 % Recycling » :
  - Transfer from a controlled area to another controlled area of the activated pieces of a cyclotron except the yoke;
  - For the rest?

info@belv.be
www.belv.be
A dose constraint to workers can be applied (10 mSv/year is sustainable).

No significant internal dose has been measured.

Contamination is considered as a residual risk which has not to be increased during dismantling process.
- To minimize this risk tools that can generate dust have to be avoided;
- Use bolt/unbolter, screwdriver, allen keys, ...
Dismantling of the Cyclone-30 in Ansto-Australia: strategy

A. Garcia, ANSTO Camperdown Project Public Presentation, P. Maharaj, ARPS, Melbourne Decommissioning and dismantling of the national medical cyclotron – a radiation protection perspective.

**Cyclone-30** (1990-2009, Mono particles, No mix of activities, Relatively simple layout, IBA machine).

- Any residual nuclear medicine product has decayed (history).
- Cyclotron and targets equipment have been surveyed and assessed as containing low levels of fixed radioactive material. Samples were taken from inside cyclotron tank.
- Survey data used to prepare a dose forecast for dismantling work.
- Low dose rates: 1-100 µSv/h at 0.5 m (up to 1 mSv/h at contact).
- Radiation protection plan included (characterisation, dose estimation and constraint, radiation management and monitoring, personal protective equipment, final status survey).
- Standard checks for radioactivity have been applied to all dismantled materials.
- License application submitted to Arpansa (RB) includes: effective control plan, safety management plan, radiation protection plan, radioactive waste management plan, security plan, emergency plan, decommissioning plan and schedule.

One year work for this part of the D&D file!
Dismantling of the Cyclone-30 in Ansto-Australia: strategy

- First step: dismantling of beam lines, cyclotron peripherals and target stations in cyclotron vault.
- All materials have been transferred to storage facilities licensed by Arpansa.
- Decommissioned materials have been transported in full compliance with international standards.
- The cyclotron has been removed from the building by effectively reversing the original delivery process.
- The cyclotron has been lifted out of the building through an existing covered roof opening.

- This strategy can be probably followed for all IBA machines set up in Belgium (Liège, Leuven, Erasme, Gent, Ibt, ...).

One more year to complete the dismantling of the cyclotron with all shielded cells used for PET production!
Dismantling of the Cyclone-30 in Ansto-Australia: Strategy

- **Management of the work space.**
  - Creation of a buffer storage zone;
  - Small items in 200 l drums;
  - Activated pieces stored in a shielded area;
  - Extra shielding put in place between target and cyclotron vault once the beam line has been removed;

- **Classical safety:** where the major risk is.
  - Cyclone-30 = 55 tons;
  - Pallet, trolleys, and ... are needed;
  - Engineered lifting equipment is requested and has to be controlled;

FAILURE!
Dismantling of the Cyclone-30 in Ansto-Australia: RP and lessons learned

• **Radiation protection and monitoring.**
  – Use of air sampler and external gamma monitors;
  – Controlled area;
  – Start with highest level of protection (tyveks, respiratory protection with particulate cartridges, overshoes and gloves, PD, extremity badge, whole body monitoring, ...);
  – AND downgraded during the project with a better understanding of the risk;
  – Dose rate surveys of the vault (0.5-1 µSv/h) were carried out to establish dose rates post-removal until re-used for new accelerator;

• **Lessons learned.**
  – Doses received less than estimated;
  – After removal of highly activated items, dose rates dropped significantly;
  – Time taken to remove some of the components less than anticipated;
  – No removable or surface airborne contamination detected throughout the project;
Decommissioning procedures for an 11 MeV self-shielded medical cyclotron after 16 years of working time.


Abstract
The present article describes the decommissioning of a compact, self-shielded, 11 MeV medical cyclotron. A Monte Carlo simulation of the possible nuclear reactions was performed in order to plan the decommissioning activities. In the course of the cyclotron dismantling, cyclotron components, shields, and floor concrete samples were measured. Residual activities were analyzed with a Ge(Li) detector and compared with simulation data. Doses to staff involved in the decommissioning procedure were monitored by individual TL dosimeters. The simulations identified five radioactive nuclides in shields and floor concrete: 55Fe and 45Ca (beta emitters, total specific activity: 2.29 \times 10(4) Bq kg\(^{-1}\)) and 152Eu, 154Eu, 60Co (gamma emitters, total specific activity: 1.62 \times 10(3) Bq kg\(^{-1}\)). Gamma-ray spectrometry confirmed the presence of gamma emitters, corresponding to a total specific activity of 3.40 \times 10(2) Bq kg\(^{-1}\). The presence of the radioisotope 124Sb in the lead contained in the shield structure, corresponding to a simulated specific activity of 9.38 \times 10(3) Bq kg\(^{-1}\), was experimentally confirmed. The measured dose from external exposure of the involved staff was <20 μSv, in accordance with the expected range of values between 10 and 20 μSv. The measured dose from intake was negligible. Finally, the decommissioning of the 11 MeV cyclotron does not represent a risk for the involved staff, but due to the presence of long-lived radioisotopes, the cyclotron components are to be treated as low level radioactive waste and stored in an authorized storage area.
### « Second hand » market

L. Carroll, Carroll & Ramsey Associates, Berkeley CA, USA, Decommissioning and recommissioning cyclotrons

<table>
<thead>
<tr>
<th>Cyclotron type</th>
<th>Initial set-up place</th>
<th>Re-export to</th>
</tr>
</thead>
<tbody>
<tr>
<td>CS 22 (TCC)</td>
<td>Berkeley (US)</td>
<td>Beijing (China)</td>
</tr>
<tr>
<td>CP 42 (TCC)</td>
<td>Houston (US)</td>
<td>Denton (US)</td>
</tr>
<tr>
<td>Cyclone 10/5 (IBA)</td>
<td>Leuven (Belgium)</td>
<td>Vietnam</td>
</tr>
<tr>
<td>MC 40 (SCX)</td>
<td>Minneapolis (US)</td>
<td>Birmingham (UK)</td>
</tr>
<tr>
<td>Cyclone 18/9 (IBA)</td>
<td>Ulm (Germany)</td>
<td>Russia</td>
</tr>
<tr>
<td>CS 30 (TCC)</td>
<td>Edinburgh (UK)</td>
<td>Aberdeen (UK)</td>
</tr>
<tr>
<td>CS 30 (TCC)</td>
<td>Miami (US)</td>
<td>Shanghai (China)</td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
« Second hand » market, few comments

- It is not a fast growing market.
- Lack of interest on the part of the cyclotron manufacturers in diluting their potential customer base.
- « residual value » not easiliy determined. A used cyclotron is most of the time « given away » to avoid the cost of the rad-waste disposal.
- What about rad-waste financial liability ?
- Spare part problems of oldest machine (electronics ?).
- Shipping cost is not negligible.
- Licensing is an issue for the recipient site as well as for the transport.
- An estimation of the residual radioactivity has to be done.

- This process is very similar to the first step of a dismantling + international transport – cost of dismantling.
- It’s a way of recycling active material.
- But it can work !
Bunker & vaults


- Re-use (e.g. UZ Gasthuisberg, UZ Brussel).
- Not activated (Erasme ??? with a partial shielding of the targets).
- Dismantle.
  - Eu-152, Eu-154, Co-60, Cs-134 (self shielded ! Unusual RI : Sb-124, ...);
  - Activation is not homogeneous in depth (first 15 cm), and position (the highest activation is found in the vicinity of the targets);
  - Theoretical estimation of the radionuclide produced in the concrete is possible (e.g. ALICE 91 code + cross section datas + nuclear reactions threshold +irradiation assumption (time/current/energy);
  - An enveloppe estimation of Bq produced/gr of concrete can be proposed;
  - Are we really facing a safety problem ?
Bunker & vaults

- **Dismantle.**
  - Activation is not homogeneous in depth (first 15 cm), and position (the highest activation is found in the vicinity of the targets);
  - Justification of the position of the bore holes;
## Discussion/summary

<table>
<thead>
<tr>
<th></th>
<th>SCX MC 40</th>
<th>Argonne</th>
<th>Ansto</th>
<th>RDS111</th>
</tr>
</thead>
<tbody>
<tr>
<td>D&amp;D file</td>
<td>1 year</td>
<td>18 months</td>
<td>1 year</td>
<td></td>
</tr>
<tr>
<td>D&amp;D field work</td>
<td>1 year</td>
<td>13 months</td>
<td>1 year</td>
<td></td>
</tr>
<tr>
<td>External dose</td>
<td>No problem occurs</td>
<td>No problem occurs</td>
<td>No problem occurs</td>
<td>No problem occurs</td>
</tr>
<tr>
<td>Dose rate of equipment</td>
<td></td>
<td>0-100 µSv/h-0.5 m 1 mSv/h contact</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Contamination</td>
<td>Residual risk</td>
<td>Residual risk</td>
<td>Residual risk</td>
<td>Residual risk</td>
</tr>
<tr>
<td>Mid term survey of the zone</td>
<td>Yes</td>
<td>Yes</td>
<td>Partial (set-up of a new cyclotron)</td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td></td>
<td>3.9 m$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Classical risk</td>
<td>High</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Planning</td>
<td>On time</td>
<td>On time</td>
<td>On time</td>
<td></td>
</tr>
</tbody>
</table>
## Conclusion 1

<table>
<thead>
<tr>
<th>Licensee</th>
<th>Cyclotron in use</th>
<th>Uncertain future</th>
<th>Stopped cyclotron</th>
<th>Future</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ulg/CHU Ulg</td>
<td>Cyclone 18/9 + CGR MeV</td>
<td>?</td>
<td></td>
<td>New cyclotron ?</td>
</tr>
<tr>
<td>UCL</td>
<td>3 Cyclone (44/30/100)</td>
<td>?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ULB/Erasme</td>
<td>Cyclone-30</td>
<td>?</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ondraf Fleurus</td>
<td></td>
<td></td>
<td>CGR MeV + Cyclone-30</td>
<td></td>
</tr>
<tr>
<td>Ibt/Bebig</td>
<td></td>
<td></td>
<td>Cyclone-14 + Cyclone-14</td>
<td></td>
</tr>
<tr>
<td>Ex IBA Fleurus</td>
<td></td>
<td></td>
<td>Cyclone-AE</td>
<td></td>
</tr>
<tr>
<td>U Gent</td>
<td>Cyclone 18/9</td>
<td></td>
<td>CGR MeV</td>
<td></td>
</tr>
<tr>
<td>VUB</td>
<td>CGR MeV</td>
<td>?</td>
<td></td>
<td>New prototype Cyclone 18</td>
</tr>
<tr>
<td>UZ Antwerpen</td>
<td>RDS 111</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UZ Leuven</td>
<td>Cyclone 18/9</td>
<td></td>
<td></td>
<td>Old Cyclone 10/5 sent to Vietnam</td>
</tr>
<tr>
<td>Woluwe</td>
<td>Cyclone 18/9</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Conclusion 2

There is a need for cyclotron decommissioning strategy to be developed in Belgium.
References

• IAEA
  – IAEA Tecdoc-1007.
  – IAEA Directory of cyclotrons used for radionuclide production in member states 2002.
  – IAEA Directory of cyclotrons used for radionuclide production in member states 2006.
  – IAEA Safety standards, draft safety guide DS452 (revision of safety guides WS-G-2.1 and 2.4) Decommissioning of nuclear installations.
  – IAEA Déclassement des installations médicales, industrielles et de recherche, WS-G-2.2.
  – IAEA Releases of sites from regulatory control on termination practices, WS-G-5.1
  – IAEA, Déclassement des installations utilisant des matières radioactives, WS-R-5.
  – IAEA, Safety assessment for the decommissioning of facilities using radioactive material, WS-G-5.2.

• Belgium
References

• **Australia**
  - A.Garcia, Ansto Camperdown project public presentation.
  - P.Maharaj, ARPS, Melbourne Decommissioning and dismantling of the national medical cyclotron – a radiation protection perspective.

• **Second hand market**
  - L.R.Carroll, et al, Recycling and recommissioning a used biomedical cyclotron.

• **Large accelerator**
  - [http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=9111980](http://journals.cambridge.org/action/displayAbstract?fromPage=online&aid=9111980).

• **Self shielded accelerator**