DECOMMISSIONING ANALYSIS OF A UNIVERSITY CYCLOTRON

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INTRODUCTION

In the widespread use of some medical nuclear facilities, such as cyclotrons for isotope production, life cycle analysis, including decommissioning, was not taken into account. The structual materials of an accelerator and the concrete shielding of the bunker are activated by neutrons. This could yield a considerable volume of nuclear waste and needs radiation protection concern for occupational workers and the environment during some decennia (1).
At the university of Brussels (VUB) a prospective radiation protection and waste analysis is being made for the later decommissining of their cyclotron (2). Only few similar studies have been published (1,3).
In Belgium future nuclear dismantling operations will be submitted to a radiation protection authorisation procedure. Meanwhile the nuclear waste authorities insist on dismantling planning, including financial provisioning.
An optimisation exercise was made at the VUB-cyclotron, taking into account international trends to clearance levels for low level nuclear waste.
Conceptual prevention opportunities e.g. selective material choice could be identified for future accelerator constructions.

ACTIVATION AROUND A CYCLOTRON

At the VUB a variable energy, multiparticle (protons, deuterons, α- and ^{3}He- particles) cyclotron (CGR-560) is in operation since 1985. The maximal current on target is 120 μA for 30 MeV protons. This machine is used for physics research and for radionuclide production in a shielded vault complex with 4 irradiation rooms (bunkers). The most important contribution to activation is due to ^{201}Tl isotope production at 27,3 MeV protons for radiopharmaceutical companies.
The bunker shielding has a thickness of 2.5 m totalling a volume of 2700 m³ of concrete.
The spectral characteristics of fast neutron beams were determined in different directions, showing an average energy of 12 Mev at 0°. Through multiple reflection on walls and elastic scattering in concrete, thermalisation of neutrons occurs in depth. The activation of trace elements in sand e.g. europium and of particular metals yields medium living radioactive products. They are created by capture reactions with high cross sections and by some threshold reactions with lower yield, as indicated below.

^{151}Eu (n,γ) ^{152}Eu	σ_{th} = 5900 barn	$t_{1/2}$ = 13.33 year
^{153}Eu (n,γ) ^{154}Eu	σ_{th} = 390 barn	$t_{1/2}$ = 8.8 year
^{133}Cs (n,γ) ^{134}Cs	σ_{th} = 29 barn	$t_{1/2}$ = 2.06 year
^{59}Co (n,γ) ^{60}Co	σ_{th} = 37 barn	$t_{1/2}$ = 5.3 year
^{45}Sc (n,γ) ^{46}Sc	σ_{th} = 26.5 barn	$t_{1/2}$ = 83 days
^{58}Fe (n,γ) ^{59}Fe	σ_{th} = 1.15 barn	$t_{1/2}$ = 44 days
^{64}Zn (n, γ) ^{65}Zn	σ_{th} = 0.78 barn	$t_{1/2}$ = 244 days

^{55}Mn (n,2n) ^{54}Mn	σ_{max} = 910 mbarn (18MeV)	$t_{1/2}$ = 312 days
^{54}Fe (n,p) ^{54}Mn	σ_{max} = 590 mbarn (10MeV)	$t_{1/2}$ = 312 days

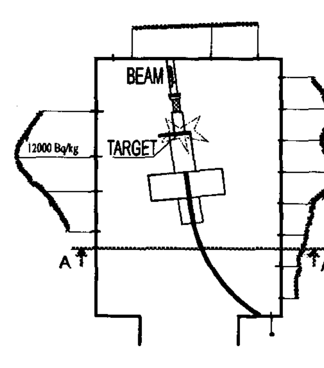

Fig 1 : Spatial distribution of maximal ^{152}Eu in concrete shielding.

The activation distribution was assessed by γ-spectrometry on 5 cm bore samples. They were systematically taken up to a depth of 50 cm throughout the shielding structure presented in fig. 1.

RESULTS OF ACTIVATION MEASUREMENTS

The highest specific activation in concrete occurs laterally near the target at 15 cm depth (fig 2). The iron reinforcement bars in the concrete shielding show maximum activation levels of 32 Bq/g. The activity decrease is exponential for both cases. Prediction of depth profiles could be derived from the measurements (fig 3). The irradiation room infrastructure consists for 70 % of steel. Specific activities up to 360 Bq/g ^{54}Mn and ^{60}Co are measured.
The huge steel accelerator yoke of 80 ton however is showing much lower level activation due to its low ^{59}Co content. These values can be compared with clearance levels of about 0,3 Bq/g (4).

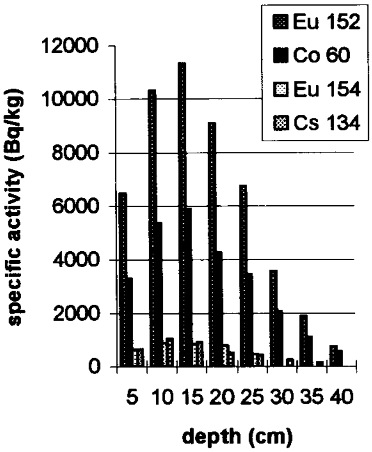

Fig 2 : Depth distribution in a concrete bore sample of specific activity for ^{152}Eu, ^{60}Co, ^{154}Eu, ^{134}Cs

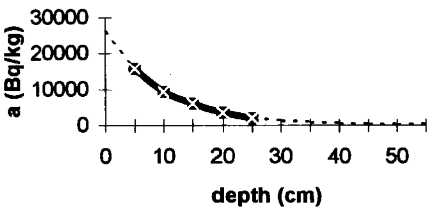

Fig 3 : Measured ^{60}Co activation in iron reinforcement bars

OPTIMISATION OF DISMANTLING SCENARIOS

Dismantling of a cyclotron will be submitted to an authorisation procedure in future Belgian regulations. Waste quantities have to be estimated with specification of their destination. The protection of man and the environment against radiation has to be guaranteed during preparatory work an dismantling operations. Site destination and future use should be specified.
In this preliminary study, the following scenarios were considered :

- Early dismantling of a cyclotron infrastructure, directly after shut-down is confronted with an internal contamination risk by ^{65}Zn. This copper activation product is easily dispersed. ^{65}Zn is detected regularly at acceptable levels in whole body monitoring of cyclotron maintenance workers.
- The waste from metal infrastructures having activities up to 1000 times clearance level could be stored for decay during 35 years in the most activated cyclotron vault. This should be done after the management of the contanimation problems.

- Early decommissioning of the concrete walls to 30-50 cm depths could yield up to 100 m^3 of nuclear waste, applying IAEA proposed clearence levels (4). The dismantling techniques available in nuclear fuel cycle industries allow to remove the activated depths. Since no provisions are made, the cost of this option is too high for an university.
  Dilution techniques, mixing active and inactive crushed concrete and melting iron bars, could be applied in order to arrive at a reasonable cost. The authorisation of such an approach has been given in the UK (5). It is not evident in Belgium, where the obligation of an environmental assessment report could need to take alternative options into account.
- A decay on site of the activity of the concrete rooms and of the metal infrastructures till clearance levels could be performed. Fig 4 illustrates that cooling times of maximum 70 y are necessary for this option.
- Restricted use of cyclotron rooms as controlled areas in the intermediate period was evaluated. Doserates in the documented bunker were calculated from the activation measurements using conservative assumptions. A maximal doserate of 60 μSv/h was derived. Measurements indicate actual doserates up to 15 μSv/h. Occupational use of such rooms yield calculated doses between 6 and 120 mSy/y.
  Surface doses were measured with TLD on concrete samples with a maximum of 2 mGy/y.

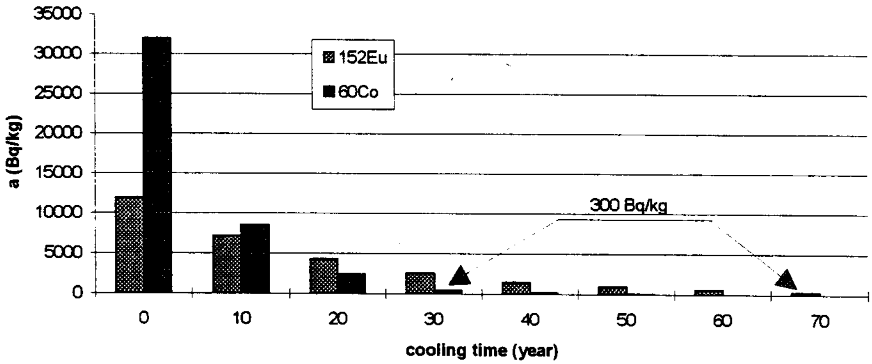

Fig 4 : Decay of Activation of Concrete Bunker

PREVENTION OPPORTUNITIES

The use of iron and scrap metal in the concrete shielding is not recommended for cyclotrons. The use of removable blocks for the inner part of the shielding walls could reduce dismantling costs. Local neutron absorption measures could be taken to reduce the source term. A selection of sand with low europium content for concrete preparation and a preference for low ^{59}Co steel or Al for the infrastructure could be taken into account in cyclotron complex conception.

CONCLUSION

Regarding the high cost of nuclear waste, decay during about 50 years of the infrastructure after shut-down is necessary to allow cooling to proposed clearance levels. Decontamination for ^{65}Zn could be performed after some years.
Considering dose limits for workers and the public, a restricted use of cyclotron rooms as controlled area, seems the most reasonable option. Life cycle analysis techniques should be integrated in the planning of isotope production facilities. It could contribute to reduction of later nuclear waste and to sustainable nuclear development.

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