Quantification Of Induced Radioactivity For A Compact 11 MeV Self-Shielded Cyclotron For Decommissioning Funding Purposes

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Decommissioning Financial Assurance

- My degree is in Nuclear Engineering – not Finance or Law so,
  - Take any interpretation of financial assurance regulations or instruments with a grain of salt!
  - You circumstances may differ
- References will be to NRC regulations or guidance – some variation for Agreement States
  - Recent significant change to NRC regulations
  - 10 CFR 30.35 Financial Assurance & Recordkeeping for Decommissioning
  - NUREG 1757 Vol. 1 – 3 (Vol.3 not yet updated to rev. 1)

I have a cyclotron, do I need funding? If so, how much is enough?

- To answer this we must quantify the activation products in the cyclotron with some accuracy
  - High estimate could result in unnecessary financial assurance burden
  - Low estimate could lead to non-compliance with financial assurance
- Previously accomplished for CTI/Siemens 11 MeV RDS-112, paper given by Canberra at 2008 HPS annual conference (WPM-A7)
  - Cyclotrons are all pretty much made out of the same stuff no matter the vendor/model
  - Results for higher energy machine will be different as more reactions are energetically possible as well as variation in cross-sections
  - Beam current, runtime hours and target material will influence quantity of activation products
- Here we shall look at developing the inventory of activation products to compare to 10 CFR 30 Appendix B

Determining the Source-Term

- Applicants must specify the maximum activity to be possessed at any one time (NUREG-1556 Vol. 21)
  - For decomm – only interested in those with $t_{1/2}$ >120 days
  - "Possession limits must include total anticipated inventory, including, licensed material in storage & waste,…" (Vol. 21)
    - Production is proportional to $t_{1/2}$ so longer-lived products will not be present in appreciable quantities early in lifespan of cyclotron
- RDS-112 was used in factory for training and R&D
  - Compared to commercial production, much lower beam time
  - More often used to produce ^{11}C later in life, which involves a (p,alpha) reaction vs. (p,n) for ^{18}F

Determining the Source-Term

- Adjustment was made to the results of the ISOCS™ measurements to account for differences in usage of the factory unit versus those in commercial production and the degree of coverage (some hand-waving follows)
  - Estimated 10% of the cyclotron was surveyed
  - Estimated another factor of 10 for lower usage & ^{11}C production

Determining the Source-Term (Cyclotron)

Results from Canberra Analysis for RDS-112m – w/o adjustment

Analyte	Total Activity items 1-38 (mCi)	Analyte	Total Activity items 1-38 (mCi)
NA-22	4.85E-04	ZN-65	2.84E+00
MN-54	9.11E-02	CD-109	2.94E-04
CO-57	8.64E-02	AG-110m	3.92E-04
NI-59	0.00E+00	CS-137	2.87E-03
CO-60	7.63E-03	W-181	1.93E-01

RDS-112 Disassembly

RDS-112 Disassembly

RDS-112 Disassembly

RDS-112 ISOCS

#19: Puller Dee Assembly

0.007 µCi ^{54}Mn

0.098 µCi ^{65}Zn

0.114 µCi ^{182}Ta

Determining the Source-Term (concrete & rebar in floor)

Tampa floor samples
pCi/gram

sample ID	Co-60	Cs-134	Eu-152	Location
1	3.39E+00	9.55E-01	4.07E+00	floor tgt 3 (shallow)
2	2.93E+00	4.36E-01		floor tgt 3 (deep)
3	2.59E+00	5.07E-01	4.90E+00	floor tgt 1
4	7.04E-02			floor ion source
Average	2.24E+00	6.33E-01	4.48E+00	

112 foot print	6'x7'	ft^3	cm^3	Density (g/cm^3)	grams
	42 sq feet to a depth of 2 feet	84	2.38E+06	2.3	5.47E+06

Putting it all together

Element and Mass Number	Maximum amount which will be possessed at any one time, uCi	10 CFR Part 30, Apx B, uCi	Ratio of the quantity of each radionuclide to the value in 10 CFR
Sodium-22	48	0.1	480
Manganese-54	9,100	10	910
Cobalt-57	8,700	0.1	87000
Cobalt-60	800	1	800
Zinc-65	285,000	10	28500
Cadmium-109	30	10	3
Silver-110m	40	1	40
Cesium-134	5	1	5
Cesium-137	300	10	30
Europium-152	250	1	250
Tungsten-181	20,000	10	2000
Total Activity =>	**324,273.000**	**Sum of the Ratios "R" value =>**	**120018**

Comparing to 10 CFR 30.35

- Greater than 10^5 = Decommissioning Cost Estimate (DCE)
- Greater than 10^4 but less than or equal to 10^5 times the applicable quantities of appendix B to part 30 in unsealed form = $1,125,000 or DCE
- Greater than 10^3 but less than or equal to 10^4 times the applicable quantities of appendix B to part 30 in unsealed form = $225,000 or DCE
- Less than 10^3 = no funding required

Comparing to 10 CFR 30.35

Determination of decommissioning funding level: "R" value divided by 10^3, 10^4 and 10^5		
R/1000	R/10000	R/100000
120.01800	12.00180	1.20018

- Our approach is to use a cost estimate developed following NUREG-1757 guidance
- For a single cyclotron site ~$350,000
  - Varies from site to site

Issues

- ^{22}Na and ^{57}Co are not listed in 10 CFR 30 Appendix B – default value of 0.1 µCi must be used
- Need ISOCS data from a cyclotron used for commercial production (two candidates this year)
- Cyclotron manufacturers and users are saying Decommissioning Funding is not required?
  - Possibly including Siemens!
  - GE used to have a section in manual
  - No data on IBA

Separation of Activation Products

- Fixed components, such as the cyclotron and the concrete below it
  - will remain in place throughout the life of the facility
- Removable/replaceable components
  - consumable items that have to be replaced on a routine basis
  - collected and disposed of as radioactive waste every few years

Typical Possession Limits Requested Fixed Components

Element and Mass Number	Maximum amount which will be possessed at any one time, mCi, per cyclotron
Sodium-22	0.048
Manganese-54	9.107
Cobalt-57	8.638
Cobalt-60	0.776
Zinc-65	283.531
Cadmium-109	0.029
Silver-110m	0.039
Cesium-134	0.003
Europium-152	0.025
Tungsten-181	19.334
Total Activity	**321.817**

Nuclide	Chem/Phys Form	Max Poss. Limit
Any radionuclide with atomic number 3-83 (excluding Zn-65)	Fixed Activated Parts and Concrete	200 mCi
Zn-65	Fixed Activated Parts and Concrete	300 mCi

NUREG 1556 Vol.21 recommends listing any radionuclide > 50 mCi separately

Typical Possession Limits Requested Removable Components

Nuclide	Chem/Phys Form	Max Poss. Limit
Any radionuclide with atomic number 3-83	Removable Components	100 mCi

Based on gamma spectroscopy work performed separately and cumulative waste disposals

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- Quantifying activation products has been a long process and we'll continue to refine it going forward!

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