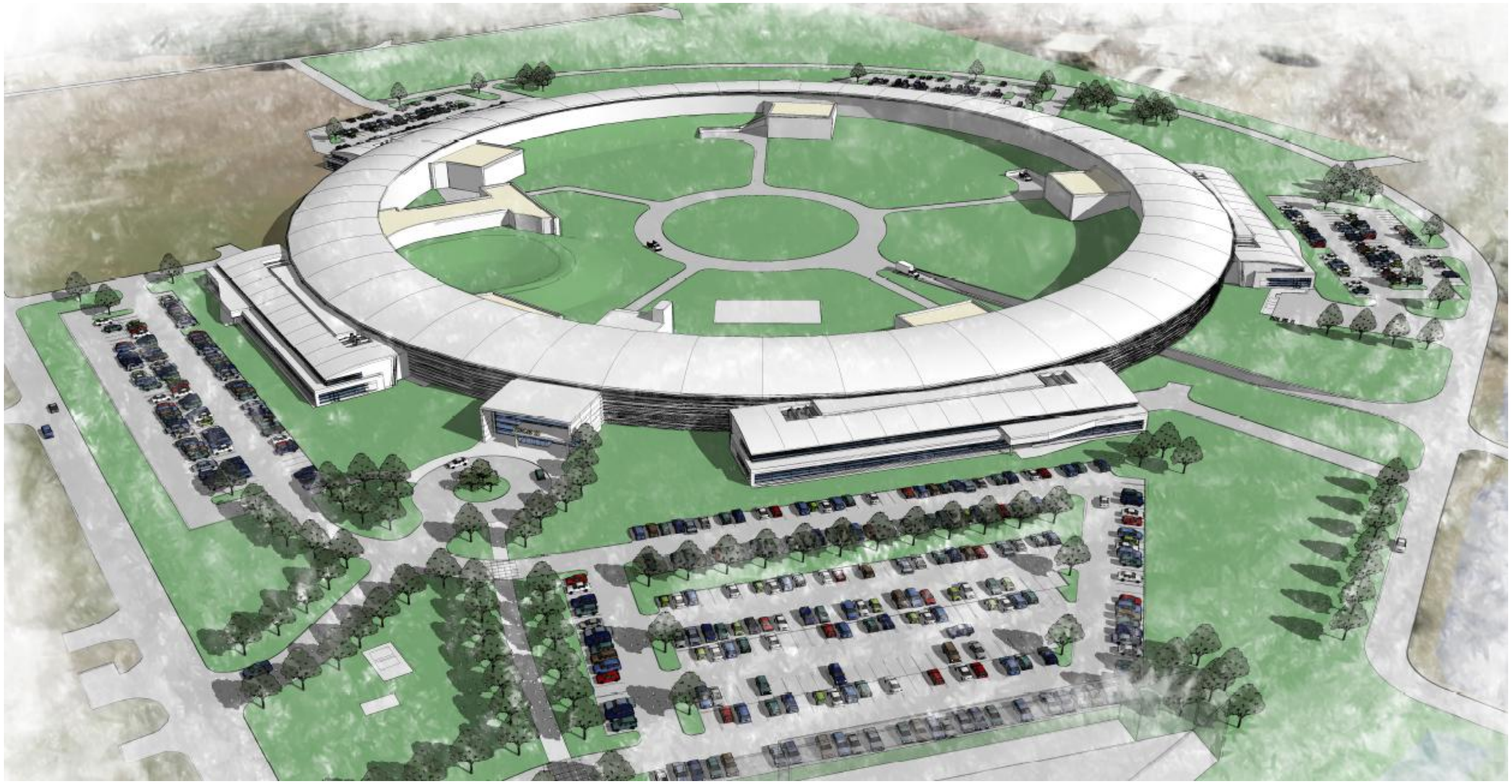
Activation Analysis of Soil, Air and Water near NSLS-II



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Outline

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- Results of Soil Activation Analysis at NSLS-II
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- Results of Air Activation Analysis at NSLS-II
- Cooling Water Activation Analysis in the Electron Storage Rings
- Results of Cooling Water Activation in NSLS-II Storage Ring

Activation Due to Beam Loss in the Electron Accelerators

- Soil activation around the enclosures due to high energy photoneutrons generated by the beam loss
- Activation of air due to bremsstrahlung interactions in the accelerator enclosures
- Water activation due to bremsstrahlung interactions in the storage ring cooling water

These effects may not require serious radiological considerations at the Light Sources, however analysis is mandatory.

Soil Activation Analysis Methodology
Soil Composition and Activation Cross Sections

Parent Nucleus	Weight (%) In soil	^{3}H Production Threshold (MeV)	^{3}H Production Cross section (mb)	^{22}NaProduction Threshold (MeV)	^{22}NaProduction Cross section (mb)
^{16}O	51.3	15.0	3.07		
^{23}Na	0.0196	20.0	6.81	15.0	36.6
^{24}Mg	0.21	25.0	6.48	25.0	28.2
^{27}Al	1.65	25.0	8.23	50.0	14.5
^{28}Si	45.1	50.0	3.54	50.0	14.5
^{39}K	0.063	50.0	3.56		
^{40}Ca	0.058	50.0	3.0		
^{55}Mn	0.012	50.0	2.0		
^{56}Fe	1.44	50.0	1.65		

Effective Cross Sections for ^{3}H and ^{22}Na Activation in Soil

Weighted average cross section for ^{3}H production	3.35 mbarns
Weighted average cross section for ^{22}Na production	14.56 mbarns
Weighted average of soil atomic mass number	22.17
Atomic Number density of soil	4.35×10^{22} atoms/cm^3
Number density of ^{3}H producers (100%)	4.35×10^{22} atoms/cm^3
Number density of ^{22}Na producers (47%)	2.04×10^{22} atoms/cm^3

Soil Activation Analysis Methodology

The high energy neutron (HEN) component in the transverse direction of the beam loss location on a thick target is provided by Fasso et al.

1.3×10^{-3} HEN / GeV/ electron/ steradian

The neutron flux at the external surface of the concrete shield wall of thickness 'r' cm at a distance of 'R' cm from the source in the transverse direction, can be estimated as;

$\Phi(0) = (1.3\ 10^{-3}.\ Ne.E.e^{-r/\lambda}) / R^2$ neutrons/cm^2.s

Where

Ne = Number of electrons interacting with the target material / s

E = Energy of the electron in GeV

R = Distance of the flux point from the source in cm

r = Thickness of the concrete shield in g/cm^2

λ = Attenuation length of HEN in concrete shield in g/cm^2

Soil Activation Analysis Methodology

The High Energy Neutron Flux in the soil as a function of soil thickness

$$\Phi (x) = \Phi (0) e^{-\Sigma X}$$

Where Σ = Neutron Removal Cross Section in the Soil

X = Soil Thickness under Consideration

(Approximately 5 mean free paths of soil thickness (3 m) and 5 highly probable beam loss locations are considered for analysis)

Maximum beam loss is assumed at the specific locations like septa and beam dumps

Summary Results of Soil Activation Analysis at NSLS-II

Activity in Soil

Soil Location	^{3}H Activity (Ci/cm^3)	Leachable ^{3}H (pCi/liter)	^{22}Na Activity (Ci/cm^3)	Leachable ^{22}Na (pCi/liter)
Booster Floor	1.87×10^{-15}	2.06	1.81×10^{-14}	1.49
Booster Lateral wall	2.40×10^{-15}	2.64	2.32×10^{-14}	1.91
Storage Ring Floor	1.27×10^{-15}	1.39	1.23×10^{-14}	1.01

100% Leachability to soil for ^{3}H and 7.5% Leachability for ^{22}Na are assumed.

BNL Action Levels for ^{3}H is 1000 pCi/liter and for ^{22}Na is 20 pCi/liter in the soil

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Air Activation in the Electron Accelerator Enclosures

^{13}N is generated in air due to (γ,**n**) interactions (threshold 10.55 MeV)

^{15}O is generated in air due to (γ,**n**) interactions (threshold 15.67 MeV)

^{11}C is generated by the photo-spallation of both nitrogen and oxygen

Methodology of Air Activation Analysis

Neutron Yield from the Photonuclear Interaction is given by;

$Y = 1.21 \times 10^{8} Z^{0.66}$ Neutrons/Joule

where Z is the Atomic Number of the Element

Implicit in the release of neutrons is the formation of an unstable nucleus in air

Methodology of Air Activation Analysis

Since these activities are short lived,
^{13}N Half Life ~10 min
^{15}O Half Life ~2.1 min
^{11}C Half Life ~ 20 min
Saturation is achieved in a short period of operation

Saturated Activity is given by;

$$\mathbf{A = WY\,(1 - e^{-x/\lambda})\ Beq}$$

where W = Beam Power Dissipated in Air (watts)
Y = Neutron Yield in Air
x = Effective Air Path of Bremsstrahlung in the enclosure
λ = Bremsstrahlung Attenuation Length in Air

Results of Air Activation Analysis for NSLS-II

Accelerator Enclosure	Enclosure Volume (m^3)	Activity in Air ^{13}N (µCi)	^{15}O (µCi)	^{11}C (µCi)	Concen. (µCi/cm^3)
Linac	473	13.20	1.43	0.28	3.0×10^{-8}
Booster	1304	39.6	4.28	0.84	3.4×10^{-8}
Storage Ring	7594	47.52	5.13	1.03	7.0×10^{-9}

Ventilation flow is ignored in the present calculations

Computed concentrations are within the acceptable limits on the site and at the site boundary

Cooling Water Activation in the Storage Ring

Photonuclear Interaction of Bremsstrahlung with Water produces

- ^{15}O Half Life ~ 2.1 min
- ^{11}C Half Life ~ 20 min
- ^{3}H Half Life ~ 12 Y
- ^{13}N Half Life ~ 10 min

^{3}H (~2% of saturated concentration) is the only long living isotope
Other isotopes attains saturation during a short period of operation

Methodology of Analysis

Same as Air Activation Analysis:

Implicit in the release of neutrons due to bremsstrahlung interaction in water is the formation of an unstable nucleus

Saturation Activity in a Closed Circuit of Water can be calculated by,

$$\mathbf{A = WY\,(1 - e^{-x/\lambda})}$$

Where W = Beam power dissipated in water circuit (watts)

Y = Neutron yield in water

x = Average bremsstrahlung path in Water

λ = Effective bremsstrahlung attenuation length in water

Cooling Water Activation Analysis
(^3H Activation)

The ^3H Activity in water after a time period t can be calculated by the expression

$$A = WY (1- e^{-x/\lambda})(1- e^{-kt})$$

k = Decay constant of ^3H

t = Period of operation

Note:

After 5000 hours of continuous operation concentration of ^3H will be only 3% of the saturation value

Results of Cooling Water Activation for NSLS-II Storage Ring

Beam loss (watts)	Charge dissipation (nC/min)	Activity in water ^{15}O (μCi)	^{11}C (μCi)	^{13}N (μCi)	^{3}H (μCi)
0.90	18	134	5.6	1.2	2.8

Charge dissipation corresponds to ~ 2 hr beam life time at 500 mA of beam current

The total volume of water in the cooling circuit of the storage ring is ~100,000 gallons.

Summary

- Activation of air, water and soil in the electron accelerators is analyzed using a methodology based on bremsstrahlung interactions
- The results of the analysis shows that the activation is not a serious concern at the electron accelerators