Potential health hazards for the Radiation Therapist

Steven de Boer
Potential health hazards for the Radiation Therapist

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Roswell Park Cancer Institute
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Niagara Falls, NY
Outline

- Ozone
- Linear accelerator produced radioactivity
- Neutrons and the doorless linac vault
- $\text{SF}_6$
This is what you are instore for!

Nuclear Physics

Environmental concerns

\[ C = \frac{C_0 G E S_{col} I_d}{N (Q/V)} \times \left( 1 - e^{-\frac{Q}{V}} \right) \times 10^9 \]
Who are you?

1. Radiation Therapist
2. Medical Dosimetrist
3. Medical Physicist
4. Physician
5. Other
6. Spy
7. Ninga
8. 6 and 7
Do you have concerns about occupational hazards?

1. Yes
2. No
3. My boss told me to say no
4. Not really, I have special powers
What is Ozone?

Elemental oxygen
– (8 electrons)

Dioxygen, $O_2$
– need to breath,
– 21% of air

Ozone, $O_3$
– three oxygen atoms,
– less stable than $O_2$,
– strong oxidizer

Had you worried? 256 slides really?
Ozone properties

Pale blue gas (condense into a violet black solid)
Pungent smell, chlorine smell,
Less stable than $\text{O}_2$
Powerful oxidant
Human detectable at 0.02 to 0.05 to 0.1 ppm
In stratosphere ozone is 2 to 8 ppm
More dense than air,
  – Relative vapor density (air = 1): 1.6
Boiling point: -112°C
Melting point: -193°C
Ozone benefits

Absorption of UV rays from the sun.
Ozone benefits

Sterilization

Ozone is the second most powerful sterilant in the world and can be used to destroy bacteria, viruses and odors
– fruits and vegetables & meat packing plants,
– water purification (drinking, pools, spas)
– manufacturing,
– medical,
– houses, cars, shoes
Ozone sterilization

Ozone destroys contaminants such as odors, bacteria or viruses by oxidation. Ozone reverts back to oxygen after it is used. Chemical half life is 30 to 50 minutes.
OZONE PAPER

FOR THE
IMMEDIATE
RELIEF AND
SUBSEQUENT
CURE OF

ASTHMA, CHRONIC BRONCHITIS,
BRONCHITIC ASTHMA, HAY FEVER, and INFLUENZA.

The "Lancet."—"A convenient and valuable remedy."
Dr. Thorowgood.—"Pure spasmodic Asthma and Asthma
due to Emphysema of the lungs with co-existent bronchitis
alike appear to me to be materially relieved by the Ozone
Paper."
Harrison Weir, Esq.—"Your Ozone Paper has got rid of my
Asthmatic affection; it is the only remedy which gave me
permanent relief."

2s. 9d. and 4s. 6d. per Box, of all Chemists; or from the
Proprietor for the amount in stamps or P.O.O. to any country
within the Postal Union.

R. HUGGINS, Chemist, 199, Strand, LONDON.
WARNING
OZONE IN USE!
Ozone risks

Hazardous at prolonged exposure to concentrations of 0.1 ppm\(^1\)\(^-\)\(^3\)

Damages mucous and respiratory tissues

DNA breakage\(^4\)

– “at current permissible levels, it is more harmful than ionizing radiation”\(^4\)

1 AMERICAN CONFERENCE OF GOVERNMENTAL INDUSTRIAL HYGIENISTS, Threshold Limit Values of Airborne Contaminants and Physical Agents with Intended; Changes Adopted by ACGIH for 1971, ACGIH, Cincinnati, Ohio (1971).


3 IAEA Radiological Safety Aspects of the Operation of Electron Linear Accelerators, Vienna, 1979

4 Inhaled ozone as a mutagen: II. Effect on the frequency of chromosome aberrations observed in irradiated Chinese hamsters; Zelac \(^2\), H.L. Cromroy, W.E. Bolch Jr., B.G. Dunavant, H.A. Bevis
Ozone can inflame the lung’s lining. These photos show a healthy lung air way (left) and an inflamed lung air way (right).
# Ozone data sheet (MSDS)

## Health Hazard Data

<table>
<thead>
<tr>
<th>Threshold Limit Value</th>
<th>The American Conference of Governmental Industrial Hygienists has set a threshold limit value for occupational exposure to ozone of 0.1 ppm as a time-weighted average over an 8-hour day. The short-term exposure limit is currently 0.3 ppm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Route of Entry</td>
<td>Pulmonary system</td>
</tr>
<tr>
<td>Effects of Single Overexposure</td>
<td>May cause irritation of the respiratory tract experienced as nasal discomfort, dryness, irritation of the throat, pain or congestion of the chest, difficult breathing or coughing. Irritation of the eyes, headache, nausea and drowsiness may also occur. Concentrations above 9 ppm have been found to result in pneumonia. Exposure to high concentrations could be fatal.</td>
</tr>
</tbody>
</table>

## Emergency First Aid

<table>
<thead>
<tr>
<th>Exposure</th>
<th>Symptom/Prevention</th>
<th>First Aid</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emergency Overview</td>
<td>Ensure adequate ventilation in the area where ozone is present</td>
<td>Remove from the presence of air containing ozone.</td>
</tr>
<tr>
<td>Inhalation</td>
<td>Irritating to respiratory system. Cough, headache, shortness of breath. Ventilation.</td>
<td>Remove from the presence of air containing ozone. Administer oxygen if necessary. If breathing is difficult or discomfort persists, obtain medical attention.</td>
</tr>
</tbody>
</table>

## Disposal Information

<table>
<thead>
<tr>
<th>Waste Disposal</th>
<th>Ozone rapidly decomposes to form oxygen (O₂). Use an ozone destruct system to convert any unused ozone or off gas into oxygen prior to discharge.</th>
</tr>
</thead>
<tbody>
<tr>
<td>AQI</td>
<td>Levels of health concern</td>
</tr>
<tr>
<td>----------</td>
<td>-------------------------------------------</td>
</tr>
<tr>
<td>0 to 50</td>
<td>Good</td>
</tr>
<tr>
<td>51 to 100</td>
<td>Moderate</td>
</tr>
<tr>
<td>101 to 150</td>
<td>Unhealthy for sensitive groups</td>
</tr>
<tr>
<td>151 to 200</td>
<td>Unhealthy</td>
</tr>
<tr>
<td>201 to 300</td>
<td>Very Unhealthy</td>
</tr>
<tr>
<td>301 to 500</td>
<td>Hazardous</td>
</tr>
</tbody>
</table>
# Ozone and AQI

## AQI Calculator: Concentration to AQI

Select a criteria pollutant and enter the pollutant concentration in the specified units above, the Air Quality Index and associated information are calculated below.

**Select a Pollutant**
- O3 – Ozone (8hr avg)

**Units Required:** ppb

**Enter the Concentration:**
- 100

**AQI Category:**
- 187

### Sensitive Groups
- Children and people with asthma are the groups most at risk.

### Health Effects Statements
- Greater likelihood of respiratory symptoms and breathing difficulty in active children and adults and people with respiratory disease, such as asthma; possible respiratory effects in general population.

### Cautionary Statements
- Active children and adults, and people with respiratory disease, such as asthma, should avoid prolonged outdoor exertion; everyone else, especially children, should limit prolonged outdoor exertion.

[www.airnow.gov](http://www.airnow.gov)
Ozone production

Air + energy = O
O + O₂ = O₃ (ozone)

Energy can be in different forms
- ultraviolet radiation
- corona discharge
- ionizing radiation
Ultraviolet radiation

Actual poster from my office wall and on “the big bang theory.”

First 35 images on google search for “ultraviolet”
Corona discharge

Two of my children → (molson)

Wrong Corona
Ionizing radiation

Can be electrons or photons
Electron conversion is more efficient

IAEA textbook on radiotherapy
Ozone in linacs

Electron beams are more efficient (than x-rays) at converting O$_2$ to O$_3$

Yield increases with
- Dose rate
- Distance of beam in air
- Area of beam
- Length of time the beam is on

These all increase in total skin electron irradiation (TSeI) treatments.

SSD = 350 cm, DR = 2500 MU/min, time = 12min
Varian TSeI

Nominal dose rate is 888 MU/min (at 1.6 m)
Dose rate at 1 m is then about 2500 MU/min
Dose per MU is about 4 cGy/MU at isocenter (measured)
Therefore dose rate at isocenter is 3552 cGy/min
About 4 to 10 times conventional electron treatments

Roswell Park Cancer Institute experience
Similar to AAPM report 23, TOTAL SKIN ELECTRON THERAPY: TECHNIQUE AND DOSIMERTRY, 1987
Ozone concentration in linear accelerators

\[ C = \frac{C_0 \text{GES}_{\text{col}} I_d}{N V (Q/V)} \times \left( 1 - e^{-\frac{(Q/V)_t}{t}} \right) \times 10^9 \]  

where

- \( C \) = fraction by weight of \( O_3 \) in air (0.232)

- \( C_0 \) = initial concentration of ozone

- \( \text{GES}_{\text{col}} \) = correction factor for ozone generation

- \( I_d \) = dose rate

- \( N \) = number of air changes per hour

- \( V \) = room volume in liters

- \( Q \) = room ventilation rate (liters s\(^{-1}\))

- \( (Q/V)_t \) = number of room air changes per second

- \( t \) = irradiation time (s).

McGinley; Shielding ...
Ozone concentration over time

Concentration (ppm)

Time (mins)

Ozone Concentration
Ozone concentration over time

Ozone concentration for an electron beam
\{SSD - Q/V - I\}

Recall MPC = 0.1 ppm
Ozone concentration over time (TSeI)

Ozone concentration for an electron beam
\{SSD - Q/V - I\}

- 100-2-0.002
- 100-6-0.002
- 350-2-0.02
- 350-6-0.02
Ozone Concentration after 10 minute exposure

Ozone concentration for an electron beam
\{SSD - Q/V - I\}

- 100-2-0.002
- 100-6-0.002
- 350-2-0.02
- 350-6-0.02
Activated carbon filters can be very effective not indefinitely because chemical reactions of ozone and carbon change the carbon. Initial efficiencies of the 1.27-cm thick flat samples varied from 4.6 to 98.3%. Consequently, removal efficiency decreased with use.
Ozone detectors

- Eco Sensors EZ-1X Ozone Monitor, continuous duty
  - $425.99
  - More Buying Choices
  - $419.00 new (2 offers)

- American Marine Pinpoint ORP Monitor
  - $115.38
  - More Buying Choices
  - $115.38 new (5 offers)

- Supco IAG50 Wall Mounted Indoor Air Quality Monitor
  - $102.23
  - More Buying Choices
  - $102.23 new (7 offers)

- Ozone Test Paper, Pack of 12
  - $21.50

- Eco Sensors A-21ZX Ozone Monitor, digital
  - $797.00
  - More Buying Choices
  - $749.00 new (3 offers)
What can be done to minimize your exposure to ozone in the radiation therapy clinic

1. Have adequate ventilation.
2. Wait a few minutes after treating a TSeI before entering the room.
3. Ask Larry to treat the total skin patient for you.
4. Be tall!
5. All of the above (unless you are Larry).
Radioactivity in the linac vault

Larry
subtleties

“When the beam is off or the door is open there is no radiation in the room”

“When the beam is off or the door is open there is no radiation being produced in the room”
Why Radiation Therapists don’t want Medical Physicists at the machine

Patient: “I won’t glow from my treatment will I?”
Therapist: “No, of course not.”
Physicist: “Well actually…..”
[Therapist kicks Physicist in shin]
Atomic Physics 101

bremsstrahlung

Electron

Nucleus

OH BREMSSTRAHLUNG! YOU SEE RIGHT THROUGH ME
The nucleus of an atom is composed of neutrons and protons.
If the ratio of neutrons to protons is not optimal the isotope will change to a more stable state
energy is released,
radioactivity
Activation: To induce radioactivity
Energy imparted to nucleus can activate it (neutrons, x-rays, γ rays, electrons ...)

Example:

\[ ^{59}\text{Co} + n \rightarrow ^{60}\text{Co} \rightarrow ^{60}\text{Ni} + e^- + \nu_e + \gamma \text{ rays} \]
Radiobiology 101

What is the effect of radiation on the healthy human body?

- get cancer
- get super powers
- become a monster

Marvel Comics 1973
Activation in high-energy accelerator treatment rooms arises from
• primarily the accelerator itself and its components,
• to a lesser extent from the walls, floor, and ceiling,
• minimally from the patient and from the air in the room.
Dose to radiation therapists from activation at high-energy accelerators used for conventional and intensity-modulated radiation therapy

J. Alan Rawlinson
Cancer Care Ontario, and Department of Medical Biophysics, University of Toronto, Toronto, Ontario M5G 2M9, Canada

Mohammad K. Islam
Radiation Physics, Princess Margaret Hospital, and Department of Radiation Oncology, University of Toronto, Toronto, Ontario M5G 2M9, Canada

Duncan M. Galbraith
Radiation Physics, Princess Margaret Hospital, 610 University Avenue, Toronto, Ontario M5G 2M9, Canada

(Received 23 October 2001; accepted for publication 14 January 2002; published 21 March 2002)
$^{28}$Al - treatment couch
$^{122}$Sb lead shielding in linac head
$^{56}$Mn and $^{24}$Na not identified

<table>
<thead>
<tr>
<th>Nuclide</th>
<th>Half-life</th>
<th>Probable nuclear reaction</th>
<th>Decay mode</th>
<th>Principal gamma Energies (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{28}$Al</td>
<td>2.3 m</td>
<td>$^{27}$Al(n, $\gamma$)$^{28}$Al</td>
<td>$\beta^-$, $\gamma$</td>
<td>1780</td>
</tr>
<tr>
<td>$^{56}$Mn</td>
<td>2.6 h</td>
<td>$^{55}$Mn(n, $\gamma$)$^{56}$Mn</td>
<td>$\beta^-$, $\gamma$</td>
<td>847, 1811, 2113</td>
</tr>
<tr>
<td>$^{24}$Na</td>
<td>15 h</td>
<td>$^{23}$Na(n, $\gamma$)$^{24}$Na</td>
<td>$\beta^-$, $\gamma$</td>
<td>1369, 2754</td>
</tr>
<tr>
<td>$^{122}$Sb</td>
<td>2.8 d</td>
<td>$^{121}$Sb(n, $\gamma$)$^{122}$Sb</td>
<td>$\beta^-$, $\beta^+$, $\gamma$</td>
<td>511, 564</td>
</tr>
</tbody>
</table>
Buildup and decay of radioactivity

“These machines had each been operated for 5 years with an average annual high-energy workload”
Dose rate beside linac table after beam off
Activation doses for different treatment regimes

Annual dose 1.6 to 13.4 mSv

<table>
<thead>
<tr>
<th>Treatment regime</th>
<th>Weekly dose (μSv/week)</th>
<th>Annual dose (mSv/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$^{28}$Al</td>
<td>$^{56}$Mn</td>
</tr>
<tr>
<td>Conventional radiation therapy</td>
<td>Benchmark</td>
<td>26.2</td>
</tr>
<tr>
<td></td>
<td>Four field</td>
<td>21.6</td>
</tr>
<tr>
<td>Mixed energies</td>
<td></td>
<td>13.0 H</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0.1 L</td>
</tr>
<tr>
<td>Benchmark with QA</td>
<td></td>
<td>27.9</td>
</tr>
<tr>
<td>Intensity-modulated radiation therapy</td>
<td>Current IMRT</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td>High efficiency IMRT</td>
<td>50.5</td>
</tr>
<tr>
<td></td>
<td>Future IMRT</td>
<td>108.3</td>
</tr>
</tbody>
</table>
Radiation Therapist exposure in extreme conditions

radiation worker limit exposure limit

USA = 50 mSv    Europe 20 mSv

“However, under extreme conditions of IMRT operation, i.e.,
• all fractions at 18 MV,
• large MU per fraction,
• short treatment delivery times,
• short patient setup times,
• maximum treatment room occupancy,
the activation dose would reach about 17 mSv/y, a value
which is close to internationally recommended occupational
dose limits” – Rawlinson, Islam, Galbraith
“These numbers show that activation dose is not negligible and suggest that, at least in conservatively shielded facilities, the therapist receives a greater occupational dose from activation than from radiation transmitted through the shielding barriers.”
Recommendations

Avoid using >10 MV for IMRT
Treat 18 MV at the end of the day (sorry physics)

Have you ever wondered why physicists have bald spots?
Radionuclides Created in High Energy Linear Accelerators by Nuclear Activation Processes

<table>
<thead>
<tr>
<th>Accelerator Component</th>
<th>Observed Contact Dose Rate (μSv/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>flattening filter</td>
<td>70</td>
</tr>
<tr>
<td>Target</td>
<td>36</td>
</tr>
<tr>
<td>primary collimator</td>
<td>11</td>
</tr>
<tr>
<td>upper jaw</td>
<td>50</td>
</tr>
<tr>
<td>lower jaw</td>
<td>30</td>
</tr>
</tbody>
</table>

50 mSv/ 50 μSv = 1/1000

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Varian CTB GE-924: Radionuclides Created in High Energy Linear Accelerators by Nuclear Activation Processes

Table 1: Isotopes Identified on Varian High Energy Accelerators

<table>
<thead>
<tr>
<th>Isotope</th>
<th>Decay Mode</th>
<th>Half-life</th>
<th>Photon Energy (keV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Na 24</td>
<td>e^-</td>
<td>15 h</td>
<td>1369</td>
</tr>
<tr>
<td>Al 28</td>
<td>e^-</td>
<td>2.24 min</td>
<td>1779</td>
</tr>
<tr>
<td>Cr 51</td>
<td>EC</td>
<td>27.7 d</td>
<td>320</td>
</tr>
<tr>
<td>Mn 54</td>
<td>e^-</td>
<td>312.3 d</td>
<td>835</td>
</tr>
<tr>
<td>Mn 56</td>
<td>e^-</td>
<td>2.58 h</td>
<td>847, 1811</td>
</tr>
<tr>
<td>Co 57</td>
<td>e^-</td>
<td>271.8 d</td>
<td>122</td>
</tr>
<tr>
<td>Co 58</td>
<td>e^-</td>
<td>70.9 d</td>
<td>811</td>
</tr>
<tr>
<td>Co 60</td>
<td>e^-</td>
<td>5.27 y</td>
<td>1173, 1333</td>
</tr>
<tr>
<td>Ni 57</td>
<td>e^-</td>
<td>35.6 h</td>
<td>1378</td>
</tr>
<tr>
<td>Cu 62</td>
<td>e^-</td>
<td>9.7 min</td>
<td>(511)</td>
</tr>
<tr>
<td>Cu 64</td>
<td>e^-, e^+</td>
<td>12.7 h</td>
<td>1346</td>
</tr>
<tr>
<td>Zn 65</td>
<td>e^-</td>
<td>244.3 d</td>
<td>1116</td>
</tr>
<tr>
<td>Br 82</td>
<td>e^-</td>
<td>35.3 h</td>
<td>619, 777</td>
</tr>
<tr>
<td>Sb 122</td>
<td>e^-, e^+</td>
<td>2.72 d</td>
<td>1141</td>
</tr>
<tr>
<td>Sb 124</td>
<td>e^-</td>
<td>60.2 d</td>
<td>603</td>
</tr>
<tr>
<td>W 181</td>
<td>EC</td>
<td>121.2 d</td>
<td>(57)</td>
</tr>
<tr>
<td>W 187</td>
<td>e^-</td>
<td>23.8 h</td>
<td>480, 686</td>
</tr>
<tr>
<td>Au 196</td>
<td>e^-, e^+</td>
<td>6.18 d</td>
<td>356</td>
</tr>
</tbody>
</table>

Potential activation products
TECHNICAL ADVISORY

Subject: Potential Increase in Ambient Dose after Extended High Energy Use

Commercial Name of Affected Product: TrueBeam® RadioTherapy Delivery System
Affected Version(s) / Lot(s): TrueBeam® versions 1.6, 2.0 and 2.5
Reference / FSCA Identifier: CP-20951
Date of Notification: 2015-07-17
Type of Action: Notification and Correction

Description of Problem
Varian recently received a report of an increase in ambient dose measurement due to target activation after extended operation in high energy mode. Only TrueBeam® RadioTherapy Delivery Systems versions 1.6, 2.0 and 2.5 with 18MV [23MV-BJR17] and 20MV [25 MV-BJR17] energies are affected. Measurements of ambient exposure simulating treatment activities consisting of repeated 4 Gy irradiations separated by 10 minutes over a 4 hour period exceeded Varian’s specification. The ambient dose measurements taken at 1 meter below the collimator face were less than 100 μSv/h.

This issue does not impact patient safety or treatment delivery. Varian has not received a report of any person receiving excess radiation exposure due to this issue.

- Edge, UNIQUE and TrueBeam version 1.5 linac devices are not affected because the energies available are lower than 18MV.
- C-Series linac devices are not affected because the target is shielded by the flattening filter.
18 MV x-rays

- Creation of $^{62}\text{Cu}$ (half life 9.7 min)
- The filter carousel moves to the field light position (moving the flattening filter out of the path)
- The activated source is no longer “shielded” by the flattening filter.
- Increase ambient dose rate in the region directly below the field aperture
trueBEAM carousel

Carousel Y-Stage
The BGM-POS node positions the carousel Y-stage axis, providing longitudinal motion for the carousel. The Y-stage axis drive (see below) moves the target out of the way when electron mode energies are used; positions foils and filters; and adjusts the field light mirror for proper focus.

Carousel Ion Chamber
Located at the end of the carousel closest to the collimator, the ion chamber (see the following figure) is intercepts the radiation beam after it has passed through the X-ray filter or electron foil. The BGM-POS subnode positions the ion chamber into the path of the beam.

The ion chamber monitors the radiation treatment beam to provide feedback to the BGM controller on actual dose rate, symmetry, and flatness.

Based on spatial distribution, the BGM generates corrective signals for radial and transverse angle and position steering servo systems.

Figure 20 Foils (1) and Filters (2)
Figure 21 Y-stage Axis
Figure 22 Ion Chamber Axis (1)
Measurements of ambient dose 1 meter below the collimator face due to target activation was less than 100 μSv/h.

below annual radiation exposure limits
- 50 mSv per year (USA) 20 mSv (Europe).
Recommended User Action

Close the jaws after high energy photon treatments are complete.
Select and mode-up an electron treatment field after treatment is complete.
Wait at least 10 minutes after the beam has been stopped, before working underneath the target (e.g. setting up QA equipment and phantoms).
DO NOT use "Mimic Treatment Room Light Field" when in service mode.
Minimize the time you spend in the proximity of the beam aperture.
Personnel exposure is more of a concern with a trueBEAM than a trilogy linac because the trueBEAM

1. has an FFF mode
2. has higher dose rates
3. retracts the flattening filter when the door is opened
4. has the awesome accent lighting
Review Paper

POTENTIAL HAZARD DUE TO INDUCED RADIOACTIVITY SECONDARY TO RADIOOTHERAPY: THE REPORT OF TASK GROUP 136 OF THE AMERICAN ASSOCIATION OF PHYSICISTS IN MEDICINE

Bruce Thomadsen,* Ravinder Nath,† Fred B. Bateman,‡ Jonathan Farr,§ Cal Glisson,** Mohammad K. Islam,†† Terry LaFrance,†‡ Mary E. Moore,§§ X. George Xu,*** and Mark Yudelev†††
Radionuclides produced by photon activation in linear accelerators

Maximum half life = 5.27 y ($^{60}$Co)
Minimum activation energy
  = 7.67 to 8.39 MeV ($^{184}$Re, $^{197}$Au, $^{203}$Pb)
Maximum gamma energy = 2.754 MeV ($^{24}$Na)
Recommendations

- Use lower beam energy
- Avoid material with high activation cross sections
- Restrict high energy for the end of the day
- Delay room entry
- Minimize wedge and compensator use
- Close the collimators following high energy deliveries
- Move couch and gantry from outside the room when possible
- Assign pregnant staff to low energy machines
- Use survey meter before service work
- Assess brass and copper buildup caps
Absorbed dose to technicians due to induced activity in linear accelerators for radiation therapy

A Almen, L Ahlgren and S Mattsson
PMB 1991

“The total annual absorbed dose to the trunk and to the hands have been estimated to be 2 mGy, of which the induced activity contributes one-third (0.7 mGy).”
Air activation $(\gamma,n)$

<table>
<thead>
<tr>
<th>Element</th>
<th>Threshold Energy (MeV)</th>
<th>Result</th>
<th>Half life (s)</th>
<th>Emission</th>
<th>Energy (MeV)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{14}\text{N}$</td>
<td>10.5</td>
<td>$^{13}\text{N} + \text{n}$</td>
<td>600</td>
<td>$\beta$</td>
<td>1.19</td>
</tr>
<tr>
<td>$^{16}\text{O}$</td>
<td>15.7</td>
<td>$^{15}\text{O} + \text{n}$</td>
<td>122</td>
<td>$\beta$</td>
<td>1.73</td>
</tr>
</tbody>
</table>

1% or less of the maximum permissible concentrations

Air activation produced by high-energy medical accelerators, McGinley, Patton; White, Thomas, MedPhys 1983
Neutrons and the door less vault
Lead is a good x-ray attenuator because it has high atomic number (lots of electrons).

Photoelectric effect + Compton scattering = X-ray attenuation
Neutrons

No charge means no coulomb interactions
Elastic collision with Hydrogen
Thermal interaction with Boron

Thermal neutron $^{10}\text{B}$

$^{11}\text{B}$

$^7\text{L}$

$\alpha$ (1.47 MeV)

$\gamma$ (0.48 MeV)
Neutron shielding door

Steel frame

Borated (5%) polyethylene

Inside of room

Outside of room

lead
Neutron door
Why doorless

Increase patient throughput 5 to 7%
Preferred by therapists
Expense
Physical safety concerns
Doorless vault design

- Limit 5 mSv / year for 16 MV beam
- Normal vault footprint
- Borated polyethylene at various points
- Result was 0.2 to 2 mSv / year

SU-FF-T-176: A Shielding Design for a High-Energy Doorless Accelerator Vault; T Bichay, J Meadows and C Chen
Med. Phys. 32, 1990 (2005); http://dx.doi.org/10.1118/1.1997847
Figure 1: Schematic of the doorless vault and various measurement points.
$\text{SF}_6$
What is Sulphur hexafluoride ($\text{SF}_6$)?

- Inert gas
- Colorless, odorless, non flammable
- Non toxic
- Heavier than air
Why do we need SF6 in linear accelerators

- SF6 is commonly used as a high voltage dielectric (an insulator that prevent discharge)
- In linacs it confines and transmits the RF (radio frequency) energy from the klystron to the accelerating waveguide
What is the potential risk of SF6

The main health hazard associated with releases of this gas is asphyxiation, by displacement of oxygen.

- headaches,
- ringing in ears
- dizziness
- drowsiness
- unconsciousness
- nausea,
- vomiting
- depression of all the senses.
- death may occur, due to the displacement of oxygen

The liquefied gas will rapidly boil at standard temperatures and pressures.

Sulfur hexafluoride has an anesthetic potency slightly lower than nitrous oxide.
RESCUERS
Self-Contained Breathing Apparatus should be worn.
Remove victim to fresh air, as quickly as possible.
If not breathing, give artificial respiration
If breathing is difficult, give oxygen

SKIN EXPOSURE:
Immediately begin decontamination with running water.
Minimum flushing is for 15 minutes.

EYE EXPOSURE
Open victim's eyes while under gentle running water.
Use sufficient force to open eyelids.

Have victim "roll" eyes.
Minimum flushing is for 15 minutes.
The SF6 defence

I’m not rolling my eyes at you, I have some SF$^6$ in my eyes
Medical Treatment

“Stand on your head and breath deeply!”
– Rick Hoffmeister, Linac engineer,
Democratic Youtube

1. Mythbusters Adam Savage Helium and Sulfur Hexafluoride

2. Neil Patrick Harris and Kelly Ripa inhale sulfur hexafluoride

3. Inhaling Helium & Sulfur Hexafluoride Starring Anna Spitz

4. Sulfur Hexafluoride vs GIRL (Anna Spitz) with Explanation

Jennifer Lawrence Plays Balloon Roulette
I just have to say... 3 out of 4 youtube videos are wrong

Speed of sound = \( \sqrt{\frac{\kappa_S}{\rho}} \)

- Mass density
- Bulk modulus (stiffness)
Conclusion

Your odds of dying in a car accident in your lifetime are 1 in 606

Work from home!
https://www.youtube.com/watch?v=IPLYfC4o3vE
https://www.youtube.com/watch?v=Kvr9LFeo50
https://www.youtube.com/watch?v=yDFgytoiGUw
https://youtu.be/oNMGZQVkNQY