Dose Estimation from Intakes of Exotic Radionuclides at the Los Alamos Neutron Science Center, 1996 to 2005

Presenter: Nick Altic, Certified Health Physicist (CHP)
Oak Ridge Associated Universities

Site Lead: John Cardarelli II, PhD, CHP, Certified Industrial Hygienist (CIH), Professional Engineer (PE)
National Institute for Occupational Safety and Health (NIOSH)
Division of Compensation Analysis and Support

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INTRODUCTION

This presentation summarizes:

Dose Estimation from Intakes of Exotic Radionuclides at the Los Alamos Neutron Science Center, 1996 to 2005

- Prepared by the Oak Ridge Associated Universities Team (ORAUT) for the National Institute for Occupational Safety and Health (NIOSH)
- Published September 15, 2023
- Referred to formally as ORAUT-RPRT-0107 Rev 00 and as **RPRT-0107** or ORAUT [2023a] in this presentation

The **Los Alamos Neutron Science Center (LANSCE)** is located within Technical Area 53 (TA-53)

LANSCE contains a proton linear accelerator used to generate intense pulses of neutrons for research on neutron scattering

PRESENTATION OUTLINE

- Background for RPRT-0107
- Reference Radionuclide Mixture and Indicator
- Significant Radionuclides in the Mark-I1L Target
- Example Committed Organ Dose Calculation
- Summary
- Cited references
- Key terms and acronyms

Background

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RPRT-0107 CONTEXT

- The LANL Work Group raised concerns about NIOSH's ability to assess doses to LANSCE workers delivered by intakes of **exotic radionuclides** (e.g., Meetings on August 15, 2017, and November 29, 2018 [NIOSH 2017, 2018])
- **RPRT-0107** evaluates this concern.

NIOSH considers an **exotic radionuclide** to be:

- "*...everything other than* $^{234/235/238}$*U*, $^{238/239}$*Pu*, ^{3}*H*, ^{241}*Am, and* ^{137}*Cs*" [ORAUT 2023b, PDF p. 9] That is: Uranium-234, 235, and 238; Plutonium-238 and 239; Tritium (Hydrogen-3); Americium-241; and Cesium-137.
- In the context of RPRT-107:
  "*activation and spallation products generated directly or indirectly by the accelerator proton beam for which bioassay results are not available for dose reconstruction*" [ORAUT 2023a, PDF p. 8]

RPRT-0107 PURPOSE AND FOCUS

- RPRT-0107 provides a framework for bounding potential dose to workers at LANSCE from intakes of radionuclides that were not effectively measured by whole body counting (i.e., exotic radionuclides)
- Methods in RPRT-0107 focus on activation and spallation products generated by the accelerator proton beam, for which bioassay data is not available

RPRT-0107 APPROACH

RPRT-107 methodology:

1. Identify a reference radionuclide mixture containing exotics
2. Identify an appropriate indicator in the mixture (i.e., a radionuclide that was monitored)
3. Calculate intakes of the indicator radionuclide using standard dose reconstruction methods
4. Scale the intakes of each exotic to the intake of the indicator

The RPRT-107 approach is similar to the approach provided in ORAUT-OTIB-0054 Rev 04, *Fission Activation Product Assignment for Internal Dose-Related Gross Beta and Gross Gamma Analyses* [ORAUT 2015]

Reference Radionuclide Mixture and Indicator

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REFERENCE RADIONUCLIDE MIXTURE AND INDICATOR (PART 1)

LANL previously reported the radionuclide mixture for seven components (nine source terms) at the accelerator's end of bombardment [Kelsey 2007]:

These components were:

1. concrete
2. uranium shielding
3. two beam inserts
4. two shields
5. a beam window
6. a beam stop
7. a tungsten spallation target (Mark-I1L)

The beam stop and tungsten target were expected to be the primary components of interest

REFERENCE RADIONUCLIDE MIXTURE AND INDICATOR (PART 2)

Additional radionuclides are produced by neutron activity of elements present in ambient air and coolant water (e.g., ^{7}Beryllium (Be-7), ^{11}Carbon (C-11), ^{13}Nitrogen (N-13), and ^{41}Argon (Ar-41))

- These activation products **were not** considered
- They are insignificant compared to the internal dose from components within the tungsten target

The assumed exposure pathway is highly conservative

- The entire target is volatilized, the mixture of which is then inhaled by the receptor
- Safety systems were in place to mitigate loss of coolant accident
- Interlocks were in place to mitigate exposure to personnel while the beam is on
- Entry was delayed to allow the ventilation to clear airborne activation products

REFERENCE RADIONUCLIDE MIXTURE AND INDICATOR (PART 3)

There are numerous radionuclides present in the LANSCE components

The following criteria were applied to reduce the number of radionuclides in each mixture:

- Targets must have ^{60}Co (Cobalt-60, the indicator radionuclide) as a significant component
  - Depleted uranium (DU) and concrete were excluded
  - DU and concrete are structural components and have no plausible release pathway
- All radionuclides that do not have an International Commission on Radiological Protection (ICRP) Publication 68 dose conversion factor (DCF) were removed

REFERENCE RADIONUCLIDE MIXTURE AND INDICATOR (PART 4)

For the radionuclide inventory:

1. Individual activities in the mixture were normalized to ^{60}Co
2. The most favorable DCF for each radionuclide solubility was determined
3. The committed effective dose (CED) for each mixture was calculated

REFERENCE RADIONUCLIDE MIXTURE AND INDICATOR (PART 5)

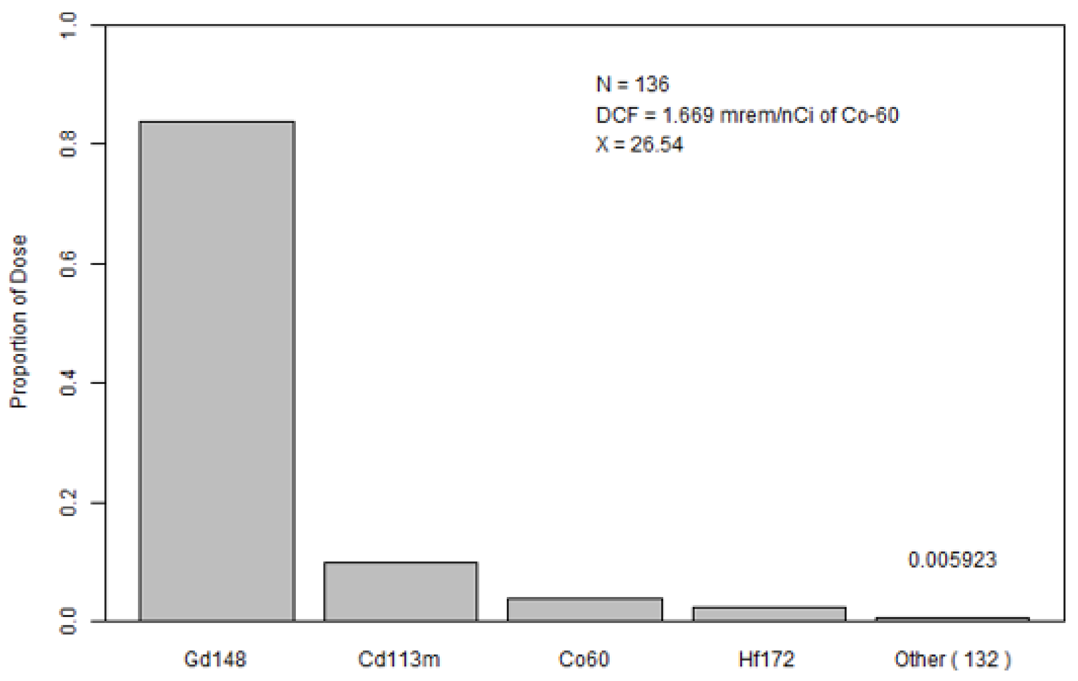
Bar plots were generated showing the percentage of the total dose contributed by each radionuclide

- Radionuclides contributing more than 1% of the dose were shown individually
- X is the factor by which the dose increases in the mixture in comparison to an intake of 1 nanoCurie (nCi) of pure Type S (soluble) ^{60}Co, which was used to select the target that gives the highest dose

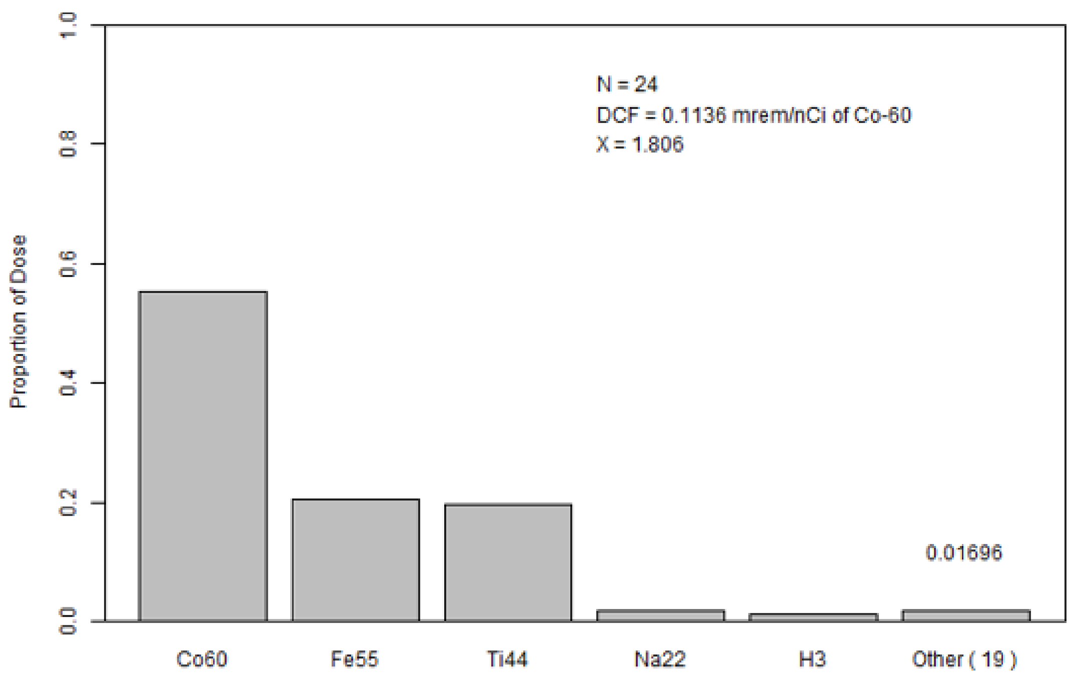
REFERENCE RADIONUCLIDE MIXTURE AND INDICATOR (PART 6)

Example bar plots for two selected target materials

Dose proportion for radionuclides in the Mark-I1L target



Dose proportion for radionuclides in the beam window



Significant Radionuclides in the Mark-I1L Target

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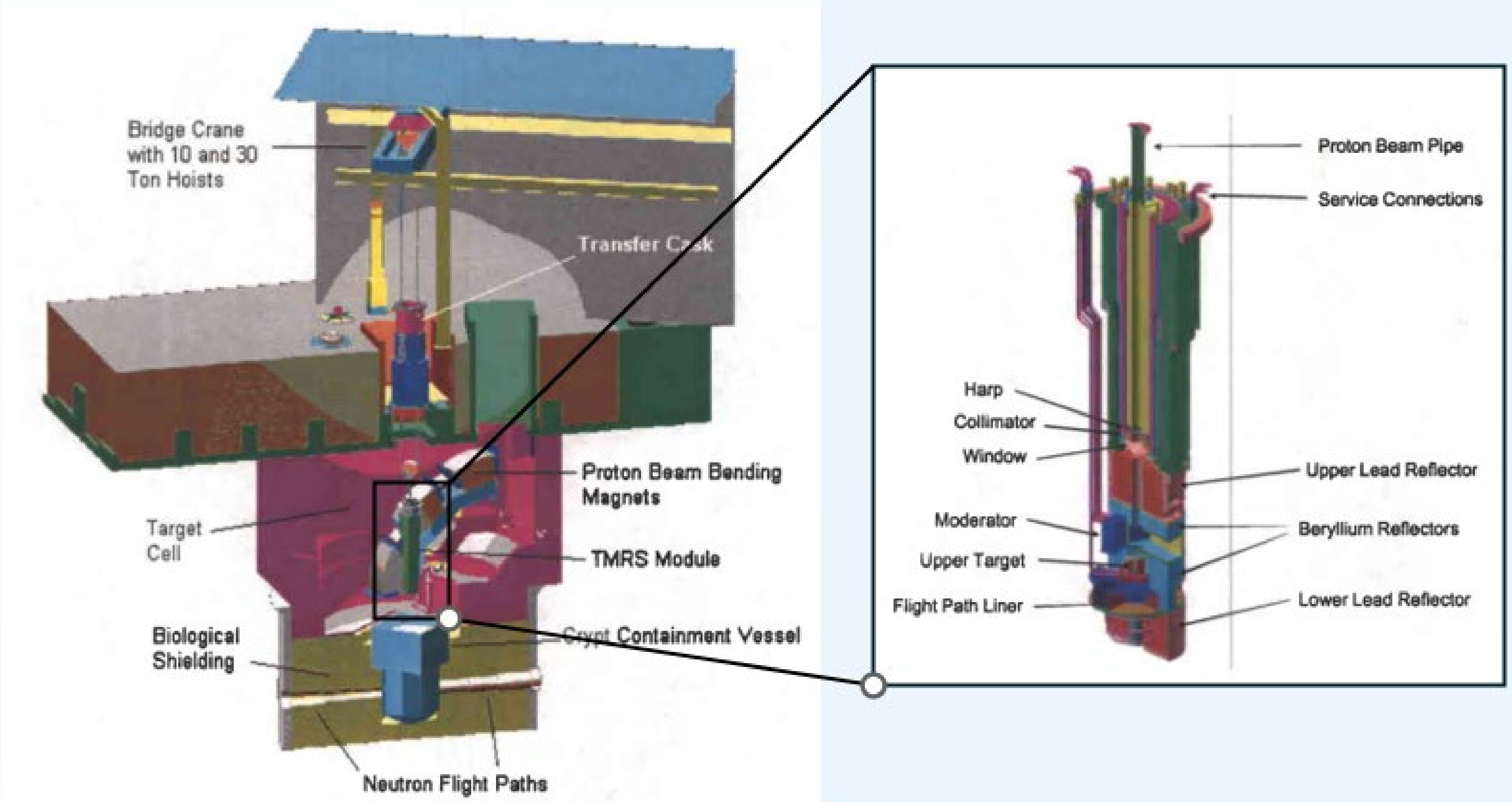
SIGNIFICANT RADIONUCLIDES IN THE MARK-I1L TARGET (PART 1)



Source: LANL 2000

800 MeV (million electronvolts) protons used to generate spallation neutrons for research applications

Target-Moderator-reflector-Shield (TMRS)

TMRS is approximately 1.5 meter tall by 0.7 meter in diameter

Upper and lower targets are tungsten

SIGNIFICANT RADIONUCLIDES IN THE MARK-I1L TARGET (PART 2)

The Mark-I1L tungsten target contains far more radionuclides than the other targets:

- 136 radionuclides
- Many do not make significant dose contribution

The number of radionuclides in the target was reduced by:

1. Calculating dose to each of the 26 effective dose organs for all 136 radionuclides
2. Retaining those radionuclides that contribute at least 1% to any organ

As a result of the reduction, there were 13 dosimetrically significant radionuclides

The reduction method is essentially the same as that in OTIB-0054 [ORAUT 2015]

SIGNIFICANT RADIONUCLIDES IN THE MARK-I1L TARGET (PART 3)

Table: Dosimetrically significant radionuclides for the Mark-I1L target

i^{th}	Radionuclide	Relative Activity	Adrenals DCF (mrem/nCi)	Bone Surface DCF (mrem/nCi)	Lungs DCF (mrem/nCi)
1	Cd-113m	0.058139	0.074	0.074	0.3441
2	Co-60	0.171287	0.0407	0.01813	0.3552
3	Fe-55	0.1127	0.000962	0.00666	0.000962
4	Gd-148	0.002156	0.00481	3700	21.83
5	H-3	0.327815	0.000152	0.000152	0.000152
6	Hf-172	0.045617	0.1073	3.293	0.1517
7	Hg-194	0.00033	0.1776	0.1443	0.1813
8	Lu-172	0.046064	0.000814	0.002775	0.02664
9	Lu-173	0.031932	0.00185	0.0925	0.03515
10	Na-22	0.003918	0.00629	0.01147	0.00481
11	Ni-63	0.01212	0.00629	0.00629	0.01036
12	Ta-179	0.151609	0.000444	0.000629	0.00666
13	Tl-204	0.036315	0.001184	0.001184	0.001295
NA	**Total:**	**1.00000**	**0.4224**	**3703.6511**	**22.9483**

Example Committed Organ Dose Calculation

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EXAMPLE COMMITTED ORGAN DOSE CALCULATION (PART 1)

In vivo counts were performed during the evaluation period, and ^{60}Co was reported only if it was identified by the whole body count (WBC) analysis software via peak search

- If no peak was identified, the result was reported as less than the minimum detectable activity (MDA) (0.83 nCi)

In this example the ^{60}Co MDA will be used to calculate missed dose

- Assume a chronic intake of Type S ^{60}Co for 1 year
- Assume a ^{60}Co body burden of MDA/2 (0.83 nCi/2 = 0.415 nCi)
- Determine intake using Integrated Modules for Bioassay (software):
    - total intake is 10.7 nCi (I_S)
    - intake rate is 10.7 nCi/365.25 d = 0.0293 nCi/d

EXAMPLE COMMITTED ORGAN DOSE CALCULATION (PART 2)

The 50-year committed organ dose from all radionuclides in the mixture can be calculated from the intake rate, organ DCFs, and relative activities. Examples for the adrenals, bone surface (bs), and lungs are shown:

$$H_{adrenals} = I_S \sum_{i=1}^{i=13} \left(\frac{A_i}{A_2}\right) DCF_{adrenals,i}$$

$$= (10.7\ nCi) \sum \left(\frac{0.058139}{0.171287}\right) \cdot 0.074 \left(\frac{mrem}{nCi}\right) + \left(\frac{0.171287}{0.171287}\right) \cdot 0.0407 \left(\frac{mrem}{nCi}\right) + \cdots = 1.04\ mrem$$

$$H_{bs} = I_S \sum_{i=1}^{i=13} \left(\frac{A_i}{A_2}\right) DCF_{bs,i} = 508\ mrem$$

$$H_{lungs} = I_S \sum_{i=1}^{i=13} \left(\frac{A_i}{A_2}\right) DCF_{lungs,i} = 8.66\ mrem$$

The above example is for Type S material. If Type M were assumed, the same maximum organ-specific DCFs would be used, but calculated intake would differ

Summary

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RPRT-0107 SUMMARY

RPRT-107 provides a proof-of-principle calculation that:

1. Specifies a reference source and relative amounts of dosimetrically significant radionuclides for the bounding Mark-I1L target
2. Specifies ^{60}Co as the indicator radionuclide that would be readily detected in a WBC
3. Uses standard dose reconstruction procedures to estimate the intake of ^{60}Co from WBC results
4. Uses the estimated ^{60}Co intake and reference source to estimate the intakes of all other radionuclides
5. Estimates a 50-year committed organ dose from the reference source intake

Next steps:

Implementation requires use of the actual annual organ dose, rather than the committed dose, which will require additional development

KEY REFERENCE DOCUMENTS

Kelsey C [2007]. Bounding radionuclide inventory and accident consequence calculations for the 1L target. CN-LANSCE-LFO-07-002. October 30. [SRDB Ref ID: 192061]

LANL [2000]. LANSCE Target Area Facility Design Description. March. [SRDB Ref ID: 196940]

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ORAUT [2023a]. Dose Estimation from Intakes of Exotic Radionuclides at the Los Alamos Neutron Science Center, 1996 to 2005. ORAUT-RPRT-0107 Rev. 00, September 15. [SRDB Ref ID: 198630]

ORAUT [2023b]. Bounding Intakes of Exotic Radionuclides at Los Alamos National Laboratory. ORAUT-RPRT-0101 Rev. 01, August 30. [SRDB Ref ID: 197263]

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KEY TERMS AND ACRONYMS (PART 1)

Term	Definition
CED committed effective dose	Sum of the effective doses to various tissues or organs in the body each multiplied by the appropriate tissue weighting factor and committed for a 50-year period following an acute intake or the onset of chronic intake. It does not include contributions from external dose The internal dose measurement LANL used to decide if a worker needed routine bioassay monitoring
^{60}Co	^{60}Cobalt
DCF dose conversion factor	Multiplier for conversion of potential dose to the personal dose equivalent to the organ of interest
DU depleted uranium	Uranium with a percentage of ^{235}Uranium lower than the 0.7% found in natural uranium
exotic radionuclides referred to as "**exotics**"	All radionuclides other than $^{234/235/238}$Uranium, $^{238/239}$Plutonium, tritium, ^{241}Americium, and ^{137}Cesium

KEY TERMS AND ACRONYMS (PART 2)

Term/Acronym	Definition
ICRP International Commission on Radiological Protection	An independent, international, non-governmental organization, with the mission to protect people, animals, and the environment from the harmful effects of ionizing radiation; its recommendations form the basis of radiological protection policy worldwide
LANL Los Alamos National Laboratory	U.S. Department of Energy laboratory in New Mexico
LANSCE Los Alamos Neutron Science Center	This complex includes the linear proton accelerator
MDA minimum detectable activity	Smallest activity of an analyte that can be detected with a probability β of nondetection (Type II error) while accepting a probability α of erroneously deciding that a positive (nonzero) quantity of analyte is present in an appropriate blank sample (Type I error)
mrem millirem	A unit measuring radiation dose

KEY TERMS AND ACRONYMS (PART 3)

Term/Acronym	Definition
NIOSH National Institute for Occupational Safety and Health	A Federal agency responsible for conducting research and making recommendations for the prevention of work-related injuries and illnesses
ORAUT Oak Ridge Associated Universities Team	Contractor team assisting NIOSH with fulfilling its responsibilities under the Energy Employees Occupational Illness Compensation Program Act (EEOICPA) ORAUT includes teaming partners (ORAU, MJW, NV5-Dade Moeller)
RPRT	An abbreviation for report It is used as part of the ORAU team's official report number (e.g., ORAUT-RPRT-0107)

KEY TERMS AND ACRONYMS (PART 4)

Term/Acronym	Definition
SRDB Site Research Database	A comprehensive record repository used by the NIOSH Dose Reconstruction Program Cited references include the associated SRDB number
TA technical areas	Subdivisions of work locations at the LANL site that generally reflect operational activities
WBC whole body count	Method used to perform *in vivo* bioassay that measures radiation emitted from radioactive material deposited throughout the body