



Initial Assessment of Radiation Exposures of Military Personnel aboard McMurdo Station, Antarctica (1962 to 1979)

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The views expressed in this presentation are those of the authors and do not necessarily reflect the official policy or position of the Department of the Navy, Department of Defense, or the U. S. Government.



Co-Authors and Acknowledgments



This work has been conducted in cooperation with personnel from the Defense Threat Reduction Agency (DTRA), SAIC, McMurdo Sound veterans, and others. Specifically:

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Briefing Outline



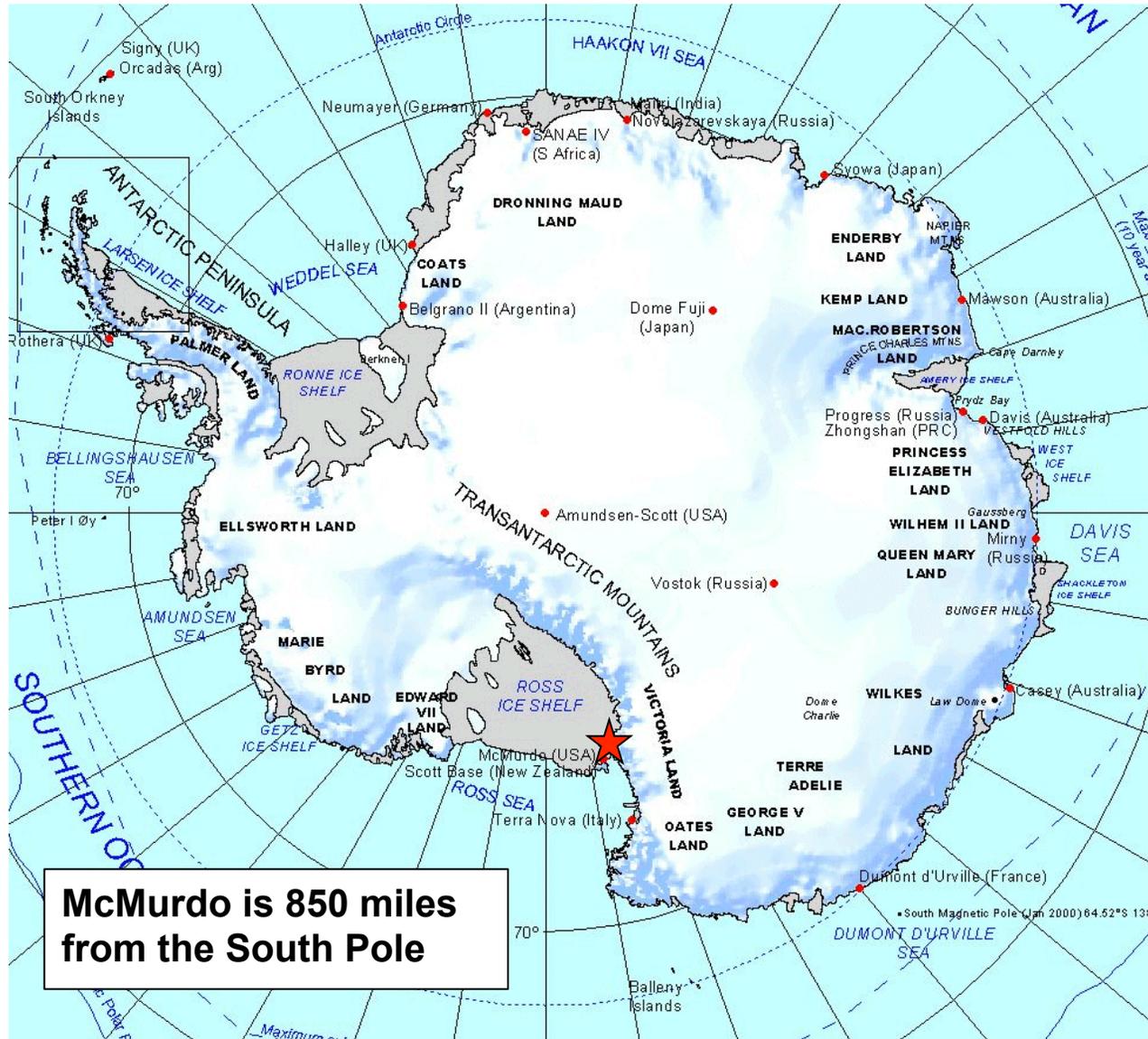
- 1. Background**
- 2. Dose Assessment Objectives & Approach**
- 3. Sources of Information for Dose Assessment**
- 4. General Parameters for McMurdo Dose Assessment**
- 5. External Radiation Exposure Scenarios and Calculations**
- 6. Internal Radiation Exposure Scenarios and Calculations**
- 7. Results**
- 8. Proposed Procedures for Individual Dose Assessments**
- 9. Conclusions**
- 10. References**



BACKGROUND



Location of McMurdo Station





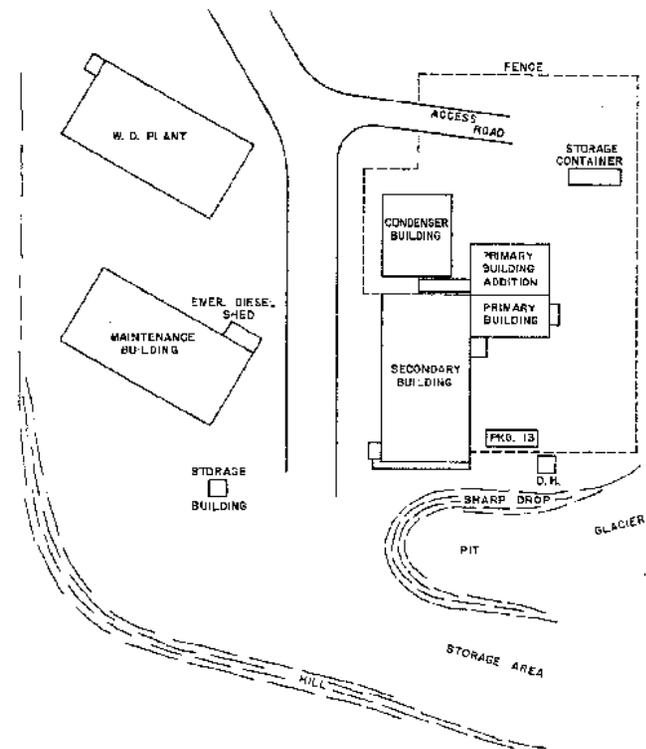
Overview of PM-3A NPP



The PM-3A Nuclear Power Plant was to the east of the main McMurdo Station, on the side of Observation Hill



FIGURE I-3
SITE PLAT PLAN



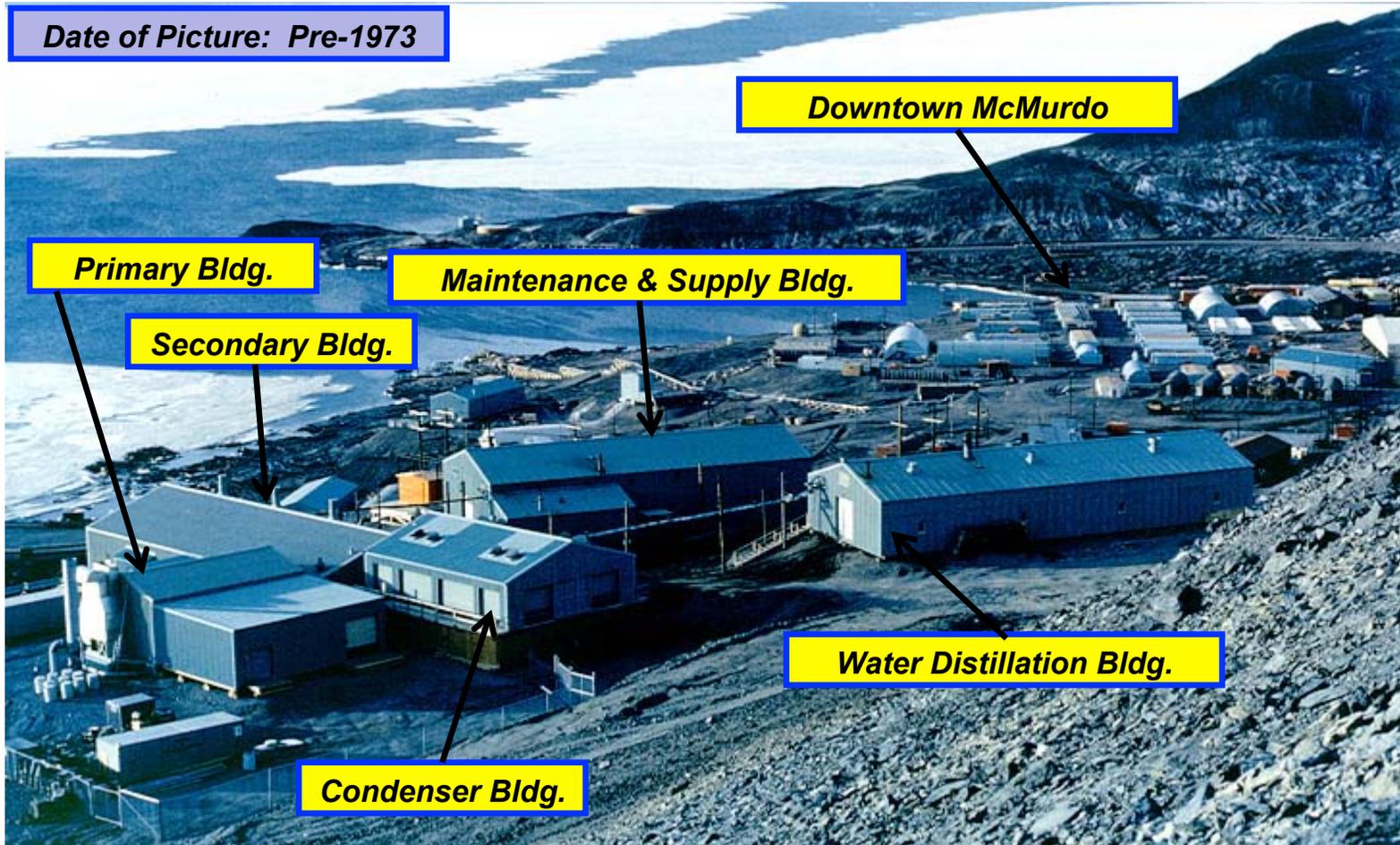
I-7



Location of the PM-3A NPP Buildings



Date of Picture: Pre-1973

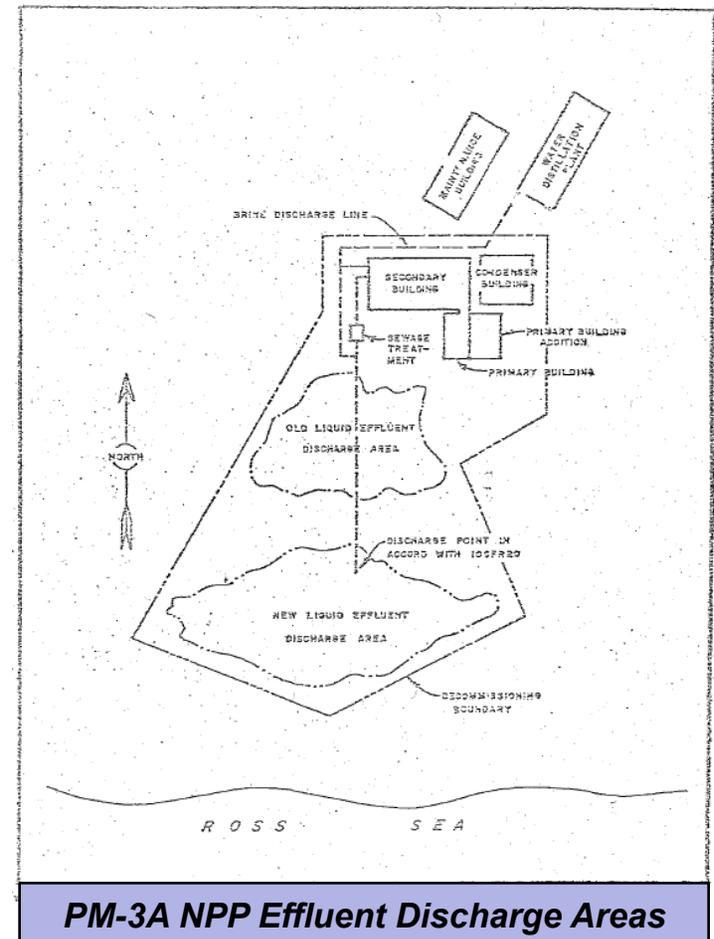




PM-3A NPP History



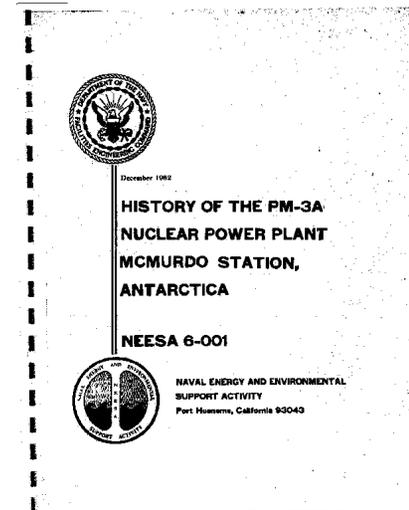
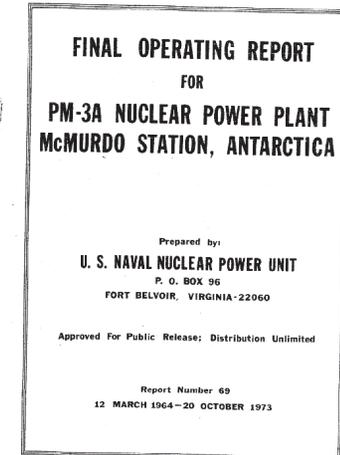
1. Assembly aboard McMurdo started in late 1961 by the Martin Company
2. Achieved criticality on March 3, 1962, with oversight by the Atomic Energy Commission
3. Navy assumed custody on March 13, 1964
4. Refueled in Dec 1964, October 1967, and June 1970
5. Shut down due to possible stress corrosion in October 1972
6. Defueled on July 5, 1973
7. Site decommissioning during austral summers between October 1973 and February 1979, including contaminated soil from effluent discharge areas





Problem Reports

1. **The Final Operating Report and History of the PM-3A (NEESA 6-001) document problems experienced during operation of the PM-3A**
2. **Some of the statistics include:**
 - 123 radiation exposures in excess of 350 mrem in one week
 - 4 reports of release of radioactive material to the environment in excess of limits
 - 41 incidents of increased activity levels in the plant (NEESA 6-001 states 11)
 - 5 reports on airborne particulate exposure to personnel greater than $3 \times 10^{-10} \mu\text{Ci ml}^{-1}$ gross beta
 - 438 PM-3A NPP malfunctions





Veteran Actions



- 1. Some veterans have expressed concern that the difficulties experienced with operation of the PM-3A NPP could have resulted in McMurdo Station personnel being exposed to harmful levels of radiation**
- 2. Veterans have sought VA radiogenic disease compensation associated with their service aboard McMurdo Station**
- 3. Naval responses to VA exposure requests only include dosimetry information for reported personnel**
- 4. A VA claim that referenced radiation exposure in Antarctica was awarded in 2004 for a McMurdo veteran**



Congressional Interest in DoD/VA Action and VBDR Review



- 1. Congressional interest arose at the possibility of veterans being exposed to radiation from the PM-3A NPP used aboard McMurdo Station**
- 2. In response to congressional requests, the Secretary of Defense and the Secretary of the Navy responded that the Navy would work with DTRA, VA, & VBDR to assess possible radiation doses**
- 3. A directive to generate guidance for assessing individual dose for veterans assigned to McMurdo Station was specifically assigned to:**
 - DTRA's Nuclear Test Personnel Review (NTPR)
 - Naval Dosimetry Center (NDC)



DOSE ASSESSMENT OBJECTIVES & APPROACH



Objectives



- 1. Estimate upper-bound doses for non-reactor personnel (veterans who were not monitored for radiation exposure)**
- 2. Develop procedures for individualized radiation dose assessments for:**
 - Non-monitored support personnel
 - Monitored, PM-3A NPP staff



Approach



- 1. Review historical information**
- 2. Collect information from veterans**
- 3. Develop scenarios of exposure from potential sources of radiation**
 - Winter-over personnel (12-14 months)**
 - Austral summer personnel (6 months or less)**



SOURCES OF INFORMATION FOR DOSE ASSESSMENT



Organizations Contacted



- 1. National Archives, College Park, MD**
- 2. Naval Operational Archives, Washington, DC**
- 3. Naval Sea Systems Command, Detachment, Radiological Affairs Support Office (RASO), Yorktown, VA**
- 4. Naval Dosimetry Center, Bethesda, MD**
- 5. US Army Reactor Office, Fort Belvoir, VA**
- 6. US Naval Seabee Museum and Archives, Port Hueneme, CA**
- 7. Navy Nuclear Power Unit (NNPU) alumni (several contacted the Navy and DTRA)**
- 8. Veterans who were assigned to McMurdo Station (several contacted the Navy and DTRA)**
- 9. National Personnel Records Center, St. Louis, MO**



Historical Reports and Publications



- 1. Historical reports (e.g. bulletins, annual summaries, etc)**
- 2. Dosimetry records for individuals assigned to PM-3A NPP**
- 3. Health physics logs**
- 4. Radioactive waste shipping documents**
- 5. Decommissioning plans**
- 6. Final surveys**
- 7. Veteran statements**
 - E-mails**
 - Phone calls**
- 8. Veteran accounts**
 - FRA article January 2012**
 - Media reports**
 - Television interviews**



GENERAL PARAMETERS FOR THE MCMURDO DOSE ASSESSMENT



Parameters Used for External and Internal Dose Calculations



Parameter	Value	Rationale/Reference/Comment
Deep Freeze winter-over	14 months	Archives Veteran statements Veteran dosimetry records
Deep Freeze austral summer	6 months	Archives Veteran statements Veteran dosimetry records
Work day	10 hours	Veteran statements
Work week	6 days	Veteran statements



EXTERNAL RADIATION EXPOSURE SCENARIOS AND CALCULATIONS



External Radiation Exposure Pathways



- 1. Tour/visit on PM-3A NPP**
- 2. Transit/hiking near PM-3A NPP**
- 3. Noble gas immersion**
- 4. Radioactive waste shipments**
- 5. Radioisotope thermal generators**
- 6. Contaminated soil on the ground**
- 7. Ship loading of bulk contaminated soil**

NOTE: The proposed parameter values for dose reconstruction in this section are selected to produce a high-sided and most favorable dose on behalf of the veterans. They are considered to be default values. Additionally, upper-bound factors account for uncertainties and relatively negligible dose components. Individual veteran's dose estimates may use different parameter values if additional information is discovered or provided by a veteran.



Tour/Visit of PM-3A NNP



Exposure Scenario:

- Entered the PM-3A NPP facility to tour or visit
- Includes assessment for personnel who used unrecorded monitoring devices (i.e. self-reading dosimeters)

Parameter	Value	Rationale/Reference/Comment
Time inside the PM-3A NPP facility	2 hours	Assumption based on veteran statements
Number of visits	1	Assumes each person visited once
Dose rate within the PM-3A NPP facility	Mean hourly dose rate ¹	Naval Dosimetry Center records

¹calculated using personnel monitoring results and estimated monitoring hours



Transit/Hiking near PM-3A NPP



Exposure Scenario:

- **Transited near the PM-3A NPP facility, such as when hiking up Observation Hill**
- **Includes radiation from the reactor, from radioactive waste, or from radioactive material in the effluent discharge areas**

Parameter	Value	Rationale/Reference/Comment
Dose rate within the PM-3A NPP facility	Mean hourly dose rate ¹	Naval Dosimetry Center records
Distance to dosimeter	70 feet	Distance from radioactive sources to reactor office and break room
Distance to fence line	105 feet	Closest distance from radioactive sources to fence line
Number of occurrences	200	Assumption based on veteran statements
Duration of proximity to fence line	0.25 hr	Assumption based on veteran statements for a routine passing by the plant without stopping

¹calculated using personnel monitoring results and estimated monitoring hours



Noble Gas Immersion



Exposure Scenario:

- Immersed in noble gas due to emissions from PM-3A NPP
- Emissions of Xe-133 and Xe-135 exceeded self-imposed reporting levels once but were below regulatory effluent limits (History of PM-3A)
- Immersion in Ar-41 at maximum regulatory effluent limit would result in highest dose due to it being the most conservative for noble gases
- No reported Ar-41 emissions greater than self-imposed emission level

Parameter	Value	Rationale/Reference/Comment
Ar-41 release concentration	$10^{-8} \mu\text{Ci ml}^{-1}$	Maximum permissible emission for Ar-41
Effluent limit for Ar-41	$10^{-8} \mu\text{Ci ml}^{-1}$	Nuclear Regulatory Commission Standards for Protection Against Radiation
General public dose from full year exposure to effluent limit	0.05 rem	Nuclear Regulatory Commission Standards for Protection Against Radiation
Time that wind was blowing toward living quarters	0.5	McMurdo Station wind rose (Lazzara, 2006) and NCRP Commentary 8 (1993)



Radioactive Waste Shipments



Exposure Scenario:

- **Dwell time near radioactive waste shipped from PM-3A NPP**
- **Includes maximum permissible exposure rates for both Yellow III and Yellow II shipments**

Parameter	Value	Rationale/Reference/Comment
Number of Yellow-III shipments	10 year ⁻¹	Assumption based on shipping documents (in review)
Number of Yellow-II shipments	10 year ⁻¹	Assumption based on shipping documents (in review)
Dose rate for Yellow-III	0.01 R hr ⁻¹ at 1 m	Maximum of US Department of Transportation danger goods package specifications
Dose rate for Yellow-II	0.001 R hr ⁻¹ at 1 m	Maximum of US Department of Transportation danger goods package specifications
Distance from shipment	3 m	Assumption
Time near shipment	1 hr	Assumption



Radioisotope Thermal Generators



Exposure Scenario:

- Dwell time near RTGs
- RTGs were labeled as Yellow III shipments

Parameter	Value	Rationale/Reference/Comment
Number of Yellow-III shipments	1 year ⁻¹	Assumption based on shipping documents during decommissioning
Dose rates for Yellow-III	0.01 R hr ⁻¹ at 1 m	Maximum of US Department of Transportation danger goods package specifications
Distance from shipment	3 m	Assumption
Time near shipments	1 hr	Assumption



Contaminated Soil on the Ground



Exposure Scenario:

- Dwell time on contaminated soil spilled during movement and loading of bulk soil from PM-3A NPP site onto cargo ships
- Possible during austral summers of decommissioning years 1976-1979
- Based on maximum permissible concentration of Cs-137

Parameter	Value	Rationale/Reference/Comment
Primary concentration	2000 pCi g ⁻¹	Maximum permissible concentration for bulk shipment soil (Decommissioning Plan, 1973)
Exposure time to primary soil	7 days / 10 hr day ⁻¹	Health Physics Logs
Residual concentration	10 pCi g ⁻¹	Maximum permissible concentration for residual soil contamination (Decommissioning Plan, 1973)
Exposure time to residual soil	4 hr day ⁻¹	Assumption
Depth of contamination	1 cm	Assumed spread over an infinite plane
Dose coefficient for exposure to soil contamination	4.3 x 10 ⁻¹⁶ Rem day ⁻¹ per (pCi m ⁻²)	EPA Federal Guidance Report 12



Ship Loading of Bulk Contaminated Soil



Exposure Scenario:

- Dwell time near contaminated soil during bulk loading onto cargo ships
- Possible during austral summers of decommissioning years 1975-1979
- Based on average of self-reading dosimeter results (1977)

Parameter	Value	Rationale/Reference/Comment
Average dose	50 mrem	Mean self-reading dosimeter results from health physics logs



Uncertainty Consideration for External Dose



- 1. In addition to using upper-bound values in the exposure parameters, all reconstructed doses for external exposure are multiplied by an uncertainty factor of 3 to:**
 - Account for uncertainties in measurements and calculations
 - Be consistent with standard operating procedures of the NTPR program
- 2. External doses considered uncorrelated**
- 3. External doses combined in quadrature**
- 4. Upper-bound doses rounded up to one significant digit**



INTERNAL RADIATION EXPOSURE SCENARIOS AND CALCULATIONS



Internal Radiation Exposure Pathways



1. Inhalation of long-lived beta emitters
2. Inhalation of contaminated soil during excavation
3. Inhalation of spilled contaminated soil
4. Ingestion of long-lived beta emitters in drinking water
5. Ingestion of tritium in drinking water
6. Incidental ingestion of contaminated soil and dust

NOTE: The proposed parameter values for dose reconstruction in this section are selected to produce a high-sided and most favorable dose on behalf of the veterans. They are considered to be default values. Additionally, upper-bound factors account for uncertainties and relatively negligible dose components. Individual veteran's dose estimates may use different parameter values if additional information is discovered or provided by a veteran.



Inhalation of Long-Lived Beta Emitters



Exposure Scenario:

- Inhalation of radioactive material released through the exhaust stack of the PM-3A NPP
- Based on air sampling data

Parameter	Value	Rationale/Reference/Comment
Air concentration	Monthly average	Values available from Jan 1962 to Dec 1972 (PM-3A History, 1973)
Exposure time - outside	4 hours day ⁻¹	Assumption
Breathing rate	0.9 m ³ hr ⁻¹	Adult averaged over 24 hours (ICRP 66)
Ratio of gaseous iodine to aerosol iodine	3	Assumption based on field measurements from Operation Tomodachi, DTRA, 2011
Infiltration factor for aerosols	0.5	Zhu, et al, 2005; DTRA,2011
Infiltration factor for gas	1	Zhu, et al, 2005; DTRA,2011
Dose coefficients	Various, based on 5 micron particle size, all I-131	ICRP 68; Results in highest doses for most organs



Inhalation of Contaminated Soil During Excavation



Exposure Scenario:

- Inhalation of contaminated soil during excavation
- Based on air sampling data during excavation

Parameter	Value	Rationale/Reference/Comment
Air concentration	Used highest value from air sampling for each year	Health Physics Logs
Exposure time - outside	10 hours day ⁻¹ 6 days week ⁻¹ / 6 months	Assumption based on veteran statements about workday
Breathing rate	1.2 m ³ hr ⁻¹	Average adult at work based on ICRP 66
Dose coefficients	Various, based on 5 micron particle size, all Cs-137	ICRP 68; Results in highest doses for most organs



Inhalation of Spilled Contaminated Soil



Exposure Scenario:

- Inhalation of contaminated soil suspended in air due spillage during bulk soil shipping operations
- Based on maximum concentration of Cs-137

Parameter	Value	Rationale/Reference/Comment
Primary concentration	2000 pCi g ⁻¹	Maximum concentration level in soil permitted for bulk shipment (Decommissioning Plan, 1973); Health Physics Logs
Exposure time to primary soil	7 days / 10 hr day ⁻¹	Health Physics Logs; veteran statements
Residual concentration	10 pCi g ⁻¹	Maximum concentration level permitted in soil (Decommissioning Plan, 1973); Health Physics Logs
Exposure time to residual soil	4 hr day ⁻¹	Assumption
Suspension factor	10 ⁻⁵ m ⁻¹	NTPR SOP (DTRA, 2010)
Depth of contamination	1 cm	NTPR SOP (DTRA, 2010)
Dose coefficients	Various, based on 5 micron particle size, all Cs-137	ICRP 68; Results in highest doses for most organs



Ingestion of Long-Lived Beta Emitters in Drinking Water



Exposure Scenario:

- **Ingestion of long-lived beta emitters in drinking water**
- **Based on drinking water sampling from the galley**

Parameter	Value	Rationale/Reference/Comment
Water concentration	Monthly average	Values from Jan 1962 to Dec 1972 (PM-3A History, 1973); Assumed Dec 1972 concentration for Jan 1973 to Mar 1979
Water intake	2 liter day ⁻¹	Exposure Factors Handbook (EPA, 2011)
Dose coefficients	Various all Cs-137	ICRP 68



Ingestion of Tritium in Drinking Water



Exposure Scenario:

- Ingestion of tritium in drinking water while reactor was operational
- Based on drinking water sampling
- Sampling occurred during period when steam from PM-3A NPP was used for distillation (Mar 1967 to Nov 1972)

Parameter	Value	Rationale/Reference/Comment
Water concentration	Monthly average	Data available from Mar 1967 to Nov 1972 (PM-3A History, 1973)
Water intake	2 liter day ⁻¹	Exposure Factors Handbook (EPA, 2011)
Dose coefficients	Various	ICRP 68



Incidental Ingestion of Contaminated Soil and Dust



Exposure Scenario:

- **Incidental ingestion of contaminated soil and dust spilled during and after shipping operations**
- **Based on maximum concentration of Cs-137**

Parameter	Value	Rationale/Reference/Comment
Primary concentration	2000 pCi g ⁻¹	Maximum concentration level in soil permitted for bulk shipment (Decommissioning Plan, 1973); Health Physics Logs
Ingestion rate	0.05 grams day ⁻¹	Mean value from EPA and Military guidance and used in NTPR SOP (DTRA, 2010)
Exposure time to primary soil	7 days	Health Physics Logs
Residual concentration	10 pCi g ⁻¹	Maximum concentration level permitted in soil (Decommissioning Plan, 1973); Health Physics Logs
Exposure time to residual soil	420 days	Assumption, based on 14 month tour
Dose coefficients	Various, all Cs-137	ICRP 68; Results in highest doses for most organs



Uncertainty Consideration for Internal Dose



- 1. In addition to using upper-bound values in the exposure parameters, all reconstructed doses for internal exposure are multiplied by an uncertainty factor of 10 to:**
 - Account for uncertainties in measurements and calculations
 - Be consistent with standard operating procedures of the NTPR program
- 2. Internal doses considered correlated**
- 3. Upper-bound doses determined from summing upper-bounds of each internal dose component**
- 4. Upper-bound doses rounded up to one significant digit**
- 5. Determined upper-bound doses for committed effective dose (50 year CED) and committed equivalent dose to the thyroid**



RESULTS



Initial Upper-Bound Estimates of External and Internal Doses for Non-Reactor Personnel



Dose	Range of Upper-Bound Doses (rem)
External Doses	
Winter	0.06 - 0.3
Summer	0.06 - 0.3
Internal Doses	
Effective dose - winter	0.004 - 0.05
Effective dose - summer	0.001- 0.03
Thyroid dose - winter	0.004 - 0.1
Thyroid dose - summer	0.001- 0.04

- **Review of possible exposure pathways and contributing factors is ongoing**
- **Upper-bound doses may be revised**



Preliminary Review of Dosimetry Records for Reactor Personnel



Year	No.	Min (rem)	Max (rem)	Mean (rem)	Remarks
DF62	13	0.137	0.716	0.329	Less than full year of operation
DF63	21	0.160	2.878	0.890	
DF63S	6	0.220	0.835	0.490	
DF72	24	0.185	9.960	6.940	Reactor shut down near end of year (weld inspections)
DF72S	4	0.064	1.420	0.740	
DF73	12	0.116	2.564	1.300	Reactor not operational

- Review of possible exposure pathways and contributing factors is ongoing
- Reported exposures may include monitoring results from assignments other than working with the PM-3A NPP aboard McMurdo Station



Medical Radiation Exposures for Relative Comparisons



Examinations and Procedures	Effective Dose (rem)
Upper GI	0.6
Barium Enema	0.7
CT Head	0.2
CT Chest	0.7
CT Abdomen/Pelvis	1.0
Whole-Body CT Screening	1.0
CT Biopsy	0.1
Chest	0.01
Cervical Spine	0.02
Thoracic Spine	0.1
Lumbar Spine	0.15
Pelvis	0.07
Abdomen or Hip	0.06

Mettler FA Jr, Huda W, Yoshizumi TT, Mahesh M. Effective doses in radiology and diagnostic nuclear medicine: A catalog. *Radiology* 248(1):254-263; 2008.



PROPOSED PROCEDURES FOR INDIVIDUAL DOSE ASSESSMENTS



Individual Dose Assessment



- 1. Determine veteran status as a McMurdo crew member**
- 2. For non-monitored PM-3A NPP personnel, individualized dose reconstructions will include:**
 - Use of exposure scenarios developed for non-reactor personnel
 - Use of specific exposure reconstruction parameters (as available) (i.e. time aboard McMurdo, duties assigned, work schedules, living and work locations, etc)
- 3. For PM-3A NPP crew members, dose reconstructions will include:**
 - External dosimetry results (as available)
 - Internal monitoring results (as available)
 - Calculated external dose for off-duty time
 - Calculated internal dose using exposure scenarios developed for non-reactor personnel and surrogate coworker measurements (in the absence of internal monitoring results)
 - Use of specific exposure reconstruction parameters (as available)
 - Radiation exposure monitoring results from other assignments



CONCLUSIONS



Conclusions



“The possibility that Service members may have been adversely affected by [radiation] exposure makes addressing this issue a high priority. The Department strives to accurately measure and document environmental exposures and provide this information to the Department of Veterans Affairs (VA).”

- Clifford L. Stanley, Under Secretary of Defense, in a letter to the Honorable Sherrod Brown, May 2, 2011



Conclusions



Finalized report will be published as a DTRA Technical Report:

“DTRA-TR-12-003: Technical Basis for McMurdo Station Nuclear Reactor Personnel Radiation Dose Assessments”



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Zhu, Y., Hinds W.C., Krudysz, M., Kuhn, T., Froines, J., Sioutas, C., 2005. *Penetration of Freeway Ultrafine Particles into Indoor Environments*. *Journal of Aerosol Science* Volume 36, pp. 303-322.



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