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RADIATION PROTECTION SERVICE

DEPARTMENT OF WELLBEING, SAFETY AND HEALTH

UNIVERSITY OF LEEDS

RADIATION RISK ASSESSMENT 40:
UNSEALED SOURCES: DEPLETED URANIUM

1. SCOPE AND PURPOSE

This radiation risk assessment relates to the use of unsealed sources of depleted uranium (DU) within the University of Leeds.

The purpose of this risk assessment is to assess the risks from exposure to ionising radiation in order to identify the measures needed to restrict the radiation exposure of employees or other persons and it has been prepared in accordance with the guidance given in ACoP 8 to the Ionising Radiations Regulations 2017.

2. DOCUMENT CONTROL

Version	Author	Date of issue/review	Comments
2.0	ARC	24 September 2018	Major update for IRR17
2.1	ARC	1 February 2019	Updated

3. NATURE OF SOURCES OF IONISING RADIATION

Depleted uranium (DU):

DU is a by-product of uranium enrichment and has reduced concentrations of U-235 and U-234 compared to natural uranium.

Typical isotopic abundances by weight are 99.8% ^{238}U, 0.2% ^{235}U, 0.001% ^{234}U; proportion by activity are 83.7% ^{238}U, 1.1% ^{235}U, 15.2% ^{234}U.

DU used in the university is usually a few decades old and significant decay products in secular equilibrium are:

^{238}U decay chain: ^{234}Th, ^{234m}Pa

^{235}U decay chain: ^{231}Th

Physical data: [i, ii] Type of decay: Alpha, beta and gamma emission.

Energy: 4.2 – 4.7 MeV alpha, up to 2.3 MeV max beta, low energy gamma up to 200keV + 1MeV from ^{234m}Pa

Physical half-life: ^{238}U $4.5x10^{9}$ years, ^{235}U $7.1x10^{8}$ years, ^{234}U $2.5x10^{5}$ years.

Specific activities: ^{238}U 12.4 $kBqg^{-1}$, ^{235}U 80 $kBqg^{-1}$, ^{234}U $2.32x10^{5}$ $kBqg^{-1}$

Shielding required: <1mm lead TVL for low energy gammas from DU (majority of gamma emissions)

Monitoring instrument: Beta probe – e.g. Mini-instruments 900EP15

Chemical data: Unsealed radioactive sources of DU used in research usually in powder or liquid form at specific activities of 16kBq/g.

Chemical forms used are uranyl acetate, nitrate, oxalate, dioxide, trioxide, octoxide, sulphate and uranium metal.

Primary stocks are usually 25, 50, or 100g. Sample amounts up to 10g are used for this assessment.

External exposure: DU has alpha and gamma emissions plus betas of significant energy are emitted by the ^{234m}Pa decay product which is in secular equilibrium with ^{238}U.

Betas will be mainly absorbed by the glass stock bottles and sample vials, however there will be a significant beta dose rate from unshielded DU.

External exposure data [iii]:

Unshielded:

1.5µSv/h per g @ 30cm (beta)

0.001µSv/h per g @ 30cm (gamma)

2.3mSv/h for 1kBq/cm2 contamination (contaminated skin dose)

Shielded:

540µSv/h per g in contact with syringe (extremity dose)

90µSv/h per 100g in contact with stock bottle (extremity dose)

0.04µSv/h per 100g bottle @ 100cm

Internal exposure: [iv] Highest dose organs – lungs (for inhalation), bone surfaces and kidneys (for ingestion).

The principal site of retention of uranium in the body is the skeleton (66%) with a biological half-life of 70-200 days. Uranium tends to follow the behaviour of calcium in bone, and the model used for the alkaline earth elements is applied, using transfer rates specific for uranium. Most of the uranium that is not in bones leaves the body in 1-2 weeks.

For soluble DU compounds the chemical toxicity to tissues, primarily the kidneys, is a much greater risk than the radiation exposure. Guidance [v] on prevention of chemical toxicity is that the concentration of uranium in the kidneys should not exceed 1µg U/g kidney tissue, which equates to an annual intake of 120mg.

Internal exposure data:

Committed effective dose coefficients for the inhalation or ingestion of DU and associated Annual Limits on Intake (ALIs):

Ingested materials	Sv/Bq	ALI for 1mSv/year (grams DU)
Soluble forms (Type F)	3.2E-08	2.0
Relatively insoluble forms (as assigned to Types M and S for inhalation)	3.2E-09	19.8
Inhaled particulate materials: (5µm AMAD aerosols)	Sv/Bq	ALI for 1mSv/year (grams DU)
Intermediate Type F/M: (uranyl nitrate, uranium trioxide)	3.7E-07	0.17
Intermediate Type M/S: (uranium octoxide, uranium dioxide)	4.9E-06	0.013

(Note: Coefficients were significantly revised in 2017 [iv])

Fetal exposure: [vi] On the basis of the data available, the CF:CM ratio adopted for the calculation of dose coefficients for uranium given in this report is 1 for intakes during pregnancy. The fetal dose from an intake is therefore equal to the mother's dose.

4. LIKELIHOOD OF CONTAMINATION ARISING AND BEING SPREAD

Surface contamination:

The likelihood of minor surface contamination arising during handling of DU sources is high, particularly during dispensing operations. Any minor contamination will be highly localised.

More major contamination arising from dropped sample vials or source stock bottles is less likely but possible.

Good laboratory practice, contamination monitoring and contamination control will minimise the risk of contamination being spread.

Airborne contamination:

The majority of uranium compounds are supplied as solid or powdered material.

There is a potential for resuspension of material whilst handling dry powdered material and all work with solid phases is undertaken in a fume-cupboard.

When solutions are released they can dry out and become resuspended with a potential route for inhalation.

Estimated levels of airborne and surface contamination

Estimates of contamination levels are based on exposure scenarios and calculations in NRPB-M443 [vii].

Assumptions:

- the maximum amount in a stock bottle is 100g DU and in a single experiment up to 10g DU
- there are up to 25 minor releases per year and one major release per year.
- 10% of the stock amount is spilt in a minor release and 100% in a major release.
- 5% of the total amount spilt remains after clean up, 10% of this is removable, and 0.1% of the removable contamination is ingested per day
- 0.3% of the activity is available for resuspension in a minor release and 3% of the activity in a major release.
- the amount of respirable activity released per day during routine 'potentially dusty' work is 5E-4 of the maximum quantity used = 5mg

5. DOSE ASSESSMENTS

EXTERNAL DOSES

University dose constraints[viii] are: 1mSv/year whole body dose, 10mSv/year extremity dose.

Estimated radiation dose rates to which anyone can be exposed:

The highest amounts handled are stocks containing up to 100g DU and samples containing up to 10g DU which give the following dose rates:

0.4µSv/h @ 30cm from stock bottle;

15µSv/h @ 30cm (beta) from unshielded 10g sample;

0.01µSv/h @ 30cm (gamma) from unshielded 10g sample;

5.4mSv/h dose to fingers whilst dispensing from stock

3.7mSv/h from 1% (0.1g) skin contamination

If a sample of 10g DU is dispensed (taking 30 seconds) the maximum estimated unshielded doses are:

Body dose = 15.01 / 120 = 0.125µSv (0.01% of annual dose constraint)

Extremity dose = 5400 / 120 = 45µSv (0.5% of annual dose constraint)

If a sample of 10g DU in a plastic vial is handled directly (10 seconds) the maximum estimated unshielded doses are:

Body dose = 15.01 / 360 = 0.04µSv (0.004% of annual dose constraint)

Extremity dose = 5400 / 360 = 15µSv (0.15% of annual dose constraint)

If a stock bottle of 100g DU is handled directly (10 seconds) the maximum estimated unshielded doses are:

Body dose = 0.4 / 360 = 1nSv (0.0001% of annual dose constraint)

Extremity dose = 90 / 360 = 0.25µSv (0.0025% of annual dose constraint)

INTERNAL DOSES

The pathways for internal exposures are ingestion of material from contaminated surfaces and inhalation of resuspended material during routine work and clean up of spillages.

Estimates of internal exposures levels are based on exposure scenarios and calculations in NRPB-M443 [vii] and the pessimistic scenarios have been used of a grade IV (medium quality chemistry lab with fume-cupboard) for the estimated inhalation doses and grade V (general purpose lab) for the estimated ingestion doses.

During normal operations using good laboratory practice there is negligible potential for intake in the absence of minor or major contamination.

During potentially dusty operations (milling and grinding solids, and crushing, grading or sieving dry powders) there is also some potential for intake during routine work.

Estimated ingestion doses:

The calculated ingestion exposure from contaminated surfaces following incomplete clean up after a release during normal work would be 1.25E-4 of the maximum amount = 1.25mg / year

This would result in an internal committed effective dose of:

1.25*16*3.2E-8 = 0.6µSv / year for soluble forms (0.06% of ALI) and

1.25*16*3.2E-9 = 0.06µSv / year for relatively insoluble forms (0.01% of ALI)

Estimated inhalation doses:

Normal work

The calculated exposure from releases during normal work would be 6.8E-6 of the maximum amount = 0.07mg / year

This would result in an internal committed effective dose of:

0.07*16*3.2E-7 = 0.4µSv / year for Intermediate Type F/M compounds (uranyl nitrate, uranium trioxide) (0.04% of ALI) and

0.07*16*4.9E-6 = 5.5µSv / year for Intermediate Type M/S compounds (uranium octoxide, uranium dioxide) (0.5% of ALI)

Work with solutions

The calculated exposure from releases during wet work would be 1.8E-7 of the maximum amount = 0.018mg / year

This would result in an internal committed effective dose of:

0.018*16*3.2E-7 = 0.09µSv / year for Intermediate Type F/M compounds (uranyl nitrate, uranium trioxide) (0.01% of ALI) and

0.018*16*4.9E-6 = 1.4µSv / year for Intermediate Type M/S compounds (uranium octoxide, uranium dioxide) (0.1% of ALI)

Potentially dusty work

The calculated exposure from releases during potentially dusty work would be 1.9E-4 of the maximum amount = 1.9mg / year

This would result in an internal committed effective dose of:

1.9*16*3.2E-7 = 9.7µSv / year for Intermediate Type F/M compounds (uranyl nitrate, uranium trioxide) (1.0% of ALI) and

1.9*16*4.9E-6 = 149µSv / year for Intermediate Type M/S compounds (uranium octoxide, uranium dioxide) (15% of ALI)

Major spillage

The calculated inhalation exposure from releases due to a major spillage during transfer from storage and subsequent clean up would be 3E-6 of the maximum amount (100g) = 0.3mg

This would result in an internal committed effective dose of:

0.3*16*3.2E-7 = 1.5µSv / year for Intermediate Type F/M compounds (uranyl nitrate, uranium trioxide) (0.15% of ALI) and

0.3*16*4.9E-6 = 23.5mSv / year for Intermediate Type M/S compounds (uranium octoxide, uranium dioxide) (2.4% of ALI)

6. DOSIMETRY

Personal dosimetry (TLDs) is used by any worker handling DU.

Both body and extremity (finger stall) TLDs are used to assess radiation doses to users.

7. MANUFACTURER'S ADVICE

Not applicable.

8. ENGINEERING CONTROL MEASURES AND DESIGN FEATURES

Work with radionuclides is carried out in suitably designed laboratories [ix] that are registered and authorised by the RPM prior to work being permitted. Radioactive work is carried out using suitably equipped radiation workstations as specified in the local rules:

- bench covered with surface protection (e.g. Benchkote);
- tray lined with an absorbent layer (e.g. Benchkote);
- appropriate shielding where necessary:
- fume-cupboards are used where there is a risk of airborne contamination, i.e. where any powdered or dusty materials are handled.

9. PLANNED SYSTEMS OF WORK

Work is carried out under local rules and Standard Operating Procedures.

The Local Rules and SOPs include:

- List of authorised radiation areas.
- List of authorised radionuclides and stock / waste limits.
- Management arrangements for radiation work including requirements for supervision.
- Requirements for competency and training.
- Access restrictions.
- Dose limits, personal dosimetry and dose investigation levels.
- Contamination monitoring.
- Requirements for source management, security and containment.
- Instructions for handling sources and controlling exposures.
- Accident procedures.

10. PPE

Laboratory coats, disposable gloves, and eye protection must always be worn when handling radioactive material.

Disposable respiratory protective equipment (RPE) may be required for clean up of any spillages of powdered material outside a fume-cupboard.

11. ACCESS TO AREAS WHERE THERE ARE SIGNIFICANT DOSE RATES OR CONTAMINATION LEVELS

All stocks of DU are stored and handled in Supervised Areas.

Access is restricted by the use of key fob/card or keypad access arrangements to authorised radiation workers. A local access permit is required for service engineers, maintenance contractors, visitors, etc. to enter these areas (issued by RPS or RSC).

Very low level samples of DU (less than 1g in solution) can be handled in non-designated areas. Handling is in demarcated areas and if equipment is used this is labelled and thoroughly monitored and de-contaminated before being released for normal use.

Access to non-designated areas is less restricted than for Supervised Areas and is managed as any general laboratory.

12. RISK EVALUATION AND CONTROLS

Work scenario	Risk evaluation	Control measures	Residual risk after controls		
			Likelihood	Severity	Risk
General handling of DU materials	External exposures: Potential beta / gamma dose from unshielded material and extremity dose from handling stock and sample containers. Internal exposures: Potential for minor contamination during work and subsequent ingestion or inhalation of material. Potential for inhalation of material during work with powdered material.	Work undertaken with stocks of DU in Supervised Areas and access restricted. Work carried out under Local rules and operating procedures (SOPs). All users undergo appropriate training (both central basic training and local training) and supervision. Time handling material is minimised. PPE must be worn (laboratory coat, disposable gloves, safety eyewear). Sample containers checked for surface contamination before and after work. All handling of material when in a powder or solid phase undertaken in a designated fume-cupboard. Work carried out at a suitable workstation (tray lined with absorbent material). Regular contamination monitoring undertaken during work and any contamination produced immediately cleaned up. Personal dosimetry used to measure doses.	**Low**	**Low**	**Low**

Work scenario	Risk evaluation	Control measures	Residual risk after controls		
			Likelihood	Severity	Risk
Storage of material	External exposures: External doses from stocks are low whilst in storage as stocks and samples are kept in glass / plastic bottles / vials. Potential exposures (see section 5): < 0.04µSv/h per 100g DU bottle at 1m Internal exposures: Negligible risk of intake in the absence of spillages as stock containers are sealed.	Storage of stocks and samples in a dedicated storage cupboard. Cupboard should be sited at least 1m away from working areas. If this is not possible then dose rates should be measured and shielding supplied if necessary to reduce dose rates to <0.1µSv/h at working areas. Storage cupboard kept locked and access restricted to trained users only. Stock bottles and sample vials sealed and checked for surface contamination before placing in storage and after removing from storage. Stocks and samples stored on a tray or secondary container to contain potential spillages.	**Low**	**Low**	**Low**
Transfers to/from storage	External exposures: External doses are low as stocks and samples are kept in glass / plastic bottles / vials. Potential exposures (see section 5): 0.25µSv (extremity), 0.001µSv (body) whilst handling a 100g DU bottle directly for 10 seconds transfer. Internal exposures:	Control measures as for *general handling* plus: Stock bottles and sample vials sealed and checked for surface contamination before placing in storage and after removing from storage.	**Low**	**Low**	**Low**

Work scenario	Risk evaluation	Control measures	Residual risk after controls		
			Likelihood	Severity	Risk
	Negligible risk of intake in the absence of spillages as stock containers are kept sealed.				
Dispensing of material from stock	External exposures: Potential beta dose from unshielded material and extremity dose from handling sample containers whilst dispensing. Potential exposures if dispensing 10g of DU for 30 seconds (see section 5): 0.5% of extremity dose constraint, 0.01% of body dose constraint. Internal exposures: Potential for minor contamination during dispensing and subsequent ingestion or inhalation of material. Potential for inhalation of material during work with powdered material. Potential exposures (see section 5): Ingestion: up to 0.06% of ALI dependant on compound used Inhalation: up to 0.5% of ALI dependant on compound used.	Control measures as for *general handling* plus: All dispensing of material from stocks undertaken in a designated fume-cupboard.	**Low**	**Low**	**Low**

Work scenario	Risk evaluation	Control measures	Residual risk after controls		
			Likelihood	Severity	Risk
Handling of solutions	External exposures: Potential beta dose from unshielded material and extremity dose from handling sample containers. Potential exposures if handling 10g of DU for 30 seconds (see section 5): 0.5% of extremity dose constraint, 0.01% of body dose constraint. Internal exposures: Potential for minor contamination during work with solutions. Potential exposures (see section 5): Ingestion: up to 0.06% of ALI dependent on compound used Inhalation: up to 0.1% of ALI dependent on compound used.	Control measures as for *general handling* plus: Secondary containment always used when transferring solutions. Additional assessment required for non-routine work with solutions.	**Low**	**Low**	**Low**
Potentially dusty operations	External exposures: Potential beta dose from unshielded material and extremity dose from handling sample containers. Potential exposures if handling 10g of DU for 30 seconds (see section 5): 0.5% of extremity dose constraint, 0.01% of body dose constraint. Internal exposures:	Control measures as for *general handling* plus: All work with potentially dusty operations to be carried out in a fume-cupboard (or with local exhaust ventilation where appropriate). All potentially dusty operations such as milling or grinding solids or crushing, grading or sieving dry powders subject to additional specific risk assessment.	**Low**	**Low**	**Low**

Work scenario	Risk evaluation	Control measures	Residual risk after controls		
			Likelihood	Severity	Risk
	Potential for surface contamination and subsequent ingestion or inhalation of material. Potential for direct inhalation of dust and inhalation of resuspended dust during clean up. Potential exposures (see section 5): Ingestion: up to 0.06% of ALI dependent on compound used Inhalation: up to 15% of ALI dependent on compound used.				
Waste disposal	External exposures: Potential beta dose from unshielded material and extremity dose from handling sample containers. Potential exposures if handling 10g of DU for 30 seconds (see section 5): 0.5% of extremity dose constraint, 0.01% of body dose constraint. Internal exposures: Potential for surface contamination and subsequent ingestion or inhalation of material. Potential for direct inhalation of dust and inhalation of resuspended dust during clean up. Potential exposures (see section 5): Ingestion: up to 0.06% of ALI dependent on compound used	Control measures as for *general handling* plus: All quantities of waste kept within authorised waste limits as described in local rules. Aqueous waste collected in appropriate containers and kept sealed. Aqueous disposal to designated sink and flushed with copious amounts of water. Solid waste segregated and potentially offensive (lab) waste de-contaminated. Only non-offensive waste disposed via green tag route. Solid waste kept in appropriate container and transferred to RPM regularly (monthly) as per local rules.	**Low**	**Low**	**Low**

Work scenario	Risk evaluation	Control measures	Residual risk after controls		
			Likelihood	Severity	Risk
	Inhalation: up to 15% of ALI dependent on compound used.				
Possible accident situations and steps to prevent or limit their consequences	**Major spillage of material** If a stock bottle is dropped and spilt during transfer or work then there would be a potential for inhalation and ingestion of material during clean up. Potential exposures (see section 5): Ingestion: up to 0.06% of ALI dependent on compound used Inhalation: up to 2.4% of ALI dependent on compound used.	Control measures as for *general handling* plus: All dispensing of material from stocks undertaken in a designated fume-cupboard. If powdered material is spilt outside a fume-cupboard then subsequent clean up should be undertaken using appropriate respiratory protective equipment (RPE), e.g. disposable dust mask.	**Low**	**Medium**	**Low**
	Fire damage Sources may become damaged when in storage through the effects of fire in the room. Although fire damaged sources may not be intact, radioactivity will most likely be retained in the damaged container or store.	Fire fighters entering Supervised Areas should assume that contamination is present and use appropriate PPE/RPE. Contamination will be spread during a fire and specialist remediation will be required.	**Low**	**Medium**	**Low**
	Loss or theft Loss of source through negligence is possible if left unattended. Theft of source through poor security.	Access to the laboratory restricted to authorised personnel only. Stock bottles must not be left unattended when not in storage. Storage cupboard kept locked and access restricted to trained users only. Loss or theft should be reported immediately to the RPM and immediate	**Low**	**Medium**	**Low**

Work scenario	Risk evaluation	Control measures	Residual risk after controls		
			Likelihood	Severity	Risk
		steps taken to recover the source.			
Failure of control measures	**Failure of systems of work** Failure to carry out work according to local rules and operating procedures (SOPs) would increase the risk of an external beta / gamma dose from unshielded material and increase the risk of the spread of contamination, and ingestion and inhalation of material.	All users undergo appropriate training (both central basic training and local training) and supervision and are authorised to undertake work with DU. Radiation Protection Supervisor and Radiation Safety Coordinator are appointed to manage and supervise work with DU.	**Low**	**Medium**	**Low**

[i] Recommended Data, Laboratoire National Henri Becquerel, http://www.nucleide.org/DDEP_WG/DDEPdata.htm

[ii] Radionuclide and Radiation Protection Data Handbook, Delacroix et al, Radiation Protection Dosimetry Vol.98 No.1, NTP 2002.

[iii] DU.xlsx

[iv] ICRP Publication 137, Occupational Intakes of Radionuclides: Part 3, ICRP 2017.

[v] Controlling Intake of Uranium in the Workplace: Applications of Biokinetic Modelling and Occupational Monitoring Data, R. W. Leggett et al, ORNL/TM-2012/14, ORNL 2012.

[vi] ICRP Publication 88, Doses to the Embryo and Fetus from Intakes of Radionuclides by the Mother, ICRP 1998.

[vii] NRPB-M443, Categorisation and Designation of Working Areas in which Unsealed Radioactive Materials are Used, NRPB 1993.

[viii] University of Leeds Protocol for the Management of Sources of Ionising Radiation.

[ix] University of Leeds RPS Information Sheet 34: Design Specification for Supervised Area Radiation & Category 2 Bio-Containment Laboratories.