Commonly Used Radionuclides
A Brief Introduction to Properties and Precautions

1. Tritium H-3, half-life 12.3 years

The emitted beta radiation has a maximum energy of 18.6 keV and does not penetrate to the basal layer of the skin, thus usually does not produce an external radiation hazard. However, tritium inhaled or ingested in a form which is readily soluble, is quickly and uniformly distributed throughout the body, and is slowly excreted with a biological half-life of about ten days. Tritiated organic compounds may be concentrated in the nucleus of cells, and the short range of the beta particle ensures that the energy is deposited within the nucleus, and thus causes damage to the DNA.

Within the University, the limited use today of small activities of tritium, either as tritiated water, or as labelled organic compounds, presents relatively low risk. However, straightforward precautions must still be adopted to ensure that the risk is a low as possible. The precautions are made rather more difficult because monitoring for contamination cannot be done by a direct method, and indirect (wipe) tests must be performed (Appendix 15). Another problem is the relative ease in which tritium can ‘migrate‘ from stored stocks and contaminate other organic materials – including laboratory structures, timber and interior plastic components of fridges and freezers. Many tritium compounds are inherently unstable and may decompose even in cool or frozen storage, releasing tritium into the working environment, and making the original compound unsuitable for its intended use. Thus, regular review of the need to retain ‘old’ stocks of tritiated products is important, not only from a safety and radiation protection perspective, but for assurance that a labelled compound continues to be the viable material that a researcher believes. Fridges and freezers where tritium is stored must be regularly defrosted in order to prevent a build-up of tritium in the ice.

Tritium may enter the body *by Ingestion, Inhalation or Absorption* through the skin or *Injection* through a puncture wound or cut. Of particular note is the route by absorption through the skin. Tritiated water can be absorbed by this route, and this may also be relevant to a greater or lesser extent, in terms of tritiated organic compounds, depending on the nature of the compound. ‘Double gloving’ is recommended when working with tritiated compounds as penetration through single gloves has been reported.

The predicted differences in the radiological effects of tritium taken into the body are referenced in the table ‘Data for some commonly encountered radionuclides’ (Appendix 2). The dose per unit intake by ingestion for tritiated water is given as 1.8×10^{-11} $Sv.Bq^{-1}$, whilst that for ‘organically bound‘ tritium is given as 4.8×10^{-11} $Sv.Bq^{-1}$. Clearly the figure for organically bound tritium is an attempt to present some realistic data in comparison with the effects from tritiated water. However, if intake was believed to be a significant factor, this value should be regarded with some caution, depending on the organic compound concerned. With the very modest uses of organically bound tritium in the University today, coupled with simple but effective control measures, the issue should not be one of great significance. Useful risk assessments can be completed, using the above data, but the most important factor in these of course being the specification of appropriate and effective control measures.

Personal monitoring - Film badges/TLDs are ineffectual for uses of tritium and should not be used in case a false sense of security is introduced into users. Contamination monitoring for tritium is by the use of ‘wipes’ followed by scintillation counting.

Assessing internal dose from tritium is done by bioassay of tritium in urine. Although it may be possible for ‘DIY’ assessments of tritium in urine to be carried out within Departments, using the techniques and equipment available, if there was a particular need for routine or emergency assessments of tritium uptake to be carried out, the Safety Office would engage the assistance of an HSE approved dosimetry service specialising in internal radiation assessments. Routine internal dose assessments would generally only be required for high, regular use of tritium, above the current level of use in the University, and the need for these assessments would be determined through the prior risk assessment process in consultation with the RPAs.

2. Carbon-14 C-14, half-life 5730 years.

The maximal 156 keV beta radiation has a range in air of 22 cm and can be monitored with a Mini 900 fitted with an EP15 probe (or equivalent). Although the beta radiation can barely penetrate the outer layers of the skin, direct skin contact with C-14 can give high skin surface doses. Additionally some C-14 compounds may penetrate gloves and skin, or become incorporated into skin giving internal doses or very high local skin doses. Always use gloves – two pairs if practicable – and avoid direct skin contact with the radionuclide. Film badges and TLDs are not effective in demonstrating exposure to C-14 as the protective coverings of the dosemeters prevent penetration of the beta radiation – regular and efficient contamination monitoring is essential. Use a 'Mini' EP15, or equivalent Geiger-Müller monitor for contamination monitoring.

3. Phosphorus-32 P-32, half-life 14.3 days

P-32 decays by beta emission, with a maximum energy of 1.71 MeV, and a mean energy of 0.69 MeV. The maximum range of the beta radiation is 7 metres in air and 8 mm in water. Thus the 'skin' or extremity dose is of particular relevance to P-32 users as the major effect of the high energy beta emission of this radionuclide will be on the first few millimetres of tissue thickness. **Skin contact doses can be very high** from P-32, with doses of more than a Sievert attainable if MBq activities are left on the skin for more than a few minutes – frequent monitoring must always take place when using P-32. A 'Mini' E or EP15 is the monitor of choice for P-32 contamination monitoring. Bremsstrahlung X-ray radiation will also be generated by the high energy beta particles, especially if shielded with dense, high atomic number absorbing material like lead. Bremsstrahlung radiation can be a significant issue when dealing with very large activities of P-32 contained in 'Perspex' stock-pot vials, and often can confuse people who are checking received boxes or containers, and who unexpectedly find that their container of 'pure beta' emitter is emitting 'radiation' that can be detected through some lead shielding, by a x-ray contamination monitor. In laboratory use, the Bremsstrahlung produced by modest activities (a few MBq) of P-32 is generally small, and the use of shielding other than Perspex screens is not required. However, unleaded 'stock pots' containing P-32, should not be handled for longer than is absolutely necessary.

As well as considering skin dose, the attachment of P-32 to bone structures means that consideration of this possibility, from ingested or inhaled material, is a very important matter when carrying out prior risk assessments. Up to 40% of ingested P-32 may attach, with a subsequent biological half-life of around nineteen days.

As discussed above, the skin contact dose, as well as the external exposure from nearby sources of small activities of P-32 can be extremely high (see data in Appendix 2). Particular techniques to be avoided are directly handling of 'eppendorf' tubes or similar - handling tools should always be employed. Perspex boxes, blocks, pipette shields and similar items should also be employed to minimise the exposure from this radionuclide. 1 cm thickness of 'Perspex' ('Plexiglas') will protect the user from the P-32 beta radiation. Do not look into an open P-32 stock container – the dose rate at the mouth of an open P-32 vial with only **1 MBq** in 1 ml of liquid, is of the order of 260 millisievert/hour.

Personal monitoring for uses of P-32 should include the use of extremity (TLD) monitors at least for the first three months of a new technique or for new users who have not used P-32 before. For small uses, based on the risk assessment of likely exposures it may be possible to discontinue extremity monitoring after that time. The use of a whole body badge can provide 'reassurance' but remember that the whole body badge will only provide an estimate of dose from sources or contamination left in an unshielded state, and not from any P-32 containing materials in use behind Perspex screens.

4. Iodine -125 I-125, half-life 59.9 days

X-ray emitter of 27-36 keV. Previously used in large activities for 'Protein labelling', but currently only modest uses of pre-labelled products. Iodinations may involve the risk of generation of volatile I-125, and the possibility of significant internal dose. These procedures must be carried out in fume cupboards within controlled areas. The thyroid is the particular organ where iodine will concentrate, and it can be retained with a biological half life well in excess of 100 days. Currently, the smaller activities used in the University are mainly in the form of pre-labelled materials of a few tens of kilobequerels activity. These type of materials can, subject to risk assessment, be suitable for 'on the bench' use. The Gamma/X-ray ionising radiation emissions from I-125 can be effectively attenuated by 1 mm of lead shielding, although on its own, this thickness of lead does not possess sufficient mechanical strength, so 3 mm lead, or lead with plywood backing is sometimes used. For practical laboratory use, a 1 cm lead-impregnated 'Perspex' shield is very effective. Lead-impregnated storage boxes and pipette shields are also avaiable. Contamination monitoring for I-125 is by the use of a 'Mini' 900 plus 44A type probe (or equivalent solid scintillant detector). If MBq activities of I-125 are used, self-monitoring of the thyroid can be carried out with a '44 A' type monitor. Contact the RPA if more than twice background readings are obtained when monitoring the thyroid. More detailed assessments of I-125 uptake can then be carried out at Addenbrooke's Hospital, particularly in the event of an accident or incident – contact the Safety Office or details.

5. Iodine-131 I-131, half-life 8 days

Beta radiaton of up to 606 keV and also significant gamma emission. More difficult to shield than I-125, and exposures can be of the order of twice that resultant from comparable activities of I-125. 11 mm of lead is needed to reduce the gamma dose rate from I-131 by 90%. Similar caution should be observed as with I-125, in terms of volatility and self-monitoring employed when using I-131. A 'Mini' EP15 (or equivalent Geiger-Muller monitor) is often the monitor of choice for contamination monitoring of I-131.

6. Sulphur-35 S-35, half-life 87.5 days

A beta emitter with a maximum energy of 168 keV. Avoid skin contact. Generally regarded as a 'safe' radionuclide, and, indeed the 'soft' beta is easily shielded by a millimetre of Perspex – but use 1 cm Perspex for mechanical strength and to prevent splashes to the body. Monitor using a Mini 900 plus EP15 probe (or equivalent). It must be remembered that some S-35 labelled products, including methionine, are prone to production of volatile fractions in storage, and **stock bottles should always be opened in a fume cupboard** to allow dispersal of any possible radioactive gaseous products. Also, if processes involving elevated temperatures are envisaged then these should be carried out in a well ventilated area or fume cupboard. Incubators used for S-35 should be mechanically ventilated to a large ventilated area. Activated charcoal will absorb some of the volatile material produced in incubators. These issues should be identified in the risk assessment. Film badges/TLDs are not useful for S-35 and may introduce a false sense of security. Regular contamination monitoring is the key to good control of S-35 in the working environment.

7. Phosphorus-33 P-33, half-life 25.6 days

The 250 keV beta emissions will barely penetrate the outer layer of the skin. However, as for C-14 and S-35, skin *contact* must be avoided as high local doses can occur. P-33 can be a 'safer' alternative to P-32, but of course with a rather longer half which can impact on waste disposal options. Contamination monitoring is best carried out with a 'Mini' 900 plus EP15 probe (or equivalent) and film badge/TLD can be used. As for P-32, this radionuclide is 'bone-seeking', thus estimating possible internal dose is an issue when considering risk assessments.

8. <u>Chromium-51</u> Cr-51, half-life 27.7 days

Cr-51 decays by electron capture, in 10% of cases via an excited state, resulting in a gamma emission of 320 keV. Now used much less frequently than previously, when many groups were undertaking 'Chromium release' assays in cell culture experiments. Cr-51 is a penetrating radionuclide, with 7 mm of lead required to reduce the radiation intensity to one tenth of the original amount. The biological half-live of ingested compounds can be long – up to 616 days is quoted, with the lung as the critical organ. Cr-51 is supplied in a thick lead pot, and should be stored and dispensed behind lead block shielding. The best monitor for Cr-51 surface contamination is a Mini-900 with a 44A or -B type probe.

9. <u>Sodium-22</u> Na-22, half-life 2.6 years.

Worthy of special mention due to the presence of significant beta+ (positron, 546 keV) and gamma (511 and 1275 keV) emissions. Close to the unshielded material the beta dose rate can be very high. Stocks of the radionuclide should be kept in "1 inch" wall thickness lead pots, surrounded, if practicable, by some further lead, with a lead sheet /plywood lid. (The amount of lead required to reduce the gamma emission by 50% is 10 mm). Ingested Na-22 can be bone deposited with extended biological half lives reported as >1% after 500 days. Users of Na-22, should, subject to risk assessment, wear whole body badges and finger TLDs. Dose rate and contamination monitoring ('Mini' E or EP15) should be carried out by users and the RPS.

10. <u>Other Positron Emitters: Fluorine 18, Carbon-11, Oxygen-15 and Copper-64</u>

These radionuclides are frequently used in Positron Emission Tomography, where annihilation photon pairs of 511 keV are used in medical diagnosis and research scanners. Positron radionuclides also emit high-energy beta+ particles/positrons which are a very significant factor when considering radiation protection for close contact handling of these materials. Handling precautions are similar as described for Na-22 above. These radionuclides have short or very short half-lives, ranging from two minutes for O-15 to 13 hours for Cu-64. This, of course, is a great benefit in medical applications, with only short periods of 'isolation' necessary for volunteers or patients who have received these radionuclides. Waste disposal options are also simplified by the short half lives, and environmental impacts are generally low, although the possible high local doses that might be received by persons working on or close to waste disposal facilities, must be considered in the prior risk assessment and BAT case.

*If you intend to use **<u>any</u>** radionuclide, including the above, and you do not have comprehensive data on its nature and effects, contact the University Safety Office for a copy of a detailed data sheet, and other advice. This will enable the proper completion of a prior risk assessment (including consideration of selective uptakes during pregnancy), and assist you to ensure that any exposures to ionising radiation are kept as low as reasonably practicable, and demonstrate that BAT is being observed*.

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Efficacy of shielding for selected isotopes

Isotope	Main emissions	shielding	comments
H-3	beta (19 keV)	< 0.1 mm Perspex	Shielding not normally needed except for splash shielding
C-11	beta (960 keV) gamma (511 keV)	beta: 3 mm Perspex gamma: 50%: 6 mm lead 90% 17 mm lead	
C-14	beta (157 keV)	0.3 mm Perspex	
O-15	beta (1732 keV) gamma (511 keV)	beta: 7 mm Perspex gamma: 50% 6 mm lead 90%: 17 mm lead	
F-18	beta (634 keV) gamma (511 keV)	beta: 2 mm Perspex gamma: 50%: 6 mm lead 90% 17 mm lead	
Na-22	beta (546 keV) gamma (511 and 1275 keV)	beta: 2 mm Perspex gamma: 50%: 10 mm lead 90%: 37 mm lead	Very high energy gamma!
P-32	beta (1710 keV)	7 mm Perspex	high foetal uptake
P-33	beta (249 keV)	1 mm Perspex	high foetal uptake otherwise safer than P-32
S-35	beta (168 keV)	1 mm Perspex	
Cr-51	gamma (320 keV)	50%: 2 mm lead 90%: 7 mm lead	
I-125	gamma (114 keV)	90%: <1 mm lead	Thyroid is main target organ if ingested

In the case of beta radiation, the depth of Perspex given will result in complete shielding. For gamma radiation, 50% refers to the half value thickness or the depth of lead needed to reduce radiation by half. 90% refers to the tenth value thickness, resulting in radiation being reduced ten-fold.