

Interpretation and implementation of adult diagnostic reference levels in nuclear medicine and PET in the UK

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In the UK, the Administration of Radioactive Substances Advisory Committee (ARSAC) sets and publishes National Diagnostic Reference Levels (NDRLs) for diagnostic nuclear medicine (NM) and Positron Emission Tomography procedures. This article summarises how these NDRLs should be applied and used within the UK and proposes a new model on how they are set. As an exemplar, the results of a recent survey of administered activities in the UK for ^{18}F -fluorodeoxyglucose (FDG) for whole-body tumour imaging and infection inflammation imaging are presented here. ARSAC recommends that the UK NDRLs for NM or PET examinations are set as either a fixed activity (MBq) or by administered activity per body weight (MBq/kg). ARSAC proposes setting the first weight-based activity

scaling NDRLs for ^{18}F -FDG whole-body tumour imaging and ^{18}F -FDG infection inflammation imaging to 3.5 MBq/kg. *Nucl Med Commun* 46: 379–383 Copyright © 2025 The Author(s). Published by Wolters Kluwer Health, Inc.

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Introduction

Diagnostic reference levels (DRLs) are defined within the Ionising Radiation (Medical Exposure) Regulations 2017 [1] and the Ionising Radiation (Medical Exposure) Regulations (Northern Ireland) 2018 [2] (IR(ME)R). For radiopharmaceuticals, DRLs are defined in IR(ME)R as levels of activity to be administered for typical examinations for groups of standard sized individuals.

IR(ME)R also requires that employers:

- establish local DRLs (LDRLs) for diagnostic exposures
- undertake appropriate reviews whenever DRLs are consistently exceeded
- ensure that corrective action is taken where appropriate
- set dose constraints or dose targets for research

LDRLs are usually specified within the examination protocols which are regularly reviewed as part of the employer's quality assurance programme. Operators should follow the examination protocols when undertaking exposures.

When setting LDRLs, employers should have regard to National DRLs (NDRLs) where available. In the UK, NDRLs for a range of commonly administered radiopharmaceuticals are presented in the Administration of Radioactive Substances Advisory Committee (ARSAC)

Notes for Guidance on the clinical administration of radiopharmaceuticals and use of sealed radioactive sources (NfG) [3]. ARSAC is an expert committee sponsored by the Department of Health and Social Care (DHSC) and members are appointed as independent experts from a range of relevant disciplines. Current NDRLs have been established by ARSAC through a combination of scientific literature reviews, committee input of good clinical practice and feedback from the nuclear medicine (NM) community. Each NDRL is published as a fixed level of activity, which are set based on a standard-size adult of 70 kg as described by the International Commission on Radiological Protection [4].

For diagnostic radiology, UK NDRLs are published on gov.uk [5] following approval by the UK Health Security Agency (UKHSA) working party on dose surveys and DRLs. This working party has representation from UKHSA, radiology professional bodies and DHSC. The methodology for establishing NDRLs for diagnostic radiology is based on national dose surveys, undertaken by UKHSA (previously Public Health England and the Health Protection Agency) or radiology professionals with input from UKHSA. The NDRLs are based on the body region examined and, where appropriate, the clinical requirement for the examination.

NDRLs for adult computed tomography (CT) examinations performed for attenuation correction and localisation as part of PET-CT and single-photon emission computed tomography-CT examinations are published on gov.uk [6].

Application of national diagnostic reference levels

The NDRLs presented within the ARSAC NfG are not expected to be consistently exceeded for standard sized

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patients (70 kg) when effective practice regarding diagnostic and technical performance is applied. However, the NDRLs are not a maximum limit. The NDRL may be exceeded for individual patients where clinical circumstances make it necessary, for example, patients who are overweight or unable to tolerate standard acquisition times.

In NM and PET, it is important that the administered activity for each individual exposure is optimised such that appropriate diagnostic information is obtained with the lowest practicable dose to the patient. This is the principle underlying optimisation. In many cases, it will be possible to administer activities less than the NDRL while still achieving diagnostic utility and this is encouraged by ARSAC. This may particularly be the case with the advancement of new technologies in clinical practice.

The application of NDRLs in NM and PET is different to the methods generally applied in diagnostic radiology where NDRLs and LDRLs are set based on surveys of groups of patients. For this reason, dose quantities from individual patients in diagnostic radiology should not be directly compared with NDRL or LDRL values. In diagnostic radiology, the NDRL is calculated as the 75th percentile of the range of expected values for patients of a standard size. It is, therefore, expected that some exposures will result in individual patient doses above the NDRL.

Diagnostic reference levels for nuclear medicine

For general NM, the NDRLs presented in the ARSAC NfG have been derived from a combination of historical data, expert advice on good clinical practice and scientific literature.

For most general NM administrations in adult patients, fixed activities are used, and weight-based scaling of the administered activity is not currently standard practice. However, for some administrations, for example, in nuclear cardiology, it is common to tailor activity to the weight range of the patient in 10 or 20 kg brackets, which may result in activity administered below or above the NDRL while maintaining diagnostic image quality. There could be scope to expand weight-based scaling to other radiopharmaceuticals and indications where there is supporting evidence. However, in some examinations where the radiopharmaceutical is taken up in a single organ or structure, the use of fixed activities is more appropriate, for example, thyroid or ioflupane (dopamine transporter) imaging. Other practicalities may need to be considered before weight-based scaling could be adopted in general NM. Where NM departments receive supplies of radiopharmaceuticals in individual patient syringes, it would not be practical to use weight-based scaling. Receiving radiopharmaceuticals in multidose vials does allow for the drawing up of activity based on the individual patient weight immediately

before administration, which will bring additional microbiological risks. Appropriate facilities would be required to draw up radiopharmaceuticals in compliance with UK Radiopharmacy Group guidance.

Diagnostic reference levels for PET

The PET NDRLs presented in the ARSAC NfG are for a 70 kg person and have been derived from a variety of sources including historical data, expert advice on good clinical practice and published sources. Some of the PET NDRLs such as ^{18}F -fluorodeoxyglucose (FDG) for whole-body tumour imaging were established when PET imaging was limited to a few UK centres. Over the last 20 years, there has been an expansion in the availability of PET imaging in the UK and the scanning technology has evolved significantly allowing improved optimisation of imaging protocols and the potential to reduce the dose to patients. The ARSAC NfG also includes guidelines for weight-based scaling for body imaging in a selection of PET procedures, but these are not formal NDRLs.

Most employer's examination protocols for whole-body PET imaging calculate the administered activity based on the patient's weight. Given the widescale use and efficacy of this approach, ARSAC supports this and accepts employer licence applications with proposed administered activities determined by weight, for example, specified as MBq/kg (with reference to EANM/SNMMI guidelines). In PET brain imaging, the use of a fixed activity may be appropriate as there is less variation in uptake and attenuation for a range of body weights. With PET administrations, the image quality depends on multiple factors beyond the administered activity, including scanner type, acquisition parameters and reconstruction methods. Practically, some protocols will adjust both administered activity and acquisition speed for the largest patients to ensure diagnostic image quality is maintained.

Employers may choose to use weight-based activity scaling or a fixed activity for their LDRL. The determination of LDRLs should use or be based on these guidelines or other published data and adapted for the optimised capabilities of local equipment and software. This should be detailed in local examination protocols including the employer's procedures. Using weight-based scaling should allow for administrations for a 70 kg person being less or equal to the current NDRL stated in the NfG.

Practical guidance on how to use local diagnostic reference levels

Within NM and PET, the administered activity for an individual patient should be measured and compared to the LDRL before administration. Where practical, this measurement should be independently checked by a second operator. The activity administered must be recorded in the individual patient record.

Table 1 Examples of local diagnostic reference levels and tolerance ranges of administered activity

Examination	NDRL	Example LDRL	Example tolerance % range	Range of activity that can be administered
^{99m}Tc -colloid: sentinel lymph node breast	40 MBq	40 MBq	$\pm 20\%$	32–48 MBq
^{99m}Tc -MDP: planar bone scans	600 MBq	600 MBq	$\pm 10\%$	540–660 MBq
^{99m}Tc -sestamibi: parathyroid studies	900 MBq	800 MBq	$-15\%/+5\%$	680–840 MBq
^{18}F -PSMA: prostate cancer imaging	280 MBq	4 MBq/kg	$\pm 10\%$	For a 60 kg patient: 216–264 MBq For a 70 kg patient: 252–308 MBq

LDRL, local diagnostic reference level; PSMA, prostate specific membrane antigen; MDP, methyl diphosphonate; NDRL, national diagnostic reference level; ^{99m}Tc , 99m-technetium.

It is common practice for employers to apply an administered activity tolerance range to their LDRLs. This considers the practical ability to accurately draw up the activity for an individual patient and the associated staff dose received when preparing and handling radiopharmaceuticals. The tolerance range can be different and/or asymmetric for specific examinations as can be seen in the examples in Table 1. The use of automatic dose drawing-up equipment may allow a narrower tolerance range to be set. It is essential that the tolerance range is defined in the employer's written procedures and consistently applied by all staff. To minimise administration errors, it is good practice to display the LDRLs and tolerance range in the area where individual patient doses are being prepared and measured before administration.

Where the LDRL is set at the same value as the NDRL, it is acceptable to administer activities above the NDRL provided it is within the local tolerance range in the employer's procedure. For example, if an employer has set the LDRL for 99m-technetium (^{99m}Tc)-MAG3 renograms at 100 MBq and an acceptable range of $\pm 10\%$ of the LDRL, operators may administer up to 110 MBq even though this is above the NDRL of 100 MBq.

Using local diagnostic reference levels to set research dose constraints and targets

Locally, employers should set a research dose constraint or target dose as appropriate for the exposures undertaken in research trials and the LDRLs may be used to establish this value as set out in the employers' procedures under IRMER. In the UK, a central review and approval is undertaken for all research trials, which includes an estimate for the total research protocol dose, usually calculated based on the NDRLs or other published guidance. Where the LDRL is higher than the NDRL this does not preclude the site from participating in the research trial or require the central review to be completed again to match the total protocol dose to the local research dose constraints or targets.

Employer licences

Where an employer makes a licence application to ARSAC for procedures by reference to functional groups

or specific procedure codes presented in the ARSAC NfG, then ARSAC expects that the LDRLs will be set at the NDRL or lower.

Where administered activity is increased beyond the LDRL based on an individual patient's weight or other clinical consideration, this should be justified by the licensed practitioner, and the details, including the actual activity administered, should be documented within the patient record. This requirement should be included in the employer's procedures. Where this becomes a regular process, but is still assessed for each individual patient, for example, where a fixed activity per kg body weight is administered, this should be included in the examination protocols. This can then be applied by staff other than the licensed practitioner, but the requirement to record the actual administered activity and the reason for the increase remains. In both the above scenarios, there is no need to inform ARSAC as the assessment of activity to administer is made on an individual patient basis.

An amendment to the employer licence should be submitted to ARSAC if there are local circumstances to justify setting the LDRL for a procedure at a fixed activity higher than the NDRL. For example, all patients for bone scans at the site have confirmed cancer, severe bone pain and are unable to tolerate a typical imaging time. If approved, the LDRL should be included within local examination protocols.

Local dose audits

To comply with IR(ME)R, employers should carry out regular audits on the administered activity. Audits are a useful tool for establishing LDRLs and ensuring compliance with LDRLs and any local tolerance range. Any administrations above the local tolerance range without a recorded justification should be investigated. As part of the audit process, actions should be identified, individuals tasked with their completion with timescales, and provision should be made to repeat the audit at an appropriate interval. Furthermore, the result of such audits in liaison with Medical Physics Experts, clinical scientists and as part of multidisciplinary Image Optimisation Teams (IOTs), can be used to optimise LDRLs, image quality and local examination protocols. The importance

of ensuring diagnostic image quality should be embedded in local IOT review processes.

Survey of the activity administered for ¹⁸F-fluorodeoxyglucose for whole-body tumour imaging and infection inflammation imaging

In October 2023, ARSAC conducted a survey on the administered activity used in the UK for ¹⁸F-FDG whole-body tumour imaging and ¹⁸F-FDG infection inflammation imaging. Responses were provided from 65 of the 114 UK sites licensed to perform these procedures (57%).

A total of 97% of the responses indicated a weight-based scaling was used, with only two responses indicating a fixed activity (350 MBq) was being used for all patients. The most used value for scaling the administered activity was 3.5 MBq/kg across all scanner technologies with the highest being 4 MBq/kg. These values are below the current weight-based scaling recommendation of 4.5 MBq/kg stated in the NfG at the time of publication.

For 80% of the responses, the sites indicated that they used the current NDRL (400 MBq) as the maximum activity they would administer for a patient of any weight, whereas the other 20% of responses indicated that the activity could be increased above this if required based on the patient’s weight. This use of the NDRL is consistent with the approach in general NM but this is not necessarily appropriate for whole-body PET imaging.

Given that image quality is also affected by the time taken to acquire the images, responders were asked about

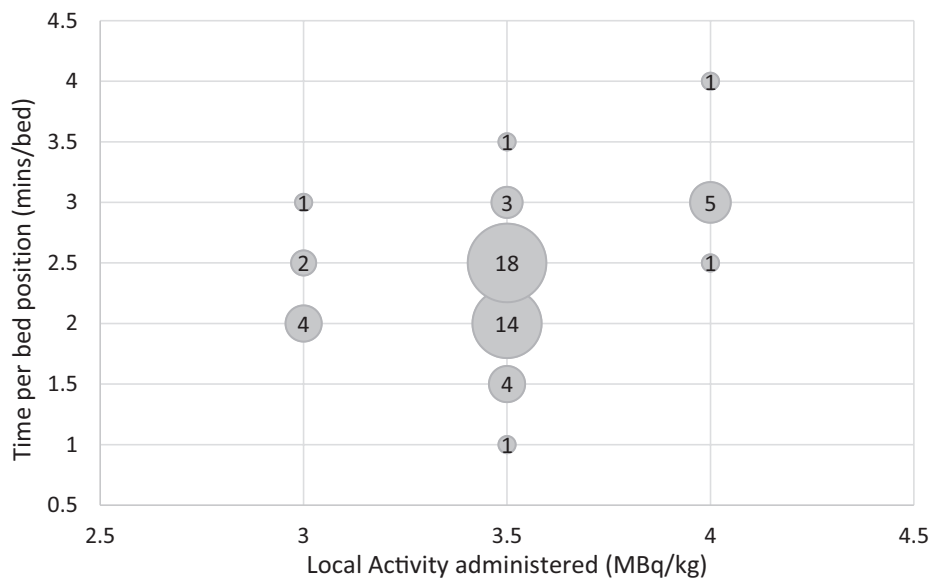
the parameters for the acquisition such as the time set to acquire in each bed position, overlap and continuous bed speed. Fifty-five responses were received with this information and Fig. 1 details the distribution of responses on the value used for tailoring the activity by weight where the time per bed position was specified. The size of the circles (and associated number) in Fig. 1 represents the number of centres using the same value for time per bed position and activity. As can be seen, the most common values were for 3.5 MBq/kg with a time of 2.5 min per bed position. At 10 sites, the weight-based activity scaling used may result in activities below the minimum recommended [7] based on the time per bed and overlap quoted.

No metrics regarding the acquired image quality were gathered during the survey so it is not possible to comment on whether this resulted in suboptimal image quality in the resultant images. Employers should ensure that the image quality of the protocol used is of sufficient diagnostic quality to answer the clinical question.

The survey results show that for a 70 kg patient, most sites are administering activity below the fixed activity NDRL of 400 MBq. The current NDRL was established when most PET scanners were using older technology which has now been improved. Newer technology allows for a reduction in administered activity while improving image quality and speeding up acquisition times.

ARSAC proposes changing the interpretation of an NDRL for NM and PET to allow either a fixed activity

Fig. 1



Distribution of the 55 survey responses showing the activity by weight (MBq/kg) against time per bed position (mins/bed). The size of the circles (and associated number) represents the number of centres using the same value for time per bed position and activity.

or a weight-based activity schedule. Based on this, and the survey data, ARSAC proposes setting the NDRL for ^{18}F -FDG whole-body tumour imaging and ^{18}F -FDG infection inflammation imaging to 3.5 MBq/kg. When this is ratified in the ARSAC NfG, the NDRL will be listed as a weight-based activity scaling factor with the fixed activity value quoted as the equivalent activity for a 70 kg standard size patient. The equivalent fixed activity NDRL for ^{18}F -FDG whole-body tumour imaging and ^{18}F -FDG infection inflammation imaging will be 245 MBq for a 70 kg patient. It would then be expected that for patients over 70 kg, the activity administered can be increased above the fixed activity NDRL to maintain image quality. As previously described, this would also not prohibit the use of greater activities or a higher weight-based scaling factor if justified by the practitioner on an individual patient basis.

Following assessment by local IOTs, employers may use weight-based activity scaling or a fixed activity for their LDRL; however, this should be set out clearly in the employers' procedures and protocol. Where weight-based scaling is used, local IOTs should determine whether a local upper limit on the activity will be set; however, this is not mandatory. The decision to set an upper limit may also be influenced by other factors including table weight limit and supply logistics. Following the change in the NDRL, employers should review their LDRL, imaging protocol and image quality to optimise local practice for this procedure. With the input of local IOTs, employers should optimise their imaging protocols for these examinations, such as the time per bed position, overlap or continuous bed speed. The fixed activity or the weight-based activity scaling used must be appropriate for the technology, equipment and protocol used while still providing optimised diagnostic quality images that are commensurate with the underlying clinical question. ARSAC would expect that where a site has an LDRL set at a weight-based scaling factor, this would be set at or below the NDRL value of 3.5 MBq/kg under standard circumstances.

Conclusion

For NM and PET imaging, NDRLs for a range of procedures are currently published by ARSAC as fixed activity values. NDRLs are not a maximum limit but should be

used by employers and other duty holders as part of the optimisation process required by IR(ME)R.

ARSAC proposes changing the interpretation of an NDRL for NM and PET imaging to allow either a fixed activity or a weight-based activity schedule. When this is ratified in the ARSAC NfG, an NDRL will be listed as a weight-based activity scaling factor with the fixed activity value quoted as the equivalent activity for a 70 kg standard-size patient.

Based on the results of the UK survey data, ARSAC proposes setting the first weight-based activity scaling NDRLs for ^{18}F -FDG whole-body tumour imaging and ^{18}F -FDG infection inflammation imaging to 3.5 MBq/kg.

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Conflicts of interest

There are no conflicts of interest.

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