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Changes to the Australian primary standards of absorbed dose and air kerma effective 1 January 2022



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Technical Report 186

January 2022 (expanded December 2022)

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Acknowledgement of Country

ARPANSA respectfully acknowledges Australia's Aboriginal and Torres Strait Islander communities and their rich culture and pays respect to their Elders past and present. We acknowledge Aboriginal and Torres Strait Islander peoples as Australia's first peoples and as the Traditional Owners and custodians of the land and water on which we rely.

We recognise and value the ongoing contribution of Aboriginal and Torres Strait Islander peoples and communities to Australian life and how this enriches us. We embrace the spirit of reconciliation, working towards the equality of outcomes and ensuring an equal voice.

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Executive Summary

On 1 January 2022 ARPANSA changed the values of the dosimetry quantities of air kerma and absorbed dose for Australia. This report documents these changes, and provides correction factors to adjust measurements made before the change (Table E1). In most cases the changes are very small and ARPANSA customers do not need to adjust calibration certificates issued before this time. However the correction factors supplied in Table E1 may be used for this purpose if the customer prefers, and may be helpful for quality assurance and consistency. The largest change, some 1%, occurs for air kerma at ⁶⁰Co.

All the changes are consistent with those made at other primary standards laboratories, and bring the Australian standards into closer agreement with international realisations of these quantities.

| Beam quality | Quantity | Primary standard | Relative change in quantity % | F Q ^α |
|--------------------|-----------------|-------------------------------------|----------------------------------|-------------------------|
| ⁶⁰ Co | Air kerma | CCC2 | -0.98 to -1.35 | 0.9864 |
| Low energy X-rays | Air kerma | LEFAC | -0.55 to -0.19 | 0.9966 ^b |
| Medium X-rays | Air kerma | MEFAC | -0.31 to -0.18 | 0.9976 ^b |
| ⁶⁰ Co | Dose to water | Calorimeter | -0.28 | 0.9972 |
| Linac MV photons | Dose to water | Calorimeter | 0 | 1 |
| Derived standards | | | | |
| Linac MV electrons | Dose to water | Calorimeter at ⁶⁰ Co | -0.28 | 0.9972 |
| ¹³⁷ Cs | Air kerma | CCC2 ⁶⁰ Co + MEFAC X-ray | -0.60 to -0.77 | 0.9923 |
| ¹³⁷ Cs | Dose equivalent | CCC2 ⁶⁰ Co + MEFAC X-ray | -0.60 to -0.77 | 0.9923 |
| ¹⁹² lr | Air kerma | CCC2 ⁶⁰ Co + MEFAC X-ray | -0.40 to -0.47 | 0.9953 |

Table E1: Changes to the Australian primary standards for absorbed dose and air kerma on 1 January 2022

^{*a*} F_Q is the correction factor which, when multiplied with a calibration coefficient issued in the period 2018-2021 (prior to the changes), results in the best estimate of the calibration coefficient including the changes. ^{*b*} This correction depends on the beam quality and is tabulated in Appendix A and B, however for the majority of beams the average value may be used.

Changes include:

- Changing from ICRU 37 to ICRU 90 interaction coefficients
- Renormalisation of photon cross sections
- Small statistical changes resulting from the recalculation of correction factors
- Small adjustments to modelled geometries
- New determinations of minor correction factors such as beam non-uniformity
- For ⁶⁰Co air kerma, a new primary standard cavity chamber, and contribution from the deviation of the source from its half-life corrected decay, which ranges from 0% in 2010 to -0.37% in 2021.

Table E2: The ARPANSA primary standards

| Acronym | Primary standard | Quantity and beam qualities |
|-------------|--------------------------------|---|
| LEFAC | Low Energy Free Air Chamber | air kerma for kilovoltage X-rays 10 kVp – 100 kVp |
| MEFAC | Medium Energy Free Air Chamber | air kerma for kilovoltage X-rays 50 kVp – 320 kVp |
| CCC2* | Carbon Cavity Chamber | air kerma at ⁶⁰ Co |
| Calorimeter | Graphite calorimeter | absorbed dose in megavoltage ⁶⁰ Co and linac beams |

*The "2" indicates the second iteration which replaced the previous standard in 2020.

1. Background

1.1 ICRU

The International Commission on Radiation Units and Measurements (ICRU) is an independent body that produces reports including recommendations on how best to measure radiation. The ICRU mission is: "To develop and promulgate internationally accepted recommendations on radiation related quantities and units, terminology, measurement procedures, and reference data for the safe and efficient application of ionizing radiation to medical diagnosis and therapy, radiation science and technology, and radiation protection of individuals and populations."

ICRU Report 37 (Berger *et al.*, 1984) contains recommendations and values for physical data which directly affect the realisation of the dosimetric quantities kerma and absorbed dose. These values have been used by standards laboratories since 1984.

1.2 BIPM, CIPM, CCRI

The International Bureau for Weights and Measures (BIPM) is an intergovernmental organisation with a mission to promote international uniformity and equivalence of measurement standards. It coordinates comparisons and communication between Member States through the International Committee for Weights and Measures (CIPM) to ensure consistency in standards and measurement methods. The Consultative Committee for Ionizing Radiation (CCRI) is comprised of representatives from National Measurement Institutes with ionising radiation measurement standards. The CCRI reports to the CIPM. Australia is a signatory to the Metre Convention which establishes the BIPM, and ARPANSA is a member of CCRI Section I.

1.3 ICRU Report 90

In 2016, the ICRU published updated key data for ionizing radiation dosimetry in ICRU Report 90 (Seltzer *et al.*, 2016). The recommendations in this document include changes to the mean excitation energy of water (I_w) and graphite (I_g), the application of the density effect correction for graphite and the uncertainty in the average energy required to create an ion pair in air (W_{air}). It included the addition of a new combined correction factor that corrects for the measurement of the charge of the particle that causes the initial ionisation as well as the increase in the W_{air} value for lower energies ($k_{ii}k_w$). It also provided a review of the available data for photon cross sections including the multi-configuration Dirac-Fock (MCDF)/Dirac-Hartree-Fock-Slater (DHFS) renormalisation factors. The CCRI subsequently endorsed the use of the updated key data in ICRU Report 90 and the renormalised photon cross sections calculated by Sabbatucci and Salvat (2016).

1.4 International adoption of ICRU Report 90

The use of primary standards to realise the dosimetric quantities of kerma and absorbed dose relies on material properties such as interaction cross sections and the energy released per ion pair in air, W_{air} . These values were adjusted in ICRU Report 90, and hence primary standards laboratories around the world have been re-evaluating their standards of kerma and dose.

At the 26th meeting of the CCRI in 2017, members agreed to implement the data in ICRU Report 90 into their standards on 1 January 2018. However, in practice most laboratories took longer than that to implement the changes, as the effort to recalculate all of the corrections and understand new corrections was considerable.

1.5 The Australian primary standards for radiation dosimetry

ARPANSA maintains four primary standards for the dosimetry of ionising radiation. These are all detectors of radiation. They realise the quantities of kerma or absorbed dose from first principles by linking the relevant dosimetry quantity to traceable measurements of the energy deposited and the mass of a material (air or graphite) when irradiated. Standards of kerma do this by measuring ionisation in air, and the ARPANSA standard of absorbed dose to water measures the temperature rise in a disk of graphite when irradiated.

| Acronym | Primary standard | Quantity and beam qualities |
|-------------|--------------------------------|---|
| LEFAC | Low Energy Free Air Chamber | air kerma for kilovoltage X-rays 10 kVp – 100 kVp |
| MEFAC | Medium Energy Free Air Chamber | air kerma for kilovoltage X-rays 50 kVp – 320 kVp |
| CCC2* | Carbon Cavity Chamber | air kerma at ⁶⁰ Co |
| Calorimeter | Graphite calorimeter | absorbed dose in megavoltage ⁶⁰ Co and linac beams |

Table 1-1: The ARPANSA primary standards

*The "2" indicates the second iteration which replaced the previous standard in 2020.

These standards are very similar to overseas standards in the given energy ranges. Changes due to the adoption of ICRU Report 90 are therefore expected to be highly correlated with changes at other primary standards laboratories.

1.6 Recommendations of ICRU Report 90

The recommendations of ICRU Report 90 are summarized in Chapter 7 of that report as follows:

"Recommended values and uncertainties are given for W_{air} , the average energy required to produce an ion pair, the heat defect of liquid water, h_w , and the radiation chemical yield for the Fricke dosimeter, G(Fe³⁺). A new value is also recommended for the product, W_{air} $s_{g,air}$ for ⁶⁰Co γ -rays. The humidity correction, k_h , for air-filled ionization chambers is reviewed, but no changes are recommended. However, it is noted that, for high precision of k_h with relative humidity or, more properly, with the partial pressure of water vapor, should be considered. Data for the heat defect of graphite are reviewed, but no definitive conclusions could be reached and more study is recommended.

The value of W_{air} for electrons is left unchanged at 33.97 eV, but its standard uncertainty has been increased from 0.05 eV (0.15 %) to 0.12 eV (0.35 %). This will have an impact on the uncertainty of air-kerma standards based on free-air chambers and will for many standards become the dominant component. The available data for W_{air} indicate that it can be considered constant at high energies. However, for electron energies below about 10 keV, W_{air} cannot be considered constant. Furthermore, when the air kerma is obtained from a charge measurement, a correction should be applied for the charge of the initial electrons set in motion by the photons. The combined correction for these last two effects can be significant for low-energy photons (up to 0.7 %) and could give rise to changes in primary standards. Recommendations have been made for the mean excitation energies for air, graphite, and liquid water as well as for the graphite density to use when evaluating the density effect (2.265 g cm⁻³). From these recommendations, tables of the stopping powers for electrons, protons, alpha particles, and carbon ions have been generated. For air, no change in the value of the mean excitation energy is recommended, i.e., I_{air} = 85.7 eV but now with an uncertainty of 1.2 eV (1.4 %); stopping power values for all particles thus remain unaltered, except for carbon ions, for which an I_{air} value of 82.8 eV was implicitly used in ICRU Report 73 (2005). The value of I_g has increased from 78 eV to 81 eV, and the standard uncertainty decreased from 4 eV to 1.8 eV. The increase in the mean excitation energy and the change in the density used to evaluate the density-effect correction both result in a decrease in the electronic stopping power in graphite decreases by about 0.7 %, while for high-energy electrons, the decrease is more than 1 %. For liquid water, there is a 4 % relative increase in I_w , from 75 eV, as used in ICRU Report 37, to 78 eV, with a relative standard uncertainty of 2.6 %, which also results in a decrease in the electronic-stopping-power values.

For protons and carbon ions, the change in electronic stopping powers relative to the values given in previous ICRU Reports, which, in addition to the changes in I values and densities mentioned above, are based on improved calculations using the Bethe–Bloch expression for $S_{\rm el/p}$, and are complemented with experimental data at low energies.

For photons, following the analysis of photoeffect cross-sections with regard to the use of renormalized values and of the two options for determining Compton cross-sections (impulse approximation versus Waller-Hartree theory), tables of mass energy-absorption coefficients for air, graphite, and water have been given. No recommendations on the choice of these options are given in this Report, but some discussion is included on the effects of considering them. With these changes, the fraction g of the photon energy transferred to charged particles and subsequently lost on average in radiative processes remains unaltered."

1.7 CCRI recommendations for primary standards

A report by the CCRI summarised the expected changes to primary standards (McEwen *et al.*, 2017) and they are reproduced here in abridged form:

1 Regarding Wair:

i No change in $W_{\rm air}$ or $g_{\rm air}$ for energies above 10 keV

ii An increase in the uncertainty for $W_{\rm air}$ from **0.15% to 0.35%** (except for the special case of 60 Co, see 4.ii)

iii Application of an energy-dependent W_{air} value for electron energies below 10 keV. This is realized through the application of the product $k_{ii}k_w$.

2 Regarding I-values and stopping powers:

i The density of graphite to be used when evaluating the graphite density effect is $\rho_{\rm g}$ = 2.265 g cm⁻³.

ii A change in the I-value for graphite from 78 eV to 81 eV, standard uncertainty = 1.8 eV

iii A change in the I-value for water from 75 eV to 78 eV, standard uncertainty = 2.0 eV.

iv No change in the I-value for air (85.7 eV), standard uncertainty = 1.2 eV.

v A change in I-value for air to 82.8 eV for <u>carbon ion dosimetry only</u>

vi Use of improved calculations of the stopping powers for proton and carbon ions (also impacted by revised I-values).

3 Regarding cross-sections:

i <u>Renormalized</u> photoeffect cross-sections should be used.

4 Regarding changes be applied to primary standards:

i New corrections for k_{ii} and k_w to be included in air-kerma determinations using free-air chambers

ii Revised value for $W_{air}.s_{g,air} = 33.72 \text{ eV}$ (relative standard uncertainty = 0.08%) to be used for ⁶⁰Co air kerma and absorbed dose standards based on a cavity ionization chamber.

iii No change in the heat defect of graphite or water.

5 Regarding other standards

The adoption of ICRU 90 data will also impact other air kerma and dose standards. However, since the changes are somewhat specific to the individual standards, it is not possible to define a firm recommendation. The impacts include, but are not limited to:

i Changes to Ir-192 air kerma standards

ii Value and uncertainty of $W_{air.sg,air}$ for Cs-137

iii Value and uncertainty of water/graphite conversions for MV absorbed dose standards based on graphite calorimeters.

The recommendations of the CCRI were adopted for the recalculation of the correction factors for the ARPANSA primary standards.

1.8 Other changes affecting the ARPANSA standards

In addition to these externally driven changes, there are some other changes that affect ARPANSA's standards that were implemented at the same time.

- Monte Carlo (MC) calculations for these updates have been performed using a newer version of the EGSnrc software (Kawrakow and Rogers, 2000) and in some cases using new applications that weren't available when the original calculations were performed.
- Some simulation geometries have been modified to match the measurement setup more accurately.
- The primary standard for air kerma in ⁶⁰Co, a carbon cavity ionisation chamber, has been replaced with a new chamber of a similar design.

- Additional MC generated correction factors for the kilovoltage free air chambers introduced with the publication of the egs_fac EGSnrc application (Kawrakow *et al.*, 1999) are also being introduced.
- Some changes to the sources (e.g. replacement of kilovoltage tubes) and small deviations from the expected decay have also resulted in small changes.

The only universal change is the use of a recent version of the EGSnrc software. All MC calculations that support the current ARPANSA standards have been performed using previous versions of the EGSnrc code, with software release dates ranging from 2008 to 2014. The calculations for these updates have been performed using the 2018 and 2020 EGSnrc releases.

The free-air chamber (FAC) modelling previously used a modification to the program in order to calculate the required corrections. Since those calculations were completed, a new application designed specifically for modelling FAC corrections, egs_fac, has been released. In this update, egs_fac was used to calculate the corrections for the low-energy and medium-energy FACs (LEFAC and MEFAC). egs_fac calculates a self-consistent set of correction factors that convert the energy deposited in the collection volume to air kerma at the point of measurement. This set includes all of the previous correction factors along with new factors that correct for the lack of charged particle equilibrium, scattering geometry differences between 'true' air kerma with and without the FAC, beam geometry, and for differences between simulations and measurements. These have been adopted except for the correction for beam geometry asymmetry and the differences between simulations and measurements. The full derivation of all the correction factors is provided in the paper by Mainegra-Hing *et al.* (2008).

In 2015, ARPANSA's Seifert X-ray tube and generator was replaced with a Gulmay Comet X-ray tube and generator in a new housing (collimators, filters, monitor chamber) supplied by Hopewell Systems Inc. As a result, the reference distance was moved from 1.3 m to 1.0 m. The MEFAC corrections were calculated for monoenergetic beams and convolved with the spectrum for each beam so it was not necessary to re-model them immediately following the new installation. In this update, however, the corrections have all been modelled at a distance of 1.0 m to match the calibration conditions. The difference in corrections due to reference distance in the simulation is small.

Finally, over the last few years ARPANSA have been commissioning a new carbon cavity chamber to replace the primary standard for air kerma in ⁶⁰Co. This commissioning is complete and with this update the old carbon cavity chamber is retired and replaced with the new chamber.

2. How to use this report

This report details the changes to the ARPANSA primary standards in ionising radiation dosimetry as a result of the updates described in Section 1. These changes are presented as a correction factor, F_Q , which corrects an air kerma or absorbed dose calibration coefficient (N_K or $N_{D,W}$) obtained prior to the 1 January 2022 so that the updates for the ICRU 90 report and other changes may be applied without re-calibrating the ionisation chamber. F_Q is a multiplicative factor specific to each beam quality; the calibration coefficient issued before the ICRU 90 changes must be multiplied by the F_Q for the same beam quality to obtain a corrected calibration coefficient:

$$N_{\mathrm{K},Q,\mathrm{ICRU90}} = F_Q N_{\mathrm{K},Q} \tag{1}$$

Where:

- $N_{K,Q,ICRU90}$ the air kerma calibration coefficient at beam quality Q corrected for the changes in the ICRU 90 report and other changes
- $N_{K,Q}$ the air kerma calibration coefficient obtained prior to 1 January 2022

The same approach applies to absorbed dose calibrations:

$$N_{\mathrm{D,w},Q,\mathrm{ICRU90}} = F_Q N_{\mathrm{D,w},Q} \tag{2}$$

The F_Q factors for all ARPANSA calibration beams are tabulated throughout this report.

The factor F_Q may also be applied to quantities of air kerma and absorbed dose and their associated rates, in cases where these quantities are traceable to ARPANSA prior to the change.

3. Absorbed dose to water for ⁶⁰Co gamma rays

ARPANSA maintains a therapy level ⁶⁰Co source for calibrations against the primary standards for absorbed dose and air kerma in ⁶⁰Co. Absorbed dose to water is realised using the graphite calorimeter which measures dose to graphite, and a calculated factor is used to determine the corresponding dose to water when the same beam is incident on a water phantom instead of the calorimeter (Lye *et al*, 2013).

3.1 Primary standard graphite calorimeter

The Australian primary standard for absorbed dose to water in ⁶⁰Co and in accelerator photon beams is a graphite calorimeter. The calorimeter is based on the design of Domen (1974). The depth of the sensitive core is approximately 0.5 cm of graphite. The measurement depth is matched to the equivalent depth in water appropriate for the source type by adding graphite plates to the front of the calorimeter to increase the total graphite thickness between the source and the core. The calorimeter is described in detail in an ARPANSA technical report by Ramanathan *et al.* (2014).



Figure 3-1: Graphite calorimeter, the primary standard for absorbed dose in ⁶⁰Co and megavoltage linac photon beams

The graphite calorimeter measures the absorbed dose to graphite directly by measuring the temperature increase in graphite due to irradiation. The absorbed dose to water is achieved using a conversion factor calculated by the EGSnrc MC code. In the MC calculation for the current standard, the entire calorimeter is simulated and the dose to the core calculated. The dose to water is calculated in a cylinder of water with a diameter of 30 cm at the calibration depth of 5 cm. The MC conversion for the current standard was calculated using the 2008 version of EGSnrc. The absorbed dose to water rate in ⁶⁰Co, \dot{D}_w , is simply the absorbed dose to graphite rate, \dot{D}_g , measured by the calorimeter multiplied by the MC conversion factor, $(D_w/D_g)_{MC}$, as in the equation below.

$$\dot{D}_w = \dot{D}_g \left(D_w / D_g \right)_{\rm MC} \tag{3}$$

3.2 Recalculation

The $(D_w/D_g)_{MC}$ conversion factor has been recalculated in the 2018 version of EGSnrc using the new interaction coefficients recommended in ICRU Report 90 and the renormalised photon cross sections. The model was re-validated with the new EGSnrc version by checking a modelled PDD against the measured PDD. This showed a slight mismatch which required a small adjustment to the ⁶⁰Co source model prior to performing the calculations for dose to water and dose to graphite.

The absorbed dose to graphite was calculated using the same modelled geometry as the original calculation and the new ⁶⁰Co source model. The new source model was used to calculate the absorbed dose to water in a cylindrical phantom matching the original calculation and also in a cubic water phantom with a side length of 35 cm and a 2.4 mm polycarbonate window.

Each modification contributes a small part to the change to the absorbed dose standard. The overall shift in absorbed dose to water in ⁶⁰Co is -0.28%. The individual components of the change and the shift attributed to each are shown below in Table 3-1. The ICRU Report 90 update correction factor is listed in Table 3-2.

| Table 3-1: Change to the ARPANSA primary standard of absorbed dose to water in ⁶⁰ Co. The change is attributed to |
|--|
| the use of a newer version of EGSnrc for the calculation, updated key data from ICRU Report 90 and a new |
| simulation geometry. The incremental changes are listed for each component, with the final change to the dose to |
| water value listed in the last line of the table. |

| Changes made | (D _w /Dg) _{MC} conversion ratio | Attributed change to <i>D</i> w | Cumulative change from original |
|--|--|------------------------------------|---------------------------------------|
| Original factor | 1.0743 ± 0.21% | 0.0% | 0.0% |
| New EGSnrc version only (old source model) | 1.0721 ± 0.11% | -0.21% | -0.21% |
| New EGSnrc version and new key data | 1.0705 ± 0.10% | -0.14% | -0.35% |
| New EGSnrc version, key data and water phantom model | 1.0713 ± 0.07% | +0.07% | -0.28% |

3.3 Changes

The combined effect of these changes on the ARPANSA absorbed dose to water at ⁶⁰Co and the calibration coefficients issued for ionisation chambers) is a reduction of 0.28% given in Table 3-2. The factor F_Q in Table 3-2 can be used to correct calibration coefficients issued before the change, by multiplication.

Table 3-2: ARPANSA update correction factor (Fq) for absorbed dose to water in ⁶⁰Co.

| Quantity | Fq |
|--|--------|
| Absorbed dose to water in ⁶⁰ Co | 0.9972 |

4. Absorbed dose to water for linac megavoltage X-rays

The calorimeter described in Section 3.1 is the primary standard for absorbed dose to water in megavoltage beams. As in ⁶⁰Co, a MC conversion is used to calculate dose to water from the measured absorbed dose to graphite. In this case, the absorbed dose to water is calculated in a geometry that matches the water phantom used for calibration. The reference depth in water is 10 cm. Secondary standard chambers are calibrated against the calorimeter annually and each client chamber is calibrated against two secondary standard chambers. The entire calibration process is described by Wright *et al.* (2015). The ARPANSA linac that is used for calibrations up until 2021 is an Elekta Synergy. Calibrations are performed at three beam qualities: 6 MV, 10 MV and 18 MV with tissue phantom ratios (TPR_{20,10}) of 0.673, 0.734 and 0.777. The Synergy was replaced by an Elekta Versa with slightly different beam qualities in 2021 but the same corrections have been shown to apply.

4.1 Primary standard graphite calorimeter

The same graphite calorimeter (Section 3.1) is used for megavoltage photon beams. A different thickness of graphite plates is used to reach a better approximation to the equivalent area density (in graphite) of 10 cm of water. The dose to water is calculated by MC methods in a cubic water phantom with a side length of 35 cm and a 2.4 mm polycarbonate window at a depth of 10 cm. The absorbed dose to water rate in each megavoltage beam, \dot{D}_w , is the absorbed dose to graphite rate, \dot{D}_g , measured by the calorimeter multiplied by the MC conversion factor, $(D_w/D_g)_{MC}$.

4.2 Recalculation

An important part of the beam model validation for the linac is the matching of PDDs in water and graphite to ensure the incident electron energy is modelled correctly. Since the changes to key data affect water and graphite, the PDDs were simulated with the updated key data to ensure the model was accurate with the new attenuation coefficients and dose deposition. The models for all beam qualities were acceptable and did not require adjustment. The absorbed dose to graphite (calorimeter core) and water were then recalculated. No change was found in the MC dose conversion ratio $(D_w/D_g)_{MC}$.

4.3 Changes

The calibration coefficients $N_{D,w}$ do not change as a result of adopting ICRU Report 90 and hence $F_Q = 1$ (Table 4-1).

Table 4-1: ARPANSA update correction factor (Fq) for N_{D,w} in megavoltage photon beams.

| Quantity | TPR _{20,10} | Fq |
|------------------------------------|-----------------------------|----|
| $N_{\rm D,w}$ in 6 MV photon beam | 0.673 | 1 |
| $N_{\rm D,w}$ in 10 MV photon beam | 0.734 | 1 |
| $N_{\rm D,w}$ in 18 MV photon beam | 0.777 | 1 |

However a complication arises because chamber calibrations are reported by ARPANSA in terms of the ⁶⁰Co calibration coefficient $N_{D,w,Co-60}$ and k_Q , the ratio of absorbed dose to water calibration coefficients in megavoltage photon and ⁶⁰Co beams. Therefore if the $N_{D,w,Co-60}$ is updated, then k_Q must also be multiplied by the inverse factor so that there is no overall change in $N_{D,w,Q}$. The F_Q factors that should be applied to the reported k_Q factors are listed in Table 4-2, noting that that the $N_{D,w,Co-60}$ coefficient must be updated at the same time, and the F_Q for k_Q is simply the inverse of the F_Q for $N_{D,w,Co-60}$.

Table 4-2: ARPANSA update correction factor (F_Q) for k_Q values in megavoltage photon beams.

| Quantity | TPR _{20,10} | Fq |
|--|----------------------|--------|
| $k_{\rm Q}$ factor in 6 MV photon beam | 0.673 | 1.0028 |
| $k_{ m Q}$ factor in 10 MV photon beam | 0.734 | 1.0028 |
| $k_{ m Q}$ factor in 18 MV photon beam | 0.777 | 1.0028 |

ARPANSA maintains two linacs and beam quality specification $TPR_{20,10}$ are slightly different for the newer model. However the same corrections apply because these relate to the shift in the ⁶⁰Co dose to water and not to the linac determination of dose to water.

Care should be taken not to mix modified k_Q factors with unmodified $N_{D,w}$ coefficients.

5. Air kerma for ⁶⁰Co gamma rays

The air kerma standard for ⁶⁰Co lost some of its importance when radiotherapy in Australia moved to dosimetry protocols based on absorbed dose to water standards around 2003. However it remains critical to establish air kerma for protection measurements, including personal monitoring, and for some radiotherapy applications such as brachytherapy, where Australia has no absorbed dose standards. Australia does not have a primary standard for ¹³⁷Cs, and the standard at ⁶⁰Co is interpolated with 250-300 kVp X-rays to provide traceability at this common beam quality.

5.1 Primary standard Carbon Cavity Chamber CCC

The primary standard for air kerma in ⁶⁰Co is a carbon (graphite) cavity chamber. The standard until 1 January 2022 is a thick-walled pancake graphite cavity chamber, 10.8 mm thick with a diameter of approximately 50 mm. The central electrode is a 1 mm thick graphite disc suspended in the cavity on teflon-coated aluminium rods. The cavity chamber is positioned with the front face centred on the beam axis and the centre of the chamber at an SDD of 100 cm.



Figure 5-1: CCC primary standard (now decommissioned)

The air kerma is calculated from the measured charge, q_{net} , using the following equation:

$$K_{air} = W_{air} \frac{q_{net}}{\rho_{air} V(1 - \bar{g}_{air})} s_{c,air} \left(\frac{\mu_{en}}{\rho}\right)_{air,c} \prod_{i} k_i$$
(5)

Where:

- K_{air} the air kerma at the point of measurement
- *W*_{air} the average energy required to create an ion pair in dry air
- ρ_{air} the density of air at standard temperature and pressure
- V the volume of air inside the cavity chamber
- g_{air} the fraction of energy lost by bremsstrahlung
- $s_{c,air}$ the ratio of stopping powers in graphite (carbon) and air in the ⁶⁰Co spectrum at the point of measurement
- $(\mu_{en}/\rho)_{air,c}$ the ratio of mass energy absorption coefficients in air and graphite in the ⁶⁰Co spectrum at the point of measurement
- $\prod_i k_i$ the product of all correction factors

There are several correction factors including measured factors and those calculated empirically or using MC simulations. Corrections for air density, considered separately for temperature (k_T) and pressure (k_P) , are calculated from measurements of the temperature and pressure at the time of the charge measurement. Other empirical corrections are recombination (k_s) , beam radial non-uniformity (k_{rn}) and scattering from the stem (k_{st}) . A humidity correction (k_H) calculated from data in ICRU Report 31 (ICRU, 1979) corrects from a relative humidity of 50% to 0%. EGSnrc was used to calculate the wall correction factor (k_{wall}) using a model of the ARPANSA carbon cavity chamber and ⁶⁰Co source. kwall is the product of the wall attenuation (k_{at}) and chamber wall scatter (k_{sc}) corrections. In addition, $s_{c,air}$, $(\mu_{en}/\rho)_{air,c}$ and g_{air} were also calculated using EGSnrc with the same ⁶⁰Co source model. MC calculations were all completed prior to 2010.

For calibrations traceable to the primary standard for air kerma in ⁶⁰Co, the air kerma rate is measured periodically and the reference air kerma rate on the calibration date is calculated using a decay correction applied to the measured air kerma rate.

5.2 Primary standard Carbon Cavity Chamber CCC2

ARPANSA has purchased a new carbon cavity chamber (CCC2) from the BIPM to replace the current primary standard. The new chamber is a more modern design and allows for future proofing in the event of failure of ageing equipment. The dimensions of the chamber were measured accurately at the National Measurement Institute Australia (NMIA) before and after assembly by the BIPM, enabling an accurate calculation of the internal air cavity volume. The new chamber is 11.1 mm thick and 51 mm in diameter with a 1 mm thick central electrode. Commissioning measurements began in 2015 and the chamber has shown excellent stability and agreement with the current primary standard. It replaced the older chamber as the Australian primary standard for air kerma in ⁶⁰Co in January 2022.

For the implementation of the new chamber the air volume V, k_{st} , k_{at} and k_{wall} were evaluated. The volume was calculated using the chamber dimensions measured by the NMIA. k_{st} was measured by attaching a dummy stem to the chamber stem. Correction factors k_{at} and k_{wall} are also affected by the key data changes and were recalculated as described below.



Figure 5-2: Carbon Cavity Chamber 2 (CCC2) primary standard

5.3 Recalculation

Some elements of the air kerma calculation are affected by the changes to key physical data. Only one of these, W_{air} , is a physical constant; the remaining affected elements are MC factors (which depend on physical constants). All MC factors were recalculated using the EGSnrc application (2018) with the new key data and using the geometry of the new cavity chamber. The factor responsible for the largest change is the stopping power ratio, $s_{c,air}$, and was calculated using the SPRRZnrc application (Rogers *et al.*, 2003). Massenergy absorption coefficients (μ_{en}/ρ)_{air,c} and bremsstrahlung loss g_{air} were calculated using the DOSRZnrc (Rogers *et al.*, 2003) and *g* applications respectively. The correction factors k_{an} and k_{wall} were both calculated using CAVRZnrc (Rogers *et al.*, 2003). The updated ⁶⁰Co source model described in Section 3.2 was used for the calculation of all air kerma factors here.

The value of W_{air} is unchanged in the ICRU 90 report and the uncertainty in its value is increased. However, due to the significant correlation between W_{air} and $s_{g,air}$ the uncertainty in the product of these quantities is reduced.

5.4 Other effects resulting in changes

While commissioning the new cavity chamber, two additional changes to the reference air kerma rate were identified. The first is due to the new standard. Although the factors calculated by MC are very similar to those calculated for the older standard, the measurements revealed a shift of -0.25%. The second change is due to drift of the ⁶⁰Co source compared to that expected rate of decay over a period of approximately 10 years. The reference air kerma rate in ⁶⁰Co was measured 10 years ago and the rate is corrected for decay during calibrations. As a result of this method, the uncorrected drift has been transferred to calibrations performed at ARPANSA. This causes a shift of up to -0.37% depending on when the calibration was performed.

The overall change in the air kerma rate in ⁶⁰Co when implementing all the changes described is -1.35%. The shifts attributed to each change are listed in Table 5-1.

| Table 5-1: | | | | | |
|--|-------------------|------------------------------------|--|--|--|
| Incremental changes made to the primary standard for air kerma in ⁶⁰ Co | Attributed change | Cumulative change from original | | | |
| New EGS version only (using ICRU Report 37 key data and old cavity chamber) | -0.14% | -0.14% | | | |
| New EGS version and ICRU Report 90 key data (old cavity chamber) | -0.79% | -0.79% | | | |
| New cavity chamber (MC only) ^{<i>a</i>} with ICRU Report 90 key data | +0.06% | -0.73% | | | |
| New cavity chamber including measurements | -0.25% | -0.98% | | | |
| Apparent source deviation from expected decay ^b | -0.37% | -1.35% | | | |

^{*a*} This shift does not include differences in the chamber volume or measured current.

^b Value at 30 November 2021, magnitude decreasing from 0 in 2010.

5.5 Changes

The correction factor for air kerma, air kerma rate and air kerma calibration coefficients in ⁶⁰Co is given in Table 5-2. The 2021 value is 0.9864 which includes all the changes.

| Table 5-2: ARPANSA update correction facto | or (F_Q) for air kerma and N_K in ⁶⁰ Co beams. |
|--|---|
|--|---|

| Quantity | Fq |
|-------------------------------|---------|
| Air kerma at ⁶⁰ Co | 0. 9864 |

6. Air kerma for 10 to 100 kVp X-rays

The primary standard maintained by ARPANSA for low energy X-rays (10 to 100 kVp) is the low energy free air chamber (LEFAC). The LEFAC measures air kerma for low energy X-ray beams generated by a Philips RT-100 X-ray tube. The RT-100 is an approximately constant-potential generator tungsten target therapy X-ray system. It generates X-rays with peak voltages ranging from 10 to 100 kV. A full summary of the beams used during calibration is shown below in Table 6-1.

| Beam ID | Nominal kVp | Nominal tube current | Effective energy ^a | Added Al filtration | Added Cu filtration | HVL |
|---------|----------------|-------------------------|----------------------------------|---------------------|------------------------|-------|
| | kV | mA | keV | mm | mm | mm Al |
| RT1 | 20 | 10 | 10 | 0.15 | | 0.109 |
| RT2 | 30 | 10 | 13 | 0.30 | | 0.20 |
| RT3 | 37 | 10 | 15 | 0.40 | | 0.33 |
| RT4 | 45 | 10 | 18 | 0.55 | | 0.52 |
| RT5 | 55 | 10 | 20 | 0.78 | | 0.79 |
| RT6 | 70 | 10 | 24 | 1.25 | | 1.28 |
| RT7 | 100 | 8 | 29 | 1.70 | | 2.17 |
| RT8 | 100 | 8 | 48 | 1.02 | 0.25 | 6.53 |

Table 6-1: Details of the low energy X-ray beams used for calibrations at ARPANSA

^a The energy of a monoenergetic beam with the same HVL in mm of Al

In addition, there are four RT-100 beams used during international comparisons with other primary standards laboratories. These are detailed in Table 6-2.

| Beam ID | Nominal kVp | Nominal tube current | Effective energy ^{a,b} | Added Al filtration | Added Cu filtration | HVL |
|----------|----------------|-------------------------|------------------------------------|------------------------|------------------------|-------|
| | kV | mA | keV | mm | mm | mm Al |
| CCRI-10 | 10 | 10 | 7.2 | 0 | | 0.038 |
| CCRI-30 | 30 | 10 | 12 | 0.205 | | 0.17 |
| CCRI-50b | 50 | 10 | 22 | 1.00 | | 1.00 |
| CCRI-50a | 50 | 10 | 30 | 4.00 | | 2.35 |

Table 6-2: Details of the low energy X-ray beams used for comparisons at ARPANSA

 $^{\it a}$ The energy of a monoenergetic beam with the same HVL in mm of Al

^b Effective energy is calculated including 50 cm of air in the beam path

The calibration procedure at ARPANSA consists of a measurement of the ratio of the electrical currents from the standard chamber (LEFAC) and the monitor chamber, followed by a measurement of the ratio of the client chamber and monitor chamber. The monitor chamber corrects for any variations in the output of the X-ray tube. The air kerma is determined from the LEFAC current and used to calculate the calibration coefficient of the client chamber.

The currents measured in the LEFAC, monitor chamber and ionisation chamber are all corrected for temperature. The ratio to the monitor chamber is assumed to correct for any pressure variation. The LEFAC

current is also corrected for the relative humidity to 0% humidity (dry air). The calibration is performed at a source to detector distance (SDD) of 30 cm and beam diameter of 5 cm. For international comparisons using the CCRI beams, a SSD of 50 cm and a beam diameter of 9 cm is used.

6.1 Primary standard Low Energy Free Air Chamber (LEFAC)

The primary standard that ARPANSA maintains for air kerma in low energy X-rays (10 - 100 kVp) is the LEFAC. The point of measurement of the LEFAC is defined by a circular limiting aperture with a radius of 0.5 cm. The collecting volume is centred 8.5 cm from the aperture. It is defined by the collecting electrode which is parallel to and 6 cm from the high voltage electrode. The collecting electrode is 6 cm in height and 2 cm wide in the beam direction. A previous publication by Lye *et al.* describes the LEFAC in more detail (Lye *et al.*, 2010).



Figure 6-1: Low Energy Free Air Chamber

The following equation converts the charge measured by the LEFAC (Q) into air kerma (K_a) at the point of measurement:

$$K_a = \frac{W_{air}}{e} \frac{Q}{m} \frac{1}{1-g} \prod k_i \tag{6}$$

Where:

- K_a the air kerma at the point of measurement
- W_{air} the average energy required to create an ion pair in dry air.
- *e* elemental charge.
- *m* the mass of the air defined by the length of the collecting volume and the area of the limiting aperture
- g the fraction of energy lost by bremsstrahlung (assumed negligible for these energies)
- $\prod_i k_i$ the product of all correction factors

The air kerma at the point of measurement is defined by several correction factors. Depending on the correction factor, they are determined using the MC method (Lye *et al.*, 2010), through measurement, or calculated analytically.

The correction factors that are measured are:

- k_{TP} corrects for temperature and pressure
- $k_{\rm H}$ corrects for humidity
- *k*_s corrects for saturation
- k_{wall} corrects for transmission through the walls of the free air chamber
- k_{dist} corrects for distortion of the electric field
- k_{rn} corrects for beam non-uniformity

The values of k_{wall} , k_{dist} and k_{rn} are set to 1 for the LEFAC, but are included here as they contribute to the uncertainty budget.

The correction factors that are calculated are:

• k_a – corrects for the air attenuation between the centre of the LEFAC and the centre of the collection volume some 8.5 cm behind the aperture. This correction is also corrected by k_{TP} as at low energies the air attenuation can change significantly with air density.

The MC calculated correction factors that were used prior to the adoption of this report were:

- $k_{\rm e}$ corrects for the electron loss
- k_{fl} corrects for the contribution due to fluorescent photons
- $k_{\rm sc}$ corrects for the contribution due to scattered photons
- $k_{\rm tr}$ corrects for transmission or scattering from the non-perfect limiting aperture

The corrections k_{TP} and k_{H} are calculated at the time of calibration, from measurements of temperature pressure and humidity. Correction k_{S} was determined at commissioning. The k_{a} value is calculated individually for each beam quality using an analytical narrow beam attenuation calculation. All MC based correction factors are calculated for monoenergetic photon beams and then convolved with the photon spectra to calculate beam specific correction factors.

6.2 Recalculation

The adoption of ICRU Report 90 by ARPANSA and the CCRI brings with it some changes to the primary standards for kilovoltage X-ray air kerma, namely the use of the renormalised photoelectric effect cross sections and the inclusion of the new correction factor $k_{ii}k_{W}$.

The measured correction factors k_s **do** not change with the adoption of ICRU Report 90 data as they are based purely on measurements. The air attenuation correction k_a , was previously calculated with a narrow beam attenuation using photon cross sections without the MCDF normalisation. The updated k_a is calculated with MC, as it has been shown that this is more self-consistent (Mainegra-Hing *et al.*, 2008), but the inclusion of the MC generated correction factor may introduce small differences.

The MCDF renormalised photoelectric effect cross sections, defined in Section 1.6, are used in conjunction with the NIST XCOM photon cross section database using the EGSnrc cross section library mcdf-xcom. The difference in the calculated FAC correction factors was assessed with and without the renormalised cross sections to determine the difference due to the new cross sections being used.

The second change due to the adoption of ICRU Report 90 is the new correction factor that corrects for the charge measurement due to the particle from the initial ionisation event and the increase in W_{air} for photons < 10 keV. This combined factor, $k_{ii}k_{w}$, is also described in Section 1.6 and in detail in the ICRU Report 90. The ICRU 90 report also lists a table of $k_{ii}k_{w}$ factors for a range of photon energies \leq 400 keV which allows for interpolation based on photon spectra. The calculated spectra of the low energy X-ray beams at ARPANSA were used to interpolate through the published monoenergetic $k_{ii}k_{w}$ values to calculate the values for these beams.

The recalculation also introduces changes due to the how the FAC was modelled. The previous MC correction factors were calculated in 2008 (Lye *et al.*, 2010). The LEFAC was modelled in a modified version of BEAMnrc to allow for the use of the latch variable to determine interaction types. Two model types were used. The first version modelled the source a parallel beam and was used to calculate the correction factors k_{e} , k_{sc} , and k_{fl} , described above. A second two-part model modelled a) the source a diverging point source incident on the aperture and scored a phase space after the aperture and then b) modelled the phase space incident on the LEFAC. This was used to calculate the k_{tr} , also described above. The two-part model was used for efficiency purposes, as the runtime of the diverging source was significantly larger. In all cases, the monoenergetic correction factors were calculated and then convolved with the calculated spectra to determine beam-specific correction factors.

In the updated modelling of the FAC, a new EGSnrc application, egs_fac, was used. egs_fac is an ESGSnrc application derived from the C++ class library that allows for the direct calculation of several correction factors, including all those mentioned in Section 6.1, as well as new correction factors (Kawrakow *et al.*, 2019). egs_fac allows for the calculation of new factors, including:

- k_{CPE} a correction for the lack of true-CPE in the direction of the beam
- k_b a correction for the difference at the point of measurement when the FAC is not present for photons that backscatter. Note that this factor is under consideration by the CCRI Section I. It is not currently included in either the pre or post ICRU 90 ARPANSA correction factors, although we expect that it will be included at some point in the future, once a consensus between the standards laboratories is reached.
- k_x a method to correct for differences between the measurement and simulation of the air attenuation (k_a)
- k_{g} a correction for the geometry of the beam not being a point source or parallel beam source, relevant as those assumptions are used to calculate other correction factors

It should also be noted that egs_fac calculates a single k_{sc} that is a product of the previous k_{sc} and k_{fl} , i.e. it accounts for secondary photons regardless of whether they are generated by a fluorescent or other scattering event. For a full derivation and discussion on these correction factors, see Mainegra-Hing *et al.* (2008).

ARPANSA has chosen to adopt k_{CPE} and $k_{ii}.k_w$, but not k_X , k_b or k_g . Factors k_{CPE} and $k_{ii}.k_w$ were adopted because they are corrections to real phenomena. The factor k_g is not included as the correction factors presented in this report are all calculated with a diverging point source (so $k_x \approx 1$). Factor k_x is not adopted as recent work has shown that the adoption of the renormalised photoelectric effect cross sections gives very good agreement between measurement and simulation (Mainegra-Hing, 2019). The backscatter correction k_b should be included however the international community should discuss this factor first, to ensure a consistent approach to the calibration of client chambers. The recalculated correction factors are therefore the product of the following correction factors defined above: k_a , k_{el} , k_{sc} (noting that the new k_{sc} is the product of the old k_{sc} and k_{fl}), k_{tr} , k_{CPE} , and $k_{ii}k_{W}$. They are compared to the product of the following previous correction factors: k_a , k_{el} , k_{sc} , k_{fl} , and k_{tr} . Detailed comparisons are given in Appendix A and B.

All previous correction factors calculated with the BEAMnrc models in 2008 were regenerated with egs_fac by calculating the monoenergetic components in 2 keV bins. Spectral weighted convolutions were then performed to determine the correction factors for each beam. This is described in detail in the previous publication (Lye *et al.*, 2010). All new correction factors for the LEFAC are calculated in a simulation that samples the photon source from the spectrum, thereby calculating the correction factors specific to the input spectrum. The monoenergetic components were also calculated to allow for comparison to previous simulations, and very good agreement was seen.

6.3 New correction factors

Table presents the correction F_Q which may be applied to calibrations performed before 1 January 2022 to correct them for the adoption of the changes detailed in this report. The contribution to the final correction due to the inclusion of the $k_{ii}k_W$ factor and the updated MC model is shown for interest.

Table 6-3: ARPANSA update correction factor (F_Q) for the low energy beam qualities. The contribution to the total correction factor is broken down to the two components, the $k_{ii}k_W$ factor, and the updated MC model (including ICRU Report 90 renormalised cross sections, and new correction factors), where F_Q is the product of both. Note: due to the precision presented in this table, differences occur in the least significant figure.

| Beam ID | HVL mm Al | Contribution from k _{ii} k _w | Contribution from new MC | Combined change |
|----------|--------------|---|-----------------------------|-----------------|
| RT1 | 0.109 | 0.9963 | 0.9983 | 0.9945 |
| RT2 | 0.20 | 0.9969 | 0.9969 | 0.9938 |
| RT3 | 0.33 | 0.9972 | 0.9991 | 0.9964 |
| RT4 | 0.52 | 0.9975 | 1.0000 | 0.9975 |
| RT5 | 0.79 | 0.9977 | 1.0009 | 0.9986 |
| RT6 | 1.28 | 0.9979 | 1.0003 | 0.9981 |
| RT7 | 2.17 | 0.9979 | 0.9990 | 0.9969 |
| RT8 | 6.53 | 0.9979 | 0.9993 | 0.9972 |
| CCRI-10 | 0.038 | 0.9954 | 1.0055 | 1.0009 |
| CCRI-30 | 0.17 | 0.9968 | 0.9983 | 0.9951 |
| CCRI-50b | 1.00 | 0.9978 | 0.9999 | 0.9977 |
| CCRI-50a | 2.35 | 0.9980 | 0.9993 | 0.9973 |

6.4 Changes

The correction factor F_Q for air kerma in low energy X-rays is given in Table 6-4. Further details of the changes are given in Appendix A.

Table 6-4: ARPANSA update correction factor (Fq) for the low energy beam qualities.

| Beam ID | Nominal kVp | Fq |
|----------|-------------|--------|
| RT1 | 20 | 0.9945 |
| RT2 | 30 | 0.9938 |
| RT3 | 37 | 0.9964 |
| RT4 | 45 | 0.9975 |
| RT5 | 55 | 0.9986 |
| RT6 | 70 | 0.9981 |
| RT7 | 100 | 0.9969 |
| RT8 | 100 | 0.9972 |
| CCRI-10 | 10 | 1.0009 |
| CCRI-30 | 30 | 0.9951 |
| CCRI-50b | 50 | 0.9977 |
| CCRI-50a | 50 | 0.9973 |

7. Air kerma for 40 to 320 kVp X-rays

The primary standard for X-rays in the 40 to 320 keV range is the medium energy free air chamber (MEFAC). The MEFAC (described in Section 7.1) is used to measure the air kerma for a range of X-ray beams generated by a tungsten target Gulmay Comet X-ray generator. Some 59 different medium energy X-ray (MEX) beams are used during a standard radiotherapy calibration, covering a range of beam energies and filtrations. A subset of these beams covering this range is shown below in Table 7-1, and the full beam data is provided in Appendix B. Other sets of beams are available for protection-level (ISO) and diagnostic (RQR, RQA, RQT, HHR) calibrations and comparisons. The details of these are all provided in Appendix B.

| Beam ID | Nominal kVp | Effective energy ^a | Added Al filtration | Added Cu filtration | HVL | HVL |
|---------|----------------|----------------------------------|---------------------|------------------------|-------|-------|
| | kV | keV | mm | mm | mm Al | mm Cu |
| NXA50 | 50 | 29.9 | 4.00 | | 2.39 | 0.08 |
| NXA70 | 70 | 34.3 | 4.00 | | 3.19 | 0.11 |
| NXB100 | 100 | 41.6 | 4.50 | | 4.74 | 0.18 |
| NXC120 | 120 | 48.9 | 6.00 | | 6.38 | 0.28 |
| NXD140 | 140 | 58.1 | 9.00 | | 8.44 | 0.45 |
| NXE150 | 150 | 72.2 | 4.00 | 0.5 | | 0.84 |
| NXF200 | 200 | 94.7 | 4.00 | 1.0 | | 1.63 |
| NXG250 | 250 | 120.1 | 4.00 | 1.6 | | 2.57 |
| NXH280 | 280 | 147.1 | 4.00 | 3.0 | | 3.50 |
| NXH300 | 300 | 153.2 | 4.00 | 3.0 | | 3.70 |

Table 7-1: Details of the medium energy X-ray beams used for calibrations at ARPANSA

^{*a*} The energy of a monoenergetic beam with the same HVL in mm of Cu

7.1 Primary standard Medium Energy Free Air Chamber (MEFAC)

The primary standard that ARPANSA maintains for air kerma in medium energy X-rays (40 - 320 kVp) is the MEFAC. The point of measurement of the LEFAC is defined by a circular limiting aperture with a radius of 0.5 cm. The collecting volume is centred 29.7 cm from the aperture. It is defined by the collecting electrode which is parallel to and 18 cm from the high voltage electrode, and is 30 cm in height and 10.1 cm wide in the beam direction. A previous publication by Lye *et al.* (2010) describes the MEFAC in more detail.

The determination of the air kerma at the point of measurement of the MEFAC is the same as for the LEFAC. The charge from ionisation events in the collecting volume of the MEFAC is measured and converted to air kerma at the point of measurement. This is done with Equation 6, using correction factors calculated for the MEFAC for each beam quality.



Figure 7-1: Medium Energy Free Air Chamber

7.2 Recalculation

The recalculation of the factors is performed in the same manner as the LEFAC recalculations using egs_fac. The same set of new MC correction factors (k_a , k_{sc} , k_{el} , k_{tr} , k_{CPE}) are calculated along with the $k_{ii}k_W$ factor. These are compared to previous MC factors (k_{sc} , k_{fl} , k_{el} , and k_{tr}) and calculated factors (k_a) to determine the effect of both the new MC approach and the adoption of ICRU Report 90. As for the LEFAC, the correction factor k_b was calculated but not used at this time.

7.3 Correction factors

Table 7-2 presents the correction F_Q for a subset of MEX beams which may be applied to calibrations performed before 1 January 2022 to correct them for the adoption of the changes detailed in this report. The contribution to the final correction due to the inclusion of the $k_{ii}k_W$ factor and the updated MC model is shown for interest. F_Q factors for the complete list of beam qualities can be found in Appendix B. Table 7-2: ARPANSA update correction factor (F_Q) for a subset of the medium energy beam qualities at ARPANSA. The contribution to the total correction factor is broken down to the two components, the $k_{ii}k_W$ factor, and the updated MC model (including ICRU Report 90 renormalised cross sections, and new correction factors), where F_Q is the product of both. Note: due to the precision presented in this table, differences occur in the least significant figure.

| Beam ID | HVL mm Cu | Contribution from k _{ii} k _w | Contribution from new MC | Combined change (F _Q) |
|---------|--------------|---|-----------------------------|--------------------------------------|
| NXA50 | 0.08 | 0.9980 | 0.9999 | 0.9979 |
| NXA70 | 0.11 | 0.9980 | 0.9998 | 0.9978 |
| NXB100 | 0.18 | 0.9979 | 0.9996 | 0.9975 |
| NXC120 | 0.28 | 0.9980 | 0.9995 | 0.9974 |
| NXD140 | 0.45 | 0.9980 | 0.9993 | 0.9973 |
| NXE150 | 0.84 | 0.9981 | 0.9991 | 0.9972 |
| NXF200 | 1.63 | 0.9984 | 0.9990 | 0.9974 |
| NXG250 | 2.57 | 0.9987 | 0.9989 | 0.9976 |
| NXH280 | 3.50 | 0.9989 | 0.9986 | 0.9975 |
| NXH300 | 3.70 | 0.9990 | 0.9984 | 0.9974 |

7.4 Changes

The correction factor F_Q for air kerma in medium energy X-rays is given in Table 7-3. Further details of the changes, itemised for the full set of available beam qualities, are given in Appendix B.

| Table 7-3: ARPANSA update correction facto | r (F _Q) for key medium energ | y radiotherapy beam | qualities (see |
|--|--|---------------------|----------------|
| Appendix B for all beam qualities). | | | |

| Appendix b for an beam quanties). | | | | | | |
|-----------------------------------|-----|--------|--|--|--|--|
| Beam ID | kVp | FQ | | | | |
| NXA50 | 50 | 0.9979 | | | | |
| NXA70 | 70 | 0.9978 | | | | |
| NXB100 | 100 | 0.9975 | | | | |
| NXC120 | 120 | 0.9974 | | | | |
| NXD140 | 140 | 0.9973 | | | | |
| NXE150 | 150 | 0.9972 | | | | |
| NXF200 | 200 | 0.9974 | | | | |
| NXG250 | 250 | 0.9976 | | | | |
| NXH280 | 280 | 0.9975 | | | | |
| NXH300 | 300 | 0.9974 | | | | |

8. Changes for other radiation qualities

For radiation qualities where a primary standard is not available, traceability to the Australian standard of air kerma is achieved by linear interpolation between two primary standard beam qualities. Where one or both of the beam qualities used in the interpolation are shifted due to corrections applied following the implementation of the ICRU 90 report, the interpolated air kerma value will also shift. Two commonly-used radiation qualities likely to be affected by the changes in this report are ¹³⁷Cs and ¹⁹²Ir.

8.1 ¹³⁷Cs

As a verifying authority for the NMI, ARPANSA provides certification of air kerma rates and calibrations in a ¹³⁷Cs beam. The measurement of air kerma uses an interpolation between the ARPANSA NXH300 X-ray beam (with an effective energy of 153 keV) and ⁶⁰Co. Interpolating the F_Q values for these beams to ¹³⁷Cs gives a shift of between -0.60% and -0.77% depending on when the calibration was performed in the period 2010-2021. We recommend the value given in Table 8-1 be applied for calibrations issued in the period 2018-2021 prior to the changes. Note however that for protection-level calibrations and air kerma measurements for low level sources, the magnitude of the shift is like to be small compared to the uncertainty of the measurement (typically at least 2% at k=1), and so for many clients a correction is not necessary.

Table 8-1: ARPANSA update correction factor (F_Q) for air kerma and N_K in ¹³⁷Cs beams.

| Quantity | Fq |
|--------------------------------|--------|
| Air kerma at ¹³⁷ Cs | 0.9923 |

8.2 ¹⁹²lr

Typically users calculate an air kerma calibration coefficient for ¹⁹²Ir by interpolating between the calibration coefficients at a high energy X-ray beam and ⁶⁰Co to a weighted average energy for ¹⁹²Ir. In this case, users should correct the X-ray and ⁶⁰Co calibration factors using the F_Q factors provided in Sections 7 and 5 respectively and then perform the interpolation as they have previously done. Alternatively, combining these values for a typical Ir-192 spectrum gives F_Q in Table 8-2 which may be applied for calibrations issued in the period 2018-2021 prior to the changes.

Table 8-2: ARPANSA update correction factor (F_Q) for air kerma and N_K in ¹⁹²Ir beams.

| Quantity | Fq |
|--------------------------------|--------|
| Air kerma at ¹⁹² Ir | 0.9953 |

8.3 Ambient dose equivalent and personal dose equivalent

The quantities ambient dose equivalent H^* and personal dose equivalent Hp are most commonly derived using factors published in the international standard ISO 4037 (ISO, 1999) which convert from the air kerma to the quantity of interest. Where this is the case the changes are exactly those as expected from the changes to the relevant ARPANSA air kerma standard. The realisation of these quantities involves significant uncertainty (2% at k=1 in ISO 4037) arising from the use of a calculation factor to get the dose at the point of interest from the air kerma. Hence for most users the change in the primary standards is less than the uncertainty and is therefore may be ignored in many cases. Nevertheless the values of F_Q are summarised in Table 8-3 for the correction of the ambient and personal dose equivalent.

Table 8-3: ARPANSA update correction factor (Fq) for ambient and personal dose equivalent.

| Quantity | Fq |
|---|--------|
| Ambient and personal dose equivalent 40 – 320 kVp X-rays | 0.9976 |
| Ambient and personal dose equivalent at ¹³⁷ Cs | 0.9923 |
| Ambient and personal dose equivalent at ⁶⁰ Co | 0.9864 |

9. References

Berger, M.J., Inokuti, M., Anderson, H.H., Bichsel, H., Dennis, J.A., Powers, D., Seltzer, S.M. and Turner, J.E., 1984, Stopping powers for electrons and positrons. *ICRU Report 37*.

Domen, S.R., and Lamperti, P.J., 1974, A heat-loss-compensated calorimeter: theory, design, and performance. *Journal of research of the National Bureau of Standards. Section A, Physics and Chemistry*, *78*(5), 595-610.

ICRU, 1979, Average energy required to produce an ion pair. ICRU Report 31.

ISO, 1999, X and gamma reference radiation for calibrating dosemeters and doserate meters and for determining their response as a function of photon energy - Part 3: Calibration of area and personal dosemeters and the measurement of their response as a function of energy and angle of incidence. *ISO* 4037-3:1999. International Organization for Standardization, Geneva.

Kawrakow, I., Mainegra-Hing, E., Tessier, F., Townson, R. and Walters, B., 2019, The EGSnrc C++ class library. *NRC Report PIRS-898*, National Research Council Canada, Ottawa.

Kawrakow, I., and Rogers, D.W.O., 2000, The EGSnrc code system. *NRC Report PIRS-701*, National Research Council Canada, Ottawa.

Lye, J.E., Butler, D.J. and Webb, D.V., 2010, Monte Carlo correction factors for the ARPANSA kilovoltage free-air chambers and the effect of moving the limiting aperture. *Metrologia*, 47(1), 11-20.

J. E. Lye, D. J. Butler, R. D. Franich, P. D. Harty, C. P. Oliver, G. Ramanathan, D. V. Webb and T. Wright, Direct MC conversion of absorbed dose to graphite to absorbed dose to water for ⁶⁰Co radiation, *Radiation Protection Dosimetry* (2013), 155 (1), 100–109.

Mainegra-Hing, E., 2019, Can we use Monte Carlo calculated free-air chamber attenuation corrections? IDOS, Vienna, Austria.

Mainegra-Hing, E., Reynaert, N. and Kawrakow, I., 2008, Novel approach for the Monte Carlo calculation of free-air chamber correction factors. *Medical physics*, *35*(8), 3650-3660.

McEwen, M., Burns, D., Darienzo, M., de Pooter, J., Pinto, M. and Rapp, B., 2017, Report to CCRI(I) on the recommendations of ICRU Report 90. *Report CCRI(I)/17-07*.

Ramanathan, G., Harty, P., Wright, T., Lye, J., Butler, D., Webb, D., and Huntley, R., 2014, The Australian Primary Standard for absorbed dose to water (graphite calorimeter). *Technical Report No. 166*, Yallambie: Australian Radiation Protection and Nuclear Safety Agency.

Rogers, D.W.O., Kawrakow, I., Seuntjens, J.P., Walters, B.R.B., and Mainegra-Hing, E., 2003, NRC user codes for EGSnrc. *NRCC Report PIRS-702* (Rev. B), National Research Council Canada, Ottawa.

Sabbatucci, L. and Salvat, F., 2016, Theory and calculation of atomic photoeffect. *Radiation Physics and Chemistry*, *121*, 122.

Seltzer, S.M., Fernandez-Varea, J.M., Andreo, P., Bergstrom, P.M., Burns, D.T., Krajcar Bronić, I., Ross, C.K., and Salvat, F., 2016, Key data for ionizing-radiation dosimetry: measurement standards and applications. *ICRU Report 90*.

Wright, T., Lye, J.E., Ramanathan, G., Harty, P.D., Oliver, C., Webb, D.V., and Butler, D.J., 2015, Direct calibration in megavoltage photon beams using Monte Carlo conversion factor: validation and clinical implications. *Physics in Medicine & Biology*, *60*(2), 883.

Appendix A: All data for 10 to 100 kVp X-rays

This appendix contains a more detailed breakdown of the changes, component by component. The beam qualities are summarised in Table B-1 and the overall changes in Table B-2. The full breakdown in individual components is given in Tables B-3 (old) and B-4 (new), and the ratio between these given in Table B-5. The definitions of the correction factors are given in Section 6.

| Beam ID | Nominal kVp | Nominal tube current | Effective energy ¹ | Added Al filtration | Added Cu filtration | HVL | Combined corrections ² prior to | Combined corrections ² post | Fq |
|-----------------------|-------------|-------------------------|----------------------------------|---------------------|------------------------|-------|---|---|--------|
| | kV | mA | keV | mm | mm | mm Al | 1 January 2022 | 1 January 2022 | |
| RT1 | 20 | 10 | 10 | 0.15 | | 0.109 | 1.0477 | 1.0420 | 0.9945 |
| RT2 | 30 | 10 | 13 | 0.30 | | 0.20 | 1.0275 | 1.0211 | 0.9938 |
| RT3 | 37 | 10 | 15 | 0.40 | | 0.33 | 1.0171 | 1.0135 | 0.9964 |
| RT4 | 45 | 10 | 18 | 0.55 | | 0.52 | 1.0103 | 1.0077 | 0.9975 |
| RT5 | 55 | 10 | 20 | 0.78 | | 0.79 | 1.0052 | 1.0038 | 0.9986 |
| RT6 | 70 | 10 | 24 | 1.25 | | 1.28 | 1.0047 | 1.0028 | 0.9981 |
| RT7 | 100 | 8 | 29 | 1.70 | | 2.17 | 1.0155 | 1.0124 | 0.9969 |
| RT8 | 100 | 8 | 48 | 1.02 | 0.25 | 6.53 | 1.0365 | 1.0337 | 0.9972 |
| CCRI-10 ³ | 10 | 10 | | 0 | | 0.038 | 1.1518 | 1.1529 | 1.0009 |
| CCRI-30 ³ | 30 | 10 | | 0.205 | | 0.17 | 1.0330 | 1.0279 | 0.9951 |
| CCRI-50b ³ | 50 | 10 | | 1.00 | | 1.00 | 1.0050 | 1.0026 | 0.9977 |
| CCRI-50a ³ | 50 | 10 | | 4.00 | | 2.35 | 1.0022 | 0.9995 | 0.9973 |

Table A-1: Details of the low energy X-ray beams used at ARPANSA

¹ The energy of a monoenergetic beam with the same HVL in mm of Cu

² Includes the correction k_{air} calculated for 20 degrees C, 101.325 kPa and an air path of 8.5 cm inside the LEFAC.

³ Corrections calculated at 50 cm SDD.

| Beam ID | ke | ksc | ktr | kfl | Product ksc.kfl | ks | kair ¹ | kii.kw | kCPE | Combined product |
|-----------------------|--------|--------|--------|--------|--------------------|--------|-------------------|--------|------|---------------------|
| RT1 | 1.0000 | 0.9974 | 1.0000 | 0.9964 | (0.9938) | 1.0005 | 1.0537 | 1 | 1 | 1.0477 |
| RT2 | 1.0001 | 0.9976 | 1.0000 | 0.9970 | (0.9946) | 1.0005 | 1.0324 | 1 | 1 | 1.0275 |
| RT3 | 1.0001 | 0.9978 | 1.0000 | 0.9973 | (0.9951) | 1.0005 | 1.0215 | 1 | 1 | 1.0171 |
| RT4 | 1.0001 | 0.9978 | 1.0000 | 0.9976 | (0.9954) | 1.0005 | 1.0143 | 1 | 1 | 1.0103 |
| RT5 | 1.0002 | 0.9979 | 0.9996 | 0.9979 | (0.9958) | 1.0005 | 1.0092 | 1 | 1 | 1.0052 |
| RT6 | 1.0023 | 0.9980 | 0.9994 | 0.9981 | (0.9961) | 1.0005 | 1.0064 | 1 | 1 | 1.0047 |
| RT7 | 1.0148 | 0.9981 | 0.9991 | 0.9985 | (0.9966) | 1.0005 | 1.0045 | 1 | 1 | 1.0155 |
| RT8 | 1.0382 | 0.9983 | 0.9981 | 0.9992 | (0.9975) | 1.0005 | 1.0023 | 1 | 1 | 1.0365 |
| CCRI-10 ² | 1.0000 | 0.9964 | 1.0000 | 0.9949 | (0.9913) | 1.0005 | 1.1613 | 1 | 1 | 1.1518 |
| CCRI-30 ² | 1.0001 | 0.9974 | 1.0000 | 0.9966 | (0.9940) | 1.0005 | 1.0386 | 1 | 1 | 1.0330 |
| CCRI-50b ² | 1.0002 | 0.9979 | 1.0000 | 0.9979 | (0.9958) | 1.0005 | 1.0085 | 1 | 1 | 1.0050 |
| CCRI-50a ² | 1.0004 | 0.9981 | 1.0000 | 0.9984 | (0.9965) | 1.0005 | 1.0048 | 1 | 1 | 1.0022 |

Table A-2 LEFAC correction factors in use from 2010 and prior to 1 January 2022

 k_{air} calculated for 20 degrees C, 101.325 kPa and an air path of 8.5 cm inside the LEFAC.

² Corrections calculated at 50 cm SDD.

| Beam ID | ke | ksc | ktr | kfl | Product ksc.kfl | ks | kair ¹ | kii.kw | kCPE | Combined product |
|-----------------------|--------|-----|--------|-----|--------------------|--------|---------------------|--------|--------|---------------------|
| RT1 | 1.0000 | - | 0.9999 | - | 0.9943 | 1.0005 | 1.0515 | 0.9963 | 0.9999 | 1.0420 |
| RT2 | 1.0000 | - | 0.9998 | - | 0.9951 | 1.0005 | 1.0290 | 0.9969 | 0.9999 | 1.0211 |
| RT3 | 1.0000 | - | 0.9998 | - | 0.9955 | 1.0005 | 1.0206 | 0.9972 | 0.9999 | 1.0135 |
| RT4 | 1.0000 | - | 0.9997 | - | 0.9959 | 1.0005 | 1.0142 | 0.9975 | 0.9999 | 1.0077 |
| RT5 | 1.0001 | - | 0.9996 | - | 0.9962 | 1.0005 | 1.0099 | 0.9977 | 0.9999 | 1.0038 |
| RT6 | 1.0019 | - | 0.9995 | - | 0.9966 | 1.0005 | 1.0065 | 0.9979 | 0.9999 | 1.0028 |
| RT7 | 1.0138 | - | 0.9988 | - | 0.9970 | 1.0005 | 1.0045 | 0.9979 | 0.9999 | 1.0124 |
| RT8 | 1.0372 | - | 0.9982 | - | 0.9977 | 1.0005 | 1.0023 | 0.9979 | 0.9999 | 1.0337 |
| CCRI-10 ² | 1.0000 | - | 1.0000 | - | 0.9927 | 1.0005 | 1.1661 ³ | 0.9954 | 1.0000 | 1.1529 |
| CCRI-30 ² | 1.0000 | - | 1.0000 | - | 0.9949 | 1.0005 | 1.0360 ³ | 0.9968 | 1.0000 | 1.0279 |
| CCRI-50b ² | 1.0002 | - | 1.0000 | - | 0.9963 | 1.0005 | 1.0079 ³ | 0.9978 | 1.0000 | 1.0026 |
| CCRI-50a ² | 1.0004 | - | 1.0000 | - | 0.9967 | 1.0005 | 1.0039 ³ | 0.9980 | 1.0000 | 0.9995 |

Table A-3 LEFAC correction factors in use after 1 January 2022

 k_{air} calculated for 20 degrees C, 101.325 kPa and an air path of 8.5 cm inside the LEFAC.

² Corrections calculated at 50 cm SDD.

³ k_{air} corrections for the four CCRI beams are calculated using MC methods. Measured k_{air} corrections are 1.1426, 1.0386, 1.0085 and 1.0047 for the CCRI-10, CCRI-30, CCRI-50b and CCRI-50a beams respectively.

| | Ratios NEW/ OLD | | | | | | | | | |
|----------|-----------------|-----|--------|-----|--------------------|----|--------|--------|--------|---------------------|
| Beam ID | ke | ksc | ktr | kfl | Product ksc.kfl | ks | kair | kii.kw | kCPE | Combined product |
| RT1 | 1.0000 | - | 0.9999 | - | 1.0005 | 1 | 0.9980 | 0.9963 | 0.9999 | 0.9945 |
| RT2 | 0.9999 | - | 0.9998 | - | 1.0005 | 1 | 0.9967 | 0.9969 | 0.9999 | 0.9938 |
| RT3 | 0.9999 | - | 0.9998 | - | 1.0004 | 1 | 0.9991 | 0.9972 | 0.9999 | 0.9964 |
| RT4 | 0.9999 | - | 0.9997 | - | 1.0005 | 1 | 0.9999 | 0.9975 | 0.9999 | 0.9975 |
| RT5 | 0.9999 | - | 1.0000 | - | 1.0004 | 1 | 1.0007 | 0.9977 | 0.9999 | 0.9986 |
| RT6 | 0.9996 | - | 1.0001 | - | 1.0005 | 1 | 1.0001 | 0.9979 | 0.9999 | 0.9981 |
| RT7 | 0.9991 | - | 0.9997 | - | 1.0004 | 1 | 0.9999 | 0.9979 | 0.9999 | 0.9969 |
| RT8 | 0.9991 | - | 1.0001 | - | 1.0002 | 1 | 1.0000 | 0.9979 | 0.9999 | 0.9972 |
| CCRI-10 | 1.0000 | - | 1.0000 | - | 1.0014 | 1 | 1.0041 | 0.9954 | 1.0000 | 1.0009 |
| CCRI-30 | 0.9999 | - | 1.0000 | - | 1.0009 | 1 | 0.9975 | 0.9968 | 1.0000 | 0.9951 |
| CCRI-50b | 1.0000 | - | 1.0000 | - | 1.0005 | 1 | 0.9994 | 0.9978 | 1.0000 | 0.9977 |
| CCRI-50a | 1.0000 | - | 1.0000 | - | 1.0002 | 1 | 0.9991 | 0.9980 | 1.0000 | 0.9973 |

Table A-4 LEFAC correction factors: relative change NEW / OLD (Table A-3 / Table A-2)

Appendix B: All data for 40 to 320 kVp X-rays

Beam specifications and correction factors for all the ARPANSA medium energy kV X-ray beams, for standard calibration conditions of 1000 mm and field size of nominally 100 mm. Prior to 2016 the X-ray generator was a Seifert Isovolt tube and the standard distance was 1331 mm. However when this tube was replaced by a Gulmay Comet tube the distance was changed to 1000 mm.

| Been ID | Nominal | | Adde | d filter | r HVL Effective | | | |
|----------|---------|-------|-------|----------|-----------------|-------|-------|------------|
| Beam ID | kVp | mm Pb | mm Sn | mm Cu | mm Al | mm Cu | mm Al | energy keV |
| CCRI-100 | 100 | | | | 3.433 | | | 39 |
| CCRI-135 | 135 | | | 0.232 | 2.23 | | | 59 |
| CCRI-180 | 180 | | | 0.485 | 2.23 | | | 77 |
| CCRI-250 | 250 | | | 1.570 | 2.23 | | | 118 |
| NXJ40 | 40 | | | | 0.5 | | 0.57 | 18 |
| NXJ50 | 50 | | | | 0.5 | | 0.68 | 20 |
| NXJ60 | 60 | | | | 0.5 | | 0.79 | 21 |
| NXJ70 | 70 | | | | 0.5 | | 0.90 | 22 |
| NXJ80 | 80 | | | | 0.5 | | 1.02 | 23 |
| NXJ90 | 90 | | | | 0.5 | | 1.15 | 25 |
| NXJ100 | 100 | | | | 0.5 | | 1.30 | 26 |
| NXK40 | 40 | | | | 1 | | 0.93 | 21 |
| NXK50 | 50 | | | | 1 | | 1.12 | 23 |
| NXK60 | 60 | | | | 1 | | 1.29 | 24 |
| NXK70 | 70 | | | | 1 | | 1.46 | 25 |
| NXK80 | 80 | | | | 1 | | 1.64 | 27 |
| NXK90 | 90 | | | | 1 | | 1.84 | 28 |
| NXK100 | 100 | | | | 1 | | 2.05 | 30 |
| NXA40 | 40 | | | | 4 | 0.06 | 1.90 | 27 |
| NXA50 | 50 | | | | 4 | 0.08 | 2.39 | 30 |
| NXA60 | 60 | | | | 4 | 0.10 | 2.81 | 32 |
| NXA70 | 70 | | | | 4 | 0.11 | 3.19 | 34 |
| NXA80 | 80 | | | | 4 | 0.13 | 3.62 | 36 |
| NXA90 | 90 | | | | 4 | 0.15 | 4.04 | 38 |
| NXB50 | 50 | | | | 4.5 | 0.08 | 2.53 | 31 |
| NXB70 | 70 | | | | 4.5 | 0.12 | 3.39 | 35 |
| NXB100 | 100 | | | | 4.5 | 0.18 | 4.74 | 42 |
| NXB120 | 120 | | | | 4.5 | 0.23 | 5.56 | 46 |
| NXB140 | 140 | | | | 4.5 | 0.28 | 6.33 | 50 |
| NXC70 | 70 | | | | 6 | 0.14 | 3.95 | 38 |
| NXC100 | 100 | | | | 6 | 0.22 | 5.49 | 45 |
| NXC120 | 120 | | | | 6 | 0.28 | 6.38 | 49 |
| NXC140 | 140 | | | | 6 | 0.34 | 7.20 | 53 |
| NXC150 | 150 | | | | 6 | 0.38 | 7.58 | 55 |
| NXD100 | 100 | | | | 9 | 0.29 | 6.61 | 49 |
| NXD120 | 120 | | | | 9 | 0.37 | 7.59 | 54 |
| NXD140 | 140 | | | | 9 | 0.45 | 8.44 | 58 |
| NXD150 | 150 | | | | 9 | 0.49 | 8.83 | 60 |
| NXD200 | 200 | | | | 9 | 0.73 | 10.53 | 70 |
| NXE120 | 120 | | | 0.50 | 4 | 0.63 | 10.31 | 65 |
| NXE140 | 140 | | | 0.50 | 4 | 0.77 | | 70 |
| NXE150 | 150 | | | 0.50 | 4 | 0.84 | | 72 |
| NXE200 | 200 | | | 0.50 | 4 | 1.21 | | 83 |
| NXE250 | 250 | | | 0.50 | 4 | 1.61 | | 93 |

Table B-1: List of all medium energy X-ray beams at ARPANSA

| Beam | Nominal | | Adde | ed filter | | н | IVL | Effective | |
|--------|---------|-------|-------|-----------|-------|-------|-------|------------|--|
| ID | kVp | mm Pb | mm Sn | mm Cu | mm Al | mm Cu | mm Al | energy keV | |
| NXF140 | 140 | | | 1.00 | 4 | 1.03 | | 79 | |
| NXF150 | 150 | | | 1.00 | 4 | 1.13 | | 81 | |
| NXF200 | 200 | | | 1.00 | 4 | 1.63 | | 95 | |
| NXF250 | 250 | | | 1.00 | 4 | 2.14 | | 107 | |
| NXF280 | 280 | | | 1.00 | 4 | 2.43 | | 115 | |
| NXG150 | 150 | | | 1.60 | 4 | 1.38 | | 89 | |
| NXG200 | 200 | | | 1.60 | 4 | 2.00 | | 105 | |
| NXG250 | 250 | | | 1.60 | 4 | 2.57 | | 120 | |
| NXG280 | 280 | | | 1.60 | 4 | 2.88 | | 128 | |
| NXG300 | 300 | | | 1.60 | 4 | 3.10 | | 134 | |
| NXH200 | 200 | | | 3.00 | 4 | 2.54 | | 120 | |
| NXH250 | 250 | | | 3.00 | 4 | 3.16 | | 137 | |
| NXH280 | 280 | | | 3.00 | 4 | 3.50 | | 147 | |
| NXH300 | 300 | | | 3.00 | 4 | 3.70 | | 153 | |
| NXH320 | 320 | | | 3.00 | 4 | 3.90 | | 159 | |
| NXI250 | 250 | | | 5.00 | 4 | 3.60 | | 150 | |
| NXI280 | 280 | | | 5.00 | 4 | 3.93 | | 160 | |
| NXI300 | 300 | | | 5.00 | 4 | 4.15 | | 167 | |
| NXI320 | 320 | | | 5.00 | 4 | 4.34 | | 173 | |
| N40 | 40 | | | 0.21 | | 0.085 | | 30 | |
| N60 | 60 | | | 0.60 | | 0.24 | | 44 | |
| N80 | 80 | | | 2.00 | | 0.58 | | 63 | |
| N100 | 100 | | | 5.00 | | 1.12 | | 82 | |
| N120 | 120 | | 1.00 | 5.00 | | 1.73 | | 100 | |
| N150 | 150 | | 2.50 | | | 2.37 | | 117 | |
| N200 | 200 | 1.00 | 3.00 | 2.00 | | 4.00 | | 164 | |
| N250 | 250 | 3.00 | 2.00 | | | 5.20 | | 208 | |
| N300 | 300 | 5.00 | 3.00 | | | 6.13 | | 251 | |
| W60 | 60 | | | 0.30 | | | | 39 | |
| W80 | 80 | | | 0.50 | | | | 51 | |
| W110 | 110 | | | 2.00 | | | | 77 | |
| W150 | 150 | | 1.00 | | | | | 103 | |
| W200 | 200 | | 2.00 | | | | | 137 | |
| W250 | 250 | | 4.00 | | | | | 173 | |
| W300 | 300 | | 6.50 | | | | | 207 | |
| RQR2 | 40 | | | | 2.12 | | 1.40 | | |
| RQR3 | 50 | | | | 2.20 | | 1.76 | | |
| RQR4 | 60 | | | | 2.51 | | 2.21 | | |
| RQR5 | 70 | | | | 2.65 | | 2.56 | | |
| RQR6 | 80 | | | | 2.87 | | 2.99 | | |
| RQR7 | 90 | | | | 2.99 | | 3.42 | | |
| RQR8 | 100 | | | | 3.30 | | 4.00 | | |
| RQR9 | 120 | | | | 3.66 | | 5.03 | | |
| RQR10 | 150 | | | | 4.30 | | 6.62 | | |
| RQA2 | 40 | | | | 6.12 | | 2.28 | | |
| RQA3 | 50 | | | | 12.20 | | 3.99 | | |
| RQA4 | 60 | | | | 18.53 | | 5.49 | | |
| RQA5 | 70 | | | | 23.67 | | 7.00 | | |
| RQA6 | 80 | | | | 28.89 | | 8.38 | | |
| RQA7 | 90 | | | | 33.00 | | 9.47 | | |
| RQA8 | 100 | | | | 37.31 | | 10.44 | | |
| RQA9 | 120 | | | | 43.68 | | 11.96 | | |
| RQA10 | 150 | | | | 49.33 | | 13.72 | | |

Table B 1: List of all medium energy X-ray beams at ARPANSA (continued)

| Deem ID | Nominal | | Adde | d filter | | HVL | | Effective |
|----------|---------|-------|-------|----------|-------|-------|-------|------------|
| Beam ID | kVp | mm Pb | mm Sn | mm Cu | mm Al | mm Cu | mm Al | energy keV |
| RQT8 | 100 | | | 0.19 | 3.30 | | 6.91 | |
| RQT9 | 120 | | | 0.24 | 3.66 | | 8.53 | |
| RQT10 | 150 | | | 0.28 | 4.30 | | 10.26 | |
| HHR1-50 | 50 | | | 0.10 | 4.00 | | 3.17 | |
| HHR2-50 | 50 | | | 0.20 | 4.00 | | 3.77 | |
| HHR3-50 | 50 | | | 0.31 | 4.00 | | 4.16 | |
| HHR4-50 | 50 | | | 0.59 | 4.00 | | 4.76 | |
| HHR5-50 | 50 | | | 0.91 | 4.00 | | 5.21 | |
| HHR1-70 | 70 | | | 0.10 | 4.00 | | 4.45 | |
| HHR2-70 | 70 | | | 0.20 | 4.00 | | 5.30 | |
| HHR3-70 | 70 | | | 0.31 | 4.00 | | 6.07 | |
| HHR4-70 | 70 | | | 0.59 | 4.00 | | 7.19 | |
| HHR5-70 | 70 | | | 0.91 | 4.00 | | 7.94 | |
| HHR1-90 | 90 | | | 0.10 | 4.00 | | 5.65 | |
| HHR2-90 | 90 | | | 0.20 | 4.00 | | 6.74 | |
| HHR3-90 | 90 | | | 0.31 | 4.00 | | 7.63 | |
| HHR4-90 | 90 | | | 0.59 | 4.00 | | 8.92 | |
| HHR5-90 | 90 | | | 0.91 | 4.00 | | 9.84 | |
| HHR1-120 | 120 | | | 0.10 | 4.00 | | 7.18 | |
| HHR2-120 | 120 | | | 0.20 | 4.00 | | 8.33 | |
| HHR3-120 | 120 | | | 0.31 | 4.00 | | 9.30 | |
| HHR4-120 | 120 | | | 0.59 | 4.00 | | 10.63 | |
| HHR5-120 | 120 | | | 0.91 | 4.00 | | 11.55 | |

Table B 1: List of all medium energy X-ray beams at ARPANSA (continued)

¹ The energy of a monoenergetic beam with the same HVL in mm of Cu

| Table B-2: List of all medium-energy x-r | ay beams and Fo correction factors |
|--|------------------------------------|
|--|------------------------------------|

| Deems ID | Combined corrections ¹ prior to | Combined corrections ¹ post | F |
|----------|--|--|--------|
| Beam ID | 1 January 2022 | 1 January 2022 | ΓQ |
| CCRI-100 | 1.0030 | 1.0005 | 0.9975 |
| CCRI-135 | 1.0008 | 0.9981 | 0.9973 |
| CCRI-180 | 1.0018 | 0.9991 | 0.9973 |
| CCRI-250 | 1.0021 | 0.9997 | 0.9976 |
| NXJ40 | 1.0367 | 1.0347 | 0.9981 |
| NXJ50 | 1.0299 | 1.0280 | 0.9982 |
| NXJ60 | 1.0253 | 1.0234 | 0.9982 |
| NXJ70 | 1.0218 | 1.0199 | 0.9981 |
| NXJ80 | 1.0189 | 1.0169 | 0.9981 |
| NXJ90 | 1.0164 | 1.0144 | 0.9980 |
| NXJ100 | 1.0144 | 1.0124 | 0.9980 |
| NXK40 | 1.0198 | 1.0179 | 0.9982 |
| NXK50 | 1.0162 | 1.0144 | 0.9982 |
| NXK60 | 1.0139 | 1.0120 | 0.9981 |
| NXK70 | 1.0122 | 1.0102 | 0.9980 |
| NXK80 | 1.0107 | 1.0086 | 0.9979 |
| NXK90 | 1.0095 | 1.0073 | 0.9978 |
| NXK100 | 1.0084 | 1.0061 | 0.9978 |
| NXA40 | 1.0075 | 1.0053 | 0.9978 |
| NXA50 | 1.0056 | 1.0035 | 0.9979 |
| NXA60 | 1.0046 | 1.0025 | 0.9979 |
| NXA70 | 1.0040 | 1.0017 | 0.9978 |
| NXA80 | 1.0034 | 1.0011 | 0.9977 |
| NXA90 | 1.0029 | 1.0005 | 0.9976 |
| NXB50 | 1.0051 | 1.0031 | 0.9979 |
| NXB70 | 1.0035 | 1.0013 | 0.9978 |
| NXB100 | 1.0022 | 0.9998 | 0.9975 |
| NXB120 | 1.0018 | 0.9993 | 0.9975 |
| NXB140 | 1.0017 | 0.9991 | 0.9974 |
| NXC70 | 1.0027 | 1.0005 | 0.9978 |
| NXC100 | 1.0016 | 0.9991 | 0.9975 |
| NXC120 | 1.0013 | 0.9987 | 0.9974 |
| NXC140 | 1.0013 | 0.9987 | 0.9974 |
| NXC150 | 1.0014 | 0.9988 | 0.9974 |
| NXD100 | 1.0009 | 0.9983 | 0.9974 |
| NXD120 | 1.0008 | 0.9981 | 0.9973 |
| NXD140 | 1.0010 | 0.9983 | 0.9973 |
| NXD150 | 1.0011 | 0.9985 | 0.9973 |
| NXD200 | 1.0019 | 0.9993 | 0.9974 |
| NXE120 | 1.0003 | 0.9973 | 0.9971 |
| NXE140 | 1.0008 | 0.9979 | 0.9972 |
| NXE150 | 1.0011 | 0.9983 | 0.9972 |
| NXE200 | 1.0023 | 0.9996 | 0.9974 |
| NXE250 | 1.0016 | 0.9992 | 0.9976 |
| NXF140 | 1.0010 | 0.9981 | 0.9971 |
| NXF150 | 1.0014 | 0.9985 | 0.9972 |
| NXF200 | 1.0028 | 1.0002 | 0.9974 |
| NXF250 | 1.0019 | 0.9995 | 0.9976 |
| NXF280 | 0.9996 | 0.9971 | 0.9976 |
| NXG150 | 1.0018 | 0.9990 | 0.9972 |
| NXG200 | 1.0034 | 1.0008 | 0.9974 |
| NXG250 | 1.0021 | 0.9997 | 0.9976 |
| NXG280 | 0.9993 | 0.9969 | 0.9975 |

| Table B-2: List of all medium-energy x-ray | beams and FQ correction | factors (continued) |
|--|-------------------------|---------------------|
|--|-------------------------|---------------------|

| Dear ID | Combined corrections ¹ prior to | Combined corrections ¹ post | - |
|---------------|--|--|--------|
| Beam ID | 1 January 2022 | 1 January 2022 | Γq |
| NXG300 | 0.9963 | 0.9938 | 0.9974 |
| NXH200 | 1.0043 | 1.0018 | 0.9974 |
| NXH250 | 1.0023 | 1.0000 | 0.9977 |
| NXH280 | 0.9988 | 0.9963 | 0.9975 |
| NXH300 | 0.9951 | 0.9925 | 0.9974 |
| NXH320 | 0.9905 | 0.9875 | 0.9970 |
| NXI250 | 1.0021 | 0.9999 | 0.9977 |
| NXI280 | 0.9979 | 0.9954 | 0.9975 |
| NXI300 | 0.9936 | 0.9909 | 0.9973 |
| NXI320 | 0.9882 | 0.9851 | 0.9969 |
| N40 | 1.0064 | 1.0043 | 0.9979 |
| N60 | 1.0011 | 0.9988 | 0.9977 |
| N80 | 0.9997 | 0.9969 | 0.9971 |
| N100 | 0.9997 | 0.9962 | 0.9965 |
| N120 | 1.0015 | 0.9989 | 0.9973 |
| N150 | 1.0045 | 1.0019 | 0.9974 |
| N200 | 1.0054 | 1.0031 | 0.9977 |
| N250 | 0.9922 | 0.9903 | 0.9980 |
| N300 | 0.9593 | 0.9546 | 0.9950 |
| W60 | 1 0019 | 0 9998 | 0 9979 |
| W80 | 1 0006 | 0 9979 | 0 9974 |
| W110 | 0 9999 | 0.9967 | 0.9968 |
| W150 | 1 0029 | 1 0001 | 0.9972 |
| W200 | 1 0054 | 1 0029 | 0.9975 |
| W250 | 1 0005 | 0.9983 | 0.9978 |
| W/300 | 0.9838 | 0.9807 | 0.9968 |
| ROR2 | 1 0106 | 1 0100 | 0.9994 |
| ROR3 | 1 0081 | 1 0073 | 0.9991 |
| ROR4 | 1.0081 | 1 0049 | 0.9981 |
| RORS | 1.0008 | 1 0036 | 0.9981 |
| RORG | 1.0034 | 1.0035 | 0.9983 |
| ROR7 | 1 0037 | 1.0025 | 0.9979 |
| RORS | 1 0032 | 1,0010 | 0.9976 |
| RORG | 1.0032 | 0.0000 | 0.9977 |
| ROR10 | 1.0022 | 0.9994 | 0.9976 |
| ROA2 | 1.0015 | 1 0037 | 0.9970 |
| ROA3 | 1 0019 | 1,0005 | 0.9986 |
| ROA/ | 1 0010 | 0.9990 | 0.9980 |
| POA5 | 1.0010 | 0.9981 | 0.9976 |
| ROAG | 1 0001 | 0.9975 | 0.9974 |
| ROA7 | 0.9998 | 0.9970 | 0.9972 |
| ROAS | 0.9998 | 0.9968 | 0.9970 |
| POAG | 1 0002 | 0.9972 | 0.9971 |
| POA10 | 1.0002 | 0.9972 | 0.9971 |
| ROAID POTS | 1.0018 | 0.9990 | 0.9972 |
| POTO | 1.0002 | 0.0079 | 0.9975 |
| POT10 | 1.0002 | 0.9978 | 0.9976 |
| | 1.0005 | 1 0015 | 0.0000 |
| | 1.0020 | 1,0015 | 0.9990 |
| | 1.0020 | 1.0007 | 0.0004 |
| | 1.0012 | 1.0001 | 0.0001 |
| | 1.0012 | 0.9995 | 0.0070 |
| | 1.0012 | 0.0000 | 0.9979 |
| HHK1-70 | 1.0012 | 0.9999 | 0.9987 |

| Beam ID | Combined corrections ¹ prior to 1 January 2022 | Combined corrections ¹ post 1 January 2022 | Fq |
|----------|--|--|--------|
| HHR2-70 | 1.0009 | 0.9991 | 0.9983 |
| HHR3-70 | 1.0007 | 0.9987 | 0.9980 |
| HHR4-70 | 1.0004 | 0.9980 | 0.9976 |
| HHR5-70 | 1.0002 | 0.9976 | 0.9974 |
| HHR1-90 | 1.0006 | 0.9989 | 0.9984 |
| HHR2-90 | 1.0003 | 0.9982 | 0.9980 |
| HHR3-90 | 1.0002 | 0.9978 | 0.9977 |
| HHR4-90 | 0.9999 | 0.9972 | 0.9973 |
| HHR5-90 | 0.9998 | 0.9969 | 0.9971 |
| HHR1-120 | 1.0003 | 0.9984 | 0.9981 |
| HHR2-120 | 1.0002 | 0.9979 | 0.9977 |
| HHR3-120 | 1.0001 | 0.9976 | 0.9975 |
| HHR4-120 | 1.0001 | 0.9973 | 0.9972 |
| HHR5-120 | 1.0001 | 0.9972 | 0.9971 |

Table B-2: List of all medium-energy x-ray beams and FQ correction factors (continued)

¹ Includes the correction k_{air} calculated for 20 degrees C, 101.325 kPa and an air path of 29.7 cm inside the MEFAC.

Table B-3 MEFAC correction factors in use from 2010 and prior to 1 January 2022

| Beam ID | ke | ksc | ktr | kfl | Product ksc.kfl | kair ¹ | kii.kw | kCPE | Combined product |
|----------|--------|--------|--------|--------|--------------------|-------------------|--------|------|---------------------|
| CCRI-100 | 1.0001 | 0.9944 | 0.9995 | 0.9984 | 0.9928 | 1.0106 | 1 | 1 | 1.0030 |
| CCRI-135 | 1.0006 | 0.9951 | 0.9989 | 0.9991 | 0.9942 | 1.0071 | 1 | 1 | 1.0008 |
| CCRI-180 | 1.0022 | 0.9957 | 0.9983 | 0.9995 | 0.9953 | 1.0061 | 1 | 1 | 1.0018 |
| CCRI-250 | 1.0049 | 0.9967 | 0.9955 | 0.9999 | 0.9966 | 1.0052 | 1 | 1 | 1.0021 |
| NXJ40 | 1.0001 | 0.9929 | 0.9999 | 0.9952 | 0.9881 | 1.0492 | 1 | 1 | 1.0367 |
| NX150 | 1.0001 | 0.9931 | 0.9999 | 0.9957 | 0.9888 | 1.0416 | 1 | 1 | 1.0299 |
| NXJ60 | 1.0001 | 0.9932 | 0.9999 | 0.9961 | 0.9893 | 1.0364 | 1 | 1 | 1.0253 |
| NXJ70 | 1.0001 | 0.9933 | 0.9998 | 0.9964 | 0.9897 | 1.0325 | 1 | 1 | 1.0218 |
| NXJ80 | 1.0001 | 0.9935 | 0.9998 | 0.9967 | 0.9901 | 1.0292 | 1 | 1 | 1.0189 |
| 09LXN | 1.0001 | 0.9936 | 0.9997 | 0.9969 | 0.9905 | 1.0264 | 1 | 1 | 1.0164 |
| NXJ100 | 1.0001 | 0.9937 | 0.9997 | 0.9971 | 0.9909 | 1.0240 | 1 | 1 | 1.0144 |
| NXK40 | 1.0001 | 0.9932 | 0.9999 | 0.9963 | 0.9895 | 1.0306 | 1 | 1 | 1.0198 |
| NXK50 | 1.0001 | 0.9934 | 0.9999 | 0.9967 | 0.9901 | 1.0265 | 1 | 1 | 1.0162 |
| NXK60 | 1.0001 | 0.9935 | 0.9998 | 0.9970 | 0.9905 | 1.0237 | 1 | 1 | 1.0139 |
| NXK70 | 1.0001 | 0.9936 | 0.9998 | 0.9972 | 0.9908 | 1.0217 | 1 | 1 | 1.0122 |
| NXK80 | 1.0001 | 0.9937 | 0.9997 | 0.9974 | 0.9911 | 1.0199 | 1 | 1 | 1.0107 |
| NXK90 | 1.0001 | 0.9938 | 0.9997 | 0.9976 | 0.9914 | 1.0184 | 1 | 1 | 1.0095 |
| NXK100 | 1.0001 | 0.9940 | 0.9996 | 0.9978 | 0.9917 | 1.0170 | 1 | 1 | 1.0084 |
| NXA40 | 1.0001 | 0.9937 | 0.9999 | 0.9978 | 0.9915 | 1.0162 | 1 | 1 | 1.0075 |
| NXA50 | 1.0001 | 0.9939 | 0.9998 | 0.9979 | 0.9918 | 1.0140 | 1 | 1 | 1.0056 |
| NXA60 | 1.0001 | 0.9940 | 0.9998 | 0.9980 | 0.9920 | 1.0128 | 1 | 1 | 1.0046 |
| NXA70 | 1.0001 | 0.9941 | 0.9997 | 0.9981 | 0.9923 | 1.0119 | 1 | 1 | 1.0040 |
| NXA80 | 1.0001 | 0.9942 | 0.9996 | 0.9983 | 0.9925 | 1.0112 | 1 | 1 | 1.0034 |
| NXA90 | 1.0001 | 0.9943 | 0.9995 | 0.9984 | 0.9927 | 1.0106 | 1 | 1 | 1.0029 |
| NXB50 | 1.0001 | 0.9939 | 0.9998 | 0.9979 | 0.9918 | 1.0134 | - 1 | - 1 | 1.0051 |
| NXB70 | 1.0001 | 0.9942 | 0.9997 | 0.9982 | 0.9923 | 1.0114 | 1 | 1 | 1.0035 |
| NXB100 | 1.0002 | 0.9945 | 0.9994 | 0.9985 | 0.9930 | 1.0097 | - 1 | - 1 | 1.0022 |
| NXB120 | 1.0003 | 0.9947 | 0.9993 | 0.9987 | 0.9934 | 1.0090 | 1 | 1 | 1.0018 |
| NXB140 | 1.0005 | 0.9948 | 0.9991 | 0.9989 | 0.9937 | 1.0084 | 1 | 1 | 1.0017 |
| NXC70 | 1.0001 | 0.9942 | 0.9997 | 0.9982 | 0.9925 | 1.0104 | 1 | 1 | 1.0027 |
| NXC100 | 1.0002 | 0.9946 | 0.9994 | 0.9986 | 0.9932 | 1.0090 | 1 | 1 | 1.0016 |
| NXC120 | 1.0003 | 0.9948 | 0.9992 | 0.9988 | 0.9936 | 1.0083 | 1 | 1 | 1.0013 |
| NXC140 | 1.0006 | 0.9949 | 0.9990 | 0.9990 | 0.9939 | 1.0079 | 1 | 1 | 1.0013 |
| NXC150 | 1.0008 | 0.9950 | 0.9989 | 0.9990 | 0.9940 | 1.0077 | 1 | 1 | 1.0014 |
| NXD100 | 1.0002 | 0.9947 | 0.9992 | 0.9988 | 0.9935 | 1.0081 | 1 | 1 | 1.0009 |
| NXD120 | 1.0003 | 0.9949 | 0.9990 | 0.9990 | 0.9939 | 1.0076 | 1 | 1 | 1.0008 |
| NXD140 | 1.0007 | 0.9951 | 0.9989 | 0.9991 | 0.9942 | 1.0073 | 1 | 1 | 1.0010 |
| NXD150 | 1.0009 | 0.9952 | 0.9988 | 0.9992 | 0.9943 | 1.0071 | 1 | 1 | 1.0011 |
| NXD200 | 1.0021 | 0.9956 | 0.9984 | 0.9994 | 0.9949 | 1.0065 | 1 | 1 | 1.0019 |
| NXE120 | 1.0004 | 0.9952 | 0.9987 | 0.9994 | 0.9946 | 1.0066 | 1 | 1 | 1.0003 |
| NXE140 | 1.0010 | 0.9954 | 0.9985 | 0.9994 | 0.9949 | 1.0064 | 1 | 1 | 1.0008 |
| NXE150 | 1.0014 | 0.9955 | 0.9984 | 0.9995 | 0.9950 | 1.0063 | 1 | 1 | 1.0011 |
| NXE200 | 1.0028 | 0.9959 | 0.9980 | 0.9996 | 0.9955 | 1.0059 | 1 | 1 | 1.0023 |
| NXE250 | 1.0036 | 0.9962 | 0.9965 | 0.9997 | 0.9959 | 1.0057 | 1 | 1 | 1.0016 |
| NXF140 | 1.0014 | 0.9957 | 0.9983 | 0.9996 | 0.9953 | 1.0060 | 1 | 1 | 1.0010 |
| NXF150 | 1.0018 | 0.9958 | 0.9982 | 0.9996 | 0.9954 | 1.0060 | 1 | 1 | 1.0014 |
| NXF200 | 1.0036 | 0.9962 | 0.9977 | 0.9997 | 0.9959 | 1.0056 | 1 | 1 | 1.0028 |
| NXF250 | 1.0043 | 0.9965 | 0.9959 | 0.9998 | 0.9963 | 1.0054 | 1 | 1 | 1.0019 |
| NXF280 | 1.0051 | 0.9967 | 0.9928 | 0.9998 | 0.9965 | 1.0052 | 1 | 1 | 0.9996 |
| NXG150 | 1.0023 | 0.9960 | 0.9980 | 0.9997 | 0.9957 | 1.0057 | 1 | 1 | 1.0018 |
| NXG200 | 1.0043 | 0.9964 | 0.9975 | 0.9998 | 0.9963 | 1.0054 | 1 | 1 | 1.0034 |
| NXG250 | 1.0050 | 0.9967 | 0.9954 | 0.9999 | 0.9966 | 1.0052 | 1 | 1 | 1.0021 |
| NXG280 | 1.0058 | 0.9969 | 0.9918 | 0.9999 | 0.9968 | 1.0050 | 1 | 1 | 0.9993 |

Table B-3 MEFAC correction factors in use from 2010 and prior to 1 January 2022 (continued)

| Beam ID | ke | ksc | ktr | kfl | Product ksc.kfl | kair ¹ | kii.kw | kCPE | Combined product |
|---------|--------|--------|--------|--------|--------------------|-------------------|--------|------|---------------------|
| NXG300 | 1.0070 | 0.9970 | 0.9876 | 0.9999 | 0.9969 | 1.0050 | 1 | 1 | 0.9963 |
| NXH200 | 1.0053 | 0.9967 | 0.9973 | 0.9999 | 0.9966 | 1.0052 | 1 | 1 | 1.0043 |
| NXH250 | 1.0058 | 0.9970 | 0.9946 | 0.9999 | 0.9970 | 1.0049 | 1 | 1 | 1.0023 |
| NXH280 | 1.0067 | 0.9972 | 0.9903 | 0.9999 | 0.9971 | 1.0048 | 1 | 1 | 0.9988 |
| NXH300 | 1.0082 | 0.9973 | 0.9852 | 0.9999 | 0.9972 | 1.0047 | 1 | 1 | 0.9951 |
| NXH320 | 1.0108 | 0.9973 | 0.9780 | 0.9999 | 0.9973 | 1.0047 | 1 | 1 | 0.9905 |
| NXI250 | 1.0063 | 0.9972 | 0.9939 | 1.0000 | 0.9971 | 1.0048 | 1 | 1 | 1.0021 |
| NXI280 | 1.0072 | 0.9973 | 0.9888 | 1.0000 | 0.9973 | 1.0047 | 1 | 1 | 0.9979 |
| NXI300 | 1.0090 | 0.9974 | 0.9828 | 1.0000 | 0.9974 | 1.0046 | 1 | 1 | 0.9936 |
| NXI320 | 1.0120 | 0.9975 | 0.9745 | 1.0000 | 0.9974 | 1.0046 | 1 | 1 | 0.9882 |
| N40 | 1.0001 | 0.9939 | 0.9999 | 0.9977 | 0.9917 | 1.0149 | 1 | 1 | 1.0064 |
| N60 | 1.0002 | 0.9944 | 0.9997 | 0.9986 | 0.9930 | 1.0083 | 1 | 1 | 1.0011 |
| N80 | 1.0001 | 0.9950 | 0.9987 | 0.9994 | 0.9944 | 1.0066 | 1 | 1 | 0.9997 |
| N100 | 1.0003 | 0.9957 | 0.9981 | 0.9997 | 0.9954 | 1.0059 | 1 | 1 | 0.9997 |
| N120 | 1.0020 | 0.9962 | 0.9979 | 0.9999 | 0.9961 | 1.0055 | 1 | 1 | 1.0015 |
| N150 | 1.0051 | 0.9966 | 0.9977 | 0.9999 | 0.9966 | 1.0052 | 1 | 1 | 1.0045 |
| N200 | 1.0075 | 0.9973 | 0.9960 | 1.0000 | 0.9973 | 1.0047 | 1 | 1 | 1.0054 |
| N250 | 1.0064 | 0.9977 | 0.9839 | 1.0000 | 0.9977 | 1.0043 | 1 | 1 | 0.9922 |
| N300 | 1.0230 | 0.9980 | 0.9358 | 1.0000 | 0.9980 | 1.0041 | 1 | 1 | 0.9593 |
| W60 | 1.0002 | 0.9943 | 0.9998 | 0.9982 | 0.9925 | 1.0095 | 1 | 1 | 1.0019 |
| W80 | 1.0002 | 0.9947 | 0.9993 | 0.9989 | 0.9936 | 1.0076 | 1 | 1 | 1.0006 |
| W110 | 1.0004 | 0.9956 | 0.9982 | 0.9996 | 0.9952 | 1.0061 | 1 | 1 | 0.9999 |
| W150 | 1.0034 | 0.9963 | 0.9978 | 0.9998 | 0.9962 | 1.0055 | 1 | 1 | 1.0029 |
| W200 | 1.0066 | 0.9970 | 0.9969 | 0.9999 | 0.9969 | 1.0050 | 1 | 1 | 1.0054 |
| W250 | 1.0068 | 0.9974 | 0.9917 | 1.0000 | 0.9974 | 1.0046 | 1 | 1 | 1.0005 |
| W300 | 1.0119 | 0.9977 | 0.9702 | 1.0000 | 0.9977 | 1.0043 | 1 | 1 | 0.9838 |
| RQR2 | 1.0001 | 0.9935 | 0.9999 | 0.9974 | 0.9910 | 1.0198 | 1 | 1 | 1.0106 |
| RQR3 | 1.0001 | 0.9937 | 0.9999 | 0.9976 | 0.9914 | 1.0169 | 1 | 1 | 1.0081 |
| RQR4 | 1.0001 | 0.9939 | 0.9998 | 0.9978 | 0.9917 | 1.0153 | 1 | 1 | 1.0068 |
| RQR5 | 1.0001 | 0.9940 | 0.9998 | 0.9980 | 0.9920 | 1.0135 | 1 | 1 | 1.0054 |
| RQR6 | 1.0001 | 0.9941 | 0.9997 | 0.9982 | 0.9923 | 1.0125 | 1 | 1 | 1.0045 |
| RQR7 | 1.0001 | 0.9942 | 0.9996 | 0.9983 | 0.9925 | 1.0116 | 1 | 1 | 1.0037 |
| RQR8 | 1.0001 | 0.9943 | 0.9995 | 0.9984 | 0.9928 | 1.0108 | 1 | 1 | 1.0032 |
| RQR9 | 1.0003 | 0.9946 | 0.9993 | 0.9986 | 0.9932 | 1.0095 | 1 | 1 | 1.0022 |
| RQR10 | 1.0007 | 0.9949 | 0.999 | 0.9989 | 0.9938 | 1.0083 | 1 | 1 | 1.0018 |
| RQA2 | 1.0001 | 0.9939 | 0.9999 | 0.9978 | 0.9916 | 1.0130 | 1 | 1 | 1.0045 |
| RQA3 | 1.0001 | 0.9942 | 0.9998 | 0.9980 | 0.9922 | 1.0098 | 1 | 1 | 1.0019 |
| RQA4 | 1.0002 | 0.9944 | 0.9997 | 0.9985 | 0.9929 | 1.0083 | 1 | 1 | 1.0010 |
| RQA5 | 1.0002 | 0.9946 | 0.9994 | 0.9988 | 0.9934 | 1.0075 | 1 | 1 | 1.0004 |
| RQA6 | 1.0002 | 0.9948 | 0.9991 | 0.9991 | 0.9939 | 1.0070 | 1 | 1 | 1.0001 |
| RQA7 | 1.0001 | 0.9950 | 0.9988 | 0.9993 | 0.9942 | 1.0067 | 1 | 1 | 0.9998 |
| RQA8 | 1.0002 | 0.9952 | 0.9986 | 0.9994 | 0.9946 | 1.0064 | 1 | 1 | 0.9998 |
| RQA9 | 1.0007 | 0.9955 | 0.9983 | 0.9996 | 0.9951 | 1.0061 | 1 | 1 | 1.0002 |
| RQA10 | 1.0023 | 0.9960 | 0.9981 | 0.9997 | 0.9957 | 1.0058 | 1 | 1 | 1.0018 |
| RQT8 | 1.0002 | 0.9948 | 0.9992 | 0.9989 | 0.9936 | 1.0073 | 1 | 1 | 1.0002 |
| RQT9 | 1.0004 | 0.9950 | 0.9989 | 0.9991 | 0.9942 | 1.0068 | 1 | 1 | 1.0002 |
| RQT10 | 1.0013 | 0.9954 | 0.9986 | 0.9994 | 0.9948 | 1.0063 | 1 | 1 | 1.0009 |
| HHR1-50 | 1.0001 | 0.9941 | 0.9998 | 0.9979 | 0.9920 | 1.0107 | 1 | 1 | 1.0026 |
| HHR2-50 | 1.0001 | 0.9942 | 0.9998 | 0.9980 | 0.9922 | 1.0100 | 1 | 1 | 1.0020 |
| HHR3-50 | 1.0002 | 0.9942 | 0.9998 | 0.9980 | 0.9923 | 1.0095 | 1 | 1 | 1.0017 |
| HHR4-50 | 1.0002 | 0.9943 | 0.9998 | 0.9983 | 0.9926 | 1.0088 | 1 | 1 | 1.0013 |
| HHR5-50 | 1.0002 | 0.9943 | 0.9998 | 0.9985 | 0.9929 | 1.0084 | 1 | 1 | 1.0012 |
| HHR1-70 | 1.0002 | 0.9943 | 0.9997 | 0.9983 | 0.9926 | 1.0088 | 1 | 1 | 1.0012 |

| | | | | | | | • | | |
|----------|--------|--------|--------|--------|--------------------|-------------------|--------|------|---------------------|
| Beam ID | ke | ksc | ktr | kfl | Product ksc.kfl | kair ¹ | kii.kw | kCPE | Combined product |
| HHR2-70 | 1.0002 | 0.9944 | 0.9996 | 0.9985 | 0.9929 | 1.0083 | 1 | 1 | 1.0009 |
| HHR3-70 | 1.0002 | 0.9945 | 0.9996 | 0.9986 | 0.9931 | 1.0079 | 1 | 1 | 1.0007 |
| HHR4-70 | 1.0002 | 0.9946 | 0.9994 | 0.9989 | 0.9935 | 1.0074 | 1 | 1 | 1.0004 |
| HHR5-70 | 1.0002 | 0.9947 | 0.9993 | 0.9990 | 0.9937 | 1.0072 | 1 | 1 | 1.0002 |
| HHR1-90 | 1.0001 | 0.9945 | 0.9994 | 0.9986 | 0.9932 | 1.0079 | 1 | 1 | 1.0006 |
| HHR2-90 | 1.0002 | 0.9947 | 0.9993 | 0.9988 | 0.9934 | 1.0075 | 1 | 1 | 1.0003 |
| HHR3-90 | 1.0002 | 0.9947 | 0.9992 | 0.9989 | 0.9937 | 1.0072 | 1 | 1 | 1.0002 |
| HHR4-90 | 1.0001 | 0.9949 | 0.9989 | 0.9992 | 0.9941 | 1.0068 | 1 | 1 | 0.9999 |
| HHR5-90 | 1.0001 | 0.9950 | 0.9988 | 0.9993 | 0.9943 | 1.0066 | 1 | 1 | 0.9998 |
| HHR1-120 | 1.0003 | 0.9949 | 0.9991 | 0.9989 | 0.9938 | 1.0072 | 1 | 1 | 1.0003 |
| HHR2-120 | 1.0004 | 0.9950 | 0.9989 | 0.9991 | 0.9941 | 1.0069 | 1 | 1 | 1.0002 |
| HHR3-120 | 1.0004 | 0.9951 | 0.9988 | 0.9992 | 0.9943 | 1.0066 | 1 | 1 | 1.0001 |
| HHR4-120 | 1.0005 | 0.9953 | 0.9986 | 0.9994 | 0.9947 | 1.0064 | 1 | 1 | 1.0001 |
| HHR5-120 | 1.0006 | 0.9955 | 0.9984 | 0.9995 | 0.9950 | 1.0062 | 1 | 1 | 1.0001 |

Table B-3 MEFAC correction factors in use from 2010 and prior to 1 January 2022 (continued)

Table B-4 MEFAC correction factors in use after 1 January 2022

| Beam ID | ke | ksc | ktr | kfl | Product ksc.kfl | kair ¹ | kii.kw | kCPE | Combined product |
|----------|--------|-----|--------|-----|--------------------|-------------------|--------|--------|---------------------|
| CCRI-100 | 1.0000 | - | 0.9993 | - | 0.9928 | 1.0107 | 0.9979 | 0.9999 | 1.0005 |
| CCRI-135 | 1.0005 | - | 0.9985 | - | 0.9941 | 1.0072 | 0.9980 | 0.9999 | 0.9981 |
| CCRI-180 | 1.0021 | - | 0.9978 | - | 0.9950 | 1.0062 | 0.9982 | 0.9999 | 0.9991 |
| CCRI-250 | 1.0047 | - | 0.9951 | - | 0.9962 | 1.0052 | 0.9987 | 0.9998 | 0.9997 |
| NXJ40 | 1.0000 | - | 0.9999 | - | 0.9898 | 1.0482 | 0.9975 | 0.9999 | 1.0347 |
| NXJ50 | 1.0000 | - | 0.9999 | - | 0.9902 | 1.0409 | 0.9976 | 0.9999 | 1.0280 |
| NXJ60 | 1.0000 | - | 0.9999 | - | 0.9905 | 1.0358 | 0.9977 | 0.9999 | 1.0234 |
| NXJ70 | 1.0000 | - | 0.9998 | - | 0.9908 | 1.0319 | 0.9977 | 0.9999 | 1.0199 |
| NXJ80 | 1.0000 | - | 0.9998 | - | 0.9910 | 1.0287 | 0.9978 | 0.9999 | 1.0169 |
| NXJ90 | 1.0000 | - | 0.9997 | - | 0.9913 | 1.0260 | 0.9978 | 0.9999 | 1.0144 |
| NXJ100 | 1.0000 | - | 0.9996 | - | 0.9915 | 1.0237 | 0.9978 | 0.9999 | 1.0124 |
| NXK40 | 1.0000 | - | 0.9999 | - | 0.9905 | 1.0302 | 0.9977 | 0.9999 | 1.0179 |
| NXK50 | 1.0000 | - | 0.9999 | - | 0.9909 | 1.0262 | 0.9978 | 0.9999 | 1.0144 |
| NXK60 | 1.0000 | - | 0.9998 | - | 0.9911 | 1.0235 | 0.9978 | 0.9999 | 1.0120 |
| NXK70 | 1.0000 | - | 0.9998 | - | 0.9913 | 1.0215 | 0.9979 | 0.9999 | 1.0102 |
| NXK80 | 1.0000 | - | 0.9997 | - | 0.9916 | 1.0198 | 0.9979 | 0.9999 | 1.0086 |
| NXK90 | 1.0000 | - | 0.9996 | - | 0.9918 | 1.0182 | 0.9979 | 0.9999 | 1.0073 |
| NXK100 | 1.0000 | - | 0.9995 | - | 0.9920 | 1.0169 | 0.9979 | 0.9999 | 1.0061 |
| NXA40 | 1.0000 | - | 0.9998 | - | 0.9915 | 1.0162 | 0.9980 | 0.9999 | 1.0053 |
| NXA50 | 1.0000 | - | 0.9998 | - | 0.9919 | 1.0140 | 0.9980 | 0.9999 | 1.0035 |
| NXA60 | 1.0000 | - | 0.9997 | - | 0.9922 | 1.0128 | 0.9980 | 0.9999 | 1.0025 |
| NXA70 | 1.0000 | - | 0.9996 | - | 0.9924 | 1.0119 | 0.9980 | 0.9999 | 1.0017 |
| NXA80 | 1.0000 | - | 0.9995 | - | 0.9926 | 1.0112 | 0.9980 | 0.9999 | 1.0011 |
| NXA90 | 1.0000 | - | 0.9994 | - | 0.9927 | 1.0106 | 0.9980 | 0.9999 | 1.0005 |
| NXB50 | 1.0000 | - | 0.9998 | - | 0.9920 | 1.0134 | 0.9981 | 0.9999 | 1.0031 |
| NXB70 | 1.0000 | - | 0.9996 | - | 0.9924 | 1.0114 | 0.9980 | 0.9999 | 1.0013 |
| NXB100 | 1.0000 | - | 0.9992 | - | 0.9930 | 1.0098 | 0.9979 | 0.9999 | 0.9998 |
| NXB120 | 1.0001 | - | 0.9990 | - | 0.9933 | 1.0090 | 0.9980 | 0.9999 | 0.9993 |
| NXB140 | 1.0004 | - | 0.9988 | - | 0.9936 | 1.0085 | 0.9980 | 0.9999 | 0.9991 |
| NXC70 | 1.0000 | - | 0.9995 | - | 0.9926 | 1.0104 | 0.9980 | 0.9999 | 1.0005 |
| NXC100 | 1.0000 | - | 0.9991 | - | 0.9932 | 1.0090 | 0.9979 | 0.9999 | 0.9991 |
| NXC120 | 1.0001 | - | 0.9989 | - | 0.9935 | 1.0084 | 0.9980 | 0.9999 | 0.9987 |
| NXC140 | 1.0005 | - | 0.9987 | - | 0.9938 | 1.0079 | 0.9980 | 0.9999 | 0.9987 |
| NXC150 | 1.0007 | - | 0.9986 | - | 0.9939 | 1.0077 | 0.9980 | 0.9999 | 0.9988 |
| NXD100 | 1.0000 | - | 0.9989 | - | 0.9935 | 1.0081 | 0.9979 | 0.9999 | 0.9983 |
| NXD120 | 1.0002 | - | 0.9987 | - | 0.9938 | 1.0077 | 0.9979 | 0.9999 | 0.9981 |
| NXD140 | 1.0006 | - | 0.9985 | - | 0.9941 | 1.0073 | 0.9980 | 0.9999 | 0.9983 |
| NXD150 | 1.0008 | - | 0.9984 | - | 0.9942 | 1.0072 | 0.9980 | 0.9999 | 0.9985 |
| NXD200 | 1.0020 | - | 0.9980 | - | 0.9947 | 1.0066 | 0.9982 | 0.9999 | 0.9993 |
| NXE120 | 1.0003 | - | 0.9982 | - | 0.9943 | 1.0067 | 0.9979 | 0.9999 | 0.9973 |
| NXE140 | 1.0009 | - | 0.9981 | - | 0.9946 | 1.0064 | 0.9980 | 0.9999 | 0.9979 |
| NXE150 | 1.0013 | - | 0.9980 | - | 0.9947 | 1.0063 | 0.9981 | 0.9999 | 0.9983 |
| NXE200 | 1.0027 | - | 0.9976 | - | 0.9952 | 1.0060 | 0.9983 | 0.9999 | 0.9996 |
| NXE250 | 1.0034 | - | 0.9961 | - | 0.9956 | 1.0057 | 0.9986 | 0.9998 | 0.9992 |
| NXF140 | 1.0013 | - | 0.9978 | - | 0.9950 | 1.0061 | 0.9980 | 0.9999 | 0.9981 |
| NXF150 | 1.0018 | - | 0.9977 | - | 0.9951 | 1.0060 | 0.9981 | 0.9999 | 0.9985 |
| NXF200 | 1.0035 | - | 0.9973 | - | 0.9956 | 1.0056 | 0.9984 | 0.9999 | 1.0002 |
| NXF250 | 1.0042 | - | 0.9955 | - | 0.9960 | 1.0054 | 0.9986 | 0.9998 | 0.9995 |
| NXF280 | 1.0048 | - | 0.9924 | - | 0.9962 | 1.0052 | 0.9988 | 0.9998 | 0.9971 |
| NXG150 | 1.0022 | - | 0.9976 | - | 0.9954 | 1.0058 | 0.9981 | 0.9999 | 0.9990 |
| NXG200 | 1.0042 | - | 0.9970 | - | 0.9959 | 1.0054 | 0.9984 | 0.9999 | 1.0008 |
| NXG250 | 1.0048 | - | 0.9950 | - | 0.9963 | 1.0052 | 0.9987 | 0.9998 | 0.9997 |
| NXG280 | 1.0055 | - | 0.9914 | - | 0.9965 | 1.0051 | 0.9988 | 0.9998 | 0.9969 |

Table B-4 MEFAC correction factors in use after 1 January 2022 (continued)

| NK1200 1.0057 - 0.9870 - 0.9986 1.0050 0.9989 0.9988 0.9998 0.9998 NK1200 1.0056 - 0.9942 - 0.9966 1.0050 0.9988 0.9998 1.0018 NK1300 1.0076 - 0.99845 - 0.9966 1.0048 0.9989 0.9997 0.9977 0.9977 0.9970 0.9970 0.9970 0.9970 0.9971 0.0048 0.9989 0.9997 0.9971 0.047 0.9990 0.9997 0.9971 0.0466 0.9990 0.9997 0.9997 0.9971 0.0466 0.9990 0.9991 <td< th=""><th>Beam ID</th><th>ke</th><th>ksc</th><th>ktr</th><th>kfl</th><th>Product ksc.kfl</th><th>kair¹</th><th>kii.kw</th><th>kCPE</th><th>Combined product</th></td<> | Beam ID | ke | ksc | ktr | kfl | Product ksc.kfl | kair ¹ | kii.kw | kCPE | Combined product |
|--|---------|--------|-----|--------|-----|--------------------|-------------------|--------|--------|---------------------|
| NNH200 1.0052 - 0.9967 - 0.9966 1.0052 0.9988 0.0000 NNH250 1.0063 - 0.9987 - 0.9968 1.0048 0.9989 0.9998 0.9993 0.9973 NNH320 1.0014 - 0.9770 - 0.9970 1.0044 0.9990 0.9997 0.9971 NN1250 1.0061 - 0.9935 - 0.9970 1.0047 0.9990 0.9997 0.9997 NN1250 1.0061 - 0.9934 - 0.9971 1.0046 0.9991 0.9991 NN1200 1.0000 - 0.9994 - 0.9911 1.0046 0.9991 0.9999 0.9989 N100 1.0000 - 0.9974 - 0.9911 1.0044 0.9981 0.9999 0.9989 N100 1.0001 - 0.9972 - 0.9952 1.0056 0.9811 0.0999 0.9998 1.0013 N200 1.00073 | NXG300 | 1.0067 | - | 0.9870 | - | 0.9966 | 1.0050 | 0.9989 | 0.9998 | 0.9938 |
| NXH250 1.0056 - 0.9942 - 0.9968 1.0050 0.9988 0.9998 1.0007 NXH280 1.0067 - 0.9968 1.0048 0.9990 0.9997 0.9925 NXH300 1.0064 - 0.9935 - 0.9970 1.0047 0.9990 0.9997 0.9991 NX1280 1.0066 - 0.9382 - 0.9971 1.0046 0.9990 0.9997 0.9997 NX1280 1.0016 - 0.93934 - 0.9971 1.0046 0.9990 0.9997 0.9981 NK0 1.0000 - 0.9994 - 0.9911 1.0046 0.9990 0.9988 NK0 1.0001 - 0.9973 - 0.9951 1.0056 0.9979 0.9989 0.9989 0.9989 0.9989 0.9989 0.9988 N1000 - 0.9971 1.0047 0.9984 0.9999 0.9988 N1001 N1031 N10050 - 0.9977 | NXH200 | 1.0052 | - | 0.9967 | - | 0.9963 | 1.0052 | 0.9985 | 0.9999 | 1.0018 |
| NNH280 1.0063 - 0.9887 - 0.9968 1.0048 0.9989 0.9993 0.9935 NNH320 1.0014 - 0.9770 - 0.9969 1.0048 0.9990 0.9997 0.9997 0.9997 0.9970 1.0047 0.9990 0.9997 0.9997 0.9991 0.9911 0.1046 0.9991 0.9991 0.9961 0.9910 0.9992 0.9962 0.10051 0.9972 0.9911 1.0044 0.9921 0.9961 0.9961 0.9961 0.9961 0.9961 0.9961 0.9961 0.9961 0.9961 0.9961 0.9961 0.9961 0.9961 0.9961 0.9961 0.9961 0.9961 0.9961 0.9961 0.0961 0.9979 0.9961< | NXH250 | 1.0056 | - | 0.9942 | - | 0.9966 | 1.0050 | 0.9988 | 0.9998 | 1.0000 |
| NXH3200 1.0078 - 0.9969 1.0047 0.9990 0.9997 0.9927 NXH320 1.0061 - 0.9935 - 0.9968 1.0048 0.9999 0.9997 0.9875 NX1280 1.0069 - 0.9382 - 0.9971 1.0046 0.9997 0.9997 0.9997 0.9997 0.9997 0.9991 0.9997 0.9991 0.9991 0.9997 0.9991 0.0481 0.066 0.9911 0.9991 0.9912 0.9912 0.9912 0.9912 0.9912 0.9912 0.9912 0.9912 0.9914 0.0051 0.9914 0.0051 0.9914 0.0051 0.9914 0.0051 0.9914 0.0051 0.9914 0.0051 0.9914 0.0051 0.9914 | NXH280 | 1.0063 | - | 0.9897 | - | 0.9968 | 1.0048 | 0.9989 | 0.9998 | 0.9963 |
| NNH220 1.0104 - 0.9770 - 0.9968 1.0048 0.9998 0.9997 0.9875 NNL250 1.0069 - 0.9882 - 0.9971 1.0046 0.9999 0.9997 0.9999 NN1300 1.0085 - 0.9871 1.0046 0.9991 0.9997 0.9908 NN1300 1.0016 0.9973 - 0.9971 1.0046 0.9999 0.9988 N40 1.0000 - 0.9984 - 0.9911 1.0064 0.9999 0.9989 N100 1.0001 - 0.9975 - 0.9950 1.0056 0.9999 0.9889 N100 1.0001 - 0.9974 - 0.9962 1.0056 0.9988 1.0011 N200 1.0073 - 0.9954 - 0.9977 1.0041 0.9998 0.9996 N300 1.0220 - 0.9334 - 0.9978 1.0041 0.9999 0.9976 <td< td=""><td>NXH300</td><td>1.0078</td><td>-</td><td>0.9845</td><td>-</td><td>0.9969</td><td>1.0048</td><td>0.9990</td><td>0.9997</td><td>0.9925</td></td<> | NXH300 | 1.0078 | - | 0.9845 | - | 0.9969 | 1.0048 | 0.9990 | 0.9997 | 0.9925 |
| NN250 1.0061 - 0.9935 - 0.9968 1.0047 0.9998 0.9997 0.9995 NX1300 1.0085 - 0.9371 1.0046 0.9997 0.9999 0.9988 N40 1.0000 - 0.9973 - 0.9953 1.0056 0.9979 0.9999 0.9962 N120 1.0021 - 0.9974 - 0.9962 1.0053 0.9998 1.0019 N200 1.0073 - 0.9974 1.0044 0.9992 0.9998 1.0013 N200 1.0070 - 0.9977 - 0.9973 1.09999 0.9996 0.9997 | NXH320 | 1.0104 | - | 0.9770 | - | 0.9970 | 1.0047 | 0.9990 | 0.9997 | 0.9875 |
| NR1280 1.0069 - 0.9821 - 0.9970 1.0046 0.9997 0.9997 0.9990 NK1300 1.0016 - 0.9734 - 0.9911 1.0046 0.9991 0.9999 0.9881 N40 1.0000 - 0.9994 - 0.9911 1.0044 0.9991 0.9999 0.9988 N60 1.0000 - 0.9994 - 0.9951 1.0084 0.9999 0.9999 N100 1.0001 - 0.9975 - 0.9952 1.0055 0.9999 0.9989 N150 1.0050 - 0.9974 1.0047 0.9994 0.9999 0.9989 N200 1.0058 - 0.9934 - 0.9974 1.0044 0.9999 0.9988 N300 1.0220 - 0.3334 - 0.9974 1.0044 0.9999 0.9978 W400 1.0000 - 0.9996 - 0.9938 1.0071 0.9979 0.99 | NXI250 | 1.0061 | - | 0.9935 | - | 0.9968 | 1.0048 | 0.9989 | 0.9998 | 0.9999 |
| NN1300 1.0045 - 0.9971 1.0046 0.9991 0.9997 0.9993 NX1320 1.0116 - 0.9734 - 0.9911 1.0046 0.9991 0.9997 0.9851 N40 1.0000 - 0.9994 - 0.9931 1.0048 0.9991 0.9999 0.9988 N60 1.0000 - 0.9973 - 0.9950 1.0055 0.9979 0.9999 0.9962 N100 1.0011 - 0.9972 - 0.9954 1.0055 0.9984 0.9999 1.0011 N200 1.0073 - 0.9972 0.9962 1.0033 0.9993 1.0011 N200 1.0073 - 0.9974 1.0044 0.9999 0.9998 1.0031 N300 1.0220 - 0.9334 - 0.9974 1.0044 0.9999 0.9977 W10 1.0003 - 0.9974 - 0.9978 1.0020 0.9997 0.9983 | NXI280 | 1.0069 | - | 0.9882 | - | 0.9970 | 1.0047 | 0.9990 | 0.9997 | 0.9954 |
| NN1220 1.0116 - 0.9734 - 0.9971 1.0046 0.9991 0.9997 0.9981 N40 1.0000 - 0.9998 - 0.9918 1.0148 0.9990 0.9999 1.0043 N60 1.0000 - 0.9984 - 0.9941 1.0066 0.9979 0.9999 0.9969 N100 1.0001 - 0.9973 - 0.9951 1.0056 0.9979 0.9989 1.0031 0.9989 1.0031 0.9989 1.0019 N200 1.0050 - 0.9972 - 0.9962 1.0053 0.9989 1.0019 N200 1.0058 - 0.9974 1.0044 0.9992 0.9993 0.9464 W60 1.0000 - 0.9996 - 0.9381 1.09999 0.9997 W101 1.0034 - 0.9977 - 0.9948 1.0061 0.9999 0.9997 W200 1.0064 - 0.9974 - | NXI300 | 1.0085 | - | 0.9821 | - | 0.9971 | 1.0046 | 0.9990 | 0.9997 | 0.9909 |
| N40 1.0000 - 0.9994 - 0.9918 1.0148 0.9980 0.9999 1.0043 N60 1.0000 - 0.9994 - 0.9931 1.0086 0.9999 0.9988 N100 1.0001 - 0.9975 - 0.9950 1.0055 0.9978 0.9999 0.9989 N100 1.0011 - 0.9975 - 0.9951 1.0055 0.9984 0.9999 0.9989 N150 1.0050 - 0.9974 - 0.9970 1.0047 0.9984 0.9999 0.9998 N200 1.0073 - 0.9334 - 0.9971 1.0041 0.9992 0.9996 0.9031 N300 1.0220 - 0.8334 - 0.9978 1.0041 0.9999 0.9998 W101 1.0003 - 0.9928 1.0051 0.9999 0.9979 W110 1.0034 - 0.9974 - 0.9981 1.0031 | NXI320 | 1.0116 | - | 0.9734 | - | 0.9971 | 1.0046 | 0.9991 | 0.9997 | 0.9851 |
| N60 1.0000 - 0.9984 - 0.9931 1.0084 0.9978 0.9999 0.9989 N80 1.0000 - 0.9973 - 0.9950 1.0056 0.9979 0.9999 0.9962 N120 1.0021 - 0.9972 - 0.9950 1.0053 0.9999 0.9962 N120 1.0050 - 0.9972 - 0.9962 1.0053 0.9998 1.0019 N200 1.0073 - 0.9334 - 0.9974 1.0044 0.9992 0.9966 N300 1.0020 - 0.9334 - 0.9978 1.0041 0.9995 0.9546 W60 1.0000 - 0.9996 - 0.9928 1.0077 0.9994 0.9999 0.9977 W110 1.0003 - 0.9974 - 0.9958 1.0055 0.9982 0.9999 1.0019 W200 1.0064 - 0.9974 - 0.9956 1.0033 | N40 | 1.0000 | - | 0.9998 | - | 0.9918 | 1.0148 | 0.9981 | 0.9999 | 1.0043 |
| N80 1.0000 - 0.9973 - 0.9941 1.0066 0.9978 0.9999 0.9969 N100 1.0001 - 0.9975 - 0.9958 1.0055 0.9999 0.9989 N120 1.0050 - 0.9972 - 0.9958 1.0053 0.9984 0.9999 1.0014 N200 1.0073 - 0.9934 - 0.9974 1.0047 0.9996 0.9996 N300 1.0220 - 0.9334 - 0.9974 1.0041 0.9994 0.9995 0.9546 W60 1.0000 - 0.9996 - 0.9935 1.0077 0.9974 0.9979 0.9999 0.9977 W110 1.0034 - 0.9974 - 0.9956 1.0055 0.9988 1.0027 W250 1.0065 - 0.9914 - 0.9971 1.0043 0.9997 0.9999 1.0073 RQR2 1.0000 - 0.9998 - | N60 | 1.0000 | - | 0.9994 | - | 0.9931 | 1.0084 | 0.9980 | 0.9999 | 0.9988 |
| N100 1.0001 - 0.9973 - 0.9950 1.0059 0.9979 0.9999 0.9962 N120 1.0021 - 0.9972 - 0.9962 1.0055 0.9984 0.9999 1.0019 N200 1.0073 - 0.9954 - 0.9970 1.0047 0.9989 0.9996 0.9995 0.9546 N200 1.0058 - 0.9334 - 0.9974 1.0044 0.9995 0.9546 W60 1.0000 - 0.9996 - 0.9928 1.0010 0.9995 0.9546 W60 1.0000 - 0.9996 - 0.9938 1.0077 0.9994 0.9999 0.9977 W100 1.0034 - 0.9974 - 0.9958 1.0055 0.9982 0.9999 0.9977 W200 1.0064 - 0.9946 - 0.9975 1.0043 0.9999 0.9983 W300 1.0112 - 0.9949 - | N80 | 1.0000 | - | 0.9984 | - | 0.9941 | 1.0066 | 0.9978 | 0.9999 | 0.9969 |
| N120 1.0021 - 0.9975 - 0.9988 1.0056 0.9999 0.9989 N150 1.0050 - 0.9977 - 0.9964 1.0033 0.9984 0.9999 1.0017 N200 1.0073 - 0.9354 - 0.9977 1.0044 0.9992 0.9996 0.9903 N300 1.0220 - 0.9344 - 0.9978 1.0044 0.9995 0.9998 0.9998 0.9998 0.9998 0.9999 0.9999 0.9999 0.9997 0.9991 0.9917 0.9938 1.0061 0.9979 0.9999 0.9979 W110 1.0003 - 0.9974 - 0.9958 1.0055 0.9977 0.9938 1.0055 0.9977 1.0046 0.9997 0.9989 0.9079 W250 1.0064 - 0.9914 1.0026 0.9977 1.0043 0.9992 0.0493 RQR2 1.0000 - 0.9928 - 0.9911 1.01215 | N100 | 1.0001 | - | 0.9973 | - | 0.9950 | 1.0059 | 0.9979 | 0.9999 | 0.9962 |
| N150 1.0050 - 0.9972 - 0.9962 1.0033 0.9984 0.9999 1.0011 N200 1.0073 - 0.9354 - 0.9970 1.0044 0.9992 0.9996 0.9903 N300 1.0220 - 0.9334 - 0.9978 1.0041 0.9995 0.9995 0.9995 W60 1.0000 - 0.9996 - 0.9978 1.0016 0.9999 0.9999 W10 1.0003 - 0.9977 - 0.9948 1.0050 0.9999 0.9999 W100 1.0034 - 0.9974 - 0.9958 1.0055 0.9998 1.0029 W250 1.0065 - 0.9914 - 0.9971 1.0046 0.9999 0.9988 1.0029 W300 1.0112 - 0.9692 - 0.9971 1.0046 0.9999 0.0073 RQR2 1.0000 - 0.9998 - 0.9915 1.0133 | N120 | 1.0021 | - | 0.9975 | - | 0.9958 | 1.0056 | 0.9981 | 0.9999 | 0.9989 |
| N200 1.0073 - 0.9954 - 0.9970 1.0047 0.9989 0.9998 1.0031 N250 1.0058 - 0.9334 - 0.9974 1.0044 0.9992 0.9996 0.9903 N300 1.0020 - 0.9334 - 0.9978 1.0041 0.9999 0.9954 W60 1.0000 - 0.9990 - 0.9328 1.0077 0.9979 0.9999 0.9977 W110 1.0034 - 0.9974 - 0.9958 1.0055 0.9982 0.9999 0.9979 W200 1.0064 - 0.9974 - 0.9956 1.0050 0.9987 0.9998 1.0021 W200 1.0065 - 0.9914 - 0.9975 1.0043 0.9999 0.90807 RQR2 1.0000 - 0.9998 - 0.9911 1.0141 0.980 0.9999 1.0010 RQR3 1.0000 - 0.9994 - | N150 | 1.0050 | - | 0.9972 | - | 0.9962 | 1.0053 | 0.9984 | 0.9999 | 1.0019 |
| N250 1.0058 - 0.9839 - 0.9974 1.0044 0.9992 0.9996 0.9903 N300 1.0220 - 0.9334 - 0.9978 1.0041 0.9994 0.9995 0.5546 W60 1.0000 - 0.9990 - 0.9928 1.0066 0.9997 0.9999 0.9979 W110 1.0003 - 0.9977 - 0.9948 1.0051 0.9979 0.9999 0.9967 W150 1.0034 - 0.9974 - 0.9958 1.0055 0.9982 0.9999 1.0001 W250 1.0064 - 0.9975 1.0046 0.9999 0.9988 0.9911 1.0215 0.9978 0.9999 1.0010 RQR2 1.0000 - 0.9998 - 0.9911 1.0215 0.9978 0.9999 1.0013 RQR3 1.0000 - 0.9998 - 0.9911 1.0141 0.9800 0.9999 1.0025 | N200 | 1.0073 | - | 0.9954 | - | 0.9970 | 1.0047 | 0.9989 | 0.9998 | 1.0031 |
| N300 1.0220 - 0.9334 - 0.9978 1.0041 0.9994 0.9995 0.9995 W60 1.0000 - 0.9996 - 0.9928 1.0096 0.9991 0.9999 0.9999 W80 1.0000 - 0.9974 - 0.9935 1.0077 0.9979 0.9999 0.9997 W150 1.0034 - 0.9974 - 0.9958 1.0055 0.9992 0.9999 1.0001 W200 1.0065 - 0.9914 - 0.9971 1.0046 0.9997 0.9988 W300 1.0112 - 0.9692 - 0.9975 1.0043 0.9997 0.9998 RQR2 1.0000 - 0.9999 - 0.9915 1.0133 0.9979 0.9999 1.0010 RQR3 1.0000 - 0.9996 - 0.9921 1.0141 0.980 0.9999 1.0025 RQR4 1.0000 - 0.9994 - | N250 | 1.0058 | - | 0.9839 | - | 0.9974 | 1.0044 | 0.9992 | 0.9996 | 0.9903 |
| W60 1.0000 - 0.9996 - 0.9928 1.0096 0.9981 0.9999 0.9998 W80 1.0000 - 0.9990 - 0.9935 1.0077 0.9979 0.9999 0.9979 W110 1.0034 - 0.9974 - 0.9948 1.0055 0.9982 0.9999 1.0001 W200 1.0064 - 0.9964 - 0.9975 1.0040 0.9998 1.0029 W200 1.0112 - 0.9974 - 0.9975 1.0043 0.9999 0.9983 0.9998 0.9997 0.9998 0.9997 0.9990 0.9977 0.9991 0.9977 0.9991 0.0073 RQR4 1.0000 - 0.9998 - 0.9918 1.0136 0.9999 1.0016 RQR5 1.0000 - 0.9996 - 0.9923 1.0128 0.9999 1.0025 RQR7 1.0000 - 0.9994 - 0.9922 1.0109 | N300 | 1.0220 | - | 0.9334 | - | 0.9978 | 1.0041 | 0.9994 | 0.9995 | 0.9546 |
| W80 1.0000 - 0.9990 - 0.9935 1.0077 0.9979 0.9999 0.9979 W110 1.0003 - 0.9977 - 0.9948 1.0061 0.9999 0.9999 0.9999 0.9999 1.0001 W150 1.0064 - 0.9964 - 0.9961 0.0950 0.9987 0.9998 1.0029 W250 1.0065 - 0.9914 - 0.9971 1.0046 0.9990 0.9997 0.9983 W300 1.0112 - 0.9692 - 0.9971 1.0046 0.9999 1.0100 RQR2 1.0000 - 0.9998 - 0.9911 1.0215 0.9978 0.9999 1.0073 RQR4 1.0000 - 0.9998 - 0.9911 1.0141 0.9980 0.9999 1.0025 RQR5 1.0000 - 0.9994 - 0.9922 1.0119 0.9980 0.9999 1.0025 RQR7 1. | W60 | 1.0000 | - | 0.9996 | - | 0.9928 | 1.0096 | 0.9981 | 0.9999 | 0.9998 |
| W110 1.0003 - 0.9977 - 0.9988 1.0061 0.9979 0.9999 0.9967 W150 1.0034 - 0.9974 - 0.9958 1.0055 0.9999 1.0001 W200 1.0065 - 0.9964 - 0.9971 1.0046 0.9990 0.9997 0.9983 W300 1.0112 - 0.9692 - 0.9975 1.0043 0.9992 0.9996 0.9807 RQR1 1.0000 - 0.9998 - 0.9915 1.0183 0.9999 1.0049 RQR4 1.0000 - 0.9998 - 0.9915 1.0183 0.9999 1.0049 RQR5 1.0000 - 0.9997 - 0.9912 1.0114 0.9980 0.9999 1.0025 RQR6 1.0000 - 0.9994 - 0.9925 1.0119 0.9999 1.0026 RQR7 1.0000 - 0.9993 - 0.9925 1.0102 | W80 | 1.0000 | - | 0.9990 | - | 0.9935 | 1.0077 | 0.9979 | 0.9999 | 0.9979 |
| W150 1.0034 - 0.9974 - 0.9958 1.0055 0.9982 0.9999 1.0001 W200 1.0064 - 0.9964 - 0.9966 1.0050 0.9987 0.9998 1.0029 W250 1.0065 - 0.9914 - 0.9971 1.0043 0.9992 0.9996 0.9998 RQR2 1.0000 - 0.9998 - 0.9911 1.0215 0.9978 0.9999 1.0100 RQR3 1.0000 - 0.9998 - 0.9911 1.0121 0.9999 1.0073 RQR4 1.0000 - 0.9997 - 0.9913 1.0114 0.9980 0.9999 1.0025 RQR6 1.0000 - 0.9994 - 0.9925 1.0119 0.9800 0.9999 1.0026 RQR8 1.0000 - 0.9993 - 0.9921 1.0103 0.9999 0.9999 RQA1 1.0000 - 0.9993 - | W110 | 1.0003 | - | 0.9977 | - | 0.9948 | 1.0061 | 0.9979 | 0.9999 | 0.9967 |
| W200 1.0064 - 0.9964 - 0.9966 1.0050 0.9977 0.9987 0.9998 1.0029 W250 1.0065 - 0.9914 - 0.9971 1.0046 0.9990 0.9983 W300 1.0112 - 0.9692 - 0.9975 1.0043 0.9992 0.9999 0.9901 RQR2 1.0000 - 0.9998 - 0.9911 1.0156 0.9999 1.0073 RQR4 1.0000 - 0.9998 - 0.9911 1.0141 0.9980 0.9999 1.0073 RQR4 1.0000 - 0.9997 - 0.9923 1.0128 0.9980 0.9999 1.0015 RQR5 1.0000 - 0.9994 - 0.9923 1.0128 0.9980 0.9999 1.0016 RQR6 1.0000 - 0.9993 - 0.9928 1.0109 0.9999 0.9999 1.0025 RQR10 1.0001 - 0.999 | W150 | 1.0034 | - | 0.9974 | - | 0.9958 | 1.0055 | 0.9982 | 0.9999 | 1.0001 |
| W250 1.0065 - 0.9914 - 0.9971 1.0046 0.9990 0.9997 0.9983 W300 1.0112 - 0.9692 - 0.9975 1.0043 0.9992 0.9996 0.9807 RQR2 1.0000 - 0.9998 - 0.9915 1.0135 0.9979 0.9999 1.0073 RQR4 1.0000 - 0.9998 - 0.9915 1.0141 0.9980 0.9999 1.0046 RQR5 1.0000 - 0.9996 - 0.9923 1.0128 0.9980 0.9999 1.0025 RQR6 1.0000 - 0.9994 - 0.9225 1.0119 0.9980 0.9999 1.0026 RQR8 1.0001 - 0.9993 - 0.9228 1.0109 0.9999 0.0088 RQR4 1.0001 - 0.9993 - 0.9232 1.007 0.9999 0.9994 RQA2 1.0000 - 0.9993 - | W200 | 1.0064 | - | 0.9964 | - | 0.9966 | 1.0050 | 0.9987 | 0.9998 | 1.0029 |
| W300 1.0112 - 0.9692 - 0.9975 1.0043 0.9992 0.9996 0.9807 RQR2 1.0000 - 0.9999 - 0.9911 1.0215 0.9978 0.9999 1.0100 RQR3 1.0000 - 0.9998 - 0.9915 1.0183 0.9979 0.9999 1.0073 RQR4 1.0000 - 0.9997 - 0.9912 1.0141 0.9800 0.9999 1.0025 RQR6 1.0000 - 0.9996 - 0.9923 1.0128 0.9980 0.9999 1.0025 RQR7 1.0000 - 0.9993 - 0.9923 1.0190 0.9999 1.0008 RQR9 1.0001 - 0.9993 - 0.9932 1.0097 0.9999 0.9999 0.9999 0.9999 0.9999 0.9999 0.9999 0.9999 0.9999 0.9999 0.9999 0.9999 0.9999 0.9991 0.0377 RQA1 0.0000 - </td <td>W250</td> <td>1.0065</td> <td>-</td> <td>0.9914</td> <td>-</td> <td>0.9971</td> <td>1.0046</td> <td>0.9990</td> <td>0.9997</td> <td>0.9983</td> | W250 | 1.0065 | - | 0.9914 | - | 0.9971 | 1.0046 | 0.9990 | 0.9997 | 0.9983 |
| RQR2 1.0000 - 0.9999 - 0.9911 1.0215 0.9978 0.9999 1.0100 RQR3 1.0000 - 0.9998 - 0.9915 1.0183 0.9979 0.9999 1.0073 RQR4 1.0000 - 0.9998 - 0.9918 1.0141 0.9980 0.9999 1.0036 RQR5 1.0000 - 0.9994 - 0.9921 1.0114 0.9980 0.9999 1.0025 RQR7 1.0000 - 0.9994 - 0.9925 1.0119 0.9980 0.9999 1.0016 RQR7 1.0000 - 0.9993 - 0.9928 1.0109 0.9999 0.9999 1.0016 RQR3 1.0001 - 0.9997 - 0.9925 1.0107 0.9999 0.9999 0.9999 0.9999 0.9999 0.9999 1.0037 RQA1 1.0000 - 0.9998 - 0.9918 1.0113 0.9980 0.9999 | W300 | 1.0112 | - | 0.9692 | - | 0.9975 | 1.0043 | 0.9992 | 0.9996 | 0.9807 |
| RQR3 1.0000 - 0.9998 - 0.9915 1.0183 0.9979 0.9999 1.0073 RQR4 1.0000 - 0.9998 - 0.9918 1.0156 0.9980 0.9999 1.0049 RQR5 1.0000 - 0.9997 - 0.9921 1.0141 0.9980 0.9999 1.0025 RQR7 1.0000 - 0.9994 - 0.9925 1.0119 0.9980 0.9999 1.0016 RQR7 1.0000 - 0.9993 - 0.9925 1.0119 0.9980 0.9999 1.0016 RQR9 1.0001 - 0.9993 - 0.9925 1.0097 0.9999 0.9994 RQA2 1.0000 - 0.9997 - 0.9938 1.0084 0.9980 0.9999 1.0037 RQA3 1.0000 - 0.9997 - 0.9930 1.0086 0.9999 0.9939 RQA4 1.0000 - 0.9997 - | RQR2 | 1.0000 | - | 0.9999 | - | 0.9911 | 1.0215 | 0.9978 | 0.9999 | 1.0100 |
| RQR4 1.0000 - 0.9998 - 0.9918 1.0156 0.9980 0.9999 1.0049 RQR5 1.0000 - 0.9997 - 0.9921 1.0141 0.9980 0.9999 1.0036 RQR6 1.0000 - 0.9994 - 0.9923 1.0128 0.9980 0.9999 1.0025 RQR7 1.0000 - 0.9994 - 0.9925 1.0119 0.9990 0.9999 1.0016 RQR8 1.0000 - 0.9990 - 0.9932 1.0097 0.9999 0.9999 RQR10 1.0007 - 0.9987 - 0.9938 1.0084 0.9980 0.9999 0.9994 RQA2 1.0000 - 0.9997 - 0.9932 1.0103 0.9981 0.9999 1.0037 RQA3 1.0000 - 0.9997 - 0.9925 1.0103 0.9981 0.9999 0.9970 RQA4 1.0000 - 0.998 | RQR3 | 1.0000 | - | 0.9998 | - | 0.9915 | 1.0183 | 0.9979 | 0.9999 | 1.0073 |
| RQR51.0000-0.9997-0.99211.01410.99800.99991.0036RQR61.0000-0.9996-0.99231.01280.99800.99991.0025RQR71.0000-0.9994-0.99251.01190.99800.99991.0016RQR81.0000-0.9993-0.99281.01090.99790.99991.0008RQR91.0001-0.9990-0.99321.00970.99800.99990.9999RQA11.0007-0.9987-0.99381.00440.99800.99990.9994RQA31.0000-0.9997-0.99251.01030.99800.99991.0037RQA31.0000-0.9997-0.99251.01030.99810.99991.0005RQA41.0000-0.9995-0.99301.00860.99800.99990.9991RQA51.0000-0.9984-0.99341.00720.99790.99990.9970RQA61.0000-0.9981-0.99431.00620.99790.99990.9972RQA71.0000-0.9981-0.99431.00620.99790.99990.9972RQA91.0002-0.9976-0.99531.00580.99790.99990.9972RQA11.0000-0.9976-0.99531.00580.99790.9999 | RQR4 | 1.0000 | - | 0.9998 | - | 0.9918 | 1.0156 | 0.9980 | 0.9999 | 1.0049 |
| RQR6 1.0000 - 0.9996 - 0.9923 1.0128 0.9980 0.9999 1.0025 RQR7 1.0000 - 0.9994 - 0.9925 1.0119 0.9980 0.9999 1.0016 RQR8 1.0000 - 0.9993 - 0.9928 1.0109 0.9999 0.9999 1.0008 RQR9 1.0001 - 0.9990 - 0.9932 1.0097 0.9999 0.9999 RQA1 1.0007 - 0.9987 - 0.9938 1.0084 0.9980 0.9999 1.0037 RQA3 1.0000 - 0.9997 - 0.9925 1.0103 0.9980 0.9999 1.0037 RQA4 1.0000 - 0.9997 - 0.9925 1.0103 0.9980 0.9999 0.9990 RQA4 1.0000 - 0.9984 - 0.9937 1.0072 0.9979 0.9999 0.9970 RQA5 1.0000 - 0.9984 | RQR5 | 1.0000 | - | 0.9997 | - | 0.9921 | 1.0141 | 0.9980 | 0.9999 | 1.0036 |
| RQR71.0000-0.9994-0.99251.01190.99800.99991.0016RQR81.0000-0.9993-0.99281.01090.99790.99991.0008RQR91.0001-0.9990-0.99321.00970.99800.99990.9999RQR101.0007-0.9987-0.99381.00840.99800.99990.9994RQA21.0000-0.9998-0.99181.01430.99800.99991.0037RQA31.0000-0.9997-0.92551.01030.98110.99990.9990RQA41.0000-0.9995-0.99301.00860.99800.99990.9990RQA51.0000-0.9991-0.99341.00720.99790.99990.9975RQA61.0000-0.9984-0.99401.00660.99790.99990.9970RQA81.0000-0.9981-0.99481.00660.99790.99990.9972RQA101.0022-0.9976-0.99531.00580.99790.99990.9972RQA101.0022-0.9985-0.99461.00660.99810.99990.9978RQT91.0003-0.9985-0.99231.01160.99810.99990.9984HHR1-501.0000-0.9997-0.99251.01050.99810.999 | RQR6 | 1.0000 | - | 0.9996 | - | 0.9923 | 1.0128 | 0.9980 | 0.9999 | 1.0025 |
| RQR81.0000-0.9993-0.99281.01090.99790.99991.0008RQR91.0001-0.9990-0.99321.00970.99800.99990.9999RQR101.0007-0.9987-0.99381.00840.99800.99990.9994RQA21.0000-0.9998-0.99181.01430.99800.99991.0037RQA31.0000-0.9995-0.99251.01030.99810.99990.9990RQA41.0000-0.9991-0.99341.00780.99790.99990.9990RQA51.0000-0.9991-0.99371.00720.99790.99990.9975RQA61.0000-0.9984-0.99371.00720.99790.99990.9970RQA71.0000-0.9981-0.99431.00660.99790.99990.9972RQA71.0000-0.9981-0.99431.00620.99790.99990.9972RQA101.0022-0.9976-0.99531.00580.99820.99990.9978RQT91.0003-0.9985-0.99461.00660.99810.99990.9978RQT101.0012-0.9981-0.99251.01160.99810.99990.9984HHR1-501.0000-0.9997-0.99251.01160.99810.999 | RQR7 | 1.0000 | - | 0.9994 | - | 0.9925 | 1.0119 | 0.9980 | 0.9999 | 1.0016 |
| RQR91.0001-0.9990-0.99321.00970.99800.99990.9999RQR101.0007-0.9987-0.99381.00840.99800.99990.9994RQA21.0000-0.9998-0.99181.01430.99800.99991.0037RQA31.0000-0.9997-0.99251.01030.99810.99991.0005RQA41.0000-0.9995-0.99301.00860.99800.99990.9990RQA51.0000-0.9991-0.99341.00780.99790.99990.9975RQA61.0000-0.9984-0.99401.00690.99780.99990.9970RQA81.0000-0.9981-0.99431.00660.99790.99990.9972RQA101.0022-0.9976-0.99481.00520.99790.99990.9972RQA101.0022-0.9976-0.99361.00790.99790.99990.9978RQT101.0012-0.9981-0.99461.00720.99790.99990.9978RQT101.0012-0.9981-0.99231.01160.99810.99991.0015HHR1-501.0000-0.9997-0.99251.01050.99810.99991.0007HHR3-501.0000-0.9997-0.99251.01050.9981 | RQR8 | 1.0000 | - | 0.9993 | - | 0.9928 | 1.0109 | 0.9979 | 0.9999 | 1.0008 |
| RQR101.0007-0.9987-0.99381.00840.99800.99990.9994RQA21.0000-0.9998-0.99181.01430.99800.99991.0037RQA31.0000-0.9997-0.99251.01030.99810.99991.0005RQA41.0000-0.9995-0.99301.00860.99800.99990.9990RQA51.0000-0.9991-0.99341.00780.99790.99990.9981RQA61.0000-0.9988-0.99371.00720.99790.99990.9975RQA71.0000-0.9984-0.99401.00690.99780.99990.9970RQA81.0006-0.9979-0.99481.00660.99790.99990.9972RQA101.0022-0.9976-0.99531.00580.99820.99990.9978RQT101.0012-0.9981-0.99461.00720.99790.99990.9978RQT101.0012-0.9981-0.99461.00660.99810.99991.0015HHR2-501.0000-0.9997-0.99251.01160.99810.99991.0007HHR3-501.0000-0.9997-0.99251.01050.99810.99991.0001HHR5-501.0000-0.9996-0.99291.00900.9981 <t< td=""><td>RQR9</td><td>1.0001</td><td>-</td><td>0.9990</td><td>-</td><td>0.9932</td><td>1.0097</td><td>0.9980</td><td>0.9999</td><td>0.9999</td></t<> | RQR9 | 1.0001 | - | 0.9990 | - | 0.9932 | 1.0097 | 0.9980 | 0.9999 | 0.9999 |
| RQA2 1.0000 - 0.9998 - 0.9918 1.0143 0.9980 0.9999 1.0037 RQA3 1.0000 - 0.9997 - 0.9925 1.0103 0.9981 0.9999 1.0005 RQA4 1.0000 - 0.9995 - 0.9930 1.0086 0.9980 0.9999 0.9990 RQA5 1.0000 - 0.9991 - 0.9934 1.0078 0.9979 0.9999 0.9990 RQA6 1.0000 - 0.9988 - 0.9937 1.0072 0.9979 0.9999 0.9970 RQA6 1.0000 - 0.9984 - 0.9940 1.0069 0.9978 0.9999 0.9970 RQA7 1.0000 - 0.9981 - 0.9943 1.0066 0.9979 0.9999 0.9972 RQA3 1.0006 - 0.9977 - 0.9943 1.0062 0.9979 0.9999 0.9972 RQA10 1.0022 | ROR10 | 1.0007 | - | 0.9987 | - | 0.9938 | 1.0084 | 0.9980 | 0.9999 | 0.9994 |
| RQA3 1.0000 - 0.9997 - 0.9925 1.0103 0.9981 0.9999 1.0005 RQA4 1.0000 - 0.9995 - 0.9930 1.0086 0.9980 0.9999 0.9990 RQA5 1.0000 - 0.9991 - 0.9934 1.0078 0.9979 0.9999 0.9981 RQA6 1.0000 - 0.9988 - 0.9937 1.0072 0.9979 0.9999 0.9975 RQA7 1.0000 - 0.9984 - 0.9940 1.0069 0.9978 0.9999 0.9970 RQA7 1.0000 - 0.9984 - 0.9943 1.0066 0.9979 0.9999 0.9970 RQA8 1.0006 - 0.9979 - 0.9948 1.0062 0.9979 0.9999 0.9972 RQA10 1.0022 - 0.9976 - 0.9953 1.0058 0.9982 0.9999 0.9978 RQT9 1.0003 | RQA2 | 1.0000 | - | 0.9998 | - | 0.9918 | 1.0143 | 0.9980 | 0.9999 | 1.0037 |
| RQA41.0000-0.9995-0.99301.00860.99800.99990.9990RQA51.0000-0.9991-0.99341.00780.99790.99990.9981RQA61.0000-0.9988-0.99371.00720.99790.99990.9975RQA71.0000-0.9984-0.99401.00690.99780.99990.9970RQA81.0000-0.9981-0.99431.00660.99790.99990.9972RQA91.0066-0.9976-0.99481.00620.99790.99990.9972RQA101.0022-0.9976-0.99531.00580.99820.99990.9978RQT81.0000-0.9985-0.99401.00720.99790.99990.9978RQT91.0012-0.9981-0.99461.00660.99810.99990.9978RQT101.0012-0.9997-0.99231.01160.99810.99990.9984HHR1-501.0000-0.9977-0.99251.01050.99810.99991.0007HHR3-501.0000-0.9997-0.99261.00990.99810.99990.9995HHR5-501.0000-0.9996-0.99201.00860.99810.99990.9995HHR5-501.0000-0.9996-0.99301.00860.9881< | RQA3 | 1.0000 | - | 0.9997 | - | 0.9925 | 1.0103 | 0.9981 | 0.9999 | 1.0005 |
| RQA51.0000-0.9991-0.99341.00780.99790.99990.9981RQA61.0000-0.9988-0.99371.00720.99790.99990.9975RQA71.0000-0.9984-0.99401.00690.99780.99990.9970RQA81.0000-0.9981-0.99431.00660.99790.99990.9968RQA91.0006-0.9979-0.99481.00620.99790.99990.9972RQA101.0022-0.9976-0.99531.00580.99820.99990.9990RQT81.0000-0.9988-0.99361.00790.99790.99990.9978RQT91.0003-0.9981-0.99461.00660.99810.99990.9978RQT101.0012-0.9981-0.99461.00660.99810.99990.9984HHR1-501.0000-0.9997-0.99231.01160.99810.99991.0015HHR2-501.0000-0.9997-0.99251.01050.99810.99991.0007HHR3-501.0000-0.9996-0.99261.00990.99810.99990.9995HHR5-501.0000-0.9996-0.99201.00860.99810.99990.9991HHR1-701.0000-0.9996-0.99281.00980.9999 <td>RQA4</td> <td>1.0000</td> <td>-</td> <td>0.9995</td> <td>-</td> <td>0.9930</td> <td>1.0086</td> <td>0.9980</td> <td>0.9999</td> <td>0.9990</td> | RQA4 | 1.0000 | - | 0.9995 | - | 0.9930 | 1.0086 | 0.9980 | 0.9999 | 0.9990 |
| RQA61.0000-0.9988-0.99371.00720.99790.99990.9975RQA71.0000-0.9984-0.99401.00690.99780.99990.9970RQA81.0000-0.9981-0.99431.00660.99790.99990.9968RQA91.0006-0.9979-0.99481.00620.99790.99990.9972RQA101.0022-0.9976-0.99531.00580.99820.99990.9990RQT81.0000-0.9988-0.99361.00720.99790.99990.9981RQT91.0003-0.9981-0.99401.00720.99790.99990.9978RQT101.0012-0.9981-0.99461.00660.99810.99990.9984HHR1-501.0000-0.9997-0.99231.01160.99810.99991.0007HHR2-501.0000-0.9997-0.99251.01050.99810.99991.0007HHR3-501.0000-0.9997-0.99261.00990.99810.99990.9995HHR5-501.0000-0.9996-0.99291.00060.99810.99990.9991HHR1-701.0000-0.9995-0.99281.00860.99810.99990.9999HHR1-701.0000-0.9995-0.99281.00980.9980 | RQA5 | 1.0000 | - | 0.9991 | - | 0.9934 | 1.0078 | 0.9979 | 0.9999 | 0.9981 |
| RQA71.0000-0.9984-0.99401.00690.99780.99990.9970RQA81.0000-0.9981-0.99431.00660.99790.99990.9968RQA91.0006-0.9979-0.99481.00620.99790.99990.9972RQA101.0022-0.9976-0.99531.00580.99820.99990.9990RQT81.0000-0.9988-0.99361.00790.99790.99990.9981RQT91.0003-0.9985-0.99461.00660.99810.99990.9978RQT101.0012-0.9981-0.99231.01160.99810.99990.9984HHR1-501.0000-0.9997-0.99251.01050.99810.99991.0007HHR3-501.0000-0.9997-0.99261.00990.99810.99991.0001HHR4-501.0000-0.9996-0.99291.00900.99810.99990.9995HHR5-501.0000-0.9996-0.99201.00860.99810.99990.9991HHR1-701.0000-0.9996-0.99281.00980.99800.99990.9999 | RQA6 | 1.0000 | - | 0.9988 | - | 0.9937 | 1.0072 | 0.9979 | 0.9999 | 0.9975 |
| RQA81.0000-0.9981-0.99431.00660.99790.99990.9968RQA91.0006-0.9979-0.99481.00620.99790.99990.9972RQA101.0022-0.9976-0.99531.00580.99820.99990.9990RQT81.0000-0.9988-0.99361.00790.99790.99990.9981RQT91.0003-0.9985-0.99401.00720.99790.99990.9978RQT101.0012-0.9981-0.99461.00660.99810.99990.9984HHR1-501.0000-0.9997-0.99231.01160.99810.99991.0015HHR2-501.0000-0.9997-0.99261.00990.99810.99991.0007HHR3-501.0000-0.9997-0.99261.00990.99810.99991.0001HHR4-501.0000-0.9996-0.99291.00900.98810.99990.9995HHR5-501.0000-0.9996-0.99301.00860.99810.99990.9991HHR1-701.0000-0.9995-0.99281.00980.99800.99990.9999 | RQA7 | 1.0000 | - | 0.9984 | - | 0.9940 | 1.0069 | 0.9978 | 0.9999 | 0.9970 |
| RQA91.0006-0.9979-0.99481.00620.99790.99990.9972RQA101.0022-0.9976-0.99531.00580.99820.99990.9990RQT81.0000-0.9988-0.99361.00790.99790.99990.9981RQT91.0003-0.9985-0.99401.00720.99790.99990.9978RQT101.0012-0.9981-0.99461.00660.99810.99990.9984HHR1-501.0000-0.9997-0.99231.01160.99810.99991.0015HHR2-501.0000-0.9997-0.99251.01050.99810.99991.0007HHR3-501.0000-0.9996-0.99261.00990.99810.99990.9995HHR5-501.0000-0.9996-0.99291.00860.99810.99990.9991HHR1-701.0000-0.9995-0.99281.00860.99810.99990.9991 | RQA8 | 1.0000 | - | 0.9981 | - | 0.9943 | 1.0066 | 0.9979 | 0.9999 | 0.9968 |
| RQA101.0022-0.9976-0.99531.00580.99820.99990.9990RQT81.0000-0.9988-0.99361.00790.99790.99990.9981RQT91.0003-0.9985-0.99401.00720.99790.99990.9978RQT101.0012-0.9981-0.99461.00660.99810.99990.9984HHR1-501.0000-0.9997-0.99231.01160.99810.99991.0015HHR2-501.0000-0.9997-0.99251.01050.99810.99991.0007HHR3-501.0000-0.9997-0.99261.00990.99810.99991.0001HHR4-501.0000-0.9996-0.99291.00900.99810.99990.9995HHR5-501.0000-0.9996-0.99301.00860.99810.99990.9991HHR1-701.0000-0.9995-0.99281.00980.99800.99990.9999 | RQA9 | 1.0006 | - | 0.9979 | - | 0.9948 | 1.0062 | 0.9979 | 0.9999 | 0.9972 |
| RQT81.0000-0.9988-0.99361.00790.99790.99990.9981RQT91.0003-0.9985-0.99401.00720.99790.99990.9978RQT101.0012-0.9981-0.99461.00660.99810.99990.9984HHR1-501.0000-0.9997-0.99231.01160.99810.99991.0015HHR2-501.0000-0.9997-0.99251.01050.99810.99991.0007HHR3-501.0000-0.9997-0.99261.00990.99810.99991.0001HHR4-501.0000-0.9996-0.99291.00900.99810.99990.9995HHR5-501.0000-0.9996-0.99301.00860.99810.99990.9991HHR1-701.0000-0.9995-0.99281.00980.99800.99990.9999 | RQA10 | 1.0022 | - | 0.9976 | - | 0.9953 | 1.0058 | 0.9982 | 0.9999 | 0.9990 |
| RQT9 1.0003 - 0.9985 - 0.9940 1.0072 0.9979 0.9999 0.9978 RQT10 1.0012 - 0.9981 - 0.9946 1.0066 0.9981 0.9999 0.9984 HHR1-50 1.0000 - 0.9997 - 0.9923 1.0116 0.9981 0.9999 1.0015 HHR2-50 1.0000 - 0.9997 - 0.9925 1.0105 0.9981 0.9999 1.0007 HHR3-50 1.0000 - 0.9997 - 0.9926 1.0099 0.9981 0.9999 1.0007 HHR3-50 1.0000 - 0.9997 - 0.9926 1.0099 0.9981 0.9999 1.0007 HHR4-50 1.0000 - 0.9996 - 0.9929 1.0090 0.9981 0.9999 0.9995 HHR5-50 1.0000 - 0.9996 - 0.9930 1.0086 0.9981 0.9999 0.99991 HHR1-70 1. | RQT8 | 1.0000 | - | 0.9988 | - | 0.9936 | 1.0079 | 0.9979 | 0.9999 | 0.9981 |
| RQT10 1.0012 - 0.9981 - 0.9946 1.0066 0.9981 0.9999 0.9984 HHR1-50 1.0000 - 0.9997 - 0.9923 1.0116 0.9981 0.9999 1.0015 HHR2-50 1.0000 - 0.9997 - 0.9925 1.0105 0.9981 0.9999 1.0007 HHR3-50 1.0000 - 0.9997 - 0.9926 1.0099 0.9981 0.9999 1.0007 HHR3-50 1.0000 - 0.9996 - 0.9929 1.0090 0.9981 0.9999 0.9995 HHR4-50 1.0000 - 0.9996 - 0.9920 1.0090 0.9981 0.9999 0.9995 HHR5-50 1.0000 - 0.9996 - 0.9930 1.0086 0.9981 0.9999 0.9991 HHR1-70 1.0000 - 0.9995 - 0.9928 1.0098 0.9980 0.9999 0.99999 | RQT9 | 1.0003 | - | 0.9985 | - | 0.9940 | 1.0072 | 0.9979 | 0.9999 | 0.9978 |
| HHR1-501.0000-0.9997-0.99231.01160.99810.99991.0015HHR2-501.0000-0.9997-0.99251.01050.99810.99991.0007HHR3-501.0000-0.9997-0.99261.00990.99810.99991.0001HHR4-501.0000-0.9996-0.99291.00900.99810.99990.9995HHR5-501.0000-0.9996-0.99301.00860.99810.99990.9991HHR1-701.0000-0.9995-0.99281.00980.99800.99990.9999 | RQT10 | 1.0012 | - | 0.9981 | - | 0.9946 | 1.0066 | 0.9981 | 0.9999 | 0.9984 |
| HHR2-50 1.0000 - 0.9997 - 0.9925 1.0105 0.9981 0.9999 1.0007 HHR3-50 1.0000 - 0.9997 - 0.9926 1.0099 0.9981 0.9999 1.0007 HHR3-50 1.0000 - 0.9996 - 0.9929 1.0090 0.9981 0.9999 0.9995 HHR5-50 1.0000 - 0.9996 - 0.9930 1.0086 0.9981 0.9999 0.9995 HHR5-50 1.0000 - 0.9996 - 0.9930 1.0086 0.9981 0.9999 0.9991 HHR1-70 1.0000 - 0.9995 - 0.9928 1.0098 0.9980 0.9999 0.9999 | HHR1-50 | 1.0000 | - | 0.9997 | - | 0.9923 | 1.0116 | 0.9981 | 0.9999 | 1.0015 |
| HHR3-50 1.0000 - 0.9997 - 0.9926 1.0099 0.9981 0.9999 1.0001 HHR3-50 1.0000 - 0.9996 - 0.9929 1.0090 0.9981 0.9999 0.9995 HHR5-50 1.0000 - 0.9996 - 0.9930 1.0086 0.9981 0.9999 0.9995 HHR5-70 1.0000 - 0.9995 - 0.9928 1.0098 0.9981 0.9999 0.9991 HHR1-70 1.0000 - 0.9995 - 0.9928 1.0098 0.9980 0.9999 0.9999 | HHR2-50 | 1.0000 | - | 0.9997 | - | 0.9925 | 1.0105 | 0.9981 | 0.9999 | 1.0007 |
| HHR4-50 1.0000 - 0.9996 - 0.9929 1.0090 0.9981 0.9999 0.9995 HHR5-50 1.0000 - 0.9996 - 0.9930 1.0086 0.9981 0.9999 0.9991 HHR1-70 1.0000 - 0.9995 - 0.9928 1.0098 0.9980 0.9999 0.9999 | HHR3-50 | 1.0000 | - | 0.9997 | - | 0.9926 | 1.0099 | 0.9981 | 0.9999 | 1.0001 |
| HHR5-50 1.0000 - 0.9996 - 0.9930 1.0086 0.9981 0.9999 0.9991 HHR1-70 1.0000 - 0.9995 - 0.9928 1.0098 0.9980 0.9999 0.9999 | HHR4-50 | 1.0000 | - | 0.9996 | - | 0.9929 | 1.0090 | 0.9981 | 0.9999 | 0.9995 |
| HHR1-70 1.0000 - 0.9995 - 0.9928 1.0098 0.9980 0.9999 0.9999 | HHR5-50 | 1.0000 | - | 0.9996 | - | 0.9930 | 1.0086 | 0.9981 | 0.9999 | 0.9991 |
| | HHR1-70 | 1.0000 | - | 0.9995 | - | 0.9928 | 1.0098 | 0.9980 | 0.9999 | 0.9999 |

| Table B-4 MEFAC | correction | factors in | use after | 1 January | 2022 | (continued) |
|-----------------|------------|------------|-----------|-----------|------|-------------|
|-----------------|------------|------------|-----------|-----------|------|-------------|

| Beam ID | ke | ksc | ktr | kfl | Product ksc.kfl | kair ¹ | kii.kw | kCPE | Combined product |
|----------|--------|-----|--------|-----|--------------------|-------------------|--------|--------|---------------------|
| HHR2-70 | 1.0000 | - | 0.9994 | - | 0.9930 | 1.0089 | 0.9980 | 0.9999 | 0.9991 |
| HHR3-70 | 1.0000 | - | 0.9993 | - | 0.9932 | 1.0084 | 0.9980 | 0.9999 | 0.9987 |
| HHR4-70 | 1.0000 | - | 0.9991 | - | 0.9934 | 1.0077 | 0.9979 | 0.9999 | 0.9980 |
| HHR5-70 | 1.0000 | - | 0.9989 | - | 0.9936 | 1.0074 | 0.9979 | 0.9999 | 0.9976 |
| HHR1-90 | 1.0000 | - | 0.9991 | - | 0.9932 | 1.0088 | 0.9979 | 0.9999 | 0.9989 |
| HHR2-90 | 1.0000 | - | 0.9990 | - | 0.9934 | 1.0081 | 0.9979 | 0.9999 | 0.9982 |
| HHR3-90 | 1.0000 | - | 0.9988 | - | 0.9936 | 1.0076 | 0.9979 | 0.9999 | 0.9978 |
| HHR4-90 | 1.0000 | - | 0.9986 | - | 0.9939 | 1.0071 | 0.9979 | 0.9999 | 0.9972 |
| HHR5-90 | 1.0000 | - | 0.9983 | - | 0.9941 | 1.0068 | 0.9978 | 0.9999 | 0.9969 |
| HHR1-120 | 1.0002 | - | 0.9987 | - | 0.9937 | 1.0080 | 0.9980 | 0.9999 | 0.9984 |
| HHR2-120 | 1.0002 | - | 0.9985 | - | 0.9940 | 1.0073 | 0.9979 | 0.9999 | 0.9979 |
| HHR3-120 | 1.0003 | - | 0.9984 | - | 0.9941 | 1.0070 | 0.9979 | 0.9999 | 0.9976 |
| HHR4-120 | 1.0004 | - | 0.9981 | - | 0.9945 | 1.0065 | 0.9979 | 0.9999 | 0.9973 |
| HHR5-120 | 1.0005 | - | 0.9979 | - | 0.9947 | 1.0063 | 0.9979 | 0.9999 | 0.9972 |

| Table B-5: MEFAC correction factors: relative change NEW / OLD (Table B-4 / Table | e <mark>B-3</mark>) |
|---|----------------------|
|---|----------------------|

| Beam ID ke ksc ktr kfl Product ksc.kfl kair ¹ kii.kw kCPE Constraint | ombined product |
|--|--------------------|
| | |
| CCRI-100 0.9999 - 0.9998 - 1.0000 1.0000 0.9979 0.9999 | 0.9975 |
| CCRI-135 0.9999 - 0.9996 - 0.9999 1.0000 0.9980 0.9999 | 0.9973 |
| CCRI-180 0.9999 - 0.9996 - 0.9997 1.0000 0.9982 0.9999 | 0.9973 |
| CCRI-250 0.9998 - 0.9996 - 0.9997 1.0000 0.9987 0.9998 | 0.9976 |
| NXJ40 0.9999 - 1.0000 - 1.0017 0.9990 0.9975 0.9999 | 0.9981 |
| NXJ50 0.9999 - 1.0000 - 1.0014 0.9992 0.9976 0.9999 | 0.9982 |
| NXJ60 0.9999 - 1.0000 - 1.0012 0.9994 0.9977 0.9999 | 0.9982 |
| NXJ70 0.9999 - 1.0000 - 1.0011 0.9995 0.9977 0.9999 | 0.9981 |
| NXJ80 0.9999 - 1.0000 - 1.0009 0.9996 0.9978 0.9999 | 0.9981 |
| NXJ90 0.9999 - 1.0000 - 1.0008 0.9996 0.9978 0.9999 | 0.9980 |
| NXJ100 0.9999 - 1.0000 - 1.0006 0.9997 0.9978 0.9999 | 0.9980 |
| NXK40 0.9999 - 1.0000 - 1.0010 0.9996 0.9977 0.9999 | 0.9982 |
| NXK50 0.9999 - 1.0000 - 1.0008 0.9997 0.9978 0.9999 | 0.9982 |
| NXK60 0.9999 - 1.0000 - 1.0006 0.9998 0.9978 0.9999 | 0.9981 |
| NXK70 0.9999 - 1.0000 - 1.0005 0.9998 0.9979 0.9999 | 0.9980 |
| NXK80 0.9999 - 1.0000 - 1.0004 0.9999 0.9979 0.9999 | 0.9979 |
| NXK90 0.9999 - 0.9999 - 1.0003 0.9999 0.9979 0.9999 | 0.9978 |
| NXK100 0.9999 - 0.9999 - 1.0002 0.9999 0.9979 0.9999 | 0.9978 |
| NXA40 0.9999 - 1.0000 - 1.0000 1.0000 0.9980 0.9999 | 0.9978 |
| NXA50 0.9999 - 0.9999 - 1.0001 1.0000 0.9980 0.9999 | 0.9979 |
| NXA60 0.9999 - 0.9999 - 1.0001 1.0000 0.9980 0.9999 | 0.9979 |
| NXA70 0.9999 - 0.9999 - 1.0001 1.0000 0.9980 0.9999 | 0.9978 |
| NXA80 0.9999 - 0.9998 - 1.0001 1.0000 0.9980 0.9999 | 0.9977 |
| NXA90 0.9999 - 0.9998 - 1.0000 1.0000 0.9980 0.9999 | 0.9976 |
| NXB50 0.9999 - 0.9999 - 1.0001 1.0000 0.9981 0.9999 | 0.9979 |
| NXB70 0.9999 - 0.9999 - 1.0001 1.0000 0.9980 0.9999 | 0.9978 |
| NXB100 0.9999 - 0.9998 - 1.0000 1.0000 0.9979 0.9999 | 0.9975 |
| NXB120 0.9999 - 0.9997 - 1.0000 1.0000 0.9980 0.9999 | 0.9975 |
| NXB140 0.9999 - 0.9997 - 0.9999 1.0000 0.9980 0.9999 | 0.9974 |
| NXC70 0.9999 - 0.9998 - 1.0001 1.0000 0.9980 0.9999 | 0.9978 |
| NXC100 0.9999 - 0.9997 - 1.0000 1.0000 0.9979 0.9999 | 0.9975 |
| NXC120 0.9999 - 0.9997 - 1.0000 1.0000 0.9980 0.9999 | 0.9974 |
| NXC140 0.9999 - 0.9997 - 0.9999 1.0000 0.9980 0.9999 | 0.9974 |
| NXC150 0.9999 - 0.9997 - 0.9999 1.0000 0.9980 0.9999 | 0.9974 |
| NXD100 0.9999 - 0.9997 - 1.0000 1.0001 0.9979 0.9999 | 0.9974 |
| NXD120 0.9999 - 0.9996 - 0.9999 1.0000 0.9979 0.9999 | 0.9973 |
| NXD140 0.9999 - 0.9996 - 0.9999 1.0000 0.9980 0.9999 | 0.9973 |
| NXD150 0.9999 - 0.9996 - 0.9999 1.0000 0.9980 0.9999 | 0.9973 |
| NXD200 0.99999 - 0.9996 - 0.9998 1.0000 0.9982 0.9999 | 0.9974 |
| NXE120 0.9999 - 0.9996 - 0.9998 1.0000 0.9979 0.9999 | 0.9971 |
| NXE140 0.99999 - 0.9996 - 0.9997 1.0000 0.9980 0.9999 | 0.9972 |
| NXE150 0.9999 - 0.9996 - 0.9997 1.0000 0.9981 0.9999 | 0.9972 |
| NXE200 0.9999 - 0.9996 - 0.9997 1.0000 0.9983 0.9999 | 0.9974 |
| NXE250 0.9998 - 0.9996 - 0.9997 1.0000 0.9986 0.9998 | 0.9976 |
| NXE150 0.0000 - 0.0006 - 0.0007 1.0000 0.0001 0.0000 | 0.9971 |
| NIXE200 0.9999 - 0.9950 - 0.9997 1.0000 0.9961 0.9999 | 0.9972 |
| NXE250 0.9999 - 0.9997 1.0000 0.9964 0.9999 | 0.5574 |
| NIXE230 0.9930 - 0.9930 - 0.9937 1.0000 0.9930 0.9998 | 0.9970 |
| NXG150 0.9999 - 0.9995 - 0.9997 1.0000 0.9986 0.9998 | 0.9970 |
| NXG200 0.9999 - 0.9995 - 0.9996 1.0000 0.9981 0.9999 | 0.997/ |
| NXG250 0.9998 - 0.9996 - 0.9997 1.0000 0.9987 0.9998 | 0.9976 |

Table B-5: MEFAC correction factors: relative change NEW / OLD (Table B-4 / Table B-3) (continued)

| | Ratio NEW / OLD | | | | | | | | | | |
|---------|-----------------|-----|--------|-----|--------------------|-------------------|--------|--------|---------------------|--|--|
| Beam ID | ke | ksc | ktr | kfl | Product ksc.kfl | kair ¹ | kii.kw | kCPE | Combined product | | |
| NXG280 | 0.9997 | - | 0.9995 | - | 0.9997 | 1.0000 | 0.9988 | 0.9998 | 0.9975 | | |
| NXG300 | 0.9997 | - | 0.9994 | - | 0.9997 | 1.0000 | 0.9989 | 0.9998 | 0.9974 | | |
| NXH200 | 0.9999 | - | 0.9995 | - | 0.9996 | 1.0000 | 0.9985 | 0.9999 | 0.9974 | | |
| NXH250 | 0.9998 | - | 0.9996 | - | 0.9997 | 1.0000 | 0.9988 | 0.9998 | 0.9977 | | |
| NXH280 | 0.9997 | - | 0.9995 | - | 0.9997 | 1.0000 | 0.9989 | 0.9998 | 0.9975 | | |
| NXH300 | 0.9996 | - | 0.9993 | - | 0.9997 | 1.0000 | 0.9990 | 0.9997 | 0.9974 | | |
| NXH320 | 0.9996 | - | 0.9990 | - | 0.9997 | 1.0000 | 0.9990 | 0.9997 | 0.9970 | | |
| NXI250 | 0.9998 | - | 0.9996 | - | 0.9997 | 1.0000 | 0.9989 | 0.9998 | 0.9977 | | |
| NXI280 | 0.9996 | - | 0.9994 | - | 0.9997 | 1.0000 | 0.9990 | 0.9997 | 0.9975 | | |
| NXI300 | 0.9996 | - | 0.9993 | - | 0.9997 | 1.0000 | 0.9990 | 0.9997 | 0.9973 | | |
| NXI320 | 0.9995 | - | 0.9989 | - | 0.9997 | 1.0000 | 0.9991 | 0.9997 | 0.9969 | | |
| N40 | 0.9999 | - | 1.0000 | - | 1.0002 | 0.9999 | 0.9981 | 0.9999 | 0.9979 | | |
| N60 | 0.9998 | - | 0.9997 | - | 1.0001 | 1.0001 | 0.9980 | 0.9999 | 0.9977 | | |
| N80 | 0.9999 | - | 0.9998 | - | 0.9997 | 1.0001 | 0.9978 | 0.9999 | 0.9971 | | |
| N100 | 0.9999 | - | 0.9993 | - | 0.9995 | 1.0000 | 0.9979 | 0.9999 | 0.9965 | | |
| N120 | 1.0000 | - | 0.9996 | - | 0.9997 | 1.0000 | 0.9981 | 0.9999 | 0.9973 | | |
| N150 | 0.9999 | - | 0.9996 | - | 0.9996 | 1.0000 | 0.9984 | 0.9999 | 0.9974 | | |
| N200 | 0.9999 | - | 0.9994 | - | 0.9997 | 1.0000 | 0.9989 | 0.9998 | 0.9977 | | |
| N250 | 0.9994 | - | 1.0000 | - | 0.9997 | 1.0000 | 0.9992 | 0.9996 | 0.9980 | | |
| N300 | 0.9990 | - | 0.9975 | - | 0.9998 | 1.0000 | 0.9994 | 0.9995 | 0.9950 | | |
| W60 | 0.9998 | - | 0.9998 | - | 1.0002 | 1.0001 | 0.9981 | 0.9999 | 0.9979 | | |
| W80 | 0.9998 | - | 0.9997 | - | 1.0000 | 1.0001 | 0.9979 | 0.9999 | 0.9974 | | |
| W110 | 0.9999 | - | 0.9995 | - | 0.9996 | 1.0000 | 0.9979 | 0.9999 | 0.9968 | | |
| W150 | 0.9999 | - | 0.9995 | - | 0.9996 | 1.0000 | 0.9982 | 0.9999 | 0.9972 | | |
| W200 | 0.9999 | - | 0.9995 | - | 0.9997 | 1.0000 | 0.9987 | 0.9998 | 0.9975 | | |
| W250 | 0.9997 | - | 0.9997 | - | 0.9997 | 1.0000 | 0.9990 | 0.9997 | 0.9978 | | |
| W300 | 0.9993 | - | 0.9989 | - | 0.9997 | 1.0000 | 0.9992 | 0.9996 | 0.9968 | | |
| RQR2 | 0.9999 | - | 1.0000 | - | 1.0001 | 1.0016 | 0.9978 | 0.9999 | 0.9994 | | |
| RQR3 | 0.9999 | - | 1.0000 | - | 1.0001 | 1.0014 | 0.9979 | 0.9999 | 0.9991 | | |
| RQR4 | 0.9999 | - | 0.9999 | - | 1.0001 | 1.0003 | 0.9980 | 0.9999 | 0.9981 | | |
| RQR5 | 0.9999 | - | 0.9999 | - | 1.0000 | 1.0006 | 0.9980 | 0.9999 | 0.9983 | | |
| RQR6 | 0.9999 | - | 0.9999 | - | 1.0000 | 1.0003 | 0.9980 | 0.9999 | 0.9980 | | |
| RQR7 | 0.9999 | - | 0.9998 | - | 1.0000 | 1.0003 | 0.9980 | 0.9999 | 0.9979 | | |
| RQR8 | 0.9999 | - | 0.9998 | - | 1.0000 | 1.0001 | 0.9979 | 0.9999 | 0.9976 | | |
| RQR9 | 0.9999 | - | 0.9997 | - | 1.0000 | 1.0002 | 0.9980 | 0.9999 | 0.9977 | | |
| RQR10 | 1.0000 | - | 0.9996 | - | 0.9999 | 1.0001 | 0.9980 | 0.9999 | 0.9976 | | |
| RQA2 | 0.9999 | - | 1.0000 | - | 1.0001 | 1.0013 | 0.9980 | 0.9999 | 0.9992 | | |
| RQA3 | 0.9999 | - | 0.9999 | - | 1.0004 | 1.0005 | 0.9981 | 0.9999 | 0.9986 | | |
| RQA4 | 0.9998 | - | 0.9997 | - | 1.0002 | 1.0003 | 0.9980 | 0.9999 | 0.9980 | | |
| RQA5 | 0.9998 | - | 0.9997 | - | 1.0000 | 1.0003 | 0.9979 | 0.9999 | 0.9976 | | |
| RQA6 | 0.9998 | - | 0.9997 | - | 0.9999 | 1.0002 | 0.9979 | 0.9999 | 0.9974 | | |
| RQA7 | 0.9999 | - | 0.9996 | - | 0.9998 | 1.0002 | 0.9978 | 0.9999 | 0.9972 | | |
| RQA8 | 0.9999 | - | 0.9995 | - | 0.9997 | 1.0002 | 0.9979 | 0.9999 | 0.9970 | | |
| RQA9 | 0.9999 | - | 0.9995 | - | 0.9997 | 1.0001 | 0.9979 | 0.9999 | 0.9971 | | |
| RQA10 | 0.9999 | - | 0.9995 | - | 0.9996 | 1.0001 | 0.9982 | 0.9999 | 0.9972 | | |
| RQT8 | 0.9999 | - | 0.9997 | - | 0.9999 | 1.0007 | 0.9979 | 0.9999 | 0.9979 | | |
| RQT9 | 0.9999 | - | 0.9996 | - | 0.9999 | 1.0004 | 0.9979 | 0.9999 | 0.9976 | | |
| RQT10 | 0.9999 | - | 0.9996 | - | 0.9998 | 1.0003 | 0.9981 | 0.9999 | 0.9975 | | |
| HHR1-50 | 0.9999 | - | 0.9999 | - | 1.0003 | 1.0009 | 0.9981 | 0.9999 | 0.9990 | | |
| HHR2-50 | 0.9999 | - | 0.9999 | - | 1.0003 | 1.0006 | 0.9981 | 0.9999 | 0.9987 | | |
| HHR3-50 | 0.9998 | - | 0.9998 | - | 1.0004 | 1.0004 | 0.9981 | 0.9999 | 0.9984 | | |
| HHR4-50 | 0.9998 | - | 0.9998 | - | 1.0002 | 1.0002 | 0.9981 | 0.9999 | 0.9981 | | |

Table B-5: MEFAC correction factors: relative change NEW / OLD (Table B-4 / Table B-3) (continued)

| | | Ratio NEW / OLD | | | | | | | | | | | |
|----------|--------|-----------------|--------|-----|--------------------|-------------------|--------|--------|---------------------|--|--|--|--|
| Beam ID | ke | ksc | ktr | kfi | Product ksc.kfl | kair ¹ | kii.kw | kCPE | Combined product | | | | |
| HHR5-50 | 0.9998 | - | 0.9998 | - | 1.0001 | 1.0002 | 0.9981 | 0.9999 | 0.9979 | | | | |
| HHR1-70 | 0.9998 | - | 0.9998 | - | 1.0002 | 1.0010 | 0.9980 | 0.9999 | 0.9987 | | | | |
| HHR2-70 | 0.9998 | - | 0.9997 | - | 1.0001 | 1.0006 | 0.9980 | 0.9999 | 0.9983 | | | | |
| HHR3-70 | 0.9998 | - | 0.9997 | - | 1.0001 | 1.0004 | 0.9980 | 0.9999 | 0.9980 | | | | |
| HHR4-70 | 0.9998 | - | 0.9997 | - | 1.0000 | 1.0003 | 0.9979 | 0.9999 | 0.9976 | | | | |
| HHR5-70 | 0.9998 | - | 0.9996 | - | 0.9999 | 1.0002 | 0.9979 | 0.9999 | 0.9974 | | | | |
| HHR1-90 | 0.9999 | - | 0.9997 | - | 1.0000 | 1.0009 | 0.9979 | 0.9999 | 0.9984 | | | | |
| HHR2-90 | 0.9998 | - | 0.9997 | - | 1.0000 | 1.0006 | 0.9979 | 0.9999 | 0.9980 | | | | |
| HHR3-90 | 0.9998 | - | 0.9996 | - | 0.9999 | 1.0004 | 0.9979 | 0.9999 | 0.9977 | | | | |
| HHR4-90 | 0.9999 | - | 0.9996 | - | 0.9998 | 1.0002 | 0.9979 | 0.9999 | 0.9973 | | | | |
| HHR5-90 | 0.9999 | - | 0.9996 | - | 0.9997 | 1.0002 | 0.9978 | 0.9999 | 0.9971 | | | | |
| HHR1-120 | 0.9999 | - | 0.9997 | - | 0.9999 | 1.0008 | 0.9980 | 0.9999 | 0.9981 | | | | |
| HHR2-120 | 0.9999 | - | 0.9996 | - | 0.9999 | 1.0005 | 0.9979 | 0.9999 | 0.9977 | | | | |
| HHR3-120 | 0.9999 | - | 0.9996 | - | 0.9998 | 1.0003 | 0.9979 | 0.9999 | 0.9975 | | | | |
| HHR4-120 | 0.9999 | - | 0.9996 | - | 0.9997 | 1.0002 | 0.9979 | 0.9999 | 0.9972 | | | | |
| HHR5-120 | 0.9999 | - | 0.9995 | - | 0.9997 | 1.0001 | 0.9979 | 0.9999 | 0.9971 | | | | |