**Design of a calibration beam for detector characterization.**

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**Abstract**. The RA6 BNCT facility consists of an epithermal neutron beam adapted in order to soften its spectrum and produce a thermal flux maximum at approximately 1cm depth in hydrogenated materials. Due to design limitations, non-negligible components of photon and fast neutron contamination are present in the functional beam. Thus, the accurate knowledge of the relative sensitivity to each component for usual instrumentation becomes relevant as all the three fields may influence its functionality. Particularly, dosimeters are calibrated comparing their performance against a reference instrument or in a reference radiation field. In this way, the photon sensitivity of a dosimeter is obtained from a calibration with an isotopic source (e.g.: 60Co, 137Cs), thermal neutron sensitivity is obtained at the reactor´s thermal column, and fast neutron sensitivity in a fast neutron beam. In Argentina, photon calibration is performed at the Ezeiza SSDL, but thermal and fast neutron calibrations are usually unfeasible since no pure beams of the respective spectra are easily attainable in the needed geometry. The ionization chambers used for the characterization and dosimetry at the RA6 facility depend on neutron sensitivities evaluated from theoretical basis, with experimental validation in a particular condition of homogeneous absorbers in the case of the thermal neutron sensitivity. However, the fast neutron sensitivities can only be compared with bibliographic data. In order to fill this gap, as well as to provide the means to obtain the sensitivity factors for all three main radiation fields in a mixed field such as the one present in our facility, an adaptation to the beam exit is under design. This device is conceived as a mobile artifact placed next to the beam exit- constructed by a thick neutron shield surrounding a centered through-opening, the exit of the calibration beam. In this central opening a set of filters and collimators can be placed or removed, becoming possible to modify selectively the resulting fluence of a given radiation field. Thus, the sensitivity of a given dosimeter or detector could be inferred from the behavior of the total response induced in the calibration beam by making use of chosen configurations. This work presents the calculation evaluations performed in order to attain the filters and collimators configurations that optimize the separation of variables in the measurement on this mixed field. All evaluations were done with MCNP5 based on the actual spectra of the BNCT. All studied materials and geometries were selected based on availability and ease of construction.

1. **Introduction**

For mixed radiation fields, composed of both photon and neutron spectra, requiring component separation is usually performed using multiple specialized detectors with different sensitivities for each type of radiation. Many detectors (particularly the usual radiation dosimeters applied to mixed beams) have simultaneously non-negligible sensitivities to three different types of radiation –thermal neutrons, non-thermal neutrons and gamma rays–, resulting in an overall response strongly dependent of the corresponding field sensitivities.

The BNCT beam of the RA6 reactor in Bariloche is used as part of a clinical protocol for irradiation of metastatic melanoma cases. The macrodosimetry of the beam requires determining the dose components with particular care and precision, given its final usage in the treatment planning assessment. The standard measurement methods (activation for neutron flux, paired ionization chambers for dose rates) are widely known, although the determination of detectors sensitivities is always a subject of improvement due to the mentioned relevance of the experimental characterization. Additionally, the introduction of new radiation detectors permanently encourages research on component separation methodologies and improving the quality of the basic detector data.

The BNCT facility at RA6 reactor consists of an array of filtering materials close to the reactor core (inner BNCT filter), so as to maximize the neutron flux available in the therapeutic beam. The inner filter is composed of approximately 80cm Aluminium and Alumina in a fixed configuration into the reactor´s pool. Also, an external filter is set downstream the beam, composed of up to 20cm Teflon and Bismuth. This configuration is able to provide a beam with strong thermal and epithermal neutron components, even considering the relatively low power of the reactor -1MW-.

The effects induced in hydrogenated materials –such as biological tissue– when irradiated with a neutron beam like the one present at the BNCT beam, produce a shallow thermal neutron flux moderation maximum (between 0.8 and 2 cm depth), while maintaining high the superficial thermal neutron flux intensity. Thus, the capabilities of the beam have a good match with the treatment of superficial or shallow lesions (eg: skin, or head and neck tumors). However, the described BNCT beam filtering configuration is insufficient to reduce to negligible levels the fast neutron and photon fluxes –considered contaminations in a BNCT treatment– originated by fissions in the reactor core. Also, the presence of Hydrogen in the tissues or materials exposed to the beam results in photon production by the 1H(n,g)2H neutron reaction, implying an additional contamination for treatment purposes, or the increase of the photon background in Hydrogenated detectors for macrodosimetry purposes. The intensity of all three radiation components of the beam –photon, thermal neutron and non-thermal neutron– must be measured in order to complete the characterization of the Beam.

The usual method for beam characterization involves measuring the neutron spectrum at two energy groups (thermal and non-thermal) by foil activation techniques, and the separation of dose-to-tissue by the method of paired ionization chambers (Graphite IC is selected because of its low neutron sensitivity and Tissue Equivalent IC with sensitivity for the three radiation components). Foil activation is virtually insensitive to photon fluence, which makes it a robust method for quantification of the neutron fluence at various ranges. However, the separation of photon and neutron doses to tissue is strongly dependant on the sensitivity of the dosimeters to each radiation component, and even to cross-components perturbations introduced by the detector itself. As an example, the recently introduced Radiochromic films are capable of precise mapping of the photon-dose distribution, but its composition (which includes lithium) is particularly sensitive to thermal neutrons. Other detectors used in dosimetry have varying degrees of these cross-perturbations, as in the case of the normally used ionization chambers, Fricke gels, and semiconductor detectors for neutron flux measurement.

The current methodology for determining the sensitivities to different radiation fields is based on the calibration of the detectors in pure, or high purity, radiation fields. Such is the case when calibrating the photon sensitivity of a dosimeter at a SSDL with isotopic sources (60Co and 137Cs) or accelerators in different configurations. Thermal neutron sensitivities can be measured at a thermal beam, or a variable flux setup, or obtained by calculation (based on the elemental composition of the detector). Fast neutron sensitivities are often more complex to measure, usually resorting to determination by calculation or bibliography.

This work propose a simplification of the calibration procedures, by merging the different required calibration facilities into a single, selectable radiation field, in such a fashion that the cross-perturbation between fields is naturally included in the determination of each sensitivity. This selectable radiation field involves the manipulation of the calibration beam geometry during irradiation, in order to modify each of the three major radiation fields individually. Successive geometry changes may provide specific component modifications, while minimizing variations in other components. Then, the difference in response of an exposed detector to successive, well studied configurations, should be primarily proportional to the change of a given radiation field, with low or negligible changes in the other fields.

In order to preserve the therapeutic BNCT beam, the design of the calibration beam is directed to the implementation of a mobile device, closely attached to the BNCT beam exit. This device will produce a well defined square beam, by further collimation and filtering of the base BNCT beam. The actual design refers to the selection of filtering materials and geometry required to achieve the radiation field selectivity. This square beam at the output of this mobile device is called "mixed calibration beam".

In the frame of the UNC Research Project “Hyperthermal BNCT Beam. R&D for its exploitation as mixed dosimetry reference”, the design of the device is primarily aimed at the characterization of dosimeters for use in radiation therapy, although it is potentially useful for any device exposed to mixed radiation fields.

1. **Materials and method**

The calibration beam design is based on the evaluation by montecarlo calculation of the characteristics from the resulting beam when modifying filtering stages, replacement of boundary conditions of the beam wall´s, and the use of gamma-boosting on the periphery of the beam´s window. For this purpose, MCNP5 is used as calculation tool [1] [2]. Calculated results are obtained for each relevant radiation field, with additional detail depending on the detection characteristics expected for the instrument under calibration.

Based on the original MCNP model for the RA6 BNCT facility [3], the mobile device is included next to the base beam exit, and the resulting field components are calculated at the calibration position, being then evaluated the various amendments to the beam tuning procedures.

* 1. **RA6 BNCT facility - Radiation transport calculation model**

The MCNP model of the RA6 BNCT facility includes the reactor core structures, inner BNCT filter, external filter and collimator (Figure I). The model use increasing particle importances downstream the beam in order to cope with the variance reduction issue in the geometry. Also, in-house libraries for 235U and 239Pu, including the Fission Products gamma generation tables as prompt gammas were used in the core materials [4], in order to transport the delayed photons of the short lived F.P. as if they were a prompt photon. The 13027.92c library for aluminium [5] was also included, for the same reason: to include the delayed photon from the 27Al(n,g)28Si.

Due to time-cost issues, in order to achieve adequate statistics for all the radiation components (particularly fast flux, and direct gamma radiation from the core), and the variety of geometries to be studied as possible configurations, the calculation will be performed in two stages: first a criticality calculation (kcode) in the complete case, with realistic core and reactivity control bars configuration in order to record a surface source of particles (Track-by-track) at the BNCT beam exit, only disturbed with a basic draw of the mobile device. This TBT source will have enough statistics for subsequent determinations of outermost positions, when changing the detailed structure in the mobile device. Then, each device configuration is calculated using the aforementioned surface source, neglecting second order effects in outer structures and multiple scatterings through the surface of the TBT.



FIGURE I: MCNP model for the complete BNCT facility

* 1. **Radiation components**

Based on the primary goal for the calibration beam –the calibration of radiotherapy dosimeters - the radiant components to be considered are naturally defined:

• conventional thermal flux: Since most of the usual dosimeters are composed of light, non resonant materials, having a neutron cross section approximately 1/V, it becomes possible to estimate the response in any of these dosimeters in accordance with a conventional flow measurement.
• photon dose to tissue: Considering the effects of the realistic photon spectrum on ICRU muscle [6], and by integrating the spectrum with the muscle´s mass-energy absorption coefficients.
• non-thermal neutron dose to tissue: Considering the effects of the realistic neutron spectrum on ICRU muscle [7], and by integrating the neutron spectrum (from 100eV) with the muscle´s neutron kerma Factors.

These components are determined by calculation in cylindrical volume, 2cm in radius and 1 cm thick – centered with the beam axis and positioned immediately outside the calibration´s beam exit. The characteristics of each calculation detector requires the use of the following variables at this volume:

• Tally integrated neutron flux,

• Tally integrated neutron flux, modified with a function proportional to 1/V multiplier,
• Tally integrated photon flux, modified with the table (Ehν \* μen / ρ) as a function of photon energy, and

• Tally integrated neutron flux (from the 100eV lower limit), modified with the neutron Kerma factor for tissue.

* 1. **Beam adaptation assembly – Studied cases**

The mobile device calibration beam consists of a borated neutron shielding block, whose lateral dimensions exceed the base, unmodified BNCT beam by 10cm. It has a square cross-section passage (window) centered with the beam. Having the base BNCT beam a circular opening of 15 cm in diameter, of which a central area of ​​about 10cm is highly uniform (~ 95% in themal flux and ~ 90% in photon fluence). On this central window calibration beam shall be delimited.

The total thickness of the beam calibration device is 10cm, providing sufficient shielding to irradiation from the periphery, and decreasing the leaked radiation that could induce spurious signal from the surrounding structures.

The mobile device is able to introduce localized perturbations around the passage window; particularly modifying the beam by direct neutron and gamma filtration, and modifying the scattering properties of the bounding walls of the window. Also, by using the area in excess from the base BNCT beam with respect the collimated calibration beam, the generation of additional photons (gamma boosting) is possible by including in the aforementioned excess area a prompt gamma generator. The materials considered for those various functions are selected among the materials commonly used for similar purposes, all with well known properties [8] [9].

TABLE I: Properties of commonly used materials for moderation and shielding of radiation fields.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Material** | **Σel** | **Σabs** | **Neutron effects** | **Photon effects** |
| Bismuth | 0.2654 | 0.0010 | Moderator (weak)/Scatterer | Negligible production / **Shielding**  |
| PMMA | 1.8842 | 0.0183 | Moderator | 2223keV from 1H(n,)2H |
| HBO2 | 1.0508 | 18.73 | Absorber/Moderator | 477keV from 10B(n,α)7Li\* |
| B2O3 | 0.4516 | 32.50 | Absorber | 477keV from 10B(n,α)7Li\* |
| PoliB | 2.3704 | 3.292 | Absorber/Moderator | 477keV from 10B(n,α)7Li\* |
| PTFE | 0.3265 | 0.0006 | Moderator (weak)/Scatterer | Negligible Production |
| Graphite | 0.4584 | 0.0004 | Moderator (weak)/Scatterer | Negligible Production |
| Cadmium | 0.3513 | 117.32 | Absorber | 558-651keV from 113Cd(n,γ)114cd |

The preceding list includes materials with specially ease of accessibility and handling. The absence of several materials are to be noted, in particular 6Li enriched LiF as neutron shielding (because material availability), heavy water as moderator / scatterer (because ease of use), and 235U as fast neutron booster (both for security classification and ease of use).

Among the materials considered, the functionality and geometry of the components to be included are decided *a priori* based in engineering judgment. In general, the components for the device are classified as:

* Beam delimitation and shielding for reducing the ambient background and to delimitate the area of effect of the assembly – PoliB (ρ=1.12 – 7% w/w natB).
* Out-of-Beam scattered contributions by the inner walls of the window passage for overall modification on the gamma/neutron population – PMMA (ρ=1.18) / Bi (ρ=9.8) / Graphite (ρ=1.85) / PoliB.
* Gamma filtering: an external plate placed at the Calibration Beams´s exit – Bismuth.
* Thermal/low epithermal neutron filtering: a plate inserted into the window´s channel - PMMA / HBO2 / B2O3.
* Gamma boosting: next to the base BNCT beam external face, and around the periphery of the calibration beam – Cadmium (ρ=8.65).



FIGURE II: Detail of the MCNP model of the mobile device for the calibration beam.

TABLE II: Materials considered with detail of their selected function and geometry.

|  |  |  |  |
| --- | --- | --- | --- |
| **Gamma Boost** | **Gamma Filter** | **Neutron Filter** | **Reflective walls** |
| NO **(0)** | NO **(0)** | NO **(0)** | 30mm PoliB  **(0)** |
| YES **(1)** | YES **(1)** | 10mm PMMA **(1)** | 30mm PTFE **(1)** |
|  |  | 3mm HBO2 **(2)** | 30mm PMMA **(2)** |
|  |  | 3mm B2O3 **(3)** | 30mm Bi **(3)** |
|  |  | 10mm HBO2 **(4)** | 30mm Graphite **(4)** |
|  |  | 10mm B2O3 **(5)** |  |

When considering the different functions and materials, a total of 120 possible configurations is obtained. Each configuration is named after its composition indices as included here: for example, the setting "1042" is gamma booster, no gamma filter, 10mm HBO2 neutron filter and reflective walls 30mm thick of PMMA.

The variables of interest for each of the possible configurations are calculated.

* 1. **Selection of optimal calibration beam method**

After proper data evaluation, every calculation rendered a set of three figures as results, namely the conventional flux (), gamma dose (G) and non-thermal neutron dose (N). In order to select the alterations to the beam configuration which maximize the variation of a given component while minimizing the change in the other components, the following method was implemented.

For each result Di, the components were labeled as:

D**i=(****i,Gi,Ni) Eq. 1**

The differences arising from the geometry modification procedure from an initial configuration “i” to a final configuration “j” is calculated:

**Δ**D**ij=**D**i-**D**j=( i − j, Gi - Gj, Ni - Nj) Eq. 2**

And three simple figures of merit were obtained for such procedure:

δij = [Δ**D**ij \* (1,0,0) ] / SQRT([Δ**D**ij \* (0,1,0)]2+ [Δ**D**ij \* (0,0,1)]2)

δGij= [Δ**D**ij \* (0,1,0) ] / SQRT([Δ**D**ij \* (1,0,0)]2+ [Δ**D**ij \* (0,0,1)]2) **Eq. 3**

δNij= [Δ**D**ij \* (0,0,1) ] / SQRT([Δ**D**ij \* (1,0,0)]2+ [Δ**D**ij \* (0,1,0)]2)

The resulting triplets “δij” describe the relative change of each component weighted with the change in the other components, when applying the procedure “ij”.

Three rankings of beam modification procedures were obtained, describing the paired configurations that provide the higher contrasts for a given component while minimizing the absolute change of the other components.

Considering that the characterization of the detector to a single component requires the change from a given configuration to another, and that this process should be repeated for each three components, some effort must be put in selecting useful pairs that not differ greatly in components, as issues in positioning repeatability and reactor power stability during the process may arise.

All the data manipulation was performed using simple functions in a data sheet, as well as the sorting and selection of configurations and change procedures.

1. **Results and Analysis**
	1. **Results**

The following table lists the ten best ranked procedures when prioritizing a given radiation component, according to the corresponding “δij”:

TABLE III: List of the ten best procedures for the determination of the sensitivity to each radiation component, according to its corresponding merit figure.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Higher Flux** **changes** |  | **Higher Neutron Dose changes** |  | **Higher Gamma Dose changes** |
| InitialConf. | FinalConf. | **δij** |  | InitialConf. | FinalConf. | **δNij** |  | InitialConf. | FinalConf. | **δGij** |
| 0103 | 1134 | **4260.5** |  | 0142 | 1134 | **19.515** |  | 0053 | 1154 | **352.8** |
| 0152 | 1111 | **1130.3** |  | 0134 | 0142 | **14.941** |  | 1051 | 1154 | **263.2** |
| 1002 | 1021 | **475.6** |  | 1134 | 1142 | **11.880** |  | 0051 | 1154 | **260.7** |
| 0103 | 1124 | **453.7** |  | 0131 | 0142 | **7.872** |  | 0144 | 1040 | **214.5** |
| 0002 | 0021 | **434.4** |  | 1034 | 1042 | **7.111** |  | 1054 | 1154 | **167.5** |
| 0142 | 1110 | **424.7** |  | 0142 | 1131 | **6.288** |  | 0054 | 1154 | **162.7** |
| 1114 | 1142 | **416.6** |  | 0134 | 1142 | **5.061** |  | 1053 | 1154 | **156.6** |
| 1002 | 1031 | **406.5** |  | 1131 | 1142 | **4.982** |  | 1040 | 1143 | **146.7** |
| 0114 | 0142 | **383.9** |  | 0141 | 0144 | **4.750** |  | 0040 | 0144 | **142.3** |
| 0002 | 0031 | **377.2** |  | 0034 | 0042 | **4.520** |  | 0040 | 0143 | **137.5** |

* 1. **Analysis**

Criteria for the selection of the optimal set of change procedures include:

1. Maximum change in the component under analysis (as defined by Eqs. 3), for each component.
2. Minimum structural difference between configuration, for each individual procedure and every component analysis.
3. Maximum in the absolute value of the component under analysis.
4. Minimum value of the components other than the one under study (especially for thermal neutrons)

Applying only criterion ***a*** may suggest the use of only the higher ranked procedures, meaning the usage of five different configurations (Case #1: (0103→1134)→(1134→0142)→(1154→0053)). This first set of procedures provides high thermal flux intensity for Flux sensitivity determination procedure (8e7), medium intensity during non-thermal sensitivity (4e6), and low intensity during gamma sensitivity (1e6).

Inclusion of criterion ***b*** reduces the number of needed different configurations to four, but using a combination outside the top ranked changes (Case #2: (1110→0142)→(0142→0134)→(0134→0030)). This set of procedures provides medium-high thermal flux intensity for Flux sensitivity determination procedure (3e7), medium intensity during non-thermal sensitivity (4e6), and medium intensity during gamma sensitivity (4e6).

The following tables show the relative change in the actual components for both cases of sets of procedures for the calibration.

TABLE IV: Radiation components on each configuration of the set of procedures “Case #1”, and their relative change due to each procedure.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Configuration** |  **** | **Dn** | **Dg** | **Procedure** | **Change in ** | **Change in Dn** | **Change in Dg** |
| 0103 | 8.06E+07 | 0.904 | 1.061 | 0103→1134 | **-94.9%** | 0.2% | 0.1% |
| 1134 | 4.11E+06 | 0.906 | 1.061 |
| 1134 | 4.11E+06 | 0.906 | 1.061 | 1134→0142 | 2.0% | **-21.3%** | 0.5% |
| 0142 | 4.20E+06 | 0.713 | 1.067 |
| 1154 | 1.18E+06 | 0.789 | 1.012 | 1154→0053 | 1.5% | 0.3% | **94.9%** |
| 0053 | 1.20E+06 | 0.792 | 1.972 |

TABLE V: Radiation components on each configuration of the set of procedures “Case #2”, and their relative change due to each procedure.

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Configuration** |  **** | **Dn** | **Dg** | **Procedure** | **Change in ** | **Change in Dn** | **Change in Dg** |
| 1110 | 3.14E+07 | 0.719 | 1.065 | 1110→0142 | **-86.6%** | -0.8% | 0.2% |
| 0142 | 4.20E+06 | 0.713 | 1.067 |
| 0142 | 4.20E+06 | 0.713 | 1.067 | 0142→0134 | -0.2% | **21.3%** | 1.0% |
| 0134 | 4.19E+06 | 0.865 | 1.077 |
| 0134 | 4.19E+06 | 0.865 | 1.077 | 0134→0030 | 1.1% | -1.5% | **131.6%** |
| 0030 | 4.23E+06 | 0.853 | 2.495 |

* 1. **Simulated application of the selected procedures to a real dosimeter**

In order to evaluate the practical aspects of the measurements in the modified calibration beam at each considered configuration, an example case is analyzed. The response of a tissue-equivalent Miniature Ionization Chamber –FarWestTech, model IC-18, commonly used in the RA6 for mixed dosimetry at the BNCT facility– is estimated for each case using the calculated radiant components and sensitivities of common usage for dosimetry purposes:

Thermal neutron sensitivity: 1.19 pA/nv

Gamma sensitivity: 0.725 pA/(cGy/min)

Non-thermal neutron sensitivity: 0.639 pA/(cGy/min)

TABLE VI: Application of the set of procedures “Case #1” on the TE FWT IC18.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Configuration** | **I due to  [pA]** | **I due to Dn****[pA]** | **I due to Dg****[pA]** | **Total I****[pA]** | **Change in I** |
| 0103 | 0.096 | 0.578 | 0.769 | 1.443 | -6.2% |
| 1134 | 0.005 | 0.579 | 0.770 | 1.353 |  |
| 1134 | 0.005 | 0.579 | 0.770 | 1.353 | -8.8% |
| 0142 | 0.005 | 0.456 | 0.774 | 1.234 |  |
| 1154 | 0.001 | 0.504 | 0.734 | 1.240 | 56.3% |
| 0053 | 0.001 | 0.506 | 1.430 | 1.937 |  |

TABLE VII: Application of the set of procedures “Case #2” on the TE FWT IC18.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Configuration** | **I due to  [pA]** | **I due to Dn****[pA]** | **I due to Dg****[pA]** | **Total I****[pA]** | **Change in I** |
| 1110 | 0.037 | 0.460 | 0.772 | 1.269 | -2.7% |
| 0142 | 0.005 | 0.456 | 0.774 | 1.234 |  |
| 0142 | 0.005 | 0.456 | 0.774 | 1.234 | 8.5% |
| 0134 | 0.005 | 0.553 | 0.781 | 1.339 |  |
| 0134 | 0.005 | 0.553 | 0.781 | 1.339 | 76.2% |
| 0030 | 0.005 | 0.545 | 1.809 | 2.359 |  |

1. **Conclusions**

A mobile device was designed in order to adapt the BNCT beam of the RA6 reactor to the requirements of a multi-component calibration beam. The sensitivities of a given radiation detector –particularly dosimeters– to the three main radiation fields in a mixed beam may be measured individually by the separation method of the detector´s signal, related to different configurations in such a calibration beam.

The device includes a bulk shielding – peripheral to the calibration beam–, and four different selectable in-, or next to- beam elements –namely a gamma filter, a gamma booster, a neutron filter and scattering passage walls. The constituent materials considered for those elements were selected from the available stock in the reactor, literally “off the shelf”. No safeguarded nor hard to handle material were considered. A computational model of the BNCT facility –including the mobile device– was generated for every proposed combination of the selectable components, and the transport calculation result on each radiation field was obtained at the calibration beam´s exit.

By sorting the relative differences between pair of elements configurations, for each radiation field –properly weighted to contrast with the changes in the other two components- two sets of optimal procedures –configuration changes– were selected. Setting as example the properties of a commonly used dosimeter, a realistic integral response of the detector was estimated for those sets of procedures. Results show that the attainable non-thermal dose differences and Thermal flux intensities are relatively low for the sensitivities calibration purposes. Nonetheless, that calibration is still possible under strict field intensities normalization (in-beam monitoring), and good quality measurement methods (charge measurement mode and statistical analysis, in the example).

The observations rendered from the example may vary for a different detector; radiochromic films are expected to have a much higher thermal sensitivity, or in the case of SPND detectors, to have a much lower non-thermal sensitivity. Also, the radiation components should be weighted with proper, detector dependant sensitivity functions, probably rendering different optimal sets of procedures that those reported in this work.

For the usage of the calibration beam with dosimeters, the Case#1 was selected, for having the highest contrast for each procedure. The following step in the project includes the construction of a prototype of the mobile device, in order to validate the calculated performance, study the sensitivities of usual dosimeters, and compare the results with available data.

1. **Acknowledgements**

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