Mitigation of Public Exposure to Magnetic Fields Generated by Indoor MV/LV Transformer Stations

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Abstract
This paper addresses the issue of low-cost magnetic B-field mitigation, in areas of public exposure, to guard against chronic health effects. More specifically, aims to develop three-dimensional models of geometric changes and screening techniques, and apply them on to pre-existing Transformer Station models. Afterwards, the value of the B field is calculated in places with continuous public exposure and the mitigation techniques are optimized.

This project anticipates stricter limits on continuous human exposure to B-fields in Portugal, than those suggested by ICNIRP, following the example from other countries. All B-field calculations are carried out according to the latest European and International standards and technical guides.

The obtained results show that the most effective solution is the Back to Back configuration, which consists of adding two of the main field sources, low voltage panel and transformer, in the centre of the Transformer Station. Additional measures were studied, such as reducing the distance between the buses of the LV panel and placing wire mesh between the LV panel and transformer, which contributed to considerably reduce the B-field when added to the Back to Back computer model.

Index Terms - ELF Magnetic Field, Low-Cost Mitigation Measures, MV/LV Transformer Station, 3D Computer Model

I. INTRODUCTION AND OBJECTIVES

The effects of extremely low frequency (ELF) magnetic fields, generated by electric infrastructures, on human health have been studied for several decades (1). The investigations that were carried out can be subdivided into two groups: one related to acute effects, which includes the momentary exposure, and one on chronic effects, related to prolonged exposure to the magnetic induction fields (B-fields).

The studies related to momentary exposure concluded that it is fundamental to limit the current density in the human body to 10 mA/m² (500 μT), which is slightly above the value normally generated by the body (see Table 1) (2).

Table 1 - Damages in the human body when exposed to ELF EM fields

<table>
<thead>
<tr>
<th>Current density J [mA/m²]</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-10</td>
<td>Minimum biological tissue response.</td>
</tr>
<tr>
<td>10-100</td>
<td>Disorders in visual and nervous system</td>
</tr>
<tr>
<td>100-1000</td>
<td>Stimuli of excitable tissues, which can lead to undesired reactions. Heart disorders, neuro-muscular irritability and disorders of the CNS.</td>
</tr>
<tr>
<td>&gt;1000</td>
<td>Extrasystoles, cardiac fibrillation. Conditions with high mortality rate.</td>
</tr>
</tbody>
</table>

Based on the previously mentioned medical findings, the International Commission on Non-Ionizing Radiation Protection (ICNIRP) determined that the limits for the general public exposure should contemplate a safety factor. Therefore, a maximum value of 2 mA/m², which equates to a B-field of 100 μT, was recommended (3).

The possibility that prolonged exposure to electromagnetic fields of low intensity might increase cancer risk, motivated a series of epidemiological and experimental studies in the 80s and 90s (1). No correlation was found between the increased risk of pathology and the exposure to B-fields, with the exception of childhood leukaemia, where there are some epidemiological studies that relate the exposure to an increased incidence (relative risk) (4).

It is worth clarifying that the epidemiological studies do not seek to establish a causal relationship between the electric field (E-field) and epidemiological diseases, e.g. childhood leukaemia, since this field cannot easily penetrate building walls. In addition, the E-field is considerably attenuated by the human skin (reduction of $10^{-5}$ to $10^{-7}$) (1).

Given the uncertainties regarding the existence of chronic effects associated with exposure to B-fields, several countries have been implementing lower limits than those suggested by the ICNIRP. For instance, Switzerland defined a limit of 1 μT in sensitive areas (see Figure 1) (5).

![Figure 1 - Schematic vertical section through a building with a transformer station (TS) in the middle part and adjoining rooms. The indicated limit values are discussed in the text. The dashed line means the measuring distance of 0.2m from the walls of the TS, where the limits have to be fulfilled (5).](image)

In Portugal, the current density limits for human exposure, defined by law, are the ones suggested by ICNIRP (6). Never-
theless, this project anticipates a possible enactment of more restrictive limits in order to guard against possible chronic health effects. For instance, we assume a limit of 1 μT for continuous human exposure, in sensitive sites. Due to the new limit assumption, all of the electric and electrical equipment have to fulfill the exposure restrictions.

One of the most controversial EMF sources are the medium voltage/low voltage (MV/LV) transformer stations (TS), and more particularly their low voltage (LV) cabling and switchboard, due to the high levels of electric current flowing through them. This characteristic, combined with the demands of space required by the construction sector trying to optimize the MV/LV TS locations size inside new buildings, forces these installations to reduce their dimensions and increase proximity to residential zones and human exposure to higher B-fields (7) (8).

The study cases consist of three computer models of MV/LV TS that were previously made, typical of urban areas of Portugal, with a transformation ratio of 10k:400 V, and they all have distinct internal configurations, equipment and areas of interest (public exposure). To correctly model the TS, site plans were used and the current values experimentally measured. The final model was calibrated with the aid of B-field measurements made in loco by LABELEC (9) (10) (11).

This project aims to develop three-dimensional models of geometric changes and screening techniques and thereafter apply them to three pre-existing TS models. Afterwards, the value of the B field will be calculated in places with continuous public exposure and the mitigation techniques are optimized.

Usage of technical software is required to accomplish these tasks. Moreover, time and skills are required to develop the TS models. Since it would be unrealistic to model every single TS, mitigation measures are applied on the models, allowing us to extract general conclusions about the performance.

All of the B-field calculations and computer model-making are carried out according the latest European and International standards and technical guides, such as IEC 62110 and CIGRÉ WG C4-203. The IEC 62110 Standard defines measurement procedures for EMF field regarding average human exposures to comply with ICNIRP guidelines (12) (13). The CIGRÉ WG C4-203 is a technical guide for measurement of low frequency electrical and magnetic fields near overhead power lines (14).

The above mentioned standards, which are related to chronic human exposure to B-fields, the field calculation and performance analysis of the mitigation measures are made admitting that the transformer(s) is(are) operating at 50% of the rated power. In addition, the B-fields are computed at three different heights (0.5m, 1.0m and 1.5m) and the arithmetic mean is calculated, because the standard IEC 62110:2009 seeks to determine spatial averages.

This paper is organized as follows. Section II is dedicated to present the used simulation software, NARDA EFC-400LF. The implemented mitigation measures are presented in Section III. In Section IV the MV/LV TS under study are characterized. Section V provides the computational results and, in the last section, Section VI, the conclusions of the work are displayed.

II. NARDA EFC-400LF - ELECTRIC AND MAGNETIC FIELD CALCULATION

Calculation of the magnetic field distribution was conducted using professional simulation software developed by Narda, the EFC-400LF, certified by the norm IEC 62271. The theoretical basis of this software package is the Biot-Savart’s and Faraday’s laws. To solve the differential equations the computer program uses the finite element method (FEM) (15) (16).

The EFC-400LF has a vast library with 3D models of electric equipment, namely transformers, LV panels, MT and LV cables, and MV Bays from several manufacturers. It is also possible to modify the physical dimensions and electric properties of the models, in order to obtain faithful representations of the equipment.

The effects of metallic materials may be simulated in three different ways:

- By defining the constant mitigation factor (MF) for the equipment’s cases (default MF values are equal to one);
- By resorting to shielding elements available in the library (extra enclosures with default constant MF values);
- By modelling the ferromagnetic material through meshes.

The former two methods are similar, because the user can define a constant MF for the blocks. A vast library is available with typical MF, which calculated based on the penetration depth.

The latter method, for simulating the effects of metallic materials, consists in adjusting the physical parameters of mesh, such as area, section and the square of the mesh. The electrical properties of the material, such as electrical permittivity, magnetic permeability and resistivity may be changed in order to obtain more realistic models (it is assumed that all the materials are linear, isotropic and the magnetic saturation isn’t supported). The downside of this assumption is the high amount of computational resources and the time required to complete the simulations.

Profiles of points may also be defined, allowing the representation of the topography of the terrain. It is also possible to import building plans in order to place the equipment with precision. The results are displayed in 2D or 3D, according to user preferences.

The maximum calculation error for the B-field, at a distance of 1.0 m, is $1 \times 10^{-7}$ for a straight conductor. If the models are complex, the error is between 0.05 and 5.2%, depending on the desired precision (16).
III. Mitigation Measures

The MV/LV TS makes the final conversion of voltage levels before electricity reaches the domestic customers (400V three phase at 50Hz in Portugal). On the LV side, the current flowing through the cabling and switchboard increases, which leads to more intense B-fields. Also transformers create B-fields around them during normal operation. All of this contributes to increasing the overall magnetic emission level of the TS.

There are numerous studies about mitigation of B-fields in this kind of installations, but, several of them include costly solutions, such as shielding the low voltage side of the transformer, as depicted in Figure 2 (17) (18) (19). Although these solutions achieve good results, they are highly impracticable and should only be applied in critical situations. Active mitigation methods have also been developed, however, they are generally too expensive and complicated to be implemented in practice (20) (21).

The studied and implemented low-cost mitigation measures are presented in the following subsections. These measures are considered in a cumulative way, whenever possible, in order to assess whether there is a gradual reduction in the calculated field as two or more steps are added.

A. Conductors Arrangements

For a given current circulating in a set of conductors, the generated B-field depends, to a great extent, on geometric aspects of the conductors’ arrangement. The first thing to be done, in order to reduce the emitted B-field, is to group the conductors as close as possible, since the distance between conductors plays a major role in the emitted field.

Another thing to take into account is the relative position between the phases (R, S and T) and the Neutral (N). The intensity and shape of the resultant B-field is determined by the position of each phase (22).

All of the studied installations have two conductors per phase and one neutral, and they are disposed as depicted in Fig. 3.

![Figure 3 - Default arrangement in the study cases](Image)

The proposed cable arrangement, depicted in Figure 4 and inspired in the disposal shown in (23) for three phase cables without Neutral, was tested on EFC-400LF against other conductor arrangements. It was chosen because of its superior performance when compared with the initial configuration. Moreover, it is simple to implement in the TS.

Figure 5 depicts a comparison between the B-field emitted by the two conductors’ arrangements.

![Figure 4 - Proposed arrangement for the conductors](Image)

![Figure 5 - Comparison between the emitted B-field using two distinct arrangements for the same set of LV conductors; A) initial configuration B) proposed configuration](Image)

B. Back to Back Configuration

The Back to Back configuration consists in aggregating the LV panel and the transformer in the centre of the TS (Figure 6). With this measure, the length of the LV circuit is greatly reduced, which means that the B-field is less dispersed in the room (24) (25).

Moreover, if the distance between the walls and the B-field sources is increased, the field will decrease naturally in intensity as a function of distance \((d)\) from the source. B-fields produced by transformers decrease very quickly \((1/d^2)\) while circuits in typical conduit decay slower \((1/d^3)\) (26).

![Figure 6 - Back to Back configuration applied to a TS (27)](Image)

C. LV Panel - Four Pole Switch

The two previously referred approaches target the optimization of the TS’s layout. In this section we propose to change the four-pole switch, which defines the distance between the LV panel buses, for a more compact one. The basic principle
is the same that was mentioned in the conductors’ arrangement: if the distance between the buses is decreased, the emitted B-field will also be decreased.

It is worth clarifying that this measure is somewhat expensive to apply if the TS is already built; if not, special attention could be given to the choice of the used four pole switch model. Sometimes, this kind of switches are used in inter-LV panel connections.

The switches which were considered in the study cases, are made by SOCOMEC and the most widely used model is the Sirco 1250A. This four-pole switch has a distance, between the centre of the adjacent buses (T in the Figure 7), of 120mm. If a more compact model is chosen, such as the Sirco CD 1250A, this distance is reduced to only 80mm and, like was seen previously, the emitted B-field is reduced.

The rated current of both switches is the same for 400V. However, there are differences for the rated short-circuit capacity and durability (28).

### Table 2 - Global material parameters used (bulk mean values)

<table>
<thead>
<tr>
<th>Material</th>
<th>Aluminium</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistivity, $\rho$ [Ω-mm²/m³]</td>
<td>0.02928</td>
<td>0.205</td>
</tr>
<tr>
<td>Relative Magnetic Permeability, $\mu_r$</td>
<td>1</td>
<td>100</td>
</tr>
<tr>
<td>Relative Electric Permittivity, $\varepsilon_r$</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

### IV. CHARACTERIZATION OF MV/LV Transformer Stations

As was mention in section I, the studied transformer stations are embedded into residential buildings. Three computer models of TS from Portuguese urban areas were studied: TS A, B and C.

The TS C, depicted in Figure 9, is located in the basement of the building and, therefore, the area of interest is the apartments located above the TS. The rated power of the oil-immersed transformer on this TS is 400 kVA and the height of the TS is 3.20 m.

In the other hand, both TS A and B, illustrated in Figures 10 and 11, are situated on the ground floor of the buildings, which means there might be houses next to the TS. In this case, the B-fields should be calculated inside the above and adjacent apartments. The TS A has a 400 kVA oil-immersed transformer, a height of 3.20 m and an area of $4.75 \times 4.65$ m². The TS B has three 630 kVA dry transformers, a height of
2.64 m and a width of 4.18 m and a length of 9.87 m, for the longest side of the trapezoid, and 8.48 m for the shorter side.

![Figure 11 - TS B computer model](image)

**A. Calculation of B-fields**

Because of the IEC 62110 Standard, which seeks to determine the average exposure level, calculation of the B-field, in the adjacent apartments, was done at 0.2 m in the interior of the houses, as depicted in Figure 12, to comply with the used standard (13). Calculation points were defined spaced 0.5 m apart, in the sides of the TS with the highest calculated B-fields.

![Figure 12 - The IEC 62110 three points measurement methods for averaging exposure levels to non-uniform fields in adjacent homes (12)](image)

When the TS is placed below the apartment blocks, the average exposure calculations should be done, instead, at 0.5m, 1.0m and 1.5m from the floor of the houses. There are profiles defined in these houses, whose calculation points are located in the highest B-field intensity places. It is assumed that the average B-field is the mean of the three calculated values.

Also, the field calculations are carried out considering that the transformers are operating at 50% of their rated power, since the aim of this work is to determine the average human exposure to B-fields. The TS B has three transformers and it is assumed that one is for backup and, because of this, it is considered that two transformers are working simultaneously. The used resolution of calculation, in Narda’s EFC-400LF, is dx=dy=dz=0.1m.

**B. Steel Frame of the Slab**

In the simulation process, the influence of the steel frame of the slab was taken into account on the calculated B-fields, on the apartments situated above the TS (depicted in Figure 9).

Typical physical and electric parameters for the steel armature were used:

- In Portugal, for a distance between adjacent pillars of 5 to 7 meters and loads of 2 to 4 kN/m², the slab should have around 25 cm of thickness and two steel meshes that have squares of 15 cm (defined by the steel rebars) and diameter of 16 mm for the inferior mesh and 10 mm for the superior;
- The steel, used in construction, has low-carbon percentage (levels of carbon of 0.15 to 0.30%) (29) and its electrical characteristics are depicted in Table 2.

The conclusions of the study were that the steel frame reduced the B-field calculated in the apartments, located above the TS, by a factor of two. However, this reduction factor greatly depends on the size of the slab (relatively to the TS) and on the diameter of the meshes (27).

**C. Initial Results of Extrapolation of the B-fields to Areas of Human Exposure**

In the calculated B-fields in sensitive areas, using the initial calibrated models with a load of 50%, the average B-field is very high in the sensitive areas, especially in the adjacent houses. That happens because, in the studied TS, all of the LV circuit is close to the walls.

For example, in the TS B, a maximum B-field of nearly 90 µT was calculated, at 1.5 m in height, in the proximity of two LV panel bus bars (directly connected to the working transformers). The same results were observed in TS A, where the B-field reaches nearly 60 µT, at 1.5 m in height, behind the LV panel bus bars.

These values are a cause for concern because if we consider a slightly higher load in the transformers the limit for the acute human exposure, defined by ICNIRP and adopted by Portugal, is exceeded.

In terms of average B-field, calculated in the adjacent apartments, it reached 31 µT on the TS A and 42 µT on the TS B.

The average B-field calculated in the homes located above the TS was much lower, and reached an average of 2 µT in the TS B, while, in TS A and C, the value was around 1 µT. The B-field was much higher in TS B because of the LV cables that are near the ceiling and the low height of the TS room, meaning that the distance between the field source and the calculation plane was low, compared with the other two TS.

**V. Computational Results and Discussion**

The computational results, obtained with the previously described models, are shown in this chapter. These include a breakdown by mitigation measure, and only the more relevant results are displayed.

The adjacent calculation profiles (cluster of points) of the TS A and B are depicted in the Figures 10 and 11. The direction of the arrows is related to the position of the assigned numbers in the calculation profile (they are pointed towards increasing numbers).

The profiles defined in the apartments located above the TS station are called P1, for the TS C, and P4 for the TS B and A.
A. Modification of the Conductors Arrangements

The first implemented mitigation measure was the modification of the conductors’ configuration on the three TS. Two variations of the proposed arrangement were implemented in the TS C, because of the Neutral connection on the LV panel (depicted in Figure 9). In the first case, the connection of the Neutral was made under the LV panel, as in the initial model, and, on the second model, the connection was made above the LV panel, like the rest of the conductors. This modification was made to evaluate the importance of the cables being together all the way.

The obtained results, for the three TSs, are depicted in the Figures 13, 14 and 15. The computed B-field isolines are illustrated in the Figures 16 and 17.

The initial average B-field, in TS B, was over 2 µT, while after the changes were applied it was reduced to around 1 µT. This TS has a reduced height and LV near the ceiling, which results in a very bad scenario, especially if we consider a load of 50% on both transformers. Because of the obtained results it is possible to conclude that the change in the conductors’ arrangement is enough to guarantee a field under 1µT, even in bad scenario situations.

Observing the results in the TS A and C, we can conclude that the proposed arrangement has a reduction effect over the calculated B-field, in the apartments located above the substation. However, although these two TS have similar characteristics, the B-field is higher on the TS C. That is because the position of the LV circuit relatively to the steel frame of the slab (depicted in Fig. 9).
B. Back to Back Configuration

When Back to Back configuration was applied, the calculated B-field was dramatically reduced. In Figure 18 it is presented the maximum calculated B-field at the profile P3 of the TS A, at 1.5m in height, when the position of the LV panel is modified. From these results, we can see that the B-field decays very quickly when distance increased.

Because of the reductions in the B-field, when the distance between the LV panel and the sensitive areas was increased, the Back to Back (B2B) configuration was implemented.

In Figures 19 and 20, the obtained results for the TS A are presented. Compared with the initial results, the B-field calculated in the sensitive areas suffered a massive reduction. In the initial model, the average B-field reached 31 µT, on the profile P3, and, after the implementation of the B2B configuration the B-field dropped 1.26 µT (Figure 20). In the profile P1, the reduction is less accentuated, because the initial field was around 4 µT and now it reaches 1.26 µT. In the profile P2 the B-field reached, initially, 14 µT, and, with the modification of the conductors’ arrangement, dropped to 7.24 µT. Now, with the B2B configuration, the highest value is only 0.56 µT.

The performance of the Back to Back configuration in the TS B is identical to the one in TS A, as we can see in Figures 21 and 22.

In this TS, when the B2B configuration was applied, the position of the LV panels and the transformers was switched, to allow the replacement of the transformer. The highest initial field was 42 µT (average) in profile P1 and, and now, with this modification, is 2.56 µT in profile P3 (this permutation has to do with the switch of the equipment position).
In the Figures 23 and 24 there is a comparison between the computed B-field isolines with the B2B model and the initial situation, for the TS B.

![Figure 23 - Computed isolines of the B-field, in the TS B, at a height of 1.0m, with the initial model](image)

![Figure 24 - Computed isolines of the B-field, in the TS B, at a height of 1.0m, with the Back to Back Configuration](image)

**C. LV Panel and Metallic Elements**

Additional reduction measures were included in the models, such as adding compact four-pole switches and Aluminium and Steel Meshes.

It is worthwhile to note that the TS B has four-pole switches between the LV panels (they are interconnected as depicted in Figure 11). Sharing the same model as the ones employed in the LV panel, the four-pole switches were substituted by a compact model, Sirco CD 1250A.

The metallic meshes used in the TS A have 2.0m by 1.6m and 5.5m by 1.4m in TS B.

The results obtained, for TS A and B, are depicted in the Figure 25 and Figure 26, respectively. The caption of both Figures means the following: CD 1250A is presented when the compact four-pole switch is used; Al and St are the types of metallic materials, next is the mesh square (reticule) in cm and then the cross section area in mm².

The results show that these measures provide additional field mitigation. The Aluminium meshes are very effective with low cross section area, contrary to the steel meshes, which need a high section due to the higher resistivity considered. Also, the compact four-pole switches provide an additional reduction of the field (in Figure 26 the calculated field in the profile P3, the highest in TS B, is only 80% of the initial B2B configuration value).

![Figure 25 - Average B-field in the profile P3 of the TS A, at 1.0m in height, using the Back to Back configuration with compact four-pole switches and metallic meshes](image)

![Figure 26 - Average B-field in the profile P3 of the TS B, at 1.0m in height, using the Back to Back configuration with compact four-pole switches and metallic meshes](image)

As expected, the highest B-field reduction occurred in the profiles that are facing the LV panel. In the profiles that are closer to the transformers, the decrease is lower, because the contribution of this equipment was not mitigated. Nevertheless, the LV panels are the highest emitting field components in the TS. The fact that the mesh is closer to them and the decrease of the distance between the LV panel buses, using a compact four-pole switch, is enough to guarantee a considerable field decrease, especially if the mesh is of aluminium or is made of steel with a considerable cross section area.

The obtained mitigation in the TS B is not as high as the one in TS A for the same measure, on profile P3. That is because
the MV bays are closer to the profile in the TS B, the transformers are bigger, when compared to TS A. Moreover, the area of the mesh had to be reduced because of computational limitations (reached the maximum number of iterations when using the higher density meshes).

VI. CONCLUSIONS

After the study it is possible to say that the field can be reduced to 1 µT, in sensitive areas, by applying different construction techniques, such as B2B configuration, adding meshes between the transformer and the LV panel, and using more compact four-pole switches.

The most effective measure was, without a doubt, the B2B configuration, which should be applied to the TSs, due to the high reduction of the calculated B-field in sensitive areas.

When the only area of interest is the area directly above the TS, changing the conductors’ arrangement is sufficient to guarantee an average B-field inferior to 1 µT.

The conclusions of the study are summarized in the Tables 3 and 4.

Table 3 – Calculated B-fields in the area directly above the TS

<table>
<thead>
<tr>
<th>Description</th>
<th>Average B-field on the area directly above the TS [µT]</th>
<th>Notice</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV cables on the floor or in the floor channel</td>
<td>≈ 1</td>
<td>Proposed cable arrangement</td>
</tr>
<tr>
<td>LV cables on the wall</td>
<td>≈ 1</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>LV cables near the ceiling</td>
<td>&gt; 1</td>
<td>≈ 1</td>
</tr>
<tr>
<td>Notice</td>
<td>Could exceed 1µT if the neutral cable is separated from the phase conductors</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Evaluation necessary if the rated power of the transformer is higher than 630 kVA</td>
<td></td>
</tr>
<tr>
<td></td>
<td>This is the worst case scenario, because the distance between the source and the rooms is very low</td>
<td></td>
</tr>
</tbody>
</table>

Table 4 – Calculated B-fields in the rooms adjacent to the TS

<table>
<thead>
<tr>
<th>Description</th>
<th>Average B-field at the rooms adjacent to TS [µT]</th>
<th>Notice</th>
</tr>
</thead>
<tbody>
<tr>
<td>LV panel is supported on the walls which delimit the facility</td>
<td>≈ 1</td>
<td>Can exceed acute human exposure limits recommended ICNIRP</td>
</tr>
<tr>
<td>Idem + Modification of the cables arrangement</td>
<td>≈ 1</td>
<td>Idem + B-field caused by other devices at the TS is more important</td>
</tr>
<tr>
<td>Back to Back configuration</td>
<td>&gt; 1</td>
<td>An average mitigation factor of 15 is expected, depending on the dimensions of the facility</td>
</tr>
<tr>
<td>Idem + Additional measures (compact 4p switches + metallic meshes)</td>
<td>≈ 1</td>
<td>These complementary measures help to reduce the B-field to the 1µT target</td>
</tr>
</tbody>
</table>

VII. REFERENCES

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11. Pinto de Sá, José Luís C., et al. An average mitigation factor of 15 is expected, depending on the dimensions of the facility.
12. Idem + Additional measures (compact 4p switches + metallic meshes) | ≈ 1 | These complementary measures help to reduce the B-field to the 1µT target |