

SPACE RADIATION SHIELDING ENCLOSURE FOR ELECTRONICS

FIELD OF THE INVENTION

The invention relates to radiation shielding, shield suited therefore, and enclosures related thereto and method for (co-)designing and related material search methods.

5 BACKGROUND OF THE INVENTION

The invention is situated in the context of satellites but is not limited thereto.

Satellites are engineered with a protective outer layer, or “wall”, which is composed of thin aluminium sheets, typically measuring 0.3 to 0.6 millimetres in thickness. These sheets are securely affixed to an aluminium chassis or framework. Within the satellite, various mechanical configurations are designed to accommodate the payload, or the operational components of the satellite. The primary component, known as the “bus”, houses essential elements such as controllers, spaceborne computers, batteries, and power converters. However, the internal arrangement of these components is not random. Each component or “box” is strategically positioned within the satellite’s total volume to optimise spatial efficiency and minimise radiation exposure. This placement is a key aspect of satellite engineering, ensuring optimal performance in each mission.

Attempts have been made to create a multilayer configuration using a combination of materials such as aluminium, titanium, and tantalum (ALTITA). However, these attempts have not been successful, primarily because adhesives or glues cannot be used between layers in space.

20 While the invention leverages to some extent on approaches adopted in the distant field of therapy environments, it is important to emphasize some key differences: (1) the type of radiation considered is of a typical other nature (space generated instead of by a human designed device) and (2) the radiation considered is going outside the shielded room wherein therapy equipment is placed.

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SUMMARY OF THE INVENTION

The invention relates to radiation shielding, shield suited therefore, and enclosures related thereto, in particular, radiation considered are those found in space and/or in reactor environment and/or in the medical sector.

- 5 The invention relates to enclosures, provided with such radiation shielding shields. The invention relates to enclosures for protecting electronic devices (EEE components, (high-performance) computing devices) against such radiation. The invention also relates to enclosures for protecting humans for such radiation. The invention also relates to enclosure, sized to contain both electronic devices and humans. The invention also relates to
10 arrangements wherein one enclosure (containing electronics) is part of a second (bigger) enclosure (wherein also one or more humans or users can fit, who may operate the electronics).

- The invention relates to radiation shielding, more in particular, to radiation shielding for electronic devices, targeting (high-performance) computing. The primary incoming radiation considered are those found in space (Heavy ions, protons, electrons) and/or in reactor
15 environment as found in nuclear energy (neutrons radiation) and/or in the medical sector (equipment used for radiation therapy as used in hadron therapy centre (ions and protons radiation). The invention also takes into account the secondary particles generated by the interaction of the primary radiation beam with the shielding material. While the above examples refer to particle radiation, further radiation such as electro-magnetic (Gamma rays
20 and X-rays) are also considered.

- The invention relates hence to an enclosure, adapted for enclosing at least one electronic device, said enclosure being designed for protecting said electronic device for radiation, said enclosure may be designed for particular radiation contexts or environments. The invented enclosure however all protect against at least a plurality of different radiations and/or takes
25 into account a plurality of (negative) radiation shielding performance effects on the to be protected item.

The invention relates also to an enclosure, adapted for enclosing at least human, said enclosure being designed for protecting said human for radiation, said enclosure may be designed for particular radiation contexts or environments.

The invention also relates to an arrangement of such enclosures, wherein one fits in the other as elaborated on above, in particular wherein those enclosures are co-designed in that the effect for radiation shielding of each of those and their mutual influence is taken into account.

The invention relates to enclosure of various sizes such as small size for a GPU, large size for a
5 earth based transformer. The invention also relates to a big enclosure, protecting EEE components, such EEE component being susceptible to be operated by a human. Such operator would also benefit from the shielding.

Electronic devices require cables and hence enclosures, wherein said electronic devices resides for (radiation) protection are provided with one, possible many (quite) different connectors
10 (such as for signals and/or power and/or grounding), and the signal connectors may be adapted for analogue (coax, RF) and/or digital signals.

In an embodiment of the invention there are one or more layers of the outer wall of the enclosures that are dedicated for particle radiation shielding while one or more other layers thereof are dedicated for (further) electro-magnetic shielding.

15 In an embodiment of the invention there are one or more layers of the outer wall of the enclosures that are dedicated for particle radiation shielding while one or more other layers thereof are dedicated for (further) secondary particles shielding.

Electronic devices, targeting (high-performance) computing, comprise of a plurality of different components for computation (like CPU's, GPU's, memory, storage, interface controllers,
20 communication chips, sensors and/or power control devices). These components are arranged on a Printed Circuit Board (PCB).

In an embodiment of the invention those electronic components are commercial-of-the-shelf (COTS) components (not designed for a radiation harsh context).

The enclosure provided in the invention can house electronic devices made on one PCB but also
25 a plurality of PCB's can be housed.

In an exemplary embodiment, the size of said enclosures is length 217 mm, width 152 mm and height 87 mm with a typical internal PCB board of size 50 mm by 50 mm, while the die size of a component is around 24 mm by 15 mm.

In an exemplary embodiment, the electronic device aimed for has at least 2 different components on one PCB. In a further exemplary embodiment, the electronic device aimed for requires 2 PCB's. In yet a further exemplary embodiment at least 3, possibly 5 (essentially different in terms of materials) connectors are required.

- 5 In summary one can state that the invention relates to an enclosure, adapted for enclosing at least one electronic device, said enclosure being designed for protecting said electronic device for radiation in terms of (a) selecting the material(s) and thickness of material(s) of at least part of the enclosure walls in terms of radiation shielding and/or the enclosure geometric design, in terms of the positioning in relation to the line-of-sight and/or the radiation throughput of one
10 or more openings (in said walls) for providing electronic connections to and from said at least one electronic device(s) and/or selecting the material(s) and thickness of material(s) of at least part internal elements within said enclosure and/or the positioning at least part internal elements in relation to the line-of-sight.

- In a preferred embodiment, the enclosure both has line-of-sight blocking internal elements and
15 radiation throughput optimized opening.

In another preferred embodiment the enclosure has a multi-layer wall and/or internal element.

A further preferred embodiment combines the above two embodiments.

- Note that the invention may provide enclosures, wherein the positioning of the electronic device within said enclosure, the location of the openings and the position of said internal
20 elements create a non-isotropic radiation environment and the design of said enclosure exploits this (on purpose created) non-isotropic radiation environment by using a non-homogenous approach (in that different material(s) and/or thicknesses of material(s) of the enclosure walls, depending on the position along the wall and/or as used for the internal elements, preferably this non-homogenous approach takes into account explicitly that discontinuities in the shield
25 needs to be avoided as this can cause again radiation issues, hence at least a requirement of smoothness must be considered, optionally non-homogenous approach takes into account explicitly the the manufacturing challenges related thereto and/or mechanical strength issues that may occur.

In an embodiment of the invention the enclosure comprising at least one heat sink for removing heat generated by said at least one electronic system, said heat sink defining another opening in said enclosure wall (in terms of radiation), whereby within said enclosure in the line-of-sights for particle radiation between said opening and the position foreseen for said electronic system, a further shield is provided.

In relation to manufacturing aspects, the invention gives consideration of the use in space and hence this is where additive manufacturing comes into play. Additive manufacturing involves the direct deposition of two materials against each other's surfaces, eliminating the need for glue or adhesive. This process prevents any outgassing, a common issue in space environments. Therefore, additive manufacturing is a more effective method for constructing satellite walls.

The invention can be formalized as an enclosure (20), adapted for enclosing at least one electronic device (10), comprising a plurality of parts, together forming said enclosure, the walls (30) of said parts acting as a multi-layer radiation shield.

In an embodiment an enclosure is provided wherein said multi-layer (space radiation) shield comprising (a) a first layer (600) (oriented to the radiation (650)) made of a first material and (b) a second layer (610) (oriented to the electronic device relative to the first layer) made of a second material (optionally boron rich material), wherein said first layer is functionally optimized for nuclear fragmentation shielding. wherein said second layer is functionally optimized for radiation dose reduction shielding.

In another embodiment said enclosure comprises at least one opening (40) (in said walls) for providing electronic connections to and from said at least one electronic device(s), whereby within said enclosure in the line of sights for particle radiation between said opening and the position foreseen for said electronic system, one or more further shield(s) (60) is (are) provided.

In a further embodiment the ensures has parts having means (210) for removably fixing said parts to each other, wherein part of said means are positioned on the side of said further shield(s) opposite the position of said electronic device. In a further preferred embodiment said parts having means for removably fixing said parts to each other, wherein part of said means,

preferably those positioned on the side of said further shield(s) opposite the position of said electronic device, also being made of a multi-layer shield.

The invention further provides a system, comprising an enclosure (20) of any of the previous claims; and an electronic device (10), placed therein, wherein the design of the enclosure takes
5 into account the performance of said electronic device against radiation into account, preferably the enclosure and the electronic system are co-designed, for the electronic system in terms of its selected hardware and/or the software operating on said electronic design and for the enclosure the amount of layers, the selected materials of layers and the thickness of said layers.

The invention further provides arrangements with a plurality of enclosures (20) (730) of any of
10 the previous claims and/or systems of any of the previous claims, wherein one or more enclosures or system fit into other of said enclosures or system and the design of the enclosures takes into account the protection against radiation of one another into account.

A few particular embodiments are emphasized below:

1. An enclosure (20), adapted for enclosing at least one electronic device (10) and
15 designed while taking into account the performance of said electronic device(s) against particle radiation, comprising (i) a plurality of parts, together forming said enclosure; (ii) at least one opening (40) in the walls (30) of/defined by said parts for providing electronic connections to and from said at least one electronic device(s), wherein said design considerations are selected from the group of: (a) for each of
20 said parts, determining the amount of layers (one or more), the selected materials of those layers and the thickness of said layers (acting as shield); (b) positioning of said opening relative to the position foreseen for said electronic device within said enclosure, wherein the design considerations further include: (c) considering adding one or more shield(s) (60) within said enclosure in the line of sights for particle
25 radiation between said opening and the position foreseen for said electronic device within the enclosure and for said one or more shields, determining the amount of layers (one or more), the selected materials of those layers and the thickness of said layers.
2. The enclosure above, further comprising: (iii) means (210) for removably fixing said
30 parts to each other, wherein the design considerations further include (d) positioning of said means for removably fixing said parts to each other relative (in

- the sense of distance or taking presence of other elements within the enclosure into account) to the position foreseen for said electronic device within the enclosure; (e) for each of said means for removably fixing said parts to each other determining the amount of layers (one or more), the selected materials of those layers and the thickness of said layers.
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3. An enclosure (20), adapted for enclosing at least one electronic device (10), comprising a plurality of parts, together forming said enclosure, the walls (30) of/defined by said parts acting as a multi-layer radiation shield and/or a single 100% radiation dose reduction layer, with a material selected from a material class with high radiation dose reduction efficiency and/or a 100% radiation dose reduction layer, with a material selected from a material class with high radiation dose reduction efficiency in combination with a further multi-layer shield.
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4. One of the enclosure mentioned above , wherein the selected materials are selected from a predetermined (filtered) ranked list of computer-generated materials (such as in accordance with search methods).
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5. A method for designing an electronic device (10) to be placed in an enclosure as mentioned above, wherein the design of the electronic device comprising selecting the hardware of and/or the software operating on said electronic design, wherein the design takes into account the performance of said electronic device against radiation to which it is exposed in the enclosure into account.
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6. A method for co-designing an enclosure (20) as mentioned before; and an electronic device (10), to be placed therein, wherein the design of the enclosure takes into account the performance of said electronic device against radiation to which it is exposed in the enclosure into account, the design of the electronic device comprises selecting the hardware of and/or the software operating on said electronic design and the design of the enclosure comprising selecting the amount of layers, the selected materials of layers and the thickness of said layers, preferably wherein said electronic device comprising (commercial-of-the shelf, COTS) components of which one or more (or all) without space radiation hardening and/or said electronic device being (at least) in part a chip-let based electronic device , preferably wherein the design of the chip-let is part of the co-design.
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- 30
7. An enclosure (20), adapted for enclosing at least one electronic device (10) and designed while taking into account the performance of said electronic device(s)

- against particle radiation, comprising (i) a plurality of parts, together forming said enclosure; (ii) at least one opening (40) (in the walls (30) of said parts) for providing electronic connections to and from said at least one electronic device(s), optionally (iii) one or more further shield(s) (60) within said enclosure in the line of sights for particle radiation between said opening and the position foreseen for said electronic device, wherein each of said parts and/or further shields, having one or more layers of material, together former a multi-layer (space radiation) shield characterized in that layers oriented to the radiation (650)) are made from metal alloys, further layers (610) oriented to the electronic device relative to the previous layer) are made of alloys or polymers and the final layers attached to the further layers oriented to the electronic device are made of ceramics or polymers (for radiation dose reduction of secondary particles). Note that the template material organization here does not prevent the addition of other layers on client requests such as an electromagnetic shielding layers and/or metal layers (like aluminium) for mechanical stability.
8. An arrangement with a plurality of enclosures (20) (730) mentioned before and/or systems discussed before, wherein one or more enclosures or system fit into other of said enclosures or system and the design of the enclosures takes into account the protection against radiation of one another into account.

SHORT DESCRIPTION OF THE DRAWINGS

- Figure 1 shows a schematic representation of the invention (side views).
Figure 2 shows a schematic outline of an embodiment of the invention.
Figure 3 shows a picture of an embodiment of the invention.
Figure 4 shows a picture of another embodiment of the invention.
Figure 5 shows another schematic representation of the invention (side views).
Figure 6 show schematically a multi-layer (space radiation) shield as invented.
Figure 7 shows different arrangements using the invented enclosures.
Figure 8 a to c provides a flow chart description of the design process for a functional system (e-box), supported by various dedicated radiation calculation routines, optimization routines with appropriate optimization criteria and material databases.
Figure 9 shows an embodiment of a design process flowchart, tackling interplay and organizing iterations, in particular in relation to the outer walls and the internal shield.

Figure 10 shows an embodiment of a design process flowchart, tackling interplay and organizing iterations, in particular the use of radiation beams ranking.

Figure 11 shows an embodiment of a design process flowchart, tackling interplay and organizing iterations, in particular the use of radiation beams ranking and use of predefined material
5 classes.

Figure 12 shows an embodiment of a design process flowchart, tackling interplay and organizing iterations, in particular the co-design of enclosure (inner loop) and electronic system (outer loop).

Figure 13 shows an embodiment of a design process flowchart, showing the leverage of using
10 computer generated materials, the ranking thereof and then executing any of the design flow explained in the Figures above.

DETAILED DISCUSSION OF THE INVENTION

15 Figures 1 and 5 show a schematic representation of the invention (side views). It shows an exemplary electronic device (10), placed in an enclosure (20) with a multi-layered wall (30). Moreover, the enclosure has an opening (40) (for providing cables (50)) and a (so-called no-line of sight or line of sight blocking) body (60) and openings (70) in said body (for further providing said cables), said openings (40) (70) being so arranged that there is no line of sight.

20 Figure 2 shows a schematic outline of an embodiment of the invention. It shows supporting elements (110) for positioning one or more electronic devices, placed in an enclosure (120) with a multi-layered wall (130) (3 layers indicated). Moreover, the enclosure has an opening (140) (for providing cables (not shown) and a (so-called no-line of sight or line of sight blocking) body (160) and openings (170) in said body (for further providing said cables), said openings (140)
25 (170) being so arranged that there is no line of sight. The enclosure has a first (top) half (180); a second (bottom) half, said halves being engaged. Moreover, said second (bottom) half itself comprises of two parts (190) (200). To removably fix said halves and parts means (210) for removably fixing said parts to each other (like screws and holes for those).

Figures 3 and 4 show a picture of an embodiment of the invention with the elements as
30 described above. In particular there are a plurality of openings (340) in the enclosure wall and

there is also (in an equivalent amount) a plurality of openings (370) in the body (360). Note that those openings are provided with appropriate connectors (390).

Figure 6 left top shows a multi-layer (space radiation) shield comprising (a) a first layer (600) (oriented to the radiation (650))) made of a first material and (b) a second layer (610) (oriented to the electronic device relative to the first layer) made of a second material. Figure 6 right top shows said multi-layer (space radiation) shield comprising a third layer (620) (attached to the second layer and oriented to the electronic device) made of a third material. Figure 6 left bottom shows in the considering of a fourth layer (630) in combination with a two-layer model, which may be the satellite wall. Figure 6 right bottom shows the fourth layer in combination with the three-layer model.

Figure 7 shows different arrangements. Figure 7 top left shows an electronic component (10) within an enclosure in accordance with the invention. Figure 7 top right shows such enclosure (20) within another enclosure (730), wherein also a human or user (700) fits. Figure 7 bottom left shows the enclosure (20) within a satellite (710) while Figure bottom right shows the enclosure with enclosure embodiment as part of a space chip (720).

Figure 8 a to c provides flow chart description of the design process for a functional system (e-box), which besides input and output software modules, is supported by various dedicated radiation calculation routines and optimization routines with appropriate optimization criteria. In Figure 8a One recognizes the following steps:

The process begins with the initiation of the system design (801), where the requirements and environmental factors are analysed.

Further on, the initial System Design is performed (803) by creating a preliminary design for the system, focusing on layout, architecture, and key functionalities. The Radiation Dose Calculation (TID) (804) is performed to estimate the radiation exposure that the system will face during its mission. In the Dose Calculation for Electronics Components (805), a break down the radiation dose at the component level is completed, ensuring that each electronic part's exposure is accounted for.

The Material Layers Selection starts (806) and appropriate material layers are selected to shield electronics and minimize radiation exposure. Consider factors like weight, efficiency, and mission-specific requirements.

- In parallel of initial system design (801), the radiation environment the system will operate in is designed (807), including potential sources like cosmic rays, solar radiation, and trapped particle belts. Multiple Radiation Source (808) are identified and classified according to the various radiation sources affecting the system to ensure accurate modelling and mitigation strategies.
- 5 In a further step (809), the System & Circuit Design are performed where the detailed design of circuits and system components is developed, factoring in the constraints imposed by radiation and other environmental conditions. Similarly, the Radiation Level Within the Spacecraft (810) is performed to evaluate the distribution of radiation levels inside the spacecraft to identify high-risk areas and optimize shielding.
- 10 An analysis of the System Response to the Radiation Environment is performed (811) to assess how the system and its components will respond to the defined radiation environment, identifying any potential vulnerabilities. Further on, individual Electronics Component Radiation Sensitivity (812) is examined for each electronic component to ensure reliability and identify any parts that require additional protection or replacement.
- 15 A decision point (813) is considered to assess if the Radiation Dose Constraints are met. If the radiation dose constraints are not met, adjustments (814) to the system design are required to mitigate risks. If the constraints are met, proceed to final system design (815). In the case of a System Design Adjustment (814), necessary modifications to the system or shielding are made to ensure compliance with radiation tolerance and mission requirements. In the case of a
- 20 Complete System Design, the overall design is completed (815), incorporating all adjustments and validations to ensure functionality, reliability, and compliance with mission objectives. The process is completed with a complete, validated design ready for implementation or further testing (816).

- Figure 8b dives in more detail into the material selection per layer subroutines or subprocesses and in particular, emphasise the computer support by using preconfigured material databases.
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The following steps are identified:

- Begin the process by evaluating the radiation sensitivity of the electronic components (8001). This step ensures that the design considers the specific tolerance levels of the components against radiation exposure. Then, identify and assess the first radiation source affecting the
- 30 system (8002). This may include cosmic rays, solar flares, or other environmental radiation types. Next evaluate the second radiation source (8003) to determine its impact on the system. Each

source adds unique constraints to the shielding requirements. And finally, consider a third radiation source (8004), ensuring that all potential threats to the system's functionality are accounted for in the material selection process.

Further on, the material selection process is initiated (8005). This involves analysing various materials for their radiation shielding properties and compatibility with the system. Starting the selection process of shielding material: choose the first shielding layer (8006), which will provide a foundational level of protection. The selection should balance effectiveness, weight, and other mission-specific factors. Add a second layer to enhance the shielding capability (8007). This layer should address specific gaps left by the first layer, providing additional protection against identified radiation sources. Finally, choose a third layer to complete the shielding system (8009). This layer should consolidate the protection, ensuring comprehensive coverage against all identified radiation sources.

A Reference a database of innovative materials (8008) is consulted to explore advanced options that offer improved shielding or reduced weight for each layer (8006), (8007), (8009). This step leverages the latest research and technology development status coming from the materials discovery campaign.

At the last step, finalize the material layers into a consolidated multi-layer design (8010). This step ensures the combined layers provide optimal protection, meeting mission requirements while considering constraints like weight and cost.

Figure 8c presents an example of actual data to be used for the design configuration selection method presented in flow chart 2:

Radiation Source (Beam)	Particle Charge	Layer Thickness	Total Ionizing Dose	Material Composition
1000 MeV / u Oxygen	+8	1 cm	1.72*10-4 mGy / 1000 particles	Fe9Mn2
1000 MeV / u Iron	+26	0.6 cm	= 1.72*10-5 mGy / 1000 particles	Fe13Ni3
400 MeV / u Helium Beam	+2	0.6 cm	= 1.82*10-3 mGy / 1000 particles	Co13Ni3

Figure 9 illustrates the design procedure for an enclosure (20), adapted for enclosing at least one electronic device (10) and designed while taking into account the performance of said electronic device(s) against particle radiation, comprising (i) a plurality of parts, together
5 forming said enclosure; (ii) at least one opening (40) (in the walls (30) of said parts) for providing electronic connections to and from said at least one electronic device(s), wherein the design considerations include: (a) for each of said parts, determining the amount of layers, the selected materials of those layers and the thickness of said layers; and thereafter the design considerations further include considering adding one or more further shield(s) (60) within said
10 enclosure in the line of sights for particle radiation between said opening and the position foreseen for said electronic system and the design (material selection and thickness thereof) for said shield, taking into account the wall selected for each of said parts (while optionally allowing for iterations).

The computer aided design method in essence considers the vulnerability of enclosures in
15 relation to radiation issues, for instance as illustrates in Figure 9, acknowledging the need for opening, considering radiation issues attributable to those, provide a solution (in terms of an internal shield) and while designing that one, taking into account the already designed walls of the enclosure. While iterating one may further improve the solution. The above considerations can also be made in relation to the means for connecting the parts, by carefully chosen the
20 positioning (relative to the internal shield and the electronic device position) and also designing shielding functionality for those means for connecting the parts. The above suggests that first Figure 9 approach is executed, following by the same for the means for connecting the parts.

Figure 9 – 12 each emphasize a particular aspect of the design process, such as use of iterations, explicitly tackling interplay (e.g. in relation to the outer walls and the internal shield, the design
25 of the enclosure and electronic system) and techniques such as radiation beams ranking and/or use of predefined material classes. One or more of these aspects can be combined. These aspects provide definite guidance (precise ordering) for the designer on how to conduct the design but also require the necessary design environment to execute those such as storage or databases for material classes, and re-computation of the radiation beam (as the shields get
30 designed repeatedly).

- (1000) is the enclosure wall shield determination (neglecting impact entering enclosure via connectors, enclosure part interface and/or part connecting means) **without assuming** presence of LOS Shield propagation.
- 5 (1010) is the enclosure LOS shield determination (*) (in addition to remaining radiation, take into account impact entering enclosure via connectors, enclosure part interface and/or part connecting means). Note that (*) instead of enclosure LOS Shield determination, also the one or more layers relating to the part connecting means may be considered or both or one after another with or without further iterations.
- 10 (1020) means adapt enclosure wall shield determination (with or without neglecting impact entering enclosure via connectors, enclosure part interface and/or part connecting means) but **with assuming** presence of LOS Shield propagation.
- (1030) means propagate remaining radiation.
- (1040) means propagate determined shield.
- (1050) means propagate remaining radiation.
- 15 (2000) means rank the various radiation beams of the context of concern.
- (2010) means determine one layer of the enclosure wall shield taking only into account highest ranked radiation beam.
- (2020) means determine second layer of the enclosure wall shield taking only into account second highest ranked radiation beam while assuming presence of already determined
- 20 layer.
- (2030) means adapt determined first layer of the enclosure wall shield taking only into account highest ranked radiation beam while assuming presence of already determined second layer.
- Note that (*) instead of enclosure wall shield determination, the same approach can also be
- 25 used for the LOS Shield, the one or more layers relating to the part connecting means may be considered or both or one after another with or without further iterations.
- (2040) means propagate first determined layer.
- (2050) means propagate second determined layer.
- (3000) means determine one or more layers of the enclosure wall shield taking only into
- 30 account one or more of the highest ranked radiations while only using one or more of the highest ranked materials to achieve a full stop objective.
- (3010) means determine one or more other layers of the enclosure wall shield taking only into account the further ranked radiation beams while assuming presence of already

determined layers while using all available materials and without assuming a full stop objective.

(3020) means adapt determined first one or more layer of the enclosure wall shield as in (*) while assuming presence of already determined further layers.

5 (3040) Rank the various materials than can be used for a layer in accordance with their **radiation stopping efficiency** (stopping power divided by cost) and/or **electronics radiation impact reduction efficiency**.

(3050) means propagate determined layers.

(3060) means propagate further determined layers.

10 (4000) means loading enclosure architecture (e.g. position of connectors, enclosure part interfaces and/or part connecting means) and electronics.

(4010) means determine one or more layers of the enclosure wall shield taking in account radiation performance of enclosure architecture electronics configuration.

15 (4020) means evaluating the solution in view of costs and either accept or adapt enclosure architecture electronics configuration (e.g. install more radiation effect mitigation mechanisms in the electronics).

(5000) relates to a search method, carried out by a computer, for determining one or more materials, by outputting their selected chemical composition including atoms and number of atoms, being selected by an optimisation method, the optimisation method comprising: iteratively computing a radiation shielding property as objective in the
20 optimisation method, the method being based on evolutionary computation or optimisation algorithms.

(5010) means ranking the generated materials in terms of a design criteria.

(5020) means design the enclosure and/electronic system.

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Figure 13 shows an embodiment of a design process flowchart, showing the leverage of using computer generated materials, the ranking thereof and then executing any of the design flow explained in the Figures above, in particular in that those found materials in the search method may be so outperforming (relative to existing materials) that it is worth to rank those (in relation
30 to the relevant design criterion for the next design step) and hence enforce their use in the next design step. Note that intermediate filtering out materials in terms of their mechanical properties and/or manufacturability is possible. Note that within the design process a by a client

imposed constraint on thickness of a certain layer can be taken into account explicitly, even at the level of the materials search algorithm.

In one particular embodiment the use of so-called full stop layers is suggested wherein with full stop layer means that for a selected radiation beam of the context of concern the thickness is chosen to fully stop the beam. Note that due to design iterations taking into account effects of further layers, a slightly less thickness may be finally used. In the case of the use of a high radiation stopping efficiency material (in general or specific in terms of electronics radiation impact, which is for certain beams), this implies anyway a not so thick layer after all. As full stop layers, certainly those with the optimal material class selection for one selected beam, are generally less effective for other beams of the content of concern, use of further shielding is recommendable. Note that given this less effectiveness, those layers are likely to exhibit also low fragmentation (and hence design iterations may be avoided also in such case) but if one like to leverage on fragmentation, it is recommendable to have as first follow-up layer a fragmentation layer.

The enclosures shown in the figures before are adapted for requires 2 PCB's.
The enclosures shown in the Figures 3 and 4 show 3 connectors while Figure 5 shows 4 inner connectors.

The shield or multilayer enclosure for satellite electronics typically consists of at least two parts: a bottom part and a top part. The bottom part serves as the base that houses the electronics, while the top part, also known as the lid, is removable, usually secured with screws, to allow access to the electronics inside.

However, in a further preferred embodiment, the bottom part of the shield is further divided into two separate parts. This means the shield is made up of three parts. This third part, which is removable from the bottom side of the shield, provides additional access to the electronics and the cabling. This design allows for easier integration and access to the electronic components (within the satellite).

In an exemplary embodiment all the above-mentioned parts are multi-layered.
As said before the invention provides an enclosure adapted for comprising one or more electronic devices, said enclosure comprising: a first half presenting a first face; a second half

presenting a second face, the second face being engaged against the first face in a first position and being separated from the first face in a second position, wherein said first and second half are made of one or more layers of (different) radiation shielding material.

- 5 In an embodiment of the invention the enclosure, more precisely said first and/or second half comprises one or more first openings (to provide signals and/or power connections to said one or more electronic devices in and out said enclosure), the enclosure further comprising a body (also called internal element above or further shield), (also) are made of one or more layers of (different) radiation shielding material (which may differ from the layers of the first and second
- 10 half), whereby the body may (also) comprise one or more openings (to further provide said signals and/or power connections entering the enclosure) to said one or more electronic devices), wherein said body and said first openings are arranged in that there is no line of sight between the first openings and the position where said electronic device is to be placed and preferably the one or more second openings in said body are arranged in that there is no line
- 15 of sight between the first openings, the second openings and the position where said electronic device is to be placed. Note that on said openings, appropriate connectors (appropriate for the type of signals to be received) may and are typically provided.

- In an embodiment to the invention the enclosure, more in particular the first and/or second half side walls, comprise matching (in the sense that they can engage with one another)
- 20 (convex) protrusions and (concave) undercut recess at the place where the sidewalls, need to connect, said protrusions and recess ensure that the first half and the second half have a single degree of freedom of relative motion. Note that first openings mentioned before are within said the first and/or second half side walls.

- In an embodiment of the invention, while the (convex) protrusions and (concave) undercut
- 25 recesses are made for engaging and (mechanical) fixing said first and second half, their shape takes into account radiation considerations and in particular contribute to a further no line-of-sight consideration between say their outer connection point and the position where said electronic device is to be placed. In an exemplary embodiment the arrangement described above result in V-shaped cross sections. It is worth mentioning here that besides radiation
- 30 shielding considerations that friction aspects (especially those to be considered during high acceleration and vibration cycles during e.g. a rocket launch, during carriage of shielded mobile

power units, during operations of a nuclear reactor on a ship or a spaceship) are to be taken into account.

The described side-walls for constructing enclosures capable of blocking radiation, including but not limited to photon, gamma and neutron radiation, have opposed front and rear surfaces
5 defining a thickness of the sidewall, have continuously curved opposed top and bottom surfaces, characterized in that the continuously curved surfaces have a regular (sinusoidal) wave pattern having a wave direction that is perpendicular to the planar opposed front and rear surfaces, and in that each one of said continuously curved surfaces is one, preferably more complete wavelengths long and extends in the wave direction over a substantial up to the
10 entire thickness of the block.

In an embodiment of the invention, because the presence of the (line of sight blocking) body divides said enclosure in two parts, one where the electronic device is present and at least adapted for position such electronic device and another part (without such electronic device), the one or more layers of (different) radiation shielding material used for said first and second
15 half for the two parts are designed to be different. Notwithstanding the foregoing, in case one elects to use a non-homogenous approach, discontinuities in the shield needs to be avoided as this can cause again radiation issues, hence at least a requirement of smoothness must be considered. The cost weight advantageous (relative to the radiation protection offered) of a non-homogenous approach are also to be weighted against manufacturing challenges related
20 thereto and/or mechanical strength issues that may occur. In any case, while being aware that for design purposes an isotropic assumption on the radiation environment is made, for considering a non-homogenous approach the design environment must be adapted accordingly.

In a preferred embodiment most, if not all, of said first openings in said side walls are made at
25 the side of the part without electronic device.

In an embodiment of the invention there may be a plurality of said (line of sight blocking) bodies, possibly even to protect for radiation entering where the top and bottom halves meet, even if there is not connector opening on that side.

In an embodiment of the invention, the positioning of the sidewall their outer connection point, the position where said electronic device is to be placed and the one or more bodies takes into account the radiation shielding aspects of the protrusion uncut recess arrangement.

5 The enclosure of the invention is adapted for comprising one or more electronic devices and particle beam radiation protection thereof to ensure proper normal operation of these electronic devices in challenging radiation environments.

In relation to the no line of sight considerations for the first openings (in the sidewall) but also protrusion uncut recess arrangements (with their inner and outer walls), in essence one defines the one or more positions wherein electronic devices are (to be) positioned and ensure that no
10 straight-line segments arise or positive framed curved paths must be defined.

As said the enclosure (made by one or more layers of radiation shielding for a given layer thickness) needs first openings for communication. Those may be made of a plurality of bent portions.

15 As said the enclosure (made by one or more layers of radiation shielding for a given layer thickness) needs first openings for communication. Those may be made such that they define a labyrinth, providing the access to the enclosure, said labyrinth being offset with the respect to the radiation (entering the enclosure) and the position of the electronics and in a further embodiment being offset with the respect to the (no line of sight) bodies.

20 As described above, in an embodiment of the invention the enclosure comprising: a first half presenting a first face; a second half presenting a second face, the second face being engaged against the first face in a first position and being separated from the first face in a second position, wherein said first and second half are made of one or more layers of (different) radiation shielding material.

25 In an alternative embodiment of the invention the enclosure comprising a plurality of (interconnected or interconnectable) parts, with complementary sidewalls for enabling said connections. In a further embodiment with no line-of-sight body, thereof a first and second half encloses the part of the enclosure where the electronic device is present and a third and fourth half enclose the other part (without such electronic device).

Notwithstanding the above, in the two first and second half and/or three half and/or the four-half embodiment described above or in the figures', said halves are not stand alone flat panels, so each half has at least 3 sidewalls.

The invention relates to a multi-layer (space radiation) shield design method and the resulting
5 multi-layer (space radiation) shield, comprising (a) a first layer made of a first material (which is then oriented to the incoming (space) radiation) and (b) a second layer made of a second material (to be oriented to the to be protected item, also called sensitive volume, which can be an electronic system).

One of the main design principles is that, while designing (which is selecting the layers material
10 and/or thickness for each of the layers and the order thereof), for the first layer, both its shielding performance due to electronic stopping power and nuclear fragmentation processes is taken into account, while for said second layer, for its shielding capability only its stopping power shielding is (in essence) taken into account, more in particular the design method performs a step of ranking (in terms of performance effects in terms of the total ionizing dose
15 reduction capability of the shield on the to be protected item) the resulting radiation (which may and actually most likely will comprise of additional other particles than the incoming (space) radiation) after the first layer and the second layer is then focusing on stopping the worst one of those while the first layer is hence focused on minimizing this worst case instead by use of fragmentation (multi-objective optimization shielding parameters, min max
20 procedure).

It is important that while we may call the first layer as a fragmenting layer that its energy effects (which are typically considered to result in energy decrease) cannot be ignored. Moreover, while we do think generally speaking in terms of shield in that they do have a stopping power shielding capability (reducing of energy while crossing the shield), one may not ignore that, due to the
25 fragmentating effects certain (lighter) particles created during the fragmentation process gain higher energy. The design method used in the invention takes this explicitly into account as it is clear that this may affect the ranking.

The invention further relates to a multi-layer (space radiation) shield design method and the resulting multi-layer (space radiation) shield comprising (c) a third layer made of a third material
30 (positioned in between said second layer and the sensitive volume), wherein the third layer is

then again focused on stopping the particles not previously considered (because we neglected fragmentation) for the second layer.

Alternatively, the invention further relates to a multi-layer (space radiation) shield design method and the resulting multi-layer (space radiation) shield comprising (c) a third layer made
5 of a third material (positioned in between said second layer and the sensitive volume), wherein the third layer is then focused on stopping secondary particles such as neutrons.

In a further embodiment the two previous embodiments are combined.

The invention further relates to a multi-layer (space radiation) shield design method and the resulting multi-layer (space radiation) shield (with or without the third layer) comprising (c) a
10 fourth layer made of a fourth material (positioned in between said first layer and the incoming radiation).

In relation to this fourth layer, it is worth noting that in the design method, one may take into account the shielding performance of the vehicle (space ship, satellite) and/or the treatment facility, or an electrical transformer outer layers wherein the to be additionally shielded sensitive
15 volume resides and while those are possibly and even likely not optimized (in terms of thickness) as part of the shield design they may at least in part have the same effect as the fourth layer. The same considerations can be made for the enclosure within another enclosure embodiments described elsewhere.

One may elect for the second layer to use materials like boron rich materials.

20 Note that due to the negative effect in the sensitive volume that neutron have due to the elastic interaction with the sensitive volume effect that in the alternative, the design method may explicitly take into account the production of such neutrons.

The invention relates to a (multi-layer) (space radiation) shield design method and the resulting (multi-layer) (space radiation) shield such as those discussed above, wherein to be considered
25 incoming (space) radiation) environment (such as the space radiation distribution) is taken explicitly into account.

In an example thereof, the invention relates to a (multi-layer) (space radiation) shield design method and the resulting (multi-layer) (space radiation) shield such as those discussed above, wherein to be considered incoming (space) radiation) is the worst case experienced by the
30 vehicle (for instance satellite while orbiting). In this way, particularities of the surrounding

magnetic radiation field (for example, a satellite orbiting Earth), for instance its donut shape (example the Van Allen Belts) and/or any other anomalies (such as the South Atlantic Anomaly) thereof, are taken explicitly into account.

The invention relates to a (multi-layer) (space radiation) shield design method and the resulting
5 (multi-layer) (space radiation) shield, such as those discussed above, wherein the so-called sensitive volume is an electronic system.

Note that while the design method performs a step of ranking (in terms of radiation shielding performance effects on the to be protected item) and attempts to minimize negative effects (like one or more or all of TID, NID, DD, SEE) to the extent possible in one or more of the layers, the
10 goal is not to minimize the energy of the considered particles per se because the goal is to either stop them before the sensitive volume or let them go through the sensitive volume. The design method therefore takes into account explicitly the position of the sensitive volume relative to the shield and uses the above design criterion.

The invention relates to a (multi-layer) (space radiation) shield design method and the resulting
15 (multi-layer) (space radiation) shield, wherein the design method exploits the performance effects on the to be protected item). In an implementation of this method, one or more or all of those performance effects are essentially modelled as a function of the dose reduction.

The invention further relates to enclosures adapted for enclosing at least one electronic system, said box comprising: a first and second part, together forming said box or enclosure, said first
20 and second part being made of a multi-layer shield as discussed above.

As both said first (top) and second (bottom) part having means for removably fixing said parts to each other (like screws and holes for those), we may consider either to shield those also and/or also make them from the (multi-layer) shield material and/or at least carefully position those such that their impact of radiation on the electronic system via those are minimized.

25 While one, during the shield design, may perform a joint optimization of the enclosure (shape, dimensions), one may alternatively consider a context wherein at least part of the shape and/or dimensions are fixed or constrained by requirements originating from the vehicle (which may be standardized to a certain extent), wherein said enclosure should be placed. The design method therefore encompassing loading such requirements in a computer system such that the
30 method takes those design requirements into account.

The invention pertains to design methods and shield as discussed above, whereby the materials of said layers are selected as a trade-off between their performance in terms of space radiation shielding and their volumetric density.

In a particular embodiment of the invention, the enclosure is made of the following materials
5 layer: a first outer layer made of a metal alloy, a second intermediate layer made of a polymer and third inner layer made of ceramics. As said, the first layer aims at fragmentating high charge and high energy particles, the second layer aims at stopping or lowering the energy of the fragmented particles while the third layer aims at stopping secondary neutrons and protons created in the previous layers.

10 The metal alloy belongs to the family of Aluminium alloy, Steel alloy, Nickel Alloy, Titanium alloy.

The polymer is chosen among polyethylene, high density polyethylene, polyethylene terephthalate, meta-aramid, para-aramid.

The third layer is chosen among boron rich ceramic, boron nitride, fibre glass, graphite sheet,
15 aluminium oxide, silicon carbide.

The first layer has a thickness of 6 to 20 mm, second layer 6 to 10 mm, third layer 3 to 6 mm, thickness being decided based on shielding parameters and density design requirements (total weight of the enclosure).

In the invention, the following manufacturing processes are considered: additive
20 manufacturing and or CNC machining of the outer layer made of alloy; polymer cold spray or polymer additive manufacturing of the intermediary layer on top of the inner side of the outer layer and additive manufacturing, cold spray, sputtering of ceramics on the inner surface of the intermediate layer.

In summary a (lightweight) (purposely designed) radiation shielding multi-layer shielding
25 enclosure is provided. The learning of the invention, by its multi-layer nature, also relates to the field of composite materials, sandwich panels, composite panels, mechanical structures, hybrid or hybridized materials as such and the co-design consideration of those with the enclosures in particular. The provided enclosure fits in an overall strategy:

The use of passive enclosure shielding, or a "box", for space electronics serves a different
30 purpose than the basic aluminum walls of a satellite. The aluminum walls, while integral to the

structure of the satellite, do not provide significant radiation reduction effects. This is why there are two main strategies when it comes to protecting the electronic components of a satellite from radiation. One approach is to construct circuit boards with radiation-hardened components. For example, a spaceborne computer would be built with these specialized components to withstand the harsh radiation environment in space. Alternatively (a strategy supported by the invention although not limited thereto), commercial off-the-shelf components can be used to build a computer, which is then placed inside a passive shielding box. This box provides the necessary protection against radiation, allowing the use of standard components. This method can be more cost-effective and allows for greater flexibility in the design and construction of space electronics.

The choice of shielding material is indeed dependent on the specific space mission and the radiation environment that the satellite will be exposed to. For instance, satellites in Low Earth Orbit (LEO) are exposed to trapped protons and electrons from the Van Allen belts.

In such cases, the shielding must be designed to handle this specific combination of radiation. If the environment is primarily filled with trapped protons and electrons, shielding from galactic cosmic ray heavy ions may be of lower priority.

The sizing or scaling of the radiation shielding enclosure is influenced by the size of the satellite. In smaller satellites, such as CubeSats which typically measure 10cm x 10cm x 10cm, the space for geometry optimization is limited.

In an alternative approach (also supported by the invention), in such cases, the computer box, which is usually placed in the middle of the satellite, may not have much room for additional shielding. However, if the satellite wall itself could be designed with a thin multilayer that has efficient radiation shielding properties, then a dedicated internal shielding box may not be necessary. This approach would allow for the efficient use of the limited space within the CubeSat, while still providing adequate protection for the sensitive components inside.

For larger satellites, such as a six-unit CubeSat which is a combination of six 1-unit satellites, there is more room and flexibility to properly position the critical elements to be shielded inside the satellite.

Typically, the most sensitive components are kept as far away as possible from the main sources of radiation. These sources of radiation, such as trapped protons or solar flares, are determined by the satellite's orbit and its inclination towards these particle sources. Therefore, a geometry

optimization exercise must be performed by satellite engineers to properly position the different satellite components.

An additional factor to consider is that the satellite walls, frame, and other bulk equipment within the satellite create inherent mass shielding. This contributes to the total radiation
5 shielding of the satellite, including the most critical components that need to be protected.

In summary the invention provides:

1. An enclosure (20), adapted for enclosing at least one electronic device (10), comprising a plurality of parts, together forming said enclosure, the walls (30) of said parts acting as a multi-layer radiation shield.
- 10 2. A system, comprising an enclosure (20) discussed above; and an electronic device (10), placed therein, wherein the design of the enclosure takes into account the performance of said electronic device against radiation into account, preferably the enclosure and the electronic system are co-designed, for the electronic system in terms of its selected hardware and/or the software operating on said electronic
15 design and for the enclosure the amount of layers, the selected materials of layers and the thickness of said layers.
3. An arrangement with a plurality of enclosures (20) (730) discussed above and/or systems discussed, wherein one or more enclosures or system fit into other of said enclosures or system and the design of the enclosures takes into account the
20 protection against radiation of one another into account.

Various features are detailed in the claims below.

CLAIMS

1. An enclosure (20), adapted for enclosing at least one electronic device (10) and designed while taking into account the performance of said electronic device(s) against particle radiation, comprising (i) a plurality of parts, together forming said enclosure; (ii) at least
5 one opening (40) in the walls (30) defined by said parts for providing electronic connections to and from said at least one electronic device(s), wherein said design considerations are selected from the group of: (a) for each of said parts, determining the amount of layers (one or more), the selected materials of those layers and the thickness of said layers (acting as shield); (b) positioning of said opening relative to the position foreseen for said electronic
10 device within said enclosure, wherein the design considerations further include: (c) considering adding one or more shield(s) (60) within said enclosure in the line of sights for particle radiation between said opening and the position foreseen for said electronic device within the enclosure and for said one or more shields, determining the amount of layers, the selected materials of those layers and the thickness of said layers.
- 15 2. The enclosure of claim 1, further comprising: (iii) means (210) for removably fixing said parts to each other, wherein the design considerations further include (d) positioning of said means for removably fixing said parts to each; (e) for each of said means for removably fixing said parts to each other determining the amount of layers, the selected materials of those layers and the thickness of said layers.
- 20 3. An enclosure (20), adapted for enclosing at least one electronic device (10), comprising a plurality of parts, together forming said enclosure, the walls (30) defined by said parts acting as a multi-layer radiation shield and/or a single 100% radiation dose reduction layer, with a material selected from a material class with high radiation dose reduction efficiency and/or a 100% radiation dose reduction layer, with a material selected from a material class
25 with high radiation dose reduction efficiency in combination with a further multi-layer shield.
4. The enclosure of claim 3, wherein said multi-layer (space radiation) shield comprising (a) a first layer (600) (oriented to the radiation (650)) made of a first material and (b) a second layer (610) (oriented to the electronic device relative to the first layer) made of a second
30 material, wherein said first layer is functionally optimized for nuclear fragmentation shielding. wherein said second layer is functionally optimized for stopping power shielding.

5. The enclosure of claim 4, wherein said multi-layer (space radiation) shield comprising a third layer (620) (attached to the second layer and oriented to the electronic device) made of a third material for radiation dose reduction of secondary particles.
- 5 6. The enclosure of any of the previous claims 3 to 5, said enclosure comprising at least one opening (40) (in said walls) for providing electronic connections to and from said at least one electronic device(s), whereby within said enclosure in the line of sights for particle radiation between said opening and the position foreseen for said electronic device, one or more further shield(s) (60) is (are) provided.
- 10 7. The enclosure of claim 6, wherein said further shield(s) (preferably optimized for radiation dose reduction of secondary particles) is (are) (also) a multi-layer shield and/or a single 100% radiation dose reduction layer, with a material selected from a material class with high electronics radiation dose-reduction efficiency.
8. The enclosure of claims 1 to 7, wherein the selected materials are selected from a predetermined ranked list of computer-generated materials.
- 15 9. The enclosure of claims 1 or 6, wherein one or more further openings (70) for providing electronic connections to and from said at least one electronic device(s) are made in said one or more further shields.
10. The enclosure of claim 2 or claim 3, wherein said parts having means (210) for removably fixing said parts to each other, wherein part of said means are positioned on the side of said further shield(s) opposite the position of said electronic device.
- 20 11. The enclosure of claim 3, wherein said parts having means for removably fixing said parts to each other, wherein part of said means, also being made of a multi-layer shield.
12. The enclosure of claim 9, wherein said (further) openings comprise a plurality of bent portions and/or arrangements defining a labyrinth, those being offset with the respect to the radiation (entering the enclosure) and the position of the electronics.
- 25 13. The enclosure of claim 9, wherein said openings comprise a plurality of bent portions and/or arrangements defining a labyrinth, those being offset with the respect to the radiation (entering the enclosure), the position of the electronics and the further openings.
14. The enclosure of any of the previous claims, wherein one or more and optionally all said layers are additively manufactured and/or cold sprayed on one another and/molecular bonding, CNC machined layers or casted layers are used.
- 30

15. A system, comprising an enclosure (20) of any of the previous claims; and an electronic device (10), placed therein, wherein the design of the enclosure takes into account the performance of said electronic device against radiation into account, preferably the enclosure and the electronic device are co-designed, for the electronic device in terms of its selected hardware and/or the software operating on said electronic design and for the enclosure the amount of layers (one or more), the selected materials of layers and the thickness of said layers.
16. The system of claim 15, wherein said electronic device comprises (commercial-of-the shelf, COTS) components of which one or more (or all) without space radiation hardening.
17. The system of claims 15 or 16, wherein said electronic device being (at least) in part a chip-let based electronic device, preferably wherein the design of the chip-let is part of the co-design.
18. The system of claims 15, 16 or 17, wherein said electronic device comprising components, wherein one or more (or all) have radiation induced fault self-protecting circuits and/or architectures and/or one or more are flexible logic units adapted for real-time task switching, provided with methods for fault tolerance enhanced execution of tasks and/or one or more are flexible logic units with computational blocks which can be physically connected or isolated and this capability is used to isolated space radiation effects, preferably the design of the enclosure takes into account these features of said components and/or the for the electronic device in particular radiation mitigation software operating on said electronic design.
19. A search method, carried out by a computer, for determining one or more materials by outputting their selected chemical composition including atoms and number of atoms, being selected by an optimisation method, the optimisation method comprising: iteratively computing a radiation shielding property as objective in the optimisation method, the method being based on evolutionary computation or optimisation algorithms such as genetic algorithms, wherein said compute step (i) being based on a method, for computing at least one radiation shielding property of a material, based on information about the chemical composition, the method comprising: (i) loading information about the chemical composition; and (ii) computing at least one radiation shielding property of a material based on said loaded information; and wherein the evolutionary computation or optimisation algorithms are based on an evolutionary engine generating populations of individuals (materials) and the multi-objective optimisation method evaluates via an

- evaluation engine fitness score for said individuals (materials) on which a portion of the variants are retained and serves as basis for further generations of candidate materials, (a) wherein said radiation shielding property of a structure, being the total dose reduction efficiency structure by linear energy transfer (LET), and computed based on information
- 5 about the chemical composition, by computing the linear energy transfer (LET) from the radiation to said structure, from said chemical composition; and finally retaining only individuals (materials) where the dose reduction is 100% (for the given context) or wherein and one or more radiation shielding properties expressed in terms of areal or volumetric density value is optimized, whereby said material density is multiplied with a weight factor,
- 10 representative for the surface area to be covered by the (finally selected) material or wherein the method being adapted for generating one or more layered structures, with a predetermined amount of layers, each being different layers of (different) materials, by loading a weight factor for said objectives for each of said layers, and the multi-objective optimisation methods of any of the previous claims are applied for each of said layers
- 15 separately with another weight factor for these objectives, whereby the place, function and size of each of said layers within the enclosure is explicitly taken into account or wherein the radiation shielding property of a structure being the impact on a sensitive volume, with a material representative for electronics (such as silicon), more in particular the impact on electronics itself, more in particular single and/or multi-bit upset, based on information
- 20 about the chemical composition.
20. An enclosure (20), adapted for enclosing at least one electronic device (10) and designed while taking into account the performance of said electronic device(s) against particle radiation, comprising (i) a plurality of parts, together forming said enclosure; (ii) at least one opening (40) (in the walls (30) of said parts) for providing electronic connections to and
- 25 from said at least one electronic device(s), optionally (iii) one or more further shield(s) (60) within said enclosure in the line of sights for particle radiation between said opening and the position foreseen for said electronic device, wherein each of said parts and/or further shields, having one or more layers of material, together former a multi-layer (space radiation) shield characterized in that layers oriented to the radiation (650)) are made from
- 30 metal alloys, further layers (610) oriented to the electronic device relative to the previous layer) are made of alloys or polymers and the final layers attached to the further layers oriented to the electronic device are made of ceramics or polymers (for radiation dose reduction of secondary particles).