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(54) **RADIATION SHIELDING FOR COMPACT AND TRANSPORTABLE NUCLEAR POWER SYSTEMS**

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G21C 13/024 (2006.01)

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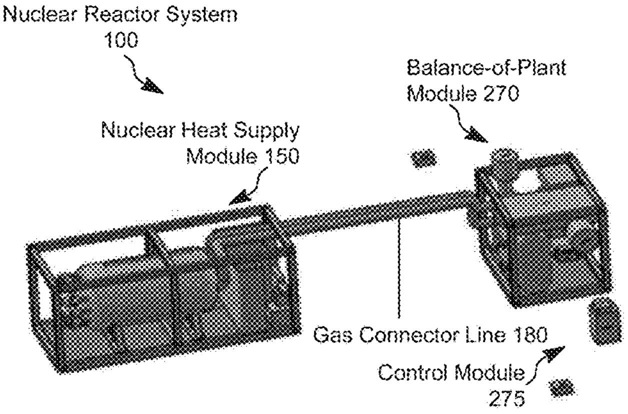
CPC ***G21C 11/024*** (2013.01); ***G21F 5/10*** (2013.01); ***G21C 13/024*** (2013.01)

(57) **ABSTRACT**

A mobile reactor radiation shielding solution prevents activation of structural materials to reduce a radiation dosage risk to living organisms and accelerates timetables for transport. The shielding solution can include: in-vessel neutron shield, in-vessel shadow shield, transport shield, and module shadow shield. In-vessel neutron shield reduces and prevents the activation of the structural materials and significantly reduces the need for heavy shielding to shield against the gamma emissions from activated structural materials. In-vessel shadow shield provides neutron and gamma shielding between the reactor and a balance-of-plant (BOP) module and control system. In-vessel shadow shield is placed near the active nuclear core to minimize size of the shield while maximizing the protected arc to shield radiation workers while preparing the nuclear reactor for transport. Transport shield is used during transportation when living organisms come into proximity of the reactor. Module shadow shield shields reactor control components and BOP module during operation.



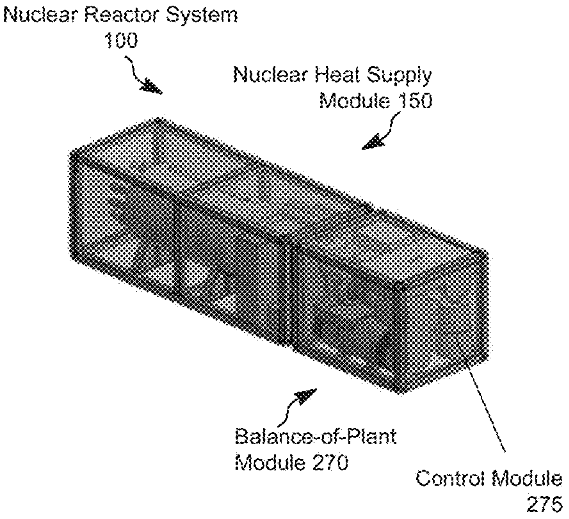


FIG. 1A

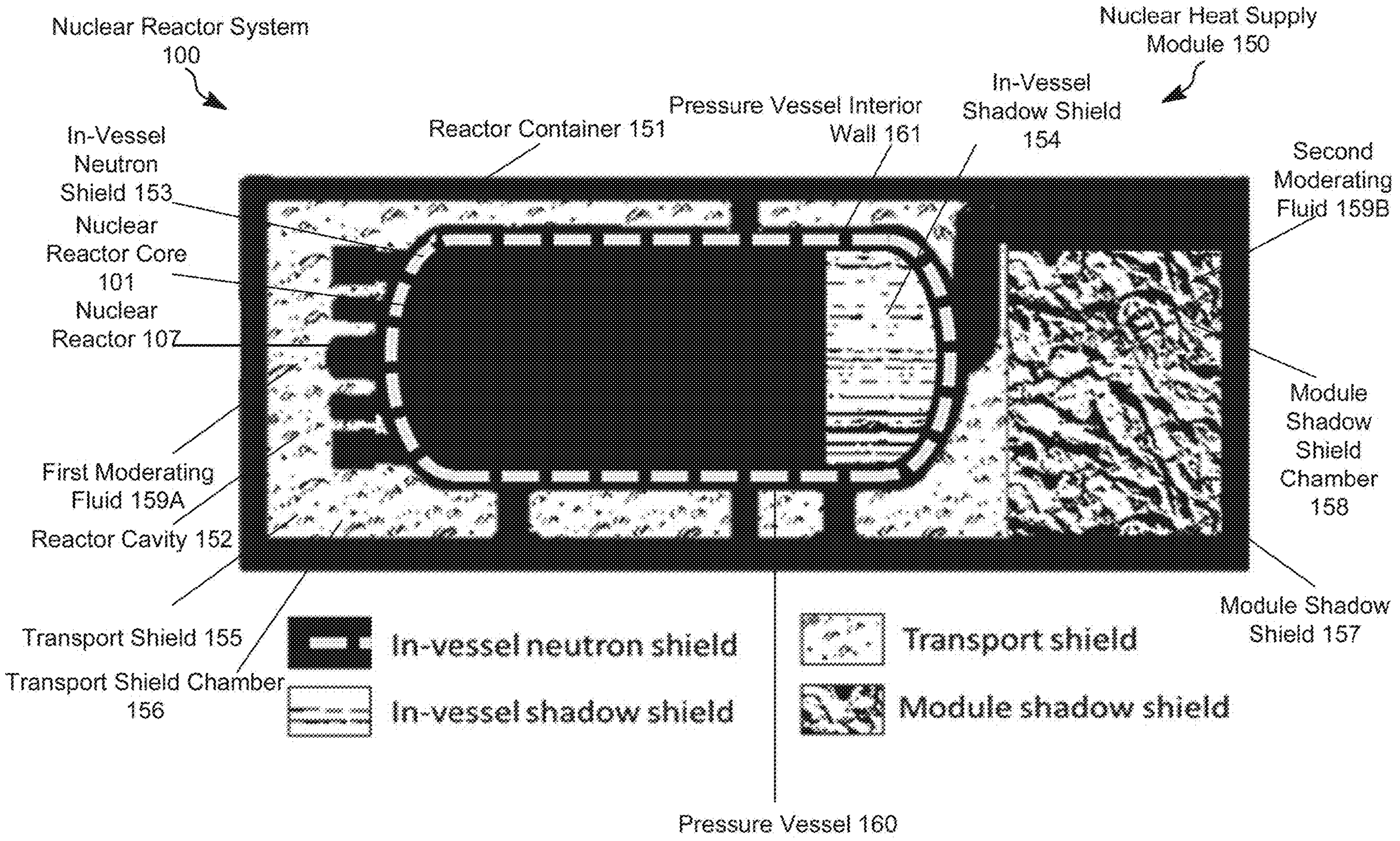

Nuclear Reactor System 100
In-Vessel Neutron Shield 153
Nuclear Reactor Core 101
Nuclear Reactor 107
First Moderating Fluid 159A
Reactor Cavity 152
Transport Shield 155
Transport Shield Chamber 156
Reactor Container 151
Pressure Vessel Interior Wall 161
In-Vessel Shadow Shield 154
Nuclear Heat Supply Module 150
Second Moderating Fluid 159B
Module Shadow Shield Chamber 158
Module Shadow Shield 157
Pressure Vessel 160
In-vessel neutron shield
In-vessel shadow shield
Transport shield
Module shadow shield

FIG. 1B

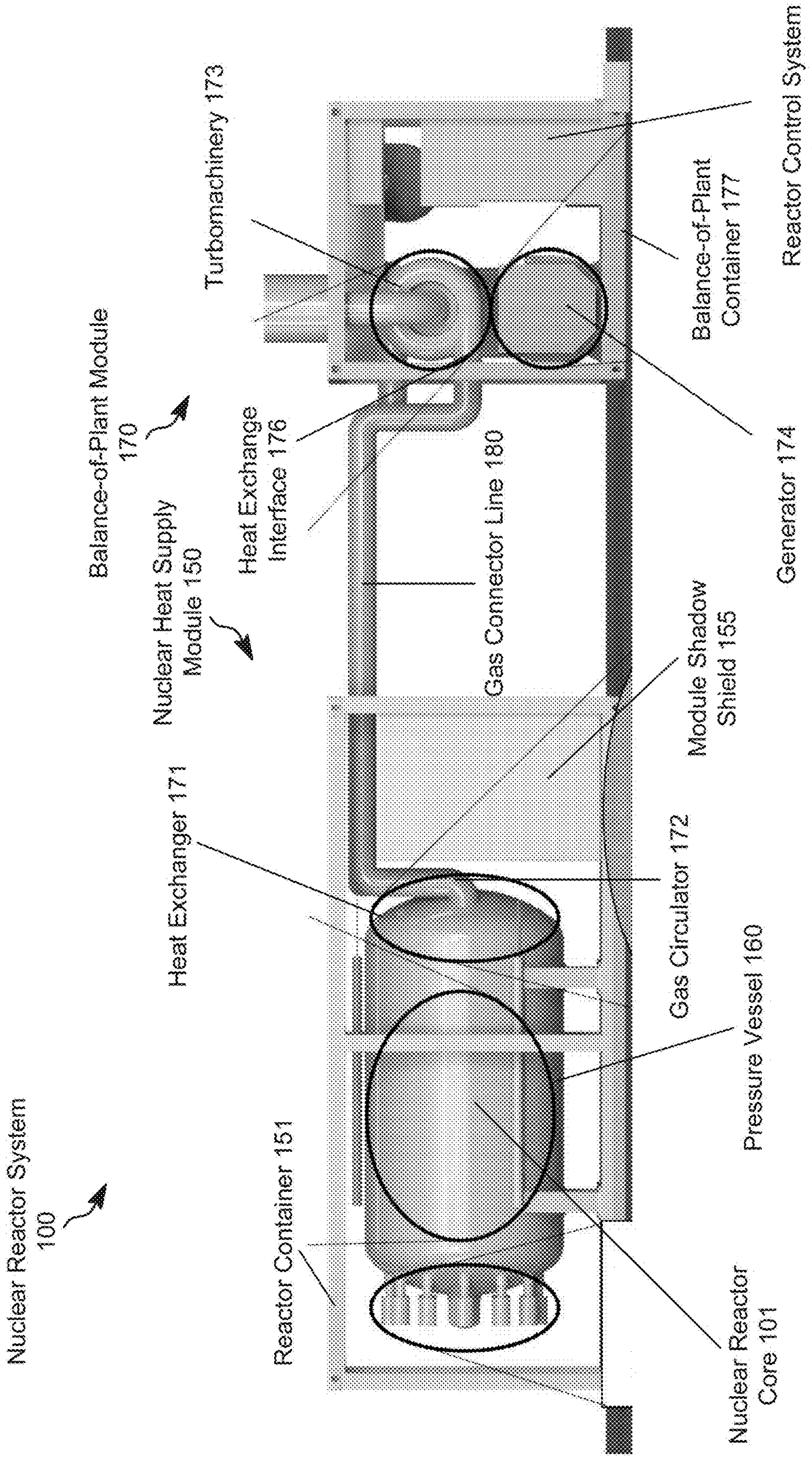

Nuclear Reactor System 100
Reactor Container 151
Nuclear Reactor Core 101
Pressure Vessel 160
Gas Circulator 172
Heat Exchanger 171
Module Shadow Shield 155
Nuclear Heat Supply Module 150
Gas Connector Line 180
Heat Exchange Interface 176
Balance-of-Plant Module 170
Generator 174
Turbomachinery 173
Balance-of-Plant Container 177
Reactor Control System 175

FIG. 1C

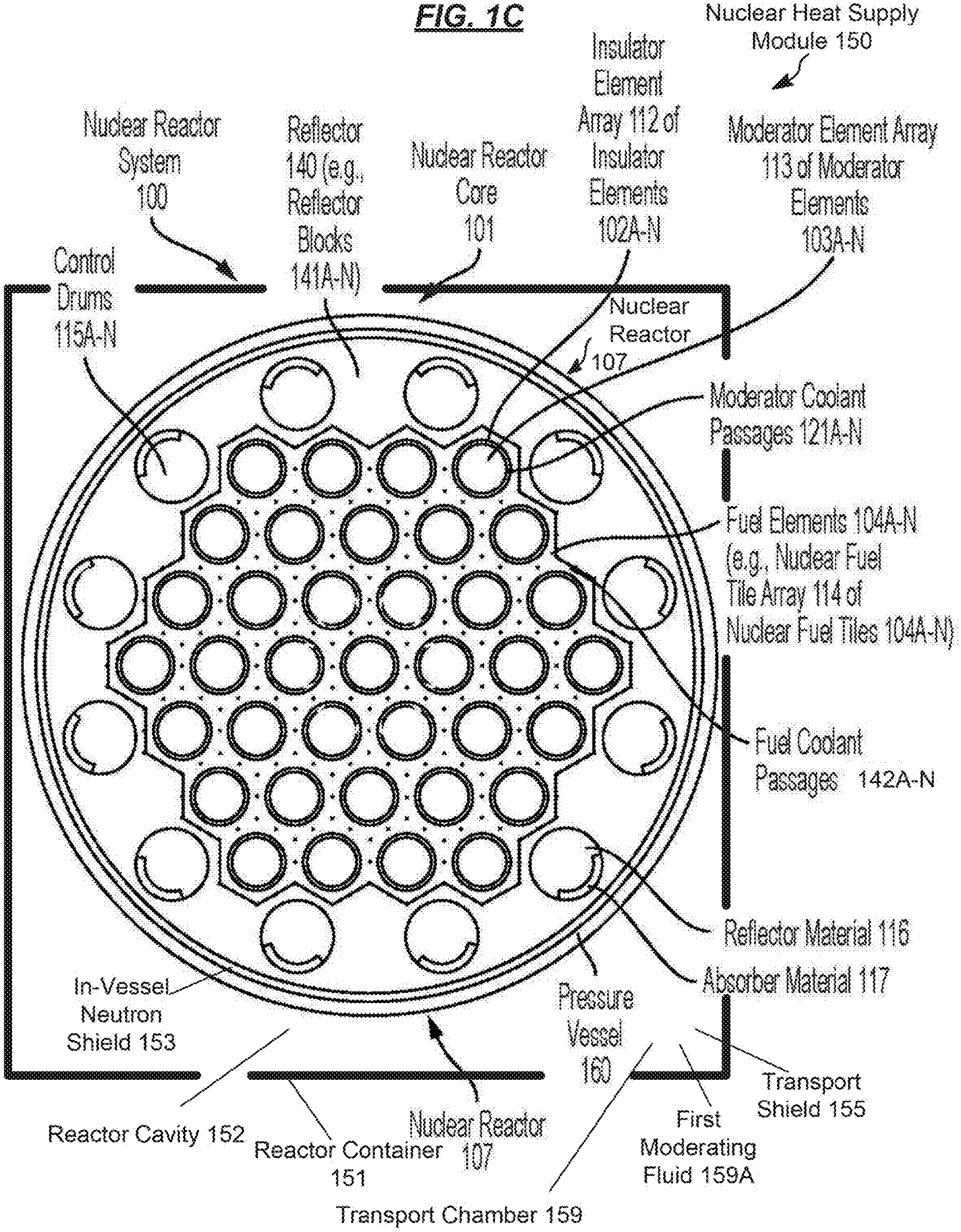

Nuclear Heat Supply Module 150
Nuclear Reactor System 100
Reflector 140 (e.g., Reflector Blocks 141A-N)
Nuclear Reactor Core 101
Insulator Element Array 112 of Insulator Elements 102A-N
Moderator Element Array 113 of Moderator Elements 103A-N
Control Drums 115A-N
Nuclear Reactor 107
Moderator Coolant Passages 121A-N
Fuel Elements 104A-N (e.g., Nuclear Fuel Tile Array 114 of Nuclear Fuel Tiles 104A-N)
Fuel Coolant Passages 142A-N
Reflector Material 116
Absorber Material 117
In-Vessel Neutron Shield 153
Pressure Vessel 160
Transport Shield 155
First Moderating Fluid 159A
Reactor Cavity 152
Reactor Container 151
Nuclear Reactor 107
Transport Chamber 159

FIG. 1D

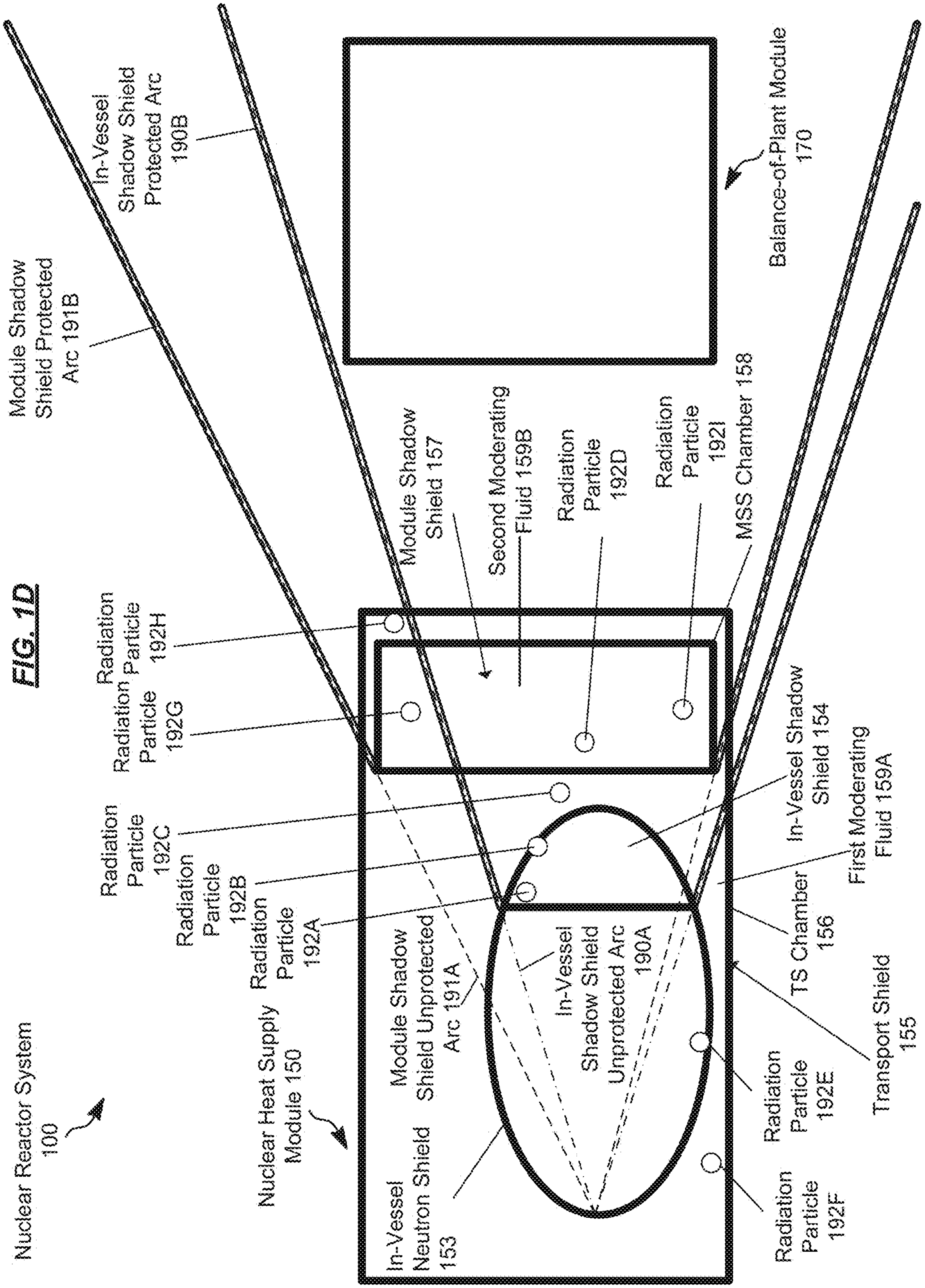

Nuclear Reactor System 100
Nuclear Heat Supply Module 150
In-Vessel Neutron Shield 153
Module Shadow Shield Unprotected Arc 191A
In-Vessel Shadow Shield Unprotected Arc 190A
Radiation Particle 192A
Radiation Particle 192B
Radiation Particle 192C
Radiation Particle 192G
Radiation Particle 192H
Module Shadow Shield Protected Arc 191B
In-Vessel Shadow Shield Protected Arc 190B
Module Shadow Shield 157
Second Moderating Fluid 159B
Radiation Particle 192D
Radiation Particle 192I
MSS Chamber 158
In-Vessel Shadow Shield 154
First Moderating Fluid 159A
TS Chamber 156
Transport Shield 155
Radiation Particle 192E
Radiation Particle 192F
Balance-of-Plant Module 170

FIG. 2

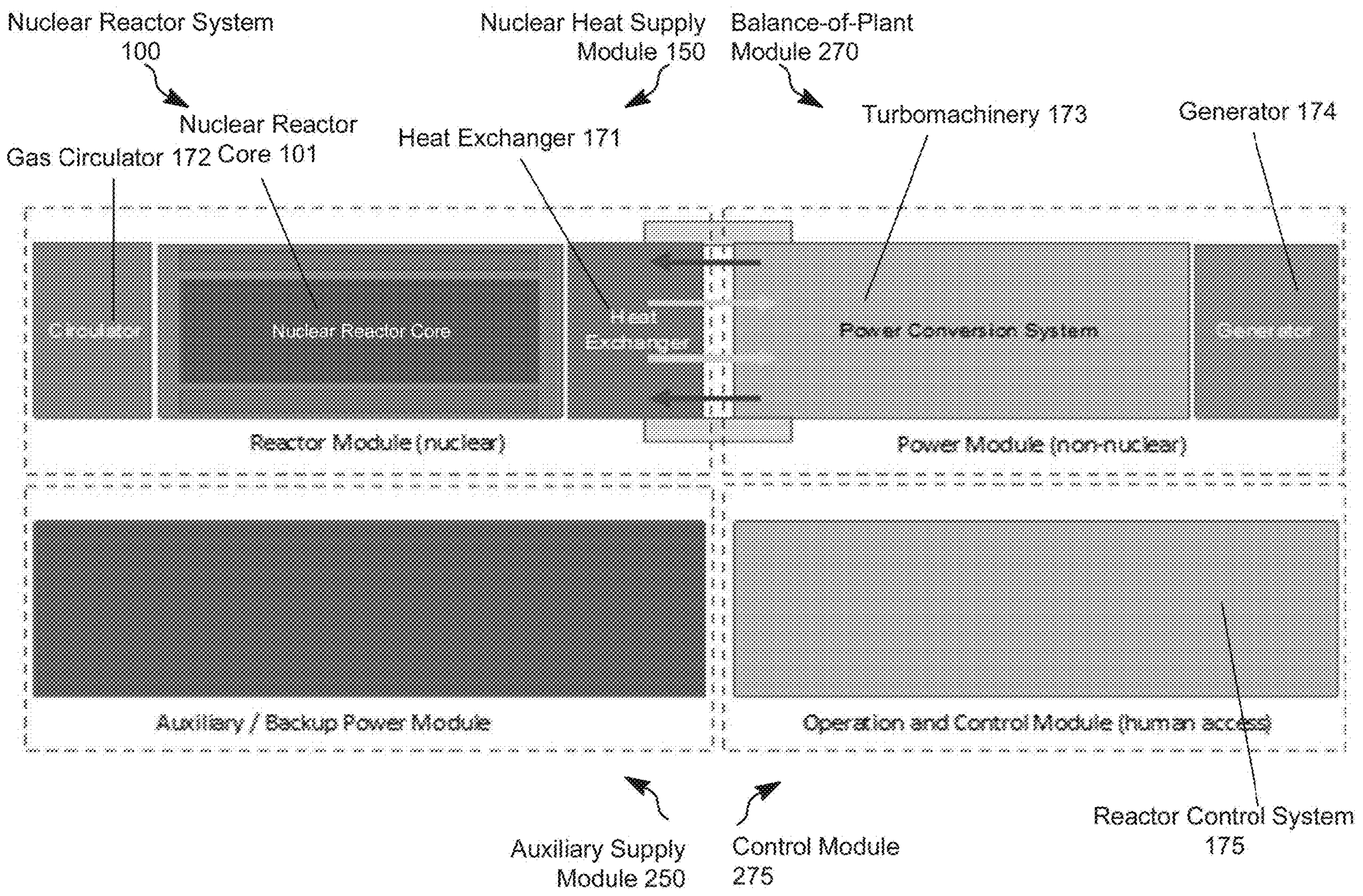

Nuclear Reactor System 100
Nuclear Heat Supply Module 150
Balance-of-Plant Module 270
Nuclear Reactor Core 101
Gas Circulator 172
Heat Exchanger 171
Turbomachinery 173
Generator 174
Circulator
Nuclear Reactor Core
Heat Exchanger
Power Conversion System
Generator
Reactor Module (nuclear)
Power Module (non-nuclear)
Auxiliary / Backup Power Module
Operation and Control Module (human access)
Reactor Control System 175
Auxiliary Supply Module 250
Control Module 275

FIG. 3A

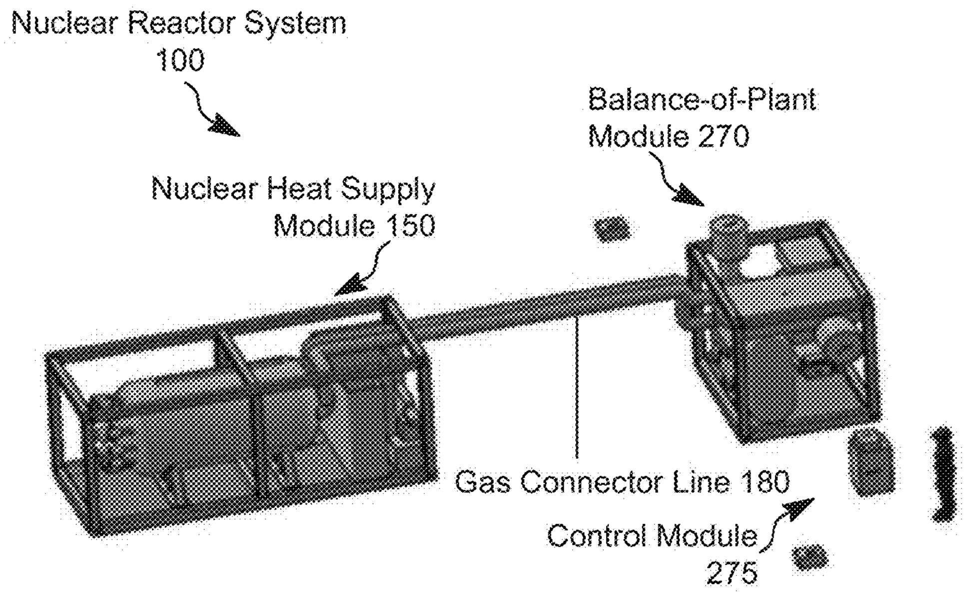

Nuclear Reactor System
100
Nuclear Heat Supply
Module 150
Balance-of-Plant
Module 270
Gas Connector Line 180
Control Module
275

FIG. 3B

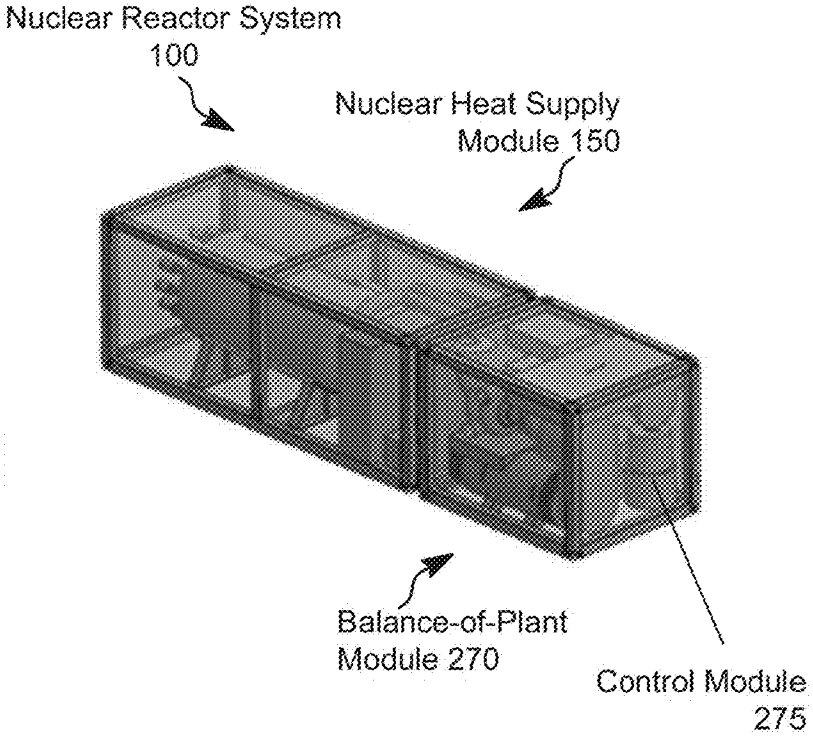
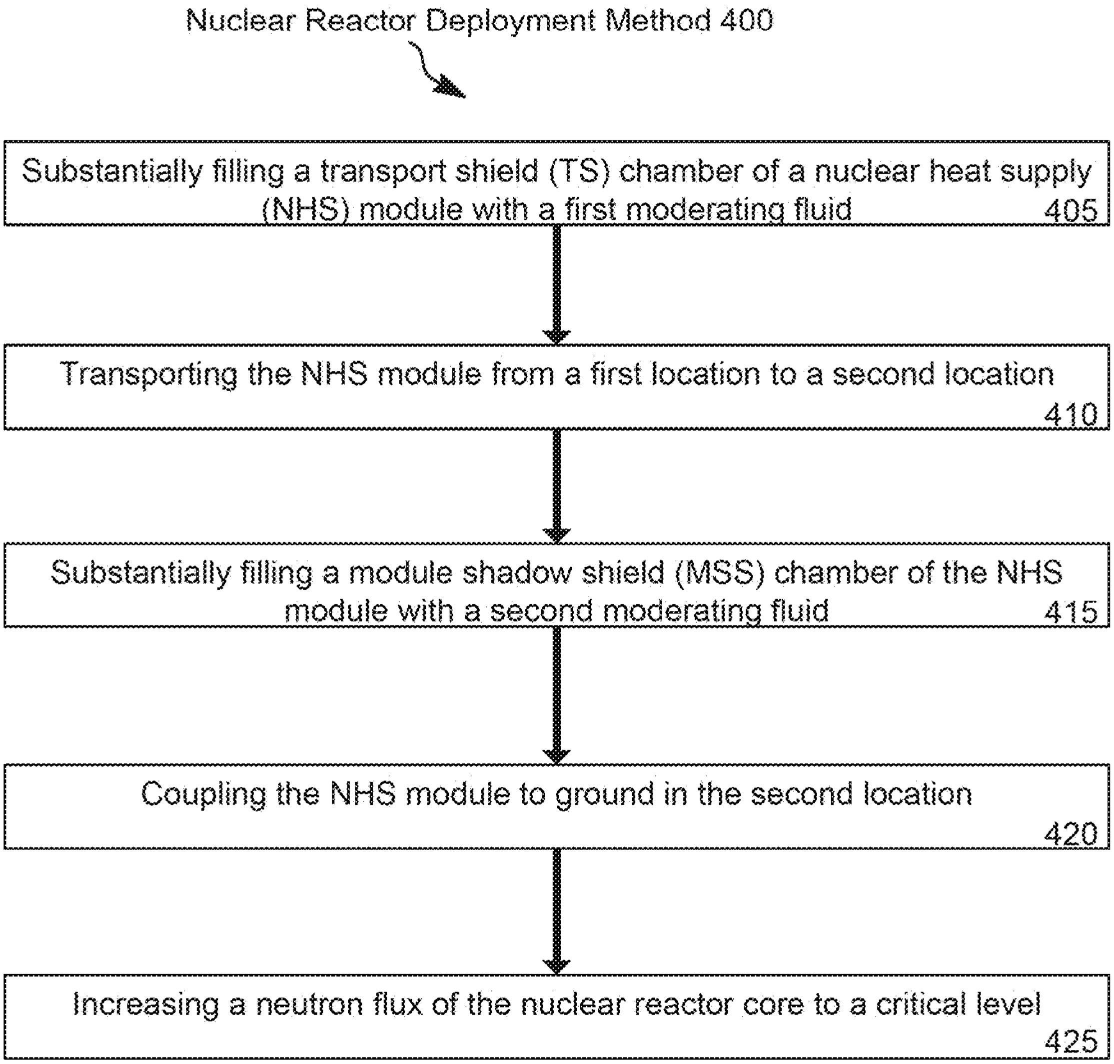

Nuclear Reactor System
100
Nuclear Heat Supply
Module 150
Balance-of-Plant
Module 270
Control Module
275

FIG. 4



Nuclear Reactor Deployment Method 400

Substantially filling a transport shield (TS) chamber of a nuclear heat supply (NHS) module with a first moderating fluid 405

Transporting the NHS module from a first location to a second location 410

Substantially filling a module shadow shield (MSS) chamber of the NHS module with a second moderating fluid 415

Coupling the NHS module to ground in the second location 420

Increasing a neutron flux of the nuclear reactor core to a critical level 425

FIG. 5A

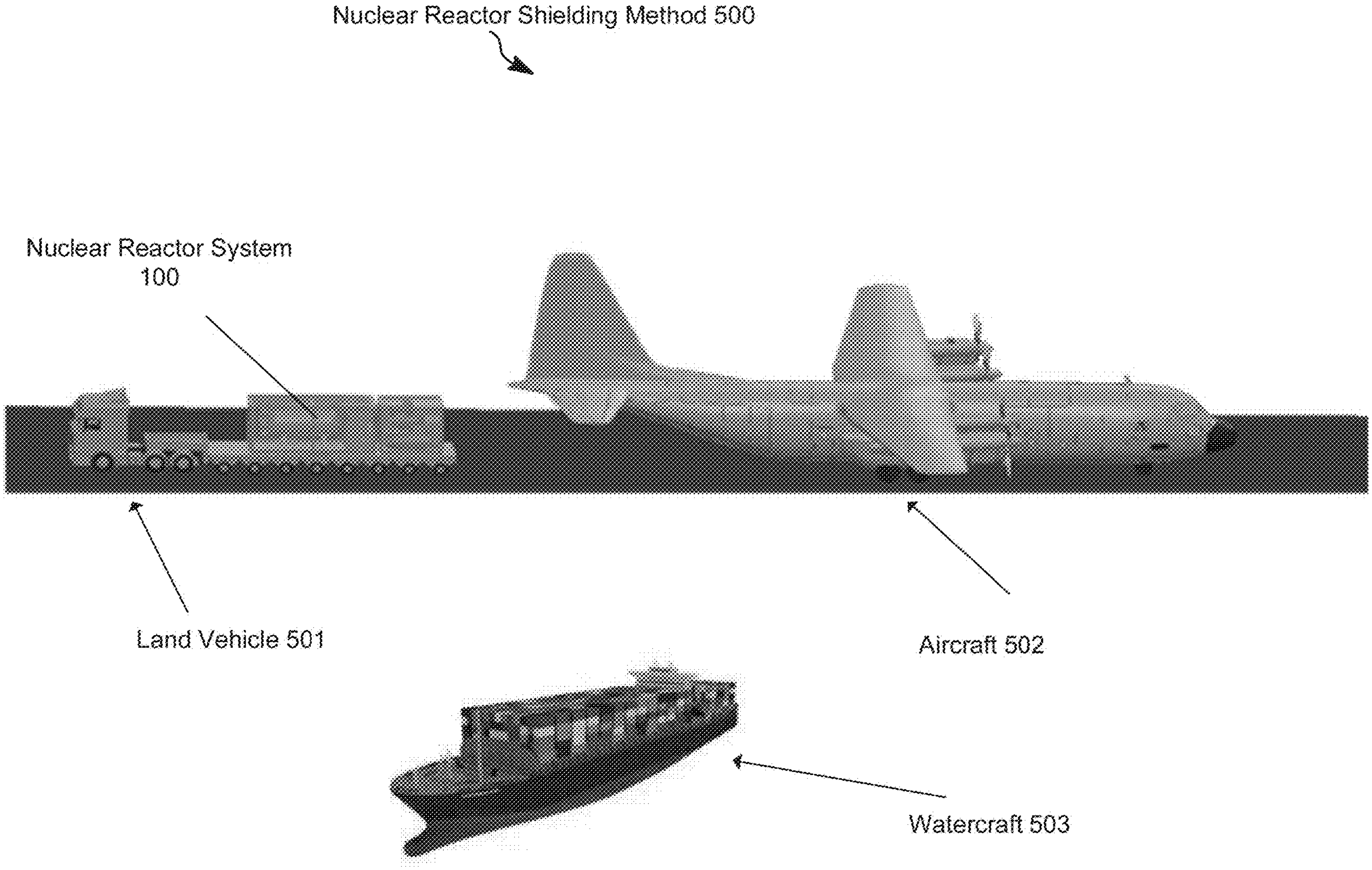

Nuclear Reactor Shielding Method 500
Nuclear Reactor System 100
Land Vehicle 501
Aircraft 502
Watercraft 503

FIG. 5B

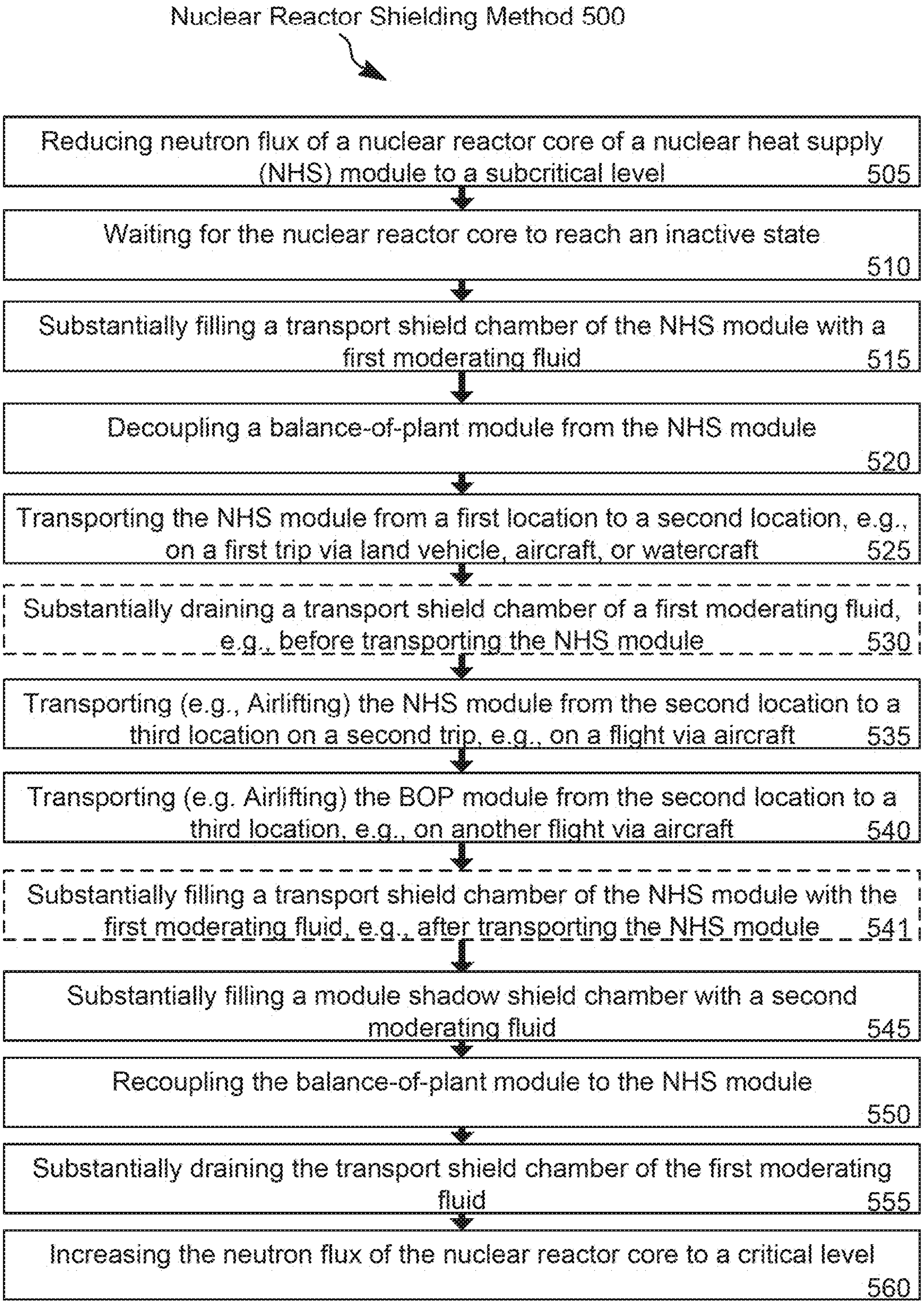

Nuclear Reactor Shielding Method 500
Reducing neutron flux of a nuclear reactor core of a nuclear heat supply (NHS) module to a subcritical level 505
Waiting for the nuclear reactor core to reach an inactive state 510
Substantially filling a transport shield chamber of the NHS module with a first moderating fluid 515
Decoupling a balance-of-plant module from the NHS module 520
Transporting the NHS module from a first location to a second location, e.g., on a first trip via land vehicle, aircraft, or watercraft 525
Substantially draining a transport shield chamber of a first moderating fluid, e.g., before transporting the NHS module 530
Transporting (e.g., Airlifting) the NHS module from the second location to a third location on a second trip, e.g., on a flight via aircraft 535
Transporting (e.g. Airlifting) the BOP module from the second location to a third location, e.g., on another flight via aircraft 540
Substantially filling a transport shield chamber of the NHS module with the first moderating fluid, e.g., after transporting the NHS module 541
Substantially filling a module shadow shield chamber with a second moderating fluid 545
Recoupling the balance-of-plant module to the NHS module 550
Substantially draining the transport shield chamber of the first moderating fluid 555
Increasing the neutron flux of the nuclear reactor core to a critical level 560

FIG. 6

Table of Weights 600

	Component	Weight (lbs)
Nuclear Heat Supply (NHS) Module 150	Nuclear Reactor Core 101, Pressure Vessel 160, Shields 153, 154	23,142
	Intermediate Heat Exchanger 171 and Gas Circulator 172	6,061
	Reactor Container 151	5,290
	Shielding 155, 157	7,714
	Miscellaneous NHS	2,010
	NHS Module Subtotal 605	44,217
Balance-of-Plant (BOP) Module 170	Turbomachinery 173	1,713
	Generator 174 & Gearbox	9,676
	Heat Exchange Interface 176	440
	Instrumentation and Reactor Control System 175	88
	BOP Container 177	2,645
	Miscellaneous BOP	1,309
	BOP Module Subtotal	15,871
	Total Nuclear Reactor System Mass 615	60,088

FIG. 7

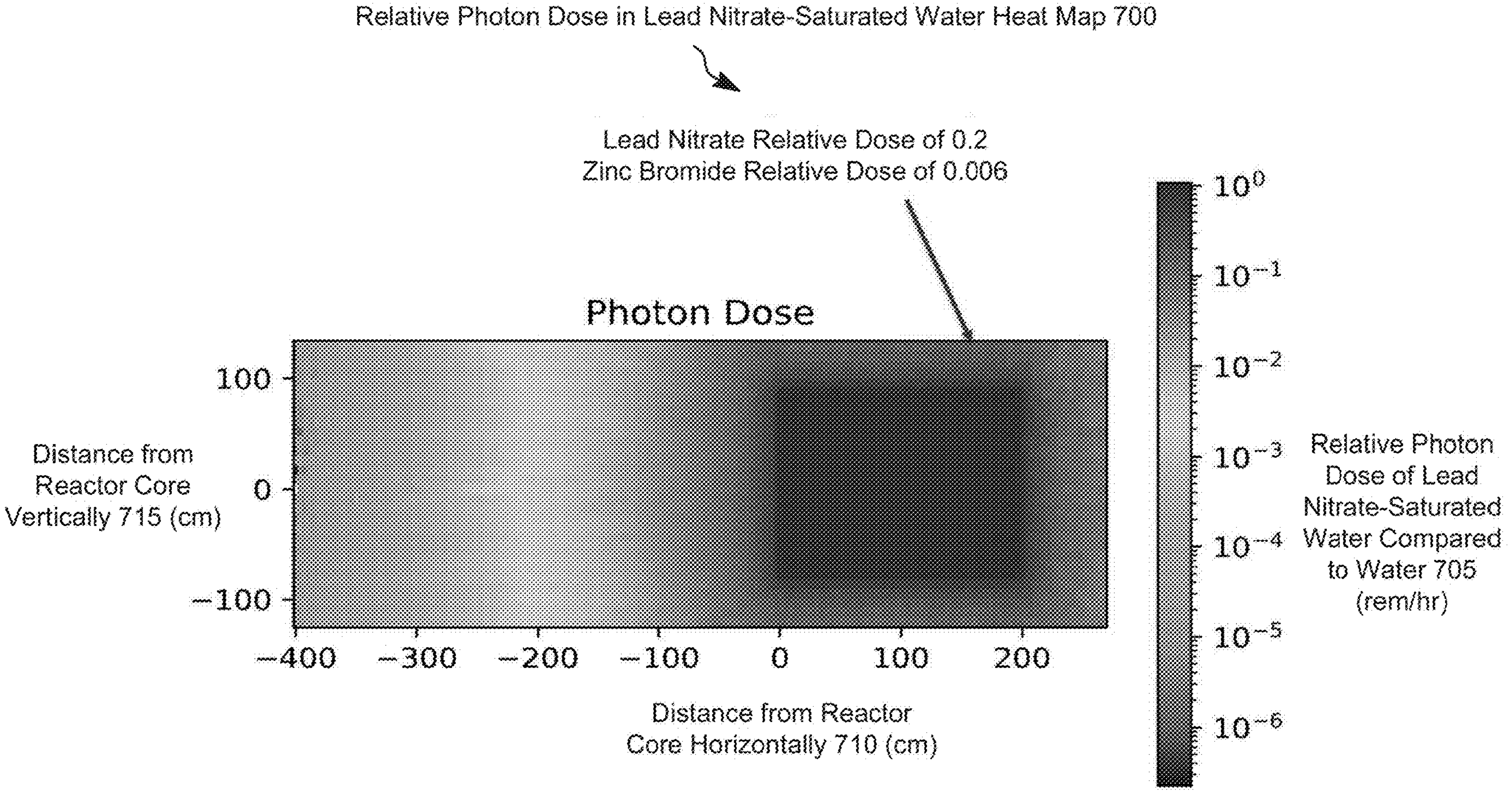
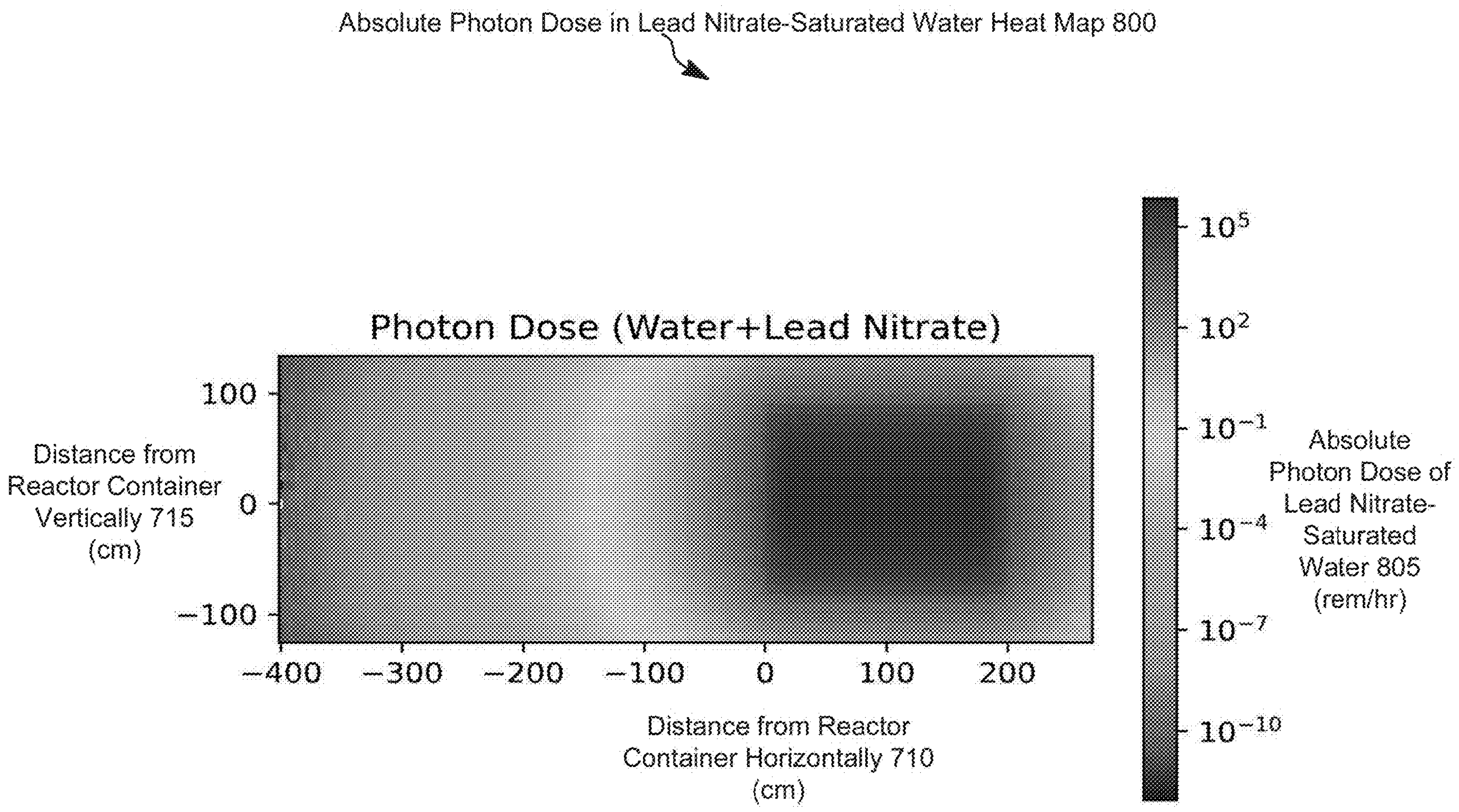

Relative Photon Dose in Lead Nitrate-Saturated Water Heat Map 700
Lead Nitrate Relative Dose of 0.2
Zinc Bromide Relative Dose of 0.006
Photon Dose
100
0
−100
Distance from Reactor Core Vertically 715 (cm)
−400
−300
−200
−100
0
100
200
Distance from Reactor Core Horizontally 710 (cm)
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
Relative Photon Dose of Lead Nitrate-Saturated Water Compared to Water 705 (rem/hr)

FIG. 8


Absolute Photon Dose in Lead Nitrate-Saturated Water Heat Map 800
Photon Dose (Water+Lead Nitrate)
Distance from Reactor Container Vertically 715 (cm)
100
0
−100
−400
−300
−200
−100
0
100
200
Distance from Reactor Container Horizontally 710 (cm)
10^5
10^2
10^{-1}
10^{-4}
10^{-7}
10^{-10}
Absolute Photon Dose of Lead Nitrate-Saturated Water 805 (rem/hr)

RADIATION SHIELDING FOR COMPACT AND TRANSPORTABLE NUCLEAR POWER SYSTEMS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This application claims priority to U.S. Provisional Patent Application No. 63/080,292, filed on Sep. 18, 2020, titled "Radiation Shielding for Compact and Transportable Nuclear Power Systems," the entire disclosure of which is incorporated by reference herein.

TECHNICAL FIELD

[0002] The present subject matter relates to examples of a nuclear reactor system, such as nuclear reactor transportation systems and transportable nuclear reactor systems. The present subject matter also encompasses radiation shielding for compact and transportable nuclear power systems.

BACKGROUND

[0003] Safe, reliable, and robust electrical power is indispensable to modern civilian and military operations. Operations occurring in remote, undeveloped, or contested areas of the world often have the same or more extensive requirements than operations occurring within the network of a contemporary power grid. Traditionally, petrochemical power generation has been used in remote operations, such as within the arctic circle or within active war zones, to supply power to critical infrastructure. However, the logistical supply lines for providing processed petrochemicals to a power plant, portable or otherwise, can be easily disrupted by adverse weather, shifting political restrictions, and blockades by adverse militia forces. Natural energy sources, such as wind turbines and solar panels, while not affected by protectionist behavior at borders, are still susceptible to cloudy weather and wind doldrums. Nuclear power deployments, which have self-contained fuel supplies designed to consistently run for upwards of a decade, are a solution to fickle or determined outside forces interrupting power supply.

[0004] Nuclear power deployments traditionally are extremely fixed in nature: massive concrete works are poured, and the structures once completed are fixed in position. These fixed structures are not suited to operations with a mobile core of power needs: sending power from a traditional power plant to a moving mining operation or a military division requires running electrical lines, and falls prey to the same issues as any other fixed-in-place power supply. Furthermore, traditional nuclear power deployments can take years to decommission and move. In many remote settings, this extensive lag period is an unacceptable burden to providing temporary robust power.

[0005] A modular transportable nuclear generator is described in U.S. Pat. No. 10,229,757, issued Mar. 12, 2019, titled "Modular Transportable Nuclear Generator," the entirety of which is incorporated by reference herein. Unfortunately, transportation of a nuclear generator typically requires waiting a long period of time before transport to minimize the radiation dosage risk of nuclear radiation to living organisms and the public.

SUMMARY

[0006] Hence, there is room for further improvement in nuclear reactor transportation systems and transportable nuclear reactor systems. To enable more rapid transport of a nuclear reactor **107**, a mobile reactor radiation shielding solution is described herein that prevents activation of structural materials to reduce the radiation dosage risk to the public and accelerates timetables for transport. The shielding solution addresses the shielding needs of a mobile nuclear reactor **107**. Specifically, the shielding solution provides necessary shielding during operation, shutdown, and transport. Shielding during operation requires two aspects to be addressed: reducing activation of structural materials and minimizing radiation dose to operators. During shutdown and transport, the shielding is focused on minimizing the radiation dose to personnel transporting the reactor and the public that may be close to the reactor during transport. Additionally, the mass of the shielding is minimized in order to enable transport.

[0007] A nuclear reactor system **100** implementing the transportable nuclear reactor technologies disclosed herein increases the portability of a nuclear power system. In contrast to other portable power systems, or other nuclear power systems, the transportable nuclear reactor technologies allow a portable nuclear reactor **107** to be transported safely. For example, the nuclear reactor **107** can be transported by a semi-truck safely through populated areas; perform a black-start within seventy-two hours from nuclear reactor arrival, and be safely removed within seven days of reactor shutdown. The transportable nuclear reactor technologies allow for a plug-and-play design, separating a balance-of-plant (BOP) module **170** from a nuclear heat supply (NETS) module **150**, and improve mass efficiency enough to allow for the BOP module **170** and the NETS module **150** to be transportable by a land vehicle **501**, transport aircraft **502**, or watercraft **503**.

[0008] In an example, a nuclear reactor system **100** includes a nuclear heat supply (NETS) module **150**. The NETS module **150** includes a reactor container **151**. The reactor container **151** includes a reactor cavity **152**. The NHS module **150** further includes a pressure vessel **160** within the reactor container **152**. The pressure vessel **160** includes an interior wall **161**. The NHS module **150** further includes a nuclear reactor core **101** located within the pressure vessel **160**. The nuclear reactor core **101** includes a plurality of fuel elements **104**A-N and at least one moderator element **103**A. The NHS module **150** further includes an in-vessel neutron shield **153** located on the interior wall **161** of the pressure vessel **160** to surround the nuclear reactor core **101**. The NHS module **150** further includes an in-vessel shadow shield **154** inside the pressure vessel **160**. The NHS module **150** further includes a transport shield (TS) **155** within the reactor container **151** and outside the pressure vessel **160** that includes a TS chamber **156** within the reactor cavity **152** for containing a first moderating fluid **159**A. The NHS module **150** further includes a module shadow shield (MSS) **157** within the reactor container **151** and outside the pressure vessel **160** that includes an MSS chamber **158** within the reactor cavity **152** for containing a second moderating fluid **159**B.

[0009] In a second example, a nuclear reactor deployment method **400** includes transporting a nuclear heat supply (NHS) module **150** including a nuclear reactor core **101** from a first location to a second location. The nuclear reactor deployment method **400** further includes coupling the NHS module **150** to ground in the second location. The nuclear reactor deployment method **400** further includes after transporting the NHS module **150** from the first location, substantially filling a transport shield (TS) chamber **156** with a first moderating fluid **159**A. The nuclear reactor deployment method **400** further includes after substantially filling the TS chamber **156** with the first moderating fluid **159**A, increasing a neutron flux of the nuclear reactor core **101** to a critical level.

[0010] In a third example, a nuclear reactor shielding method **500** includes substantially filling a transport shield chamber **156** of a nuclear heat supply (NHS) module **150** of a nuclear reactor system **100** with a first moderating fluid **159**A. The NHS module **150** includes a nuclear reactor core **101**. The nuclear reactor shielding method **500** further includes transporting the NHS module **150** from a first location to a second location. The nuclear reactor shielding method **500** further includes substantially draining the transport shield chamber **156** of the first moderating fluid **159**A.

[0011] Additional objects, advantages and novel features of the examples will be set forth in part in the description which follows, and in part will become apparent to those skilled in the art upon examination of the following and the accompanying drawings or may be learned by production or operation of the examples. The objects and advantages of the present subject matter may be realized and attained by means of the methodologies, instrumentalities and combinations particularly pointed out in the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] The drawing figures depict one or more implementations, by way of example only, not by way of limitations. In the figures, like reference numerals refer to the same or similar elements.

[0013] FIG. **1**A is a cutaway view of a nuclear reactor system that depicts a nuclear heat supply module and implements a shielding solution that includes: (1) an in-vessel neutron shield, (2) an in-vessel shadow shield, (3) a transport shield, and (4) a module shadow shield.

[0014] FIG. **1**B is an isometric view of the nuclear reactor system of FIG. **1**A including both the NHS module of FIG. **1**A as well as a balance-of-plant (BOP) module connected to the NHS module.

[0015] FIG. **1**C is a cross-sectional view of the nuclear heat supply module showing a nuclear reactor core, the in-vessel neutron shield, the transport shield, and a reactor container.

[0016] FIG. **1**D illustrates an in-vessel shadow shield protected arc, a module shadow shield protected arc, and a plurality of radiation particles and paths when emitted by the nuclear reactor core.

[0017] FIG. **2** is a block diagram of the nuclear reactor system of FIG. **1**B, but further including an auxiliary supply module and a discrete control module.

[0018] FIG. **3**A is an isometric view the nuclear reactor system of FIG. **1**B in a deployed state, with the BOP module at a distance from the NHS module.

[0019] FIG. **3**B is an isometric view of the nuclear reactor system of FIG. **1**B in a packaged state, with the BOP module in close proximity to the NHS module.

[0020] FIG. **4** is a flowchart of a nuclear reactor deployment method.

[0021] FIG. **5**A is a schematic of steps of a nuclear reactor shielding method in which the nuclear reactor system is in a packaged state, loaded on a land vehicle, and prepared to load into an aircraft.

[0022] FIG. **5**B is a flowchart of the nuclear reactor shielding method to mitigate the risk of living organisms being exposed to radiation.

[0023] FIG. **6** is a table of weights containing a projected or estimated weight of various components of the nuclear reactor system.

[0024] FIG. **7** is a heat map of the photon dose received in different locations of the NHS module when lead nitrate-saturated water is used to fill the transport shield chamber, as compared to when water alone is used to fill the transport shield chamber.

[0025] FIG. **8** is a heat map of the photon dose received in different locations of the NHS module when lead nitrate-saturated is used to fill the transport shield chamber.

PARTS LISTING

[0026] **100** Nuclear Reactor System
[0027] **101** Nuclear Reactor Core
[0028] **102**A-N Insulator Elements
[0029] **103**A-N Moderator Elements
[0030] **104**A-N Fuel Elements
[0031] **107** Nuclear Reactor
[0032] **112** Insulator Element Array
[0033] **113** Moderator Element Array
[0034] **114** Nuclear Fuel Tile Array
[0035] **115**A-N Control Drums
[0036] **116** Reflector Material
[0037] **117** Absorber Material
[0038] **140** Reflector
[0039] **141**A-N Reflector Blocks
[0040] **142**A-N Fuel Coolant Passages
[0041] **150** Nuclear Heat Supply (NETS) Module
[0042] **151** Reactor Container
[0043] **152** Reactor Cavity
[0044] **153** In-Vessel Neutron Shield
[0045] **154** In-Vessel Shadow Shield
[0046] **155** Transport Shield (TS)
[0047] **156** Transport Shield (TS) Chamber
[0048] **157** Module Shadow Shield (MSS)
[0049] **158** Module Shadow Shield (MSS) Chamber
[0050] **159**A First Moderating Fluid
[0051] **159**B Second Moderating Fluid
[0052] **160** Pressure Vessel
[0053] **161** Pressure Vessel Interior Wall
[0054] **170** Balance-of-Plant Module
[0055] **171** Heat Exchanger
[0056] **172** Gas Circulator
[0057] **173** Turbomachinery
[0058] **174** Generator
[0059] **175** Reactor Control System
[0060] **176** Heat Exchange Interface
[0061] **177** Balance-of-Plant Container
[0062] **180** Gas Connector Line
[0063] **190**A In-Vessel Shadow Shield Unprotected Arc
[0064] **190**B In-Vessel Shadow Shield Protected Arc
[0065] **191**A Module Shadow Shield Unprotected Arc
[0066] **191**B Module Shadow Shield Protected Arc
[0067] **192**A-I Radiation Particles
[0068] **250** Auxiliary Supply Module
[0069] **270** Balance-of-Plant Module

[0070] **275** Control Module

[0071] **400** Nuclear Reactor Deployment Method

[0072] **405-425** Nuclear Reactor Deployment Method Steps

[0073] **500** Nuclear Reactor Shielding Method

[0074] **501** Land Vehicle

[0075] **502** Aircraft

[0076] **503** Watercraft

[0077] **505-560** Nuclear Reactor Shielding Method Steps

[0078] **600** Table of Weights

[0079] **605** NHS Module Subtotal

[0080] **610** BOP Module Subtotal

[0081] **615** Total Nuclear Reactor System Mass

[0082] **700** Relative Photon Dose in Lead Nitrate-Saturated Water Heat Map

[0083] **705** Relative Photon Dose of Lead Nitrate-Saturated Water Compared to Water

[0084] **710** Distance from Reactor Core Horizontally

[0085] **715** Distance from Reactor Core Vertically

[0086] **800** Absolute Photon Dose in Lead Nitrate-Saturated Water Heat Map

[0087] **805** Absolute Photon Dose of Lead Nitrate-Saturated Water

DETAILED DESCRIPTION

[0088] In the following detailed description, numerous specific details are set forth by way of examples in order to provide a thorough understanding of the relevant teachings. However, it should be apparent to those skilled in the art that the present teachings may be practiced without such details. In other instances, well known methods, procedures, components, and/or circuitry have been described at a relatively high-level, without detail, in order to avoid unnecessarily obscuring aspects of the present teachings.

[0089] The term "coupled" as used herein refers to any logical or physical connection. Unless described otherwise, coupled elements or devices are not necessarily directly connected to one another and may be separated by intermediate components, elements, etc. The term "fluid communication" as used herein means that a substance, such as a liquid or a gas, can flow. The terms "block," "blocks," "blocked," or "blocking" as used herein when referring to a respective radiation particle **192**A-I means to absorb, reflect, deflect, or moderate the respective radiation particle **192**A-I.

[0090] The term "substantially filling" as used herein means occupying by fifty to one-hundred percent. The term "substantially fills" as used herein means occupies by fifty to one-hundred percent. The term "substantially filled" as used herein means occupied by fifty to one-hundred percent. The phrase "substantially draining" as used herein means emptying by ninety to one-hundred percent. The phrase "substantially drained" as used herein means emptied by ninety to one-hundred percent.

[0091] Unless otherwise stated, any and all measurements, values, ratings, positions, magnitudes, sizes, angles, and other specifications that are set forth in this specification, including in the claims that follow, are approximate, not exact. Such amounts are intended to have a reasonable range that is consistent with the functions to which they relate and with what is customary in the art to which they pertain. For example, unless expressly stated otherwise, a parameter value or the like may vary by as much as ±5% or as much as ±10% from the stated amount. The term "approximately" means that the parameter value or the like varies up to ±10% from the stated amount.

[0092] The orientations of the nuclear reactor system **100**, nuclear reactor **107**, nuclear reactor core **101**, nuclear heat supply module **150**, balance-of-plant module **170**, associated components, and/or any nuclear reactor system **100** incorporating the nuclear reactor core **101**, fuel elements **104**A-N, control drums **115**A-N, in-vessel neutron shield **153**, in-vessel shadow shield **154**, transport shield **155**, or module shadow shield **157**, such as shown in any of the drawings, are given by way of example only, for illustration and discussion purposes. In operation for a particular nuclear reactor system **100**, the components may be oriented in any other direction suitable to the particular application of the nuclear reactor system **100**, for example upright, sideways, or any other orientation. Also, to the extent used herein, any directional term, such as lateral, longitudinal, up, down, upper, lower, top, bottom, and side, are used by way of example only, and are not limiting as to direction or orientation of any nuclear reactor system **100** or component of the nuclear reactor system **100** constructed as otherwise described herein.

[0093] The transportable nuclear reactor technologies disclosed herein substantially increase the portability of a nuclear power system **100** to improve the speed of deployment and teardown, improve power production stability, and reduce fuel supply dependency during operation. Key to the success of the nuclear power system **100** is the novel approach to radiation shielding. Whereas traditional shielding is centered around building heavy radiation protection barriers around the nuclear reactor core **101**, the nuclear reactor system **100** focuses on using a multi-layered radiation strategy focused on minimizing activation of structural materials and using in-situ materials and resources for shielding during operation. This results in a nuclear reactor system **100** that is lightweight and capable of being moved in less than ten days after shutdown, for example.

[0094] Specifically, the shielding solution provides necessary shielding during operation, shutdown, and transport. Shielding during operation requires two aspects to be addressed: reducing activation of structural materials and minimizing radiation dose to operators. During shutdown and transport, the shielding is focused on minimizing radiation dose to personnel transporting the reactor and the public that may be close to the nuclear reactor **107** during transport. An additional requirement is that the mass of the shielding must be minimized in order to enable transport.

[0095] The mobile nuclear reactor system **100** radiation shielding solution is comprised of four shields integrated in the nuclear heat supply (NETS) module **150**: (1) an in-vessel neutron shield **153**, (2) an in-vessel shadow shield **154**, (3) a transport shield (TS) **155**, and (4) a module shadow shield (MSS) **157**. The in-vessel neutron shield **153** will reduce activation of the pressure vessel **160** and the surrounding structures by reducing the neutron fluence leaving the nuclear reactor core **101**. The in-vessel shadow shield **154** will allow for radiation workers to approach one side of the NHS module **150** to prepare it for transport while remaining below mandated dose limits. The transport shield **155** can include a first moderating fluid **159**A substantially filling the reactor cavity **152** of the NHS module **150**, for example a hydrogen bearing liquid (such as water) substantially filling the TS chamber **156**. The transport shield **155** may be implemented after shutdown of the nuclear reactor **107** to allow the NHS module **150** to be transported over land through public area and remain below public dose limits. The first moderating fluid **159**A of the transport shield **155** can be drained prior to the NHS module **150** being loaded into an aircraft **502** for transport. The module shadow shield **157** can be placed in the NHS module **150** on the other side of the nuclear reactor **107** inlet/outlet to allow for the balance-of-plant module **170** to be placed in closer proximity to the NHS module **150** and accessed by base-personnel. The module shadow shield **157** can include an empty MSS chamber **158** during transport, which during installation is substantially filled with a second moderating fluid **159**B, such as water or other onsite materials during installation. The module shadow shield **157** can be filled with water, as water will easily fill in all of the voids in the MSS chamber **158**.

[0096] The four shields integrated in the NHS module **150** comprise a shielding solution, which itself is comprised of four elements: (1) the in-vessel neutron shield **153**, (2) the in-vessel shadow shield **154**, (3) the transport shield (TS) **155**, and (4) a module shadow shield (MSS) **157**. The shielding solution described herein is applicable to both terrestrial and space nuclear reactor systems **100**. All four components can be applied together, individually, or in different combinations to meet the shielding, mass, volume, and operating requirements of the nuclear reactor system **100**. This shielding solution can be the baseline shielding solution for any mobile nuclear reactor **107**.

[0097] The transportable nuclear reactor technologies can utilize fully ceramic microencapsulated (FCM™) TRISO based fuel and a ceramic conductive "armored" core using silicon carbide. In both cases fully dense, structural silicon carbide can replace the graphite traditionally used in high temperature gas-cooled reactors, introducing improvements in strength, resistance to external hazards, and radioactivity retention. Deployment of the nuclear reactor system **100** will facilitate rapid deployment of remote bases, greatly enhance the mobility of temporary bases, and dramatically reduce potential damage and other risks associated with base resupply.

[0098] Reference now is made in detail to the examples illustrated in the accompanying drawings and discussed below. FIG. **1**A is a cutaway view of a nuclear reactor system **100** that depicts a nuclear heat supply (NHS) module **150** and implements a shielding solution. The shielding solution includes: (1) an in-vessel neutron shield **153**, (2) an in-vessel shadow shield **154**, (3) a transport shield **155**, and (4) a module shadow shield **157**. The NHS module **150** includes a reactor container **151**. This reactor container **151** in this example is a shipping container in the style of a CONEX or ISO box. The reactor container **151** can be approximately twenty feet long, and is configured to mount and house the nuclear reactor **107** in a safe and stable manner. The void space within the reactor container **151** forms a reactor cavity **152** (e.g. an interior volume), within which the nuclear reactor **107** resides. Within the reactor cavity **152** is a transport shield (TS) chamber **156** (e.g. a first chamber). The TS chamber **156** can be impermeable to fluid (e.g., watertight) after being substantially filled with the first moderating fluid **159**A, either because the reactor container **151** is watertight, or because a sealant or envelope interior to the reactor cavity **152** makes the TS chamber **156** watertight. The reactor container **151** or a sub-chamber of the reactor container **151** needs to be able to contain the first moderating fluid **159**A. The reactor cavity **152** in some examples may itself be the TS chamber **156** if there is no further dividing walls or volumes within the reactor cavity **152** to subdivide the reactor cavity **152**.

[0099] In most circumstances, the shape and volume of the TS chamber **156** conforms to the dimensions of the reactor cavity **152**, meaning that the TS chamber **156** is shaped like a right rectangular prism or can be a rounded shape if the reactor container **151** is shaped like a capsule. In some embodiments, however, the TS chamber **156** may conform to the dimensions of the nuclear reactor **107**, meaning that the TS chamber **156** would be generally shaped like a capsule, with a diameter larger than the diameter of the nuclear reactor **107**, but a diameter less than or equal to the width or height of the reactor container **151**.

[0100] The reactor container **151** is designed to be transported by any means conventional to a shipping or storage container in the style of a CONEX or ISO box, which are typically a large metal, weather-resistant container used to store or transport items. The reactor container **151** can be placed on a truck bed, trailer, or rail car of a land vehicle **501** like a semi-trailer truck or train; on an aircraft **502** such as the Lockheed Hercules™ C-100 or C-130™; or a watercraft **503**, such as a ship. The nuclear reactor **107** is mounted within the reactor container **151**, and is designed to withstand expected shocks, drops, temperature changes, pressure changes, humidity, and any other typical environmental effects the contents of a CONEX or ISO box is expected to withstand. Additionally, the nuclear reactor **107** in a military setting may experience higher accident probabilities than any commercial power system. The attractiveness of the NHS module **150** as a target and possibility of accidents during transport make the resiliency and safety of the nuclear reactor **107** paramount. Therefore, the nuclear reactor **107** has large material temperature margins, strong negative reactivity feedback, and near complete fission product retention.

[0101] Within the reactor container **151** in the reactor cavity **152**, mounted near the nuclear reactor **107**, is a module shadow shield (MSS) chamber **158** (e.g. a second chamber). The MSS chamber **158** can also be impermeable to fluid (e.g., watertight) after being substantially filled with the second moderating fluid **159**B. After being substantially filled, both the TS chamber **156** and the MSS chamber **158** can prevent fluid communication between the MSS chamber **158** and the TS chamber **156** to keep the first moderating fluid **159**A and the second moderating fluid **159**B separated and isolated from each another. When the TS chamber **156** and the MSS chamber **158** are being substantially drained, then the TS chamber **156** and the MSS chamber **158** are no longer impermeable to fluid.

[0102] In some examples, the MSS chamber **158** directly contacts the top, bottom, sides, and front of the reactor container **151**, as shown in FIG. **1**A. In those examples, the first moderating fluid **159**A in the TS chamber **156** cannot flow around the MSS chamber **158**, only up to the shared wall between the TS chamber **156** and the MSS chamber **158**. In FIG. **1**B, however, the MSS chamber **158** is shown with a small gap on all faces between the MSS chamber **158** and the reactor container **151**. In those examples, like FIG. **1**B, the MSS chamber **158** may technically be inside the TS chamber **156**, and the first moderating fluid **159**A within the TS chamber **156** may flow around the MSS chamber **158**.

[0103] The TS chamber **156** and MSS chamber **158** are watertight in order to selectively hold moderating fluid **159**A-B. Moderating fluids **159**A-B are a fluid selected for the ability to moderate neutron flux, slowing down fast neutrons within the TS chamber **156** and MSS chamber **158**. Moderating fluids **159**A-B in a simple approach are water. The water used as moderating fluids **159**A-B does not need to be chemically pure water, and in-situ potable or untreated water can be used as moderating fluids **159**A-B. The moderating fluids **159**A-B can be water, liquid organic compounds with a high hydrogen content, and can contain additives to enhance neutron and gamma shielding. FIGS. **7**-**8** discuss improvements over using water, in particular utilizing water saturated with lead nitrate, and utilizing water saturated with zinc bromide. Moderating fluids **159**A-B may be the same fluid, i.e., they may both be water saturated with lead nitrate. Alternatively, the first moderating fluid **159**A could be a different fluid, such as well water, from the second moderating fluid **159**B, which may be water saturated with zinc bromide. The first moderating fluid **159**A may be a more available, less efficient moderating fluid like potable water, while the second moderating fluid **159**B may be a water saturated with metal, which requires bringing particulate metal on-site to combine with water, or bringing water previously saturated with metal on-site, in exchange for improved moderating efficiency. Different moderating fluids **159**A-B have different efficacies as moderators: water works as a good moderating fluid because of a high number of hydrogen and oxygen atoms, which work well to shield against gamma radiation produced during the decay of fission products in the nuclear reactor core **101**. Metals added to water either absorb fast neutrons, or direct fast neutrons away from the reactor container **151**.

[0104] When the TS chamber **156** is at least substantially filled with a first moderating fluid **159**A the first moderating fluid **159**A in the TS chamber **156** forms a transport shield (TS) **155**. The transport shield **155**, as it comprises the first moderating fluid **159**A, surrounds the nuclear reactor **107** and reduces neutron fluence within the transport shield **155** and outside the transport shield **155**. Note that the transport shield **155** and the first moderating fluid **159**A do not extend into the nuclear reactor **107**. There is no fluid communication between the interior of the nuclear reactor **107** and the TS chamber **156**, and the first moderating fluid **159**A does not reduce neutron fluence within the nuclear reactor **107**.

[0105] The purpose of the transport shield **155** is primarily to make the nuclear reactor **107** safe to transport during ground transportation, or when moving through populated areas. The transport shield **155** is used during transportation when living organisms (e.g., people) are going to come into proximity of the nuclear reactor **107** from multiple directions. The transport shield **155** is designed to make a human operator/worker walking around the nuclear reactor **107** safe while the TS chamber **156** is filled with moderating fluid **159**A. The first moderating fluid **159**A can be a hydrogen dense liquid, which can be removed during operation, added during ground transportation, or when moving through populated areas. The first moderating fluid **159**A of the transport shield **155** can then be removed if loaded into an aircraft **502** for air transport and reloaded once back on the ground. Depending upon the implementation, the TS chamber **156** does not necessarily need to be substantially drained of the first moderating fluid **159**A in order to activate the nuclear reactor **107**. However, as the submerged nuclear reactor **107** is more difficult for technicians to access and maintain in the event of equipment failure, it is preferred that the first moderating fluid **159**A not remain in the transport shield **155** indefinitely or during active use.

[0106] When the MSS chamber **158** is substantially filled with the second moderating fluid **159**B, the second moderating fluid **159**B in the MSS chamber **158** forms a module shadow shield **157**. The module shadow shield **157** is designed to block fast neutrons travelling in a module shadow shield unprotected arc **191**A from the nuclear reactor core **101** which would otherwise pass through the module shadow shield **157** through a module shadow shield protected arc **191**B, and serves to shield reactor control system **175** components and the balance-of-plant module (BOP) **170** during operation. The size, shape, and position of the module shadow shield **157** are such that the module shadow shield **157** is designed to protect the BOP module **170** as further discussed in FIG. **1**B, and to shield radiation workers while preparing the nuclear reactor **107** for transport. The module shadow shield **157** is placed near the nuclear reactor core **101** to minimize size of the module shadow shield **157** while maximizing the module shadow shield protected arc **191**B.

[0107] Generally, the module shadow shield **157** is empty during transport of the nuclear reactor **107** and is substantially filled for reactor operation. In-situ materials or materials transported separately are used to fill the module shadow shield **157**. For some regimes of operation, the transport shield **155** can be substantially filled during operation to reduce neutron activation of the structure of the nuclear reactor system **100**.

[0108] Moving to the nuclear reactor **107** itself, the nuclear reactor **107** has a pressure vessel **160**. The pressure vessel **160** is discussed below in FIG. **1**C. The pressure vessel **160** exterior may be treated with a coating, or forged or manufactured with particular metals or chemicals in order to further reduce corrosion or oxidation experienced by modular reactors submerged in moderating fluids **159**A-B (e.g., water or more complex fluids).

[0109] The pressure vessel **160** has a pressure vessel interior wall **161**, upon which an in-vessel neutron shield **153** is mounted. The in-vessel neutron shield **153** serves the primary purpose of reducing and preventing the activation of the structural materials. The in-vessel neutron shield **153** significantly reduces the need for heavy shielding to shield against the gamma emissions from the activated structural materials. The in-vessel neutron shield **153** can be a composite material or a multi-layered material with neutron moderators (such as metal hydrides, polyethylene, plastics, beryllium-bearing compounds, or a combination thereof) and neutron absorbing materials (such as boron, boron carbide, gadolinium (Gd), europium, tungsten (W), or a combination thereof) enriched in specific isotopes or natural isotopic composition.

[0110] The in-vessel neutron shield **153** is on the inside pressure vessel interior wall **161** of the pressure vessel **160**, and the in-vessel neutron shield **153** can either be a continuous material or a sum of smaller modular components assembled to coat the inside pressure vessel interior wall **161** of the pressure vessel **160**. In-vessel neutron shield **153** be made of medium to high temperature materials, and operate at temperatures above 300 degrees Celsius. The in-vessel neutron shield **153** can have distinct moderating and neutron absorbing layers, and can have the neutron absorbing material, a bulk material, or be further embedded in a high-temperature matrix to increase the operating temperature of the in-vessel neutron shield **153**. The in-vessel neutron shield **153** reduces activation of the pressure vessel **160** and the surrounding structures such as the reactor container **151** or the BOP module **170** by reducing the neutron fluence leaving the nuclear reactor core **101**. The in-vessel neutron shield **153** can be implemented like the in-vessel shield **105** described in International Application. No. PCT/US2020/054188, filed on Oct. 4, 2020, titled "Integrated In-Vessel Neutron Shield," which published as International Publication No. WO 2021/067901 on Apr. 8, 2021, the entirety of which is incorporated by reference herein.

[0111] On the interior of the in-vessel neutron shield **153**, between the nuclear reactor core **101** and the MSS chamber **158**, is the in-vessel shadow shield **154**. The in-vessel shadow shield **154** provides neutron and gamma shielding between the nuclear reactor **107** and the BOP module **170** as well as the reactor control system **175**. The in-vessel shadow shield **154** is placed near the active nuclear reactor core **101** to minimize the size of the in-vessel shadow shield **154** while maximizing the in-vessel shadow shield protected arc **190**B. The purpose of the in-vessel shadow shield **154** is to shield radiation workers while preparing the nuclear reactor **107** for transport.

[0112] The in-vessel shadow shield **154** is made up of heavy metals, and is designed to block fast neutrons and provide shielding from gamma radiation travelling in an in-vessel shadow shield unprotected arc **190**A from the nuclear reactor core **101** which would otherwise pass through the in-vessel shadow shield **154** in an in-vessel shadow shield protected arc **190**B. The size, shape, and position of the in-vessel shadow shield **154** are such that the in-vessel shadow shield **154** is designed to protect the BOP module **170** further discussed in FIG. **1**B. The in-vessel shadow shield **154** is placed near the nuclear reactor core **101**, within the pressure vessel **160** to minimize size of the in-vessel shadow shield **154** while maximizing the in-vessel shadow shield protected arc **190**B.

[0113] The transport shield **155** and the in-vessel neutron shield **153** can be thought of as a pair of analogous shields, and the module shadow shield **157** and the in-vessel shadow shield **154** can be thought of as another pair of analogous shields. The transport shield **155** (when active and filled with the first moderating fluid **159**A) and the in-vessel neutron shield **153** fully surround the nuclear reactor core **101**, and seek to dampen the fast neutrons leaving the nuclear reactor core **101** in all directions. The module shadow shield **157** (when active and filled with second moderating fluid **159**B) and the in-vessel shadow shield **154** are placed at the same end of the nuclear reactor core **101**, as close as possible to the nuclear reactor core **101**, in order to establish a module shadow shield protected arc **191**B and further enhance an in-vessel shadow shield protected arc **190**B extending from the nuclear reactor core **101**. An "unprotected arc" refers to a three-dimensional space between the nuclear reactor core **101** and the respective shield **154**, **157** in which radiation is unblocked by the respective shield **154**, **157**. A "protected arc" refers to a three-dimensional space whose boundaries are between the respective shield **154**, **157** and beyond the respective shield **154**, **157** in which radiation is blocked by the respective shield **154**, **157**. The module shadow shield **157**, the in-vessel shadow shield **154**, and the BOP module **170** are placed such that the BOP module **170** is within the protected arcs **190**A, **191**A protected by the module shadow shield **157** and the in-vessel shadow shield **154**.

[0114] Likewise, the transport shield **155** and the module shadow shield **157** can be thought of as a different type of pair of analogous shields, and the in-vessel neutron shield **153** and the in-vessel shadow shield **154** can be thought of as another pairing of analogous shields. The transport shield **155** and the module shadow shield **157** are selectively activated by filling their respective chambers (TS chamber **156** and MSS chamber **158**) with moderating fluid **159**A-B. The transport shield **155** and the module shadow shield **157** moderate by virtue of the moderating fluids **159**A-B: in this example, the TS chamber **156** and MSS chamber **158** are made of stainless steel, and the TS chamber **156**, MSS chamber **158** have marginal moderating effect without the moderating fluids **159**A-B. Alternative metals for the TS chamber **156** and MSS chamber **158** include aluminum alloy, carbon-composite, titanium alloy, a radiation resilient SiC composite, nickel based alloys (e.g., Inconel™ or Haynes™), or a combination thereof. Note that in other examples, the TS chamber **156** and MSS chamber **158** can be formed of a solid moderating material. However, the increased weight and thickness of a solid moderating material can result in unacceptable tradeoffs to improve moderating ability of the transport chamber **158** and MSS chamber **158** themselves. The fluid selectivity of the transport shield **155** and the module shadow shield **157** allows the NHS module **150** to shed substantial mass when the TS chamber **156** or MSS chamber **158** are substantially drained of the moderating fluids **159**A-B, with the tradeoff of increased radioactivity in areas beyond the TS chamber **156** and MSS chamber **158**.

[0115] By comparison, the in-vessel neutron shield **153** and the in-vessel shadow shield **154** are permanently active, and are always reducing neutron flux in the areas beyond the nuclear reactor core **101** which pass through the volumes of the in-vessel neutron shield **153** and the in-vessel shadow shield **154**. The in-vessel neutron shield **153** and the in-vessel shadow shield **154** are made of metals, not fluid, and cannot be selectively engaged. The mass of the in-vessel neutron shield **153** and the in-vessel shadow shield **154** are always present in the NHS module **150**.

[0116] FIG. **1**B is an isometric view of the nuclear reactor system **100** of FIG. **1**A including both the nuclear heat supply (NHS) module **150** as well as a balance-of-plant (BOP) module **170** connected to the NHS module **150**. The nuclear reactor system **100** depicted here is in a deployed state, where the NHS module **150** and the BOP module **170** are separated, but connected by a gas connector line **180**. The nuclear reactor **107** is also active here: the nuclear reactor core **101** is critical, and the nuclear reactor **107** is optimally generating heat.

[0117] Separating the BOP module **170** from the NHS module **150** reduces the radiation exposure of the BOP module **170** and a human operator of the BOP module **170** in two ways. First, the increased distance allows fast neutrons to slow down or be absorbed as they escape the reactor container **151** and head toward the BOP module **170**. Second, the in-vessel shadow shield **154** and the module shadow shield **157** moderate fast neutrons travelling in unprotected arcs **190**B, **191**B from the nuclear reactor core **101**. As the distance from the in-vessel shadow shield **154** and the module shadow shield **157** to the BOP module **170** increases relative to the fixed distance from the in-vessel shadow shield **154** and the module shadow shield **157** to the nuclear reactor core **101**, the protected arcs **190**A, **191**A protected by the in-vessel shadow shield **154** and the module shadow shield **157** become larger, and protect more of the BOP module **170** as well as the human operator standing nearby the BOP module **170**.

[0118] The pressure vessel **160** of the nuclear reactor **107** is shown to also contain a heat exchanger **171**, which exchanges heat from the nuclear reactor core **101** from one medium to another medium (e.g., gas, liquid, solid, or a combination thereof). The heat exchanger **171** in this example also acts as the in-vessel shadow shield **154**, but these two components can be discrete, and the heat exchanger **171** does not need to be on the same side or portion of the pressure vessel **160** as the in-vessel shadow shield **154**.

[0119] The gas (e.g., He) heated by the heat exchanger **171** is circulated by the gas circulator **171** of the NHS module **150** down the gas connector line **180** toward the BOP module **170**. Once the BOP module **170** has utilized the hot gas and thereby cooled the gas, the gas circulator **172** circulates the gas through the remainder of the gas connector line **180** back to the heat exchanger **171**, to be reheated by the heat exchanger **171** and recirculated. This recirculation occurs as long as the nuclear reactor **107** is active, and the BOP module **170** is configured to accept hot gas.

[0120] The BOP module **170** is also in BOP container **177**, which is a shipping container in the style of a CONEX or ISO box or capsule similar to the reactor container **151**. The BOP container **177** is also designed to be transported by any means conventional to a shipping container in the style of a CONEX or ISO box, like the reactor container **151**. However, in this example, because the BOP module **170** requires less space, the BOP container **177** is only 10 feet long. Meaning, when this example nuclear reactor system **100** is in a packaged state, and the NHS module **150** and the BOP module **170** are packaged together, the nuclear reactor system **100** is thirty feet long: twenty feet of NHS module **150**, and ten feet of BOP module **170**.

[0121] The BOP module **170** is configured to transform the heat in hot gas from the gas connector line **180** into synchronous electricity. The BOP module **170** achieves this as follows: turbomachinery **173** has a heat exchange interface **176**, and intakes the hot gas. The hot gas enters a compressor turbine in the turbomachinery **173**, and the compressor turbine produces mechanical work output via a shaft of the turbomachinery **173**. That shaft of the turbomachinery **173** is directly or indirectly controlled via gears or belts coupled to a generator **174**. The generator **174** converts the mechanical work output of the turbomachinery **173** into synchronous alternating current electrical output. That electrical output of the generator **174** is the electrical output for which the nuclear reactor system **100** is operated.

[0122] The nuclear reactor **107** and internal components such as control rods **115**A-N, heat exchanger **171**, gas circulator **172**, turbomachinery **173**, and generator **174** are controlled by a reactor control system **175** with instrumentation. In this example the reactor control system **175** is housed within the BOP container **177**, however in other example the reactor control system **175** can be removed and operated remotely from the BOP container **177**.

[0123] FIG. **1**C is a cross-sectional view of the NHS module **150**, showing a nuclear reactor core **101**, in-vessel neutron shield **153**, and transport shield **155**. Also shown are the outline of the reactor container **151** and components that comprise the nuclear reactor **107**. As previously stated, the nuclear reactor system **100** includes a pressure vessel **160** and a nuclear reactor core **101** disposed in the pressure vessel **160**. The pressure vessel **160** is surrounded by the transport shield **155** that includes the first moderating fluid **159**A substantially filing the TS chamber **156**. The TS chamber **156** is itself within the reactor cavity **152** of the reactor container **151**.

[0124] The nuclear reactor core **101** includes a plurality of fuel elements **104**A-N and at least one moderator element **103**A. The fuel element **104**A emits free neutrons, and is designed to generate heat energy within the nuclear reactor core **101** of the nuclear reactor system **100**. In the example of FIG. **1**C, a moderator element **103**A is paired with the fuel element **104**A, and is designed to slow down fast neutrons while still allowing the nuclear reactor core **101** to produce heat energy. Nuclear reactor system **100** further includes a plurality of control drums **115**A-N disposed longitudinally within the pressure vessel **160** and laterally surrounding the plurality of fuel elements **104**A-N and the at least one moderator element **103**A to control reactivity of the nuclear reactor core **101**. Each of the control drums **115**A-N includes a reflector material **116** on a first portion **166** of an outer surface **165** and an absorber material **117** on a second portion **167** of the outer surface **165**. Burnable poison can be integrated within the plurality of fuel elements **104**A-N and the at least one moderator element **103**A to shut down the nuclear reactor core **101** in an emergency.

[0125] Control drums **115**A-N regulate the neutron population in the nuclear reactor core **101** and nuclear reactor **107** power level like control rods in other nuclear reactor systems. To increase or decrease neutron flux in the nuclear reactor core **101**, the control drums **115**A-N are rotated; whereas control rods are inserted or removed from the nuclear reactor core **101**. Because the control drums **115**A-N are rotated to adjust reactivity of the nuclear reactor core **101**, instead of being inserted and removed, the control drums **115**A-N have a permanently fixed longitudinal position: the control drums **115**A-N do not move in or out of the nuclear reactor core **101** or pressure vessel **160**. There are risks that control rods may not insert fully into the nuclear reactor core **101** due to misalignment or blockages in a control rod hole, and utilizing control drums **115**A-N advantageously reduces those risks. Control rods nevertheless could be utilized: in this example the heads of the control drums **115**A-N as shown in FIGS. **1**A-B are away from the module shadow shield **157**.

[0126] As shown in FIG. **1**C, a first portion of an outer surface of the control drum **115**A includes a reflector material **116**, which is generally formed of a material with a high elastic scattering neutron cross section. When the reflector material **116** faces inwards towards the nuclear reactor core **101**, the neutron flux increases, which increases the reactivity and operating temperature of the nuclear reactor core **101**. A second portion of the outer surface of the control drum **115**A includes an absorber material **117**, which can be formed of a neutron poison. Neutron poisons are isotopes or molecules with a high absorption neutron cross section particularly suited to absorbing free neutrons. When the absorber material **117** faces inwards towards the nuclear reactor core **101**, the neutron flux decreases, which decreases the reactivity and operating temperature of the nuclear reactor core **101**.

[0127] Nuclear reactor system **100** can selectively rotate the control drum **115**A or a plurality of control drums **115**A-N to face either the absorber material **117** towards the nuclear reactor core **101**, decreasing neutron flux and operating temperature; or the reflector material **116** towards the nuclear reactor core **101**, increasing neutron flux and operating temperature. Therefore, the nuclear reactor system **100** can selectively increase or decrease neutron flux of the nuclear reactor core **101**. To rapidly decrease neutron flux and achieve a decreased flux state, the nuclear reactor system **100** can rotate the control drum **115**A to maximally expose the absorber material **117** of the control drum **115**A to the fuel elements **104**A-N of the nuclear reactor core **101**, thereby absorbing more free neutrons and decreasing neutron flux. To rapidly increase neutron flux and achieve an increased flux state, the nuclear reactor system **100** can rotate the control drum **115**A to maximally expose the reflector material **116** of the control drum **115**A to the fuel elements **104**A-N of the nuclear reactor core **101**, thereby reflecting more free neutrons and increasing neutron flux. To make an intermediate adjustment or sustain a continuous level of neutron flux, the nuclear reactor core **100** can rotate the control drum **115**A to a partial exposure of the absorber material **117** of the control drum **115**A to the fuel elements **104**A-N of nuclear reactor core **101**.

[0128] Partial or full exposure of the reflector material **116** can move the nuclear reactor **107** to a critical state, and a sustained critical state will induce an active state. When the nuclear reactor **107** is in an active state, the nuclear reactor **107** is producing an optimal amount of heat and therefore electricity via the BOP module **170**, as well as a high level of free neutrons that may escape the nuclear reactor core **101**. In this example, the nuclear reactor **107** takes approximately three days to reach a fully active state from an inactive state.

[0129] Partial or full exposure of the absorber material **117**, or the materially complete consumption of the fuel elements **104**A-N, will move the nuclear reactor **107** to a sub-critical state; a sustained sub-critical state will induce an inactive state. When the nuclear reactor **107** is in an inactive state, the nuclear reactor **107** is producing a minimal amount of heat, and very likely no electricity via the BOP module **170**, should the BOP module **170** be coupled to an inactive NHS module **150**. The nuclear reactor **107** in the inactive state is also producing a minimal amount of free neutrons that may escape the nuclear reactor core **101**. In this example, the nuclear reactor **107** takes approximately seven days to reach a fully inactive state from an active state.

[0130] Once the nuclear reactor **107** and therefore the NHS module **150** reach an inactive state, and the transport shield **155** is deployed due to the TS chamber **156** being filled with moderator fluid **159**A, the NHS module **150** is ready for transport.

[0131] The plurality of fuel elements **104**A-N in the nuclear reactor core **101** are arranged as a nuclear fuel tile array **114** of nuclear fuel tiles **104**A-N. The nuclear reactor core **101** includes a plurality of moderator elements **103**A-N. Such an implementation of the nuclear reactor core **101** is described in International Application No. PCT/US2020/054190, filed on Oct. 4, 2020, titled "Nuclear Reactor Core Architecture with Enhanced Heat Transfer and Safety," which published as International Publication No. WO 2021/067903 on Apr. 8, 2021, the entirety of which is incorporated by reference herein. In a second example, the nuclear reactor core **101** can be implemented like the nuclear reactor core **110** described in FIGS. **3**-**4** and the associated text of U.S. Pat. No. 10,643,754 to Ultra Safe Nuclear Corporation of Seattle, Wash., issued May 5, 2020, titled "Passive Reactivity Control of Nuclear Thermal Propulsion Reactors" the entirety of which is incorporated by reference herein. In the second example, the fuel elements **104**A-N can be implemented like the fuel elements **310**A-N, and the moderator elements **103**A-N can be implemented like the tie tubes **320**A-N described in FIGS. **3**-**4** and the associated text of U.S. Pat. No. 10,643,754.

[0132] In a third example, the nuclear reactor core **101** can be implemented like the nuclear reactor core **101** described in FIG. **2**C and the associated text of U.S. Patent Pub. No. 2020/0027587 to Ultra Safe Nuclear Corporation of Seattle, Wash., published Jan. 23, 2020, titled "Composite Moderator for Nuclear Reactor Systems," the entirety of which is incorporated by reference herein. In the third example, the fuel elements **104**A-N can be implemented like the fuel elements **102**A-N and the moderator elements **103**A-N can be implemented like the composite moderator blocks described in FIG. **2**C and the associated text of U.S. Patent Pub. No. 2020/0027587.

[0133] The nuclear reactor **107** includes a reflector **140** (e.g., an outer reflector region) located inside the pressure vessel **160**. Reflector **140** includes a plurality of reflector blocks **141**A-N laterally surrounding the plurality of fuel elements **104**A-N and the at least one moderator element **103**A.

[0134] Nuclear reactor **107** includes the nuclear reactor core **101**, in which a controlled nuclear chain reaction occurs, and energy is released. The neutron chain reaction in the nuclear reactor core **101** is critical—a single neutron from each fission nucleus results in fission of another nucleus—the chain reaction must be controlled. By sustaining controlled nuclear fission, the nuclear reactor system **100** produces heat energy. In an example implementation, the nuclear reactor system **100** is implemented as a gas-cooled high temperature nuclear reactor **107**. However, the nuclear reactor system **100** can be implemented as a heat pipe nuclear reactor, molten-salt-cooled nuclear reactor, helium-cooled nuclear reactor, graphite moderated nuclear reactor, fuel-in-salt nuclear reactor, a supercritical CO2 reactor, an (open or closed) Brayton cycle reactor, or a sodium-cooled fast nuclear reactor. In particular, the nuclear reactor system **100** can be implemented with a gas-cooled graphite-moderated nuclear reactor, a fluoride salt-cooled high-temperature nuclear reactor with a higher thermal neutron flux than the gas-cooled graphite-moderated nuclear reactor, or a sodium fast nuclear reactor with a faster neutron flux than the gas-cooled graphite-moderated nuclear reactor.

[0135] Each of the fuel elements **104**A-N, shown as nuclear fuel tiles **104**A-N, includes a nuclear fuel. The nuclear fuel includes a fuel compact comprised of coated fuel particles, such as tristructural-isotropic (TRISO) fuel particles embedded inside a high-temperature matrix. In some implementations, the nuclear fuel includes a fuel compact comprised of bistructural-isotropic (BISO) fuel particles embedded inside the high-temperature matrix. In yet another implementation, the nuclear fuel includes a fuel compact comprised of a variation of TRISO known as TRIZO fuel particles. A TRIZO fuel particle replaces the silicon carbide layers of the TRISO fuel particle with zirconium carbide (ZrC). Alternatively, the TRIZO fuel particle includes the typical coatings of a TRISO fuel particle and an additional thin ZrC layer coating around the fuel kernel, which is then surrounded by the typical coatings of the TRISO fuel particle. The high-temperature matrix includes silicon carbide, zirconium carbide, titanium carbide, niobium carbide, tungsten, molybdenum, or a combination thereof. Each of the TRISO fuel particles can include a fuel kernel surrounded by a porous carbon buffer layer, an inner pyrolytic carbon layer, a binary carbide layer (e.g., ceramic layer of SiC or a refractory metal carbide layer), and an outer pyrolytic carbon layer. The refractory metal carbide layer of the TRISO fuel particles can include at least one of titanium carbide (TiC), zirconium carbide (ZrC), niobium carbide (NbC), tantalum carbide, hafnium carbide, ZrC-ZrB_2 composite, ZrC-ZrB_2-SiC composite, or a combination thereof. The high-temperature matrix can be formed of the same material as the binary carbide layer of the TRISO fuel particles.

[0136] The nuclear fuel retains fission products within itself, reducing the immediate need to dispose of nuclear waste products. The coated fuel particles also reduce proliferation risk as compared to commercial light water reactor fuel.

[0137] A description of TRISO fuel particles dispersed in a silicon carbide matrix to form a cylindrical shaped nuclear fuel compact is provided in the following patents and publications of Ultra Safe Nuclear Corporation of Seattle, Washington: U.S. Pat. No. 9,299,464, issued Mar. 29, 2016, titled "Fully Ceramic Nuclear fuel and Related Methods"; U.S. Pat. No. 10,032,528, issued Jul. 24, 2018, titled "Fully Ceramic Micro-encapsulated (FCM) fuel for CANDUs and Other Reactors"; U.S. Pat. No. 10,109,378, issued Oct. 23, 2018, titled "Method for Fabrication of Fully Ceramic Microencapsulation Nuclear Fuel"; U.S. Pat. Nos. US 9,620,248, issued Apr. 11, 2017 and U.S. Pat. No. 10,475,543, issued Nov. 12, 2019, titled "Dispersion Ceramic Micro-encapsulated (DCM) Nuclear Fuel and Related Methods"; U.S. Patent Pub. No. 2020/0027587, published Jan. 23, 2020, titled "Composite Moderator for Nuclear Reactor Systems"; and U.S. Pat. No. 10,573,416, issued Feb. 25, 2020, titled "Nuclear Fuel Particle Having a Pressure Vessel Comprising Layers of Pyrolytic Graphite and Silicon Carbide," the entireties of which are incorporated by reference herein. As described in those Ultra Safe Nuclear Corporation patents, the nuclear fuel can include a cylindrical fuel compact or pellet comprised of TRISO fuel particles embedded inside a silicon carbide matrix to create a cylindrical shaped nuclear fuel compact. A description of TRISO, BISO, or TRIZO fuel particles dispersed in a zirconium carbide matrix to form a cylindrical shaped nuclear fuel compact is provided in U.S. Patent Pub. No. 2021/0005335 to Ultra Safe Nuclear Corporation of Seattle, Washington, published Jan. 7, 2021, titled "Processing Ultra High Temperature Zirconium Carbide Microencapsulated Nuclear Fuel," the entirety of which is incorporated by reference herein.

[0138] As shown, nuclear reactor core **101** includes an insulator element array **112** of insulator elements **102**A-N and a moderator element array **113** of moderator elements **103**A-N. Insulator elements **102**A-N are formed of a high-temperature thermal insulator material with low thermal conductivity. The high-temperature thermal insulator material can include low density carbides, metal-carbides, metal-oxides, or a combination thereof. More specifically, the high-temperature thermal insulator material includes low density SiC, stabilized zirconium oxide, aluminum oxide, low density ZrC, low density carbon, or a combination thereof. Moderator elements **103**A-N are formed of a low-temperature solid-phase moderator. The low-temperature solid-phase moderator can include MgH_x, YH_x, ZrH_x, CaH_x, ZrO_x, CaO_x, BeO_x, BeC_x, Be, enriched boron carbide, $^{11}B_4C$, CeH_x, LiH_x, or a combination thereof.

[0139] In this nuclear reactor system **100**, the nuclear reactor **107** can include a plurality of control drums **115**A-N and a reflector **140**. The control drums **115**A-N may laterally surround the insulator element array **112** of insulator elements **102**A-N, the moderator element array **113** of moderator elements **103**A-N, and nuclear fuel tile array **114** of nuclear fuel tiles **104**A-N to change reactivity of the nuclear reactor core **101** by rotating the control drums **115**A-N. As depicted, the control drums **115**A-N reside on the perimeter or periphery of a pressure vessel **160** and are positioned circumferentially around the insulator elements **102**A-N, moderator elements **103**A-N, and nuclear fuel tiles **104**A-N of the nuclear reactor core **101**. Control drums **115**A-N may be located in an area of the reflector **140**, e.g., an outer reflector region formed of reflector blocks **141**A-N immediately surrounding the nuclear reactor core **101**, to selectively regulate the neutron population and reactor power level during operation. For example, the control drums **115**A-N can be a cylindrical shape and formed of both a reflector material **116** (e.g., beryllium (Be), beryllium oxide (BeO), BeSiC, BeMgO, Al_2O_3, etc.) on a first portion of an outer surface **165** and an absorber material **117** on a second portion of the outer surface (e.g., outer circumference).

[0140] The reflector material **116** and the absorber material **117** can be on opposing sides of the cylindrical shape, e.g., portions of an outer circumference, of the control drums **115**A-N. The reflector material **116** can include a reflector substrate shaped as a cylinder or a truncated portion thereof. The absorber material **117** can include an absorber plate or an absorber coating. The absorber plate or the absorber coating are disposed on the reflector substrate to form the cylindrical shape of each of the control drums **115**A-N. For example, the absorber plate or the absorber coating covers the reflector substrate formed of the reflector material **116** to form the control drums **115**A-N. When the reflector material **116** is the truncated portion of the cylinder, the absorber material **117** is a complimentary body shape to the truncated portion to form the cylindrical shape.

[0141] Control drums **115**A-N can be formed of a continuous surface, e.g., rounded, aspherical, or spherical surfaces to form a cylinder or other conical surfaces to form a quadric surface, such as a hyperboloid, cone, ellipsoid, paraboloid, etc. Alternatively or additionally, the control drums **115**A-N can be formed of a plurality of discontinuous surfaces (e.g., to form a cuboid or other polyhedron, such as a hexagonal prism). As used herein, "discontinuous" means that the surfaces in aggregate do not form a continuous outer surface **165** that is round (e.g., circular or oval) perimeter of the control drums **115**A-N. In FIG. **1**C, the outer surface shown is a rounded continuous surface.

[0142] Rotating the depicted cylindrical-shaped control drums **115**A-N changes proximity of the absorber material **117** (e.g., boron carbide, B_4C) of the control drums **115**A-N to the nuclear reactor core **101** to alter the amount of neutron reflection. When the reflector material **116** is inwards facing towards the nuclear reactor core **101** and the absorber material **117** is outwards facing, neutrons are scattered back (reflected) into the nuclear reactor core **101** to cause more fissions and increase reactivity of the nuclear reactor core **101**. When the absorber material **117** is inwards facing towards the nuclear reactor core **101** and the reflector material **116** is outwards facing, neutrons are absorbed and further fissions are stopped to decrease reactivity of the nuclear reactor core **101**.

[0143] Neutron reflector **140**, e.g., shown as the outer reflector region, can be filler elements disposed between outermost nuclear fuel tiles **104**A-N and the control drums **115**A-N as well as around the control drums **115**A-N. Reflector **140** can be formed of a moderator that is disposed between the outermost nuclear fuel tiles **104**A-N and an optional barrel (e.g., formed of beryllium). The reflector **140** can include hexagonal or partially hexagonal shaped filler elements and can be formed of a neutron moderator (e.g., beryllium oxide, BeO). Although not required, nuclear reactor **107** can include the optional barrel (not shown) to surround the bundled collection that includes the insulator element array **112**, moderator element array **113**, nuclear fuel tile array **114** of the nuclear reactor core **101**, as well as the reflector **140**. As depicted, the control drums **115**A-N reside on the perimeter of the pressure vessel **160** and can be interspersed or disposed within the reflector **140**, e.g., surround a subset of the filler elements (e.g., reflector blocks **141**A-N) forming the reflector **140**.

[0144] Pressure vessel **160** can be formed of aluminum alloy, carbon-composite, titanium alloy, a radiation resilient SiC composite, nickel based alloys (e.g., Inconel™ or Haynes™), or a combination thereof. Pressure vessel **160** and nuclear reactor system **100** can be comprised of other components, including cylinders, piping, and storage tanks that transfer a moderator coolant that flows through moderator coolant passages **121**A-N; and a separate nuclear fuel coolant, such as a propellant (e.g., hydrogen gas or liquid) that flows through the fuel coolant passages **142**A-N.

[0145] The moderator coolant and the nuclear fuel coolant can be a gas or a liquid that are not in fluid communication with the moderating fluids **159**A-B.

[0146] In the example of FIG. **1**C, nuclear reactor system **100** enables the moderator coolant to flow through the moderator coolant passages **121**A-N and a separate nuclear fuel coolant to flow through the fuel coolant passages **142**A-N. The moderator coolant passages **121**A-N are flattened ring shaped (e.g., O-shape) openings, such as a channels or holes to allow the moderator coolant to pass through in the nuclear reactor core **101** and into a heat sink (not shown) via a dedicated moderator coolant loop, for example. The fuel coolant passages **142**A-N are channels or holes to allow the nuclear fuel coolant to pass through in the nuclear reactor core **101** and into or near the heat exchanger **171** in order to heat the gas for the BOP module **170**.

[0147] In an alternative implementation, a coolant that is shared between the moderator elements **103**A-N and the nuclear fuel tiles **104**A-N may be flowed through both the moderator coolant passages **121**A-N and the fuel coolant passages **141**A-N. In the alternative implementation, the coolant that flows through the plurality of fuel elements **104**A-N can include helium, FLiBe molten salt formed of lithium fluoride (LiF), beryllium fluoride (BeF_2), sodium, He, HeXe, CO_2, neon, or HeN. The shared coolant flows through the moderator coolant passages **121**A-N before the shared coolant is heated in the nuclear fuel tiles **104**A-N. This keeps the moderator elements **103**A-N cool.

[0148] FIG. **1**D illustrates an in-vessel shadow shield unprotected arc **190**A, an in-vessel shadow shield protected arc **190**B, a module shadow shield unprotected arc **191**A, a module shadow shield protected arc **191**B, and a plurality of radiation particles **192**A-I and paths when emitted by the nuclear reactor core **101**. The in-vessel shadow shield protected arc **190**B established by the in-vessel shadow shield **154** and the module shadow shield protected arc **191**B established by the module shadow shield **157** may not completely overlap. Therefore, individual radiation particles **192**A-I emanating from the nuclear reactor core **101** can be blocked along a variety of routes. The in-vessel neutron shield **153**, in-vessel shadow shield **154**, transport shield **155**, and module shadow shield **157** can block a variety of radiation particles, notably alpha, beta, and gamma particles. However, due to their ability to travel through moderators with ease as compared to other radioactive particles, and due to the risk to equipment and human life they present, the in-vessel neutron shield **153**, in-vessel shadow shield **154**, transport shield **155**, and module shadow shield **157** can be preferably designed to block gamma particles.

[0149] A first radiation particle **192**A can strike the in-vessel shadow shield **154** and is blocked. A second radiation particle **192**B can pass through the in-vessel shadow shield **154**, strike the in-vessel neutron shield **153**, and is blocked. A third radiation particle **192**C can pass through the in-vessel shadow shield **154** and in-vessel neutron shield **153**, strike the transport shield **155**, and is blocked. A fourth radiation particle **192**D can pass through the in-vessel shadow shield **154**, the in-vessel neutron shield **153**, and the transport shield **155**, strike the module shadow shield **157**, and is blocked.

[0150] A fifth radiation particle **192**E can strike the in-vessel neutron shield **153** directly and stop. A sixth neutron particle **192**F can pass through the in-vessel neutron shield **153** and strike the transport shield **155** and is blocked. A seventh radiation particle **192**G can pass through the in-vessel neutron shield **153** and the transport shield **155**, strike the module shadow shield **157**, and is blocked. In an example where the TS chamber **156** surrounds the MSS chamber **158**, an eighth radiation particle **192**H can pass through the in-vessel neutron shield **153**, the transport shield **155** for a first time, and the module shadow shield **157**, strike the transport shield **155** for a second time, and is blocked. In another example where the TS chamber **156** surrounds the MSS chamber **158**, a ninth radiation particle **192**I can pass through the in-vessel shadow shield **154**, the in-vessel neutron shield **153**, the transport shield **155** for a first time, the module shadow shield **157**, strike the transport shield **155** for a second time, and is blocked.

[0151] Therefore, FIGS. **1**A-D depict a nuclear reactor system **100** that includes a nuclear heat supply (NETS) module **150**. The NETS module includes a reactor container **151**. The reactor container **151** includes a reactor cavity **152**. The NETS module **150** further includes a pressure vessel **160** within the reactor container **152**. The pressure vessel **160** includes an interior wall **161**. The NETS module **150** further includes a nuclear reactor core **101** located within the pressure vessel **160**. The nuclear reactor core **101** includes a plurality of fuel elements **104**A-N and at least one moderator element **103**A. The NETS module **150** further includes an in-vessel neutron shield **153** located on the interior wall **161**

of the pressure vessel **160** to surround the nuclear reactor core **101**. The NETS module **150** further includes an in-vessel shadow shield **154** inside the pressure vessel **160**. The NETS module **150** further includes a transport shield (TS) **155** within the reactor container **151** and outside the pressure vessel **160** that includes a TS chamber **156** within the reactor cavity **152** for containing a first moderating fluid **159**A. The NETS module **150** further includes a module shadow shield (MSS) **157** within the reactor container **151** and outside the pressure vessel **160** that includes an MSS chamber **158** within the reactor cavity **152** for containing a second moderating fluid **159**B.

[0152] The transport shield **155** further includes the first moderating fluid **159**A substantially filling the TS chamber **156**. The module shadow shield **157** further includes the second moderating fluid **159**B substantially filling the MSS chamber **158**. The NHS module **150** further includes an intermediate heat exchanger **171** and a gas circulator **172**. The heat exchanger **171** is thermally coupled to the nuclear reactor core **101**. The transport shield **155** further includes the first moderating fluid **159**A. The first moderating fluid **159**A substantially fills the TS chamber **156**.

[0153] The NHS module **150** includes an active and an inactive state. In a first example, a roentgen equivalent man (rem) dose outside the NHS module **150** induced by the NHS module **150** while the NHS module **150** is in the inactive state is less than 50 rem per hour (rem/hr). The first moderating fluid includes water (H_2O). In a second example, a rem dose outside the NHS module **150** induced by the NHS module **150** while the NHS module **150** is in the inactive state is less than 10 rem per hour (rem/hr). The first moderating fluid **159**A includes water (H_2O), and the first moderating fluid **159**A contains a concentration of $Pb(NO_3)_2$ (lead nitrate) of approximately 1.63 grams per cubic centimeter (g/cc) or greater. In a third example, a rem dose outside the NHS module **150** induced by the NHS module **150** while the NHS module **150** is in the inactive state is less than 0.5 rem per hour (rem/hr). The first moderating fluid **159**A includes water (H_2O), and the first moderating fluid **159**A contains a concentration of $ZnBr_2$ (zinc bromide) of approximately 5 grams per cubic centimeter (g/cc) or greater.

[0154] The module shadow shield **157** further includes the second moderating fluid **159**B. The second moderating fluid **159**B substantially fills the MSS chamber **158**. The plurality of fuel elements **104**A-N emit a plurality of radiation particles **192**A-I. The in-vessel shadow shield **154** initially blocks a first radiation particle **192**A of the plurality of radiation particles **192**A-I. The in-vessel shadow neutron shield **153** blocks a second radiation particle **192**B of the plurality of radiation particles **192**A-I that passes through the in-vessel shadow shield **154**. The transport shield **155** blocks a third radiation particle **192**C of the plurality of radiation particles **192**A-I that passes through the in-vessel shadow shield **154** and the in-vessel neutron shield **153**. The module shadow shield **157** blocks a fourth radiation particle **192**D of the plurality of radiation particles **192**A-I that passes through the in-vessel shadow shield **154**, the in-vessel neutron shield **153**, and the transport shield **155**.

[0155] The nuclear reactor system **100** further includes a balance-of-plant (BOP) module **170** disposed outside the NHS module **150**. The reactor container **151** houses the transport shield **155**, the module shadow shield **157**, the pressure vessel **160**, the in-vessel shadow shield **154**, the nuclear reactor core **101**, and the in-vessel neutron shield **153**. The BOP module **170** includes turbomachinery **173**, a generator **174**, and a reactor control system **175**. The first moderating fluid **159**A blocks a radiation particle **192**C (e.g., by absorbing the radiation particle **192**C) to prevent the radiation particle **192**C from traveling to the BOP module **170**. The second moderating fluid **159**B blocks a radiation particle **192**D (e.g., by absorbing the radiation particle **192**D) to prevent the radiation particle **192**D from traveling to the BOP module **170**.

[0156] The in-vessel shadow shield **154**, the in-vessel neutron shield **153**, the first moderating fluid **159**A, and the second moderating fluid **159**B include one or more neutron absorbing materials. The in-vessel neutron shield **153** is formed of a composite material or a multi-layered material with a neutron moderator and a neutron absorbing material enriched in specific isotopes or natural isotopic composition. The first moderating fluid **159**A includes a hydrogen-dense liquid. The second moderating fluid **159**B includes water (H_2O). The neutron moderator includes metal hydrides, polyethylene, plastics, beryllium bearing compounds, or a combination thereof. The neutron absorbing material includes boron, boron carbide, metal boride, gadolinium, europium, tungsten, or a combination thereof. The in-vessel neutron shield **153** is formed of two or more neutron absorbing materials. The two or more neutron absorbing materials include a near black neutron absorbing material and a gray absorbing material.

[0157] FIG. **2** is a block diagram of the nuclear reactor system **100** of FIG. **1**B, but further including an auxiliary supply module **250** and a discrete control module **275**. The NHS module **150** is the same as in FIGS. **1**A-D, with a nuclear reactor core **101** generating heat, exchanged into a heat exchanger **171**, then circulated by the gas circulator **172** to the BOP module **170**. The BOP module **270** is similar to the BOP module **170** in FIGS. **1**A-D, but the reactor control system **175** is implemented in a separated control module **270**. The BOP module **270** still accepts heat from the NHS module **170**, uses turbomachinery **173** in a power conversion system to convert hot gas energy into mechanical rotational energy, which turns a generator **174**, generating synchronous alternating current electricity. This NHS module **150** is a helium-cooled nuclear reactor **107** coupled through a heat exchanger **171** to a secondary loop for power conversion.

[0158] The nuclear reactor system **100** includes an auxiliary supply module **250**. This auxiliary supply module **250** runs when the NHS module **150** is in the inactive state. This auxiliary supply module **250** can be powered by petrochemicals, can be a large battery, or can use alternative energy sources. The auxiliary supply module **250** can also be designed to absorb the residual heat from the nuclear reactor core **101**. The auxiliary supply module **250** may use this residual heat to generate electricity, mechanical energy, or even hot gas like the NHS module **150**. Or the auxiliary supply module **250** may simply assist in bleeding off heat or free neutrons from the NHS module **150**, more quickly moving the NHS module **150** from the active state to the inactive state when desired.

[0159] Further, the nuclear reactor system **100** includes the control module **275** discussed above. The control module **275** incorporates the reactor control system **175** directed to controlling the NHS module and the BOP module. Additionally, the control module **275** can control the auxiliary supply module **250**.

[0160] FIG. **3**A is an isometric view of the nuclear reactor system **100** of FIG. **1**B in a deployed state, with the BOP module **270** at a distance from the NHS module **150**. In this deployed state, personnel can more safely interact with the BOP module **270** due to the increased distance from the NHS module **150**. Heated gas can still move from the NHS module **150** to the BOP module **270** via the gas connector line **180**. The depictions of the nuclear reactor system **100** in the deployed state all depict the NHS module **150** and the BOP module **170**, **270** as oriented as axially horizontal, e.g., flat or flush to the ground. These axially horizontal orientations can improve logistics and deployment, and minimize seismic concerns. However, the NHS module **150** can be oriented in any direction, and can even be buried at or below grade. Being partially or completely buried below grade can reduce the rem dose experienced by near the NHS module **150**, and may reduce shielding requirements or safety requirements for those personnel. Burying should be understood as burying in earth, cementing in concrete, as well as sinking into water. The NHS module **150** can also be placed in a building, at, above, or below grade. Placing the NHS module **150** up very high, or below grade in a basement, can also reduce shielding requirements or safety requirements for personnel. The NHS module **150** can also be at any reasonable distance from the BOP module **170**, **270**, though a longer gas connector line **180** will likely result in more heat loss as the gas circulator **172** sends heated gas from the NHS module **150** to the BOP module **170**, **270**.

[0161] FIG. **3**B is an isometric view of the nuclear reactor system of FIG. **1**B in a packaged state, with the BOP module **270** in close proximity to the NHS module **150**. The control module **275** is packed in with the BOP module **270**, in the BOP container **177**. In this packaged state, the nuclear reactor system **100** is easy to transport, fitting on a single semi-trailer truck trailer. The nuclear reactor system **100** can be operated in this configuration; however, this may place excess radiation on the BOP module **270** and personnel operating the nuclear reactor system **100**. For example, if the in-vessel shadow shield protected arc **190**B and the module shadow shield protected arc **191**B do not fully cover the BOP module **270** and the immediate area around the BOP module where personnel would stand.

[0162] FIG. **4** is a flowchart of a nuclear reactor deployment method **400** for a nuclear reactor system **100**. Steps **405**, **410**, **415**, **420**, and **425** of the nuclear reactor deployment method **400** can be performed in any order, but the order presented is likely most safe for living organisms or plant personnel in close enough proximity to components of the nuclear reactor system **100** where radiation exposure is a concern. The order of steps establishes the broadest shield (the transport shield **155**) first, then the specific shield (the MSS **157**), before having plant personnel work closely near the nuclear reactor **107** to mount the NHS module **150**.

[0163] Beginning in step **405**, the nuclear reactor deployment method **400** includes substantially filling a transport shield (TS) chamber **156** of a nuclear heat supply (NETS) module **150** with a first moderating fluid **159**A. The NETS module **150** includes a nuclear reactor core **101**. Moving to step **410**, the nuclear reactor deployment method **400** further includes transporting the NETS module **150** from a first location to a second location.

[0164] Continuing now to step **415**, the nuclear reactor deployment method **400** further includes after transporting the NETS module, substantially filling a module shadow shield (MSS) chamber **158** of the NETS module **150** with a second moderating fluid **159**B. In step **420**, the nuclear reactor deployment method **400** further includes coupling the NETS module **150** to ground in the second location. Coupling the NETS module **150** to the ground can mean affixing the NETS module **150** to the ground, a structure or platform, or partially or fully burying the NETS module **150** in the ground, below grade. Affixing the NETS module **150** to an object that is itself directly or indirectly affixed or coupled to the ground affixes and couples the NETS module **150** to the ground. Finishing in step **425**, the nuclear reactor deployment method **400** further includes increasing a neutron flux of the nuclear reactor core **101** to a critical level, ultimately generating enough heat for the balance-of-plant module **170** to generate electricity. Typically, the step **425** of increasing the neutron flux of the nuclear reactor core **101** to the critical level occurs after the step of substantially filling the MSS chamber **158** with the second moderating fluid **159**B.

[0165] FIG. **5**A is a schematic of steps of a nuclear reactor shielding method **500** in which the nuclear reactor system **100** is in a packaged state, loaded on a land vehicle **501**, and prepared to load into an aircraft **502**, or possibly a watercraft **503**. As discussed previously, the nuclear reactor system **100** when packaged can fit on a semi-trailer truck trailer. When on a land vehicle **501**, the nuclear reactor system **100** is in the inactive state, and the transport shield **155** is filled with the first moderating fluid **159**A and moderating.

[0166] The nuclear reactor system **100** can also fit within an aircraft **502**, such as the Lockheed Hercules™ C-100 or C130™. However, in order to meet size and weight requirements of certain aircraft **502** (and some land vehicle(s) **501**), the NHS module **150** and BOP module **170** may need to be separated and transported separately. Then, upon completing their respective journeys, the NHS module **150** and the BOP module **170** can be rejoined, either in a packaged state to continue their journey, or in a deployed state to begin providing power. As the nuclear reactor system **100** can fit within the volume of, and has the safety tolerances of a shipping container in the style of a CONEX or ISO box, the nuclear reactor system **100** can also be accommodated by a watercraft **503**, like a container ship.

[0167] FIG. **5**B is a flowchart of the nuclear reactor shielding method **500** to mitigate the risk of living organisms being exposed to radiation. The steps of the nuclear reactor shielding method **500** can be performed in any order, but the order presented is likely most safe for living organisms or plant personnel in close enough proximity to components of the nuclear reactor system **100** where radiation exposure is a concern. Broadly, this nuclear reactor shielding method **500** covers a nuclear reactor system **100** going inactive, travelling by truck, then plane, then truck again, and going active. Beginning in step **505**, the nuclear reactor shielding method **500** includes before transporting a nuclear heat supply (NETS) module **150**, reducing a neutron flux of a nuclear reactor core **101** of the NETS module **150** to a subcritical level. Next, in step **510**, the nuclear reactor shielding method **500** includes after reducing the neutron flux of the nuclear reactor core to the subcritical level, waiting for the nuclear reactor core **101** to reach an inactive state. In this example, the inactive state is reached within seven days. Step **510** can be skipped, but the NHS module **150** when transported will emit substantially more radiation and more preventative measures will need to be taken. Next in step **515**, or at the same time as steps **505** and **510**, the nuclear reactor shielding method **500** includes substantially filling a transport shield (TS) chamber **156** of the nuclear heat supply (NETS) module **150** of a nuclear reactor system **100** with a first moderating fluid **159**A. As noted above, the nuclear reactor system **100** includes the nuclear reactor core **101**.

[0168] Moving to step **520**, if the weight of the BOP module **170** causes the nuclear reactor system **100** to exceed the weight capacity limit of the land vehicle **501**, aircraft **502**, or watercraft **503**, or for safety or efficient logistics reasons, the nuclear reactor shielding method **500** can include after reducing the neutron flux of the nuclear reactor core **101** to a subcritical level, decoupling a balance-of-plant (BOP) module **170** from the NETS module **150**. In step **520**, assume that, for example, due to weight capacity issues of the land vehicle **501**, the BOP module **170** needs to be separated from the NETS module **150**. Alternatively, step **520** can occur before airlifting the NETS module **150** from the second location to a third location on a second trip, but after step **525**.

[0169] Continuing to step **525**, the nuclear reactor shielding method **500** includes transporting the NETS module **150** from a first location to a second location. The step **525** of transporting the NETS module **150** from the first location to the second location can include transporting the NETS module **150** from the first location to the second location on a first trip via land vehicle **501**, aircraft **502**, or watercraft **503**. For example, the NETS module **150** and/or the balance-of-plant (BOP) module **170** can be loaded onto a land vehicle **501**, aircraft **502**, or watercraft **503**, and transported from a first location to a second location on a first trip. Before step **525**, the nuclear reactor system **100** is placed in a packaged state, unless the BOP module **170** is being transported separately from the NETS module **150**. In examples where the nuclear reactor system **100** only takes a single trip over land or sea, step **545** can be skipped to. In examples where the nuclear reactor system **100** only takes a single trip over land or sea, and the BOP module **170** is transported with the NETS module **150**, step **545** can be skipped to, and step **550** can be omitted.

[0170] Continuing now to optional step **530**, if the weight of the first moderating fluid **159**A causes the nuclear reactor system **100** to exceed the weight capacity limit of a second aircraft, the nuclear reactor shielding method **500** can include substantially draining the TS chamber **156** of the first moderating fluid **159**A before transporting (e.g., airlifting) the NHS module **150**. Step **530** is optional and if weight capacity is not an issue, the first moderating fluid **159**A is not substantially drained from the TS chamber **156**. Step **520** preferably occurs before step **530** because the transport shield **155** will protect personnel decoupling the NHS module **150** from the BOP module **170**.

[0171] In step **535**, the nuclear reactor shielding method **500** includes transporting the NHS module **150** from the second location to a third location on a second trip. Typically, before airlifting the NHS module **150** from the second location to the third location on the flight, the nuclear reactor shielding method **500** implements step **520** of decoupling the balance-of-plant module **170** from the NHS module **170**. For example, step **535** can include airlifting the NHS module **150** from the second location to the third location on a second trip e.g., on a flight via aircraft **502**. Either using a second aircraft (with a potentially lower weight capacity than the first aircraft, vehicle **501** or watercraft **503**), or the same aircraft **502** before or after step **535**, step **540** of the nuclear reactor shielding method **500** can include transporting (e.g. airlifting) the BOP module **170** from the second location to the third location, for example, on another flight via aircraft **502**. Once the NHS module **150** flight lands, step **545** can occur, but optional step **541** occurs if optional step **530** occurred.

[0172] In optional step **541**, the nuclear reactor shielding method **500** includes substantially filling the TS chamber with the first moderating fluid **159**A, e.g., after transporting (e.g., airlifting) the NHS module **150**. Step **541** is optional and may only occur if step **530** occurs. This second substantial filling of the first moderating fluid **159**A can be literally the same fluid, transported on another flight, or a chemically equivalent fluid. A different fluid can also be used, so long as that fluid also has strong neutron moderating properties like the first moderating fluid **159**A.

[0173] The NHS module **150** can wait for the BOP module **170** to land at the third location. Once the NHS module **150** reaches the third location, step **545** occurs. In step **545**, the nuclear reactor shielding method **500** includes after transporting the NHS module **150**, substantially filling a module shadow shield (MSS) **158** chamber of a module shadow shield **157** with a second moderating fluid **159**B.

[0174] Moving now to step **550**, the nuclear reactor shielding method **500** includes after transporting the NHS module **150**, and before increasing the neutron flux of the nuclear reactor core **101** to the critical level, recoupling the balance-of-plant module **170** to the NHS module **150**. For example, step **550** can include after airlifting the balance-of-plant module **170** from the second location to the third location, recoupling the balance-of-plant module **170** to the NHS module **150**. Note that this step only occurs if the BOP module **170** was decoupled from the NHS module **150** in step **520**. At this point, the nuclear reactor system **100** is then placed in the deployed state. With a deployed NHS module **150**, in step **555**, the nuclear reactor shielding method **500** includes substantially draining the TS chamber **156** of the first moderating fluid **159**A. Finishing now in step **560**, the nuclear reactor shielding method **500** includes after substantially filling the MSS chamber **158** with the second moderating fluid **159**B, increasing the neutron flux of the nuclear reactor core **101** to a critical level. Soon after, the nuclear reactor core **101** will enter a critical state, and the BOP module **170** can produce electricity.

[0175] In some circumstances, steps can be skipped or performed out of order. In particular, the final draining of the TS chamber **156** in step **555** may be omitted. The MSS chamber **158** may be filled before taking the nuclear reactor system **100** on a trip in a land vehicle **501** or watercraft **503**, in order to protect crew who may be seated near the NHS module **150** for extended periods of time. Likewise, if weight limits allow, the MSS chamber **158** may be filled when the TS chamber **156** is drained to take a flight, in order to protect the aircraft crew who may be seated near the NHS module **150** for extended periods of time. Alternatively, the TS chamber **156** may be sectioned into separate sections that will allow only parts of the liquid moderator **159**A-B to remain during air transport to stay within weight limits and shield aircraft crew.

[0176] FIG. **6** is a table of weights **600** containing a projected or estimated weight of various components of the nuclear reactor system **100**. The table of weights **600** is important because a semi-trailer truck is generally only rated to transport 80,000 lbs., a C-130 only rated to transport 42,000 lbs., and a C-100 only rated to transport 51,050 lbs. Looking at the table of weights **600** it can be seen that the total nuclear reactor system mass **615** is projected to be 60,088 lbs. Meaning, the nuclear reactor system **100** can fit on a single semi-trailer truck trailer rated for 80,000 lbs., but is too heavy for even the C-100. However, the NHS module subtotal **605**, which is the weight of the NHS module **150**, is 44,217 lbs. and can be accommodated on a C-100. To fit within a C-130, the 7,714 lbs. of shielding (i.e., transport shield **155** and module shadow shield **157**) in the form of moderating fluids **159**A-B, can be partially or fully drained. Once 2,217 lbs. or more of shielding **155**, **157** in the form of moderating fluids **159**A-B are drained, the NHS module **150** can be transported by the C-130, as the NHS module **150** would then weigh 42,000 lbs. The minimum weight of the NHS module **150**, with all of the shielding **155**, **157** in the form of moderating fluids **159**A-B drained, is 36,503 lbs.

[0177] The BOP module subtotal **610**, which is the weight of the BOP module **170**, indicates that the BOP module should fit in a C-130 or C-100, with room to spare. Some of the drained moderating fluids **159**A-B can potentially be paired with the BOP module **170**, and the moderating fluids **159**A-B could be packaged with the BOP module **170** in a C-100 flight. This packaged moderating fluids **159**A-B could then be pumped back into the NHS module **150** upon arrival.

[0178] FIG. **7** is a relative photon dose in lead nitrate-saturated water heat map **700** of the photon dose received in different locations in the NHS module **150** when lead nitrate-saturated water is used to fill the TS chamber **156** as a moderating fluid **159**A, as compared to when water alone is used to fill the TS chamber **156** as a moderating fluid. Lead nitrate ($Pb(NO_3)_2$) is a good dopant for use with water, as lead nitrate is completely soluble in water. Lead nitrate effectively increases the density of water by about 50%, and adds a high Z material to water. Lead nitrate does not add a new material as an activation concern. A good moderating fluid **159**A-B will include a high-Z material, and will not be an activation concern. The solubility of lead nitrate in water ranges from 376 grams per liter (g/l) at 0 degrees Celsius, to 1270 g/l at 100 degrees Celsius. FIGS. **6** and **7** assume a solubility of 1000 g/l, which results in a lead nitrate density in water of 1.63 g/cc. Zinc Bromide (ZnBr2) is another common dopant that allows for higher dopant density, at the expense being of a lower Z-material. In a warm reactor, a zinc bromide density in water of 5 g/cc is achievable.

[0179] In FIG. **7**, the relative photon dose in lead nitrate-saturated water heat map **700** is representative of a nuclear reactor **107** which has been active for four years, and then taken subcritical and inactive for seven days, allowing for seven days of decay. The dose plane, which is the exterior of the nuclear reactor core, is at (0,0). The units of distance from reactor core vertically **715** are in centimeters, and the units of distance from reactor core horizontally **710** are also in centimeters. It can be seen at (0,0), and in the area bounded by (0, 100), (200, 100), (200, −100), and (0, −100) that there is no improvement in the relative photon dose of lead nitrate saturated water compared to water **705**. This is because the box constitutes the nuclear reactor core **101** itself. Moving left, it can be seen that the relative photon dose of lead nitrate saturated water compared to water **705** decreases, ultimately to around 10^{-5} at 400 centimeters to the left. Additionally, at the top, it can be seen that at around (100, 125) the relative photon dose of lead nitrate saturated water compared to water **705** is 0.2, or the lead nitrate water dose is one fifth of the dose of water. If zinc bromide were to be used instead, the zinc bromide-saturated water relative dose as compared to water would be 0.0006, or the water dose is 1,667 times larger than the zinc bromide-saturated water dose at that distance.

[0180] FIG. **8** is an absolute photon dose in lead nitrate-saturated water heat map **800** of the photon dose received in different locations in the NHS module **150** when lead nitrate-saturated is used to fill the transport shield chamber **156**. In FIG. **8**, the actual photon dose experienced when the transport shield chamber **156** is filled with water is shown. At (−50,0), approximately where the exterior surface of the reactor container **151** would be, the lead nitrate-saturated water reduced the photon dose by a factor of 5 to around 10 rem/hr. By using zinc bromide at 5 g/cc the photon dose can be reduced by an additional factor of 20, resulting in a 0.5 rem/hr dose at the exterior surface of the reactor container **151**.

[0181] The scope of protection is limited solely by the claims that now follow. That scope is intended and should be interpreted to be as broad as is consistent with the ordinary meaning of the language that is used in the claims when interpreted in light of this specification and the prosecution history that follows and to encompass all structural and functional equivalents. Notwithstanding, none of the claims are intended to embrace subject matter that fails to satisfy the requirement of Sections 101, 102, or 103 of the Patent Act, nor should they be interpreted in such a way. Any unintended embracement of such subject matter is hereby disclaimed.

[0182] It will be understood that the terms and expressions used herein have the ordinary meaning as is accorded to such terms and expressions with respect to their corresponding respective areas of inquiry and study except where specific meanings have otherwise been set forth herein. Relational terms such as first and second and the like may be used solely to distinguish one entity or action from another without necessarily requiring or implying any actual such relationship or order between such entities or actions. The terms “comprises,” “comprising,” “includes,” “including,” “has,” “having,” “containing,” “contain”, “contains,” “with,” “formed of,” or any other variation thereof, are intended to cover a non-exclusive inclusion, such that a process, method, article, or apparatus that comprises or includes a list of elements or steps does not include only those elements or steps but may include other elements or steps not expressly listed or inherent to such process, method, article, or apparatus. An element preceded by “a” or “an” does not, without further constraints, preclude the existence of additional identical elements in the process, method, article, or apparatus that comprises the element.

[0183] In addition, in the foregoing Detailed Description, it can be seen that various features are grouped together in various examples for the purpose of streamlining the disclosure. This method of disclosure is not to be interpreted as reflecting an intention that the claimed examples require more features than are expressly recited in each claim. Rather, as the following claims reflect, the subject matter to be protected lies in less than all features of any single disclosed example. Thus, the following claims are hereby incorporated into the Detailed Description, with each claim standing on its own as a separately claimed subject matter.

[0184] While the foregoing has described what are considered to be the best mode and/or other examples, it is understood that various modifications may be made therein and that the subject matter disclosed herein may be implemented in various forms and examples, and that they may be applied in numerous applications, only some of which have been described herein. It is intended by the following claims to claim any and all modifications and variations that fall within the true scope of the present concepts.

1. A nuclear reactor system, comprising:

a nuclear heat supply (NHS) module including:

a reactor container that includes a reactor cavity;

a pressure vessel within the reactor container, wherein the pressure vessel includes an interior wall;

a nuclear reactor core located within the pressure vessel, wherein the nuclear reactor core includes a plurality of fuel elements and at least one moderator element;

an in-vessel neutron shield located on the interior wall of the pressure vessel to surround the nuclear reactor core;

an in-vessel shadow shield inside the pressure vessel;

a transport shield (TS) within the reactor container and outside the pressure vessel that includes a TS chamber within the reactor cavity for containing a first moderating fluid; and

a module shadow shield (MSS) within the reactor container and outside the pressure vessel that includes an MSS chamber within the reactor cavity for containing a second moderating fluid.

2. The nuclear reactor system of claim **1**, wherein:

the transport shield further includes the first moderating fluid substantially filling the TS chamber; and

the module shadow shield further includes the second moderating fluid substantially filling the MSS chamber.

3. The nuclear reactor system of claim **1**, wherein:

the NHS module further includes an intermediate heat exchanger and a gas circulator; and

the heat exchanger is thermally coupled to the nuclear reactor core.

4. The nuclear reactor system of claim **1**, wherein:

the transport shield further includes the first moderating fluid; and

the first moderating fluid substantially fills the TS chamber.

5. The nuclear reactor system of claim **4**, wherein:

the NHS module includes an active state and an inactive state;

a roentgen equivalent man (rem) dose outside the NHS module induced by the NHS module while the NHS module is in the inactive state is less than 50 rem per hour (rem/hr); and

the first moderating fluid includes water (H_2O).

6. The nuclear reactor system of claim **4**, wherein:

the NHS module includes an active state and an inactive state;

a roentgen equivalent man (rem) dose outside the NHS module induced by the NHS module while the NHS module is in the inactive state is less than 10 rem per hour (rem/hr); and

the first moderating fluid includes water (H_2O), and the first moderating fluid contains a concentration of $Pb(NO_3)_2$ of approximately 1.63 grams per cubic centimeter (g/cc) or greater.

7. The nuclear reactor system of claim **4**, wherein:

the NHS module has an active state and an inactive state;

a roentgen equivalent man (rem) dose outside the NHS module induced by the NHS module while the NHS module is in the inactive state is less than 0.5 rem per hour (rem/hr); and

the first moderating fluid includes water (H_2O), and the first moderating fluid contains a concentration of $ZnBr_2$ of approximately 5 grams per cubic centimeter (g/cc) or greater.

8. The nuclear reactor system of claim **1**, wherein:

module shadow shield further includes the second moderating fluid; and

the second moderating fluid substantially fills the MSS chamber.

9. The nuclear reactor system of claim **1**, wherein:

the plurality of fuel elements emit a plurality of radiation particles;

the in-vessel shadow shield initially blocks a first radiation particle of the plurality of radiation particles.

10. The nuclear reactor system of claim **9**, wherein:

the in-vessel neutron shield blocks a second radiation particle of the plurality of radiation particles that passes through the in-vessel shadow shield.

11. The nuclear reactor system of claim **9**, wherein:

the transport shield blocks a third radiation particle of the plurality of radiation particles that passes through the in-vessel shadow shield and the in-vessel neutron shield.

12. The nuclear reactor system of claim **9**, wherein:

the module shadow shield blocks a fourth radiation particle of the plurality of radiation particles that passes through the in-vessel shadow shield, the in-vessel neutron shield, and the transport shield.

13. The nuclear reactor system of claim **1**, further comprising:

a balance-of-plant module disposed outside the NHS module;

wherein:

the reactor container houses the transport shield, the module shadow shield, the pressure vessel, the in-vessel shadow shield, the nuclear reactor core, and the in-vessel neutron shield;

the balance-of-plant module includes turbomachinery, a generator, and a reactor control system.

14. The nuclear reactor system of claim **13**, wherein:

the first moderating fluid blocks a radiation particle to prevent the radiation particle from traveling to the balance-of-plant module.

15. The nuclear reactor system of claim **13**, wherein:

the second moderating fluid blocks a radiation particle to prevent the radiation particle from traveling to the balance-of-plant module.

16. The nuclear reactor system of claim **1**, wherein:

the in-vessel shadow shield, the in-vessel neutron shield, the first moderating fluid, and the second moderating fluid include one or more neutron absorbing materials.

17. The nuclear reactor system of claim **1**, wherein:

the in-vessel neutron shield is formed of a composite material or a multi-layered material with a neutron moderator and a neutron absorbing material enriched in specific isotopes or natural isotopic composition;

the first moderating fluid includes a hydrogen-dense liquid;

the second moderating fluid includes water (H_2O).

18. The nuclear reactor system of claim **17**, wherein:

the neutron moderator includes metal hydrides, polyethylene, plastics, beryllium bearing compounds, or a combination thereof

19. The nuclear reactor system of claim **17**, wherein:

the neutron absorbing material includes boron, boron carbide, metal boride, gadolinium, europium, tungsten, or a combination thereof

20. The nuclear reactor system of claim **1**, wherein:

the in-vessel neutron shield is formed of two or more neutron absorbing materials, and the two or more neutron absorbing materials include a near black neutron absorbing material and a gray neutron absorbing material.

21. A nuclear reactor deployment method, comprising steps of:

substantially filling a transport shield (TS) chamber of a nuclear heat supply (NHS) module with a first moderating fluid, wherein the NHS module includes a nuclear reactor core;

transporting the NHS module from a first location to a second location;

coupling the NHS module to ground in the second location; and

increasing a neutron flux of the nuclear reactor core to a critical level.

22. The nuclear reactor deployment method of claim **21**, further comprising a step of:

after transporting the NHS module, substantially filling a module shadow shield (MSS) chamber of the NHS module with a second moderating fluid;

wherein the step of increasing the neutron flux of the nuclear reactor core to the critical level occurs after the step of substantially filling the MSS chamber with the second moderating fluid.

23. A nuclear reactor shielding method, comprising steps of:

substantially filling a transport shield (TS) chamber of a nuclear heat supply (NHS) module of a nuclear reactor system with a first moderating fluid, wherein the NHS module includes a nuclear reactor core;

transporting the NHS module from a first location to a second location; and

substantially draining the TS chamber of the first moderating fluid.

24. The nuclear reactor shielding method of claim **23**, further comprising steps of:

before transporting the NHS module, reducing a neutron flux of the nuclear reactor core to a subcritical level; and

after transporting the NHS module, substantially filling a module shadow shield (MSS) chamber of a module shadow shield with a second moderating fluid.

25. The nuclear reactor shielding method of claim **24**, further comprising a step of:

after substantially filling the MSS chamber with the second moderating fluid, increasing the neutron flux of the nuclear reactor core to a critical level.

26. The nuclear reactor shielding method of claim **25**, further comprising steps of:

after reducing the neutron flux of the nuclear reactor core to a subcritical level, and before transporting the NHS module, decoupling a balance-of-plant module from the NHS module;

after transporting the NHS module, and before increasing the neutron flux of the nuclear reactor core to the critical level, recoupling the balance-of-plant module to the NHS module.

27. The nuclear reactor shielding method of claim **26**, further comprising a step of:

after reducing the neutron flux of the nuclear reactor core to the subcritical level, waiting for the nuclear reactor core to reach an inactive state.

28. The nuclear reactor shielding method of claim **23**, wherein:

the step of transporting the NHS module from the first location to the second location includes transporting the NHS module from the first location to the second location on a first trip via land vehicle, aircraft, or watercraft.

29. The nuclear reactor shielding method of claim **23**, further comprising steps of:

airlifting the NHS module from the second location to a third location on a flight via aircraft;

substantially draining the TS chamber of the first moderating fluid before airlifting the NHS module; and

substantially filling the TS chamber with the first moderating fluid after airlifting the NHS module.

30. The nuclear reactor shielding method of claim **29**, further comprising steps of:

before airlifting the NHS module from the second location to the third location on the flight, decoupling a balance-of-plant module from the NHS module;

airlifting the balance-of-plant module from the second location to the third location on another flight; and

after airlifting the balance-of-plant module from the second location to the third location, recoupling the balance-of-plant module to the NHS module.

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