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(54) **SERVICING A NUCLEAR REACTOR MODULE**

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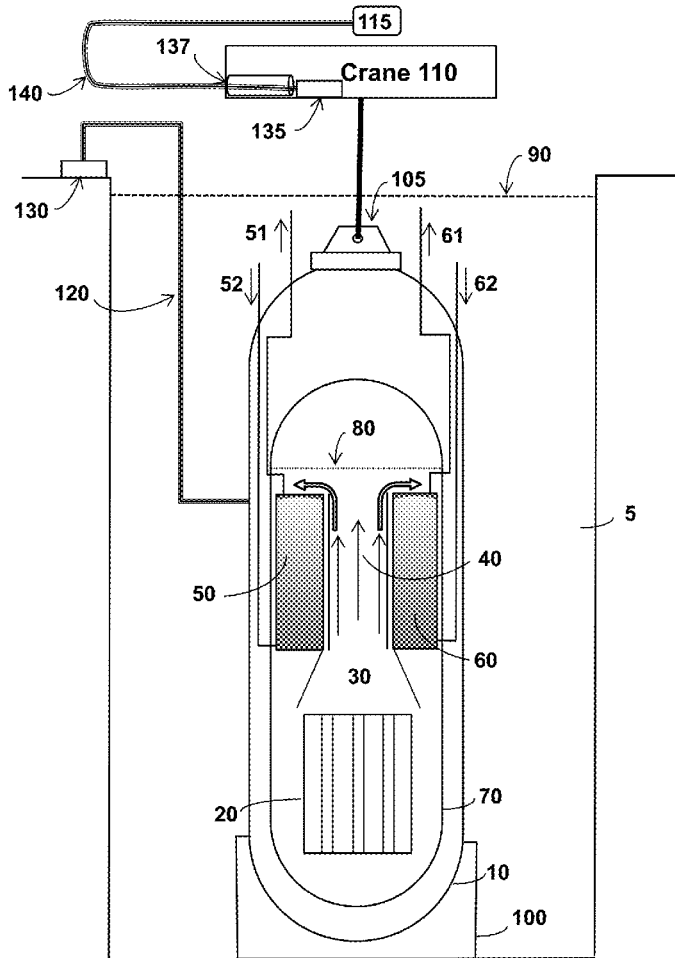
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(57) **ABSTRACT**

**Related U.S. Application Data**

(62) Division of application No. 14/350,689, filed on Apr. 9, 2014, now Pat. No. 9,697,917, filed as application No. PCT/US2012/027525 on Mar. 2, 2012.

A system for servicing a nuclear reactor module comprises a crane operable to attach to the nuclear reactor module, wherein the crane includes provisions for routing signals from one or more sensors of the nuclear reactor module to one or more sensor receivers.



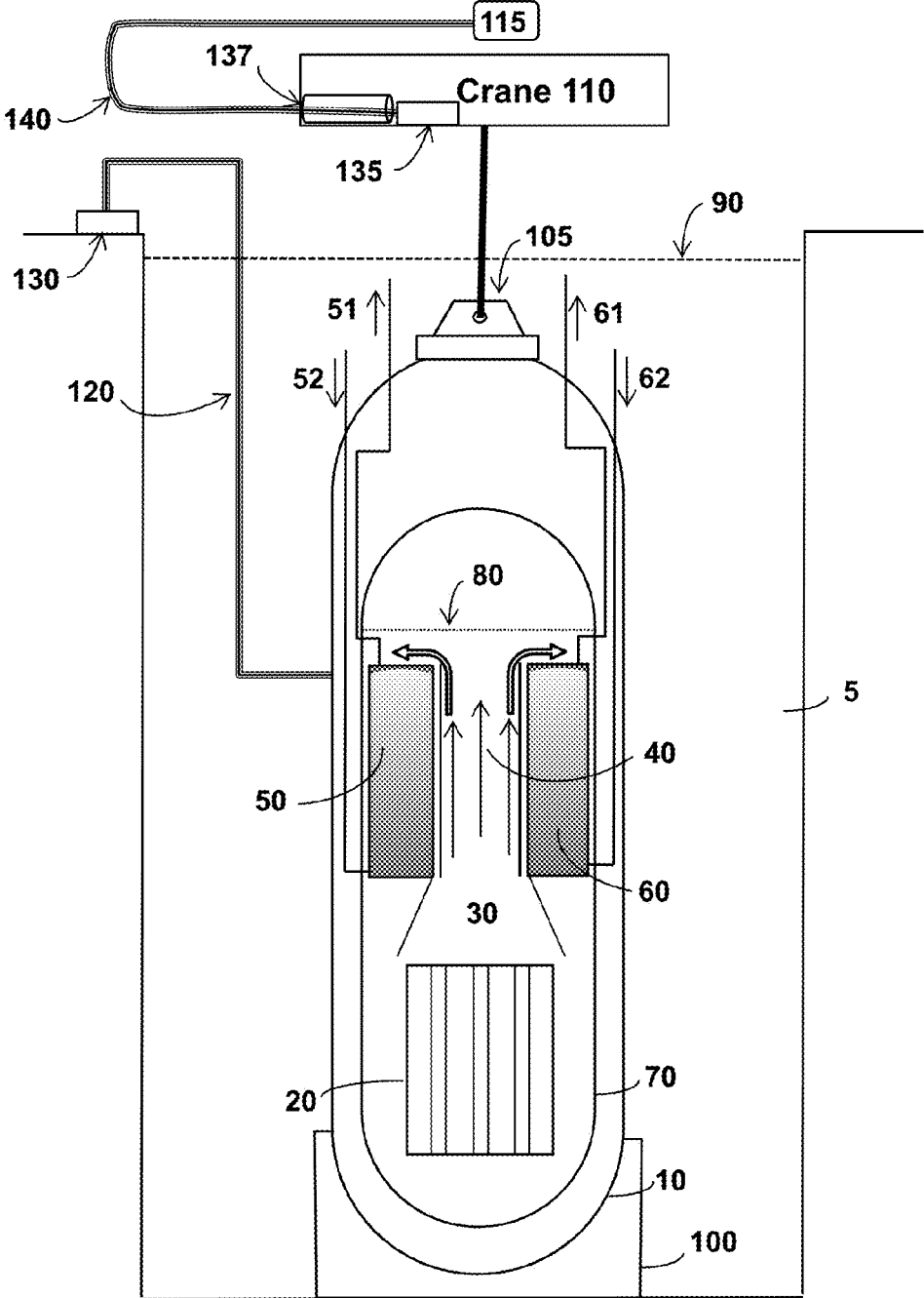


Figure 1

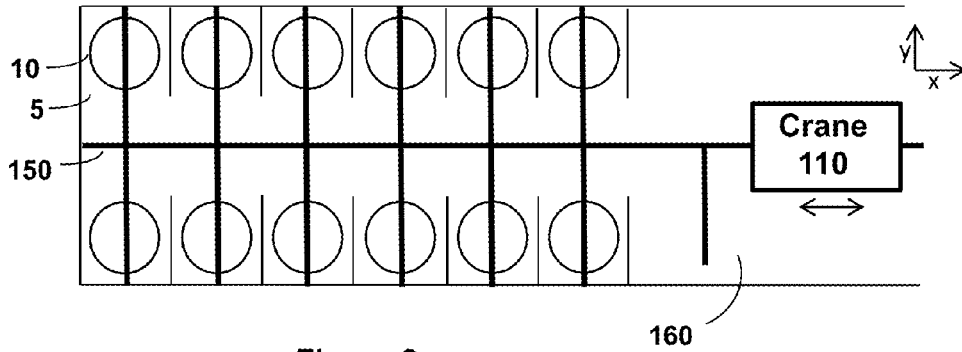


Figure 2

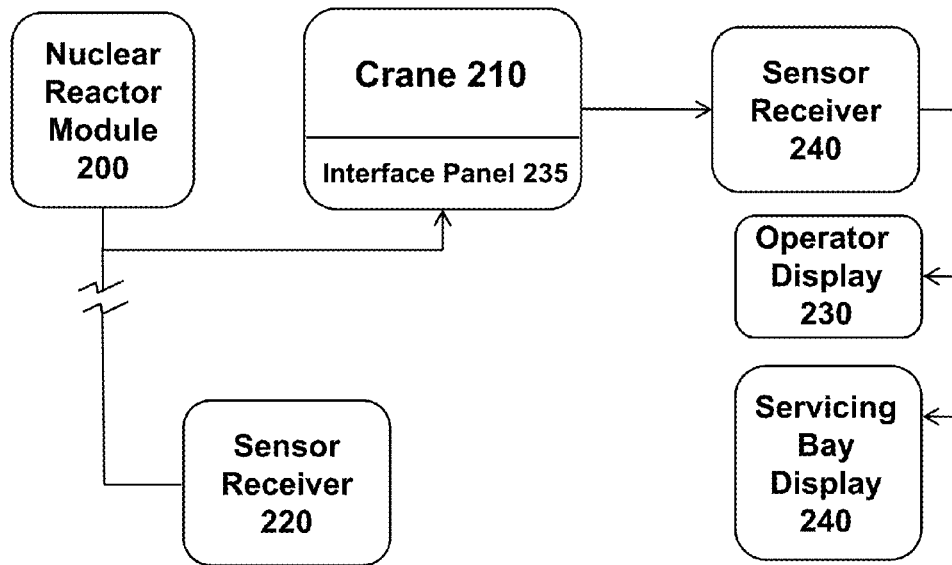


Figure 3

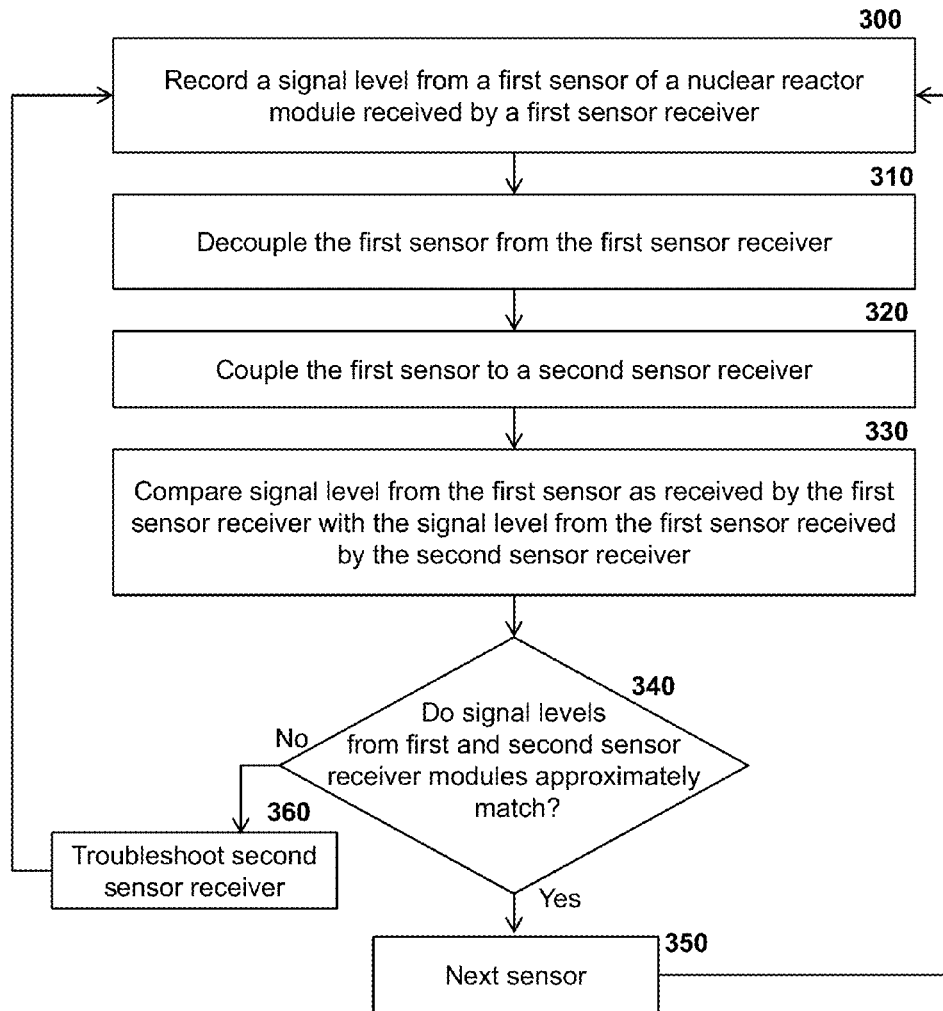


Figure 4

## SERVICING A NUCLEAR REACTOR MODULE

### PRIORITY CLAIM

**[0001]** This application is a 35 U.S.C. §371 national stage application of International Application No. PCT/US2012/027525, filed Mar. 2, 2012, the entire contents of which is incorporated herein by reference.

### BACKGROUND OF THE INVENTION

**[0002]** In a nuclear reactor, a core of nuclear material is confined to a small volume internal to the reactor so that a reaction may occur. In many instances, a controlled nuclear reaction may persist for an extended period of time, such as several years or even longer, before refueling of the nuclear core is required. Accordingly, when used as a source of heat for converting quantities of water into steam, a properly designed nuclear reactor may provide a long-lasting, carbon-free, and highly reliable source of energy.

**[0003]** Relatively small, modular or standalone nuclear reactors may be built in a manufacturing environment and transported to a reactor bay at a power generating facility that is far removed from the manufacturing location. A group of modular nuclear reactors of the same design may be aggregated at the power generating facility to provide a multiple of the power output of a single, standalone reactor module. This allows additional modules to be placed into service over time so that the output of a power generating station may be incrementally increased to keep pace with a growing demand for electrical power. For example, a power generating station that initially employs two nuclear reactor modules servicing a small town may incorporate additional modules in several increments as the town increases in size and the demand for electrical power increases correspondingly.

**[0004]** When refueling a nuclear reactor module, a servicing crew may disassemble various reactor components so that spent fuel can be removed and stored in a spent fuel pool. In addition to loading fresh fuel into the reactor, the servicing crew may be required to perform additional maintenance operations. These operations may include inspecting the reactor module components for excessive wear, leak testing of components that operate under pressure, and inspecting structural and load-bearing components for stress cracks. In some instances, it may be useful to perform such servicing at a location separate from the reactor's normal operating bay.

### SUMMARY OF THE INVENTION

**[0005]** In a general embodiment, a method of servicing a nuclear reactor module includes decoupling one or more sensors of the nuclear reactor module from a first sensor receiver, followed by coupling the one or more sensors of the nuclear reactor module to a second sensor receiver, and moving the nuclear reactor module from a first location, such as a reactor bay, to a second location, such as a servicing area.

**[0006]** A first aspect combinable with the general embodiment includes displaying a representation of at least one signal from the one or more sensors of the nuclear reactor module on a display located within a servicing area.

**[0007]** In a second aspect combinable with any of the previous aspects, the representation of the at least one signal

from the one or more sensors of the nuclear reactor module may be displayed on a display located in a reactor operator area.

**[0008]** Include transmitting signals from the one or more sensors of the nuclear reactor module through a conduit located on a crane coupled to the nuclear reactor module to the second receiver.

**[0009]** In an aspect, which may be combinable with any previous aspect, the decoupling and coupling occur in a sensor-by-sensor manner wherein a first sensor of two or more sensors of the nuclear reactor module is decoupled from the first sensor receiver and coupled to the second sensor receiver prior to a second sensor of the two or more sensors of the nuclear reactor module being decoupled from the first sensor receiver.

**[0010]** In an aspect of an embodiment, the method may further include comparing a signal level from the first sensor received by the first sensor receiver with a signal level from the first sensor received by the second sensor receiver. Wherein, in an aspect that may be combinable with any previous aspect, if the signal level from the first sensor received by the first sensor receiver approximates the signal level from the first sensor received by the second sensor receiver, the method may include decoupling a second sensor from the first sensor receiver. In an aspect, which may be combinable with any previous aspect, the method may further include approximately continuously monitoring the nuclear reactor module during the moving using the second sensor receiver.

**[0011]** In another embodiment, a system for servicing a nuclear reactor module includes a crane operable to couple to the nuclear reactor module, wherein the crane includes a conduit for routing signals from one or more sensors of the nuclear reactor module to one or more sensor receivers. In an aspect, which may be combinable with any previous aspect, the crane may include a drive mechanism operable to move the nuclear reactor module from a reactor bay to a servicing area. In an aspect, which may be combinable with any previous aspect, the drive mechanism may move the nuclear reactor module in a first direction and a second direction approximately orthogonal to the first direction. In an aspect, which may be combinable with any previous aspect, the crane may further include at least one support bracket for mounting one or more sensor signal receivers operable to receive signals from one or more sensors within the nuclear reactor module. In an aspect, which may be combinable with any previous aspect, the system may further include a display operable to display representations of signals from the one or more sensors of the nuclear reactor module in a servicing area and may further include a display operable to display representations of signals from the one or more sensors of the nuclear reactor module in an operator area.

**[0012]** In another general embodiment, an apparatus includes a fastener operable to couple to a nuclear reactor module, an interface panel for accepting one or more signals from the nuclear reactor module, and a device operable to move the nuclear reactor module in a lateral direction.

**[0013]** In a first aspect combinable with the general embodiment, the device is operable to move the nuclear reactor module in the lateral direction operates to move the nuclear reactor module in a first direction and a second direction approximately orthogonal to the first direction.

[0014] A second aspect combinable with any of the previous aspects includes a track for maintaining a minimum bend radius of at least one conductor conveying the one or more signal.

[0015] A third aspect, which may be combinable with any of the previous aspects, includes a controller for assisting and relocating a nuclear reactor module to a lower containment vessel removal fixture located in a servicing area. A fourth aspect, which may be combinable with any of the previous aspects, includes a conduit operable to hold a receiver that receives signals from one or more sensors located within the nuclear reactor module.

#### BRIEF DESCRIPTION OF THE DRAWINGS

[0016] Preferred and alternative examples of the present invention are described in detail below with reference to the following drawings:

[0017] FIG. 1 shows a crane fastened to a nuclear reactor module according to an example implementation.

[0018] FIG. 2 is a top view showing 12 nuclear reactor modules that may be moved within a power generating station using an overhead crane according to an example implementation.

[0019] FIG. 3 is a diagram of a nuclear reactor module coupled to sensor receivers and displays according to an example implementation.

[0020] FIG. 4 is a flowchart for a method for servicing a nuclear reactor module according to an example implementation.

#### DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0021] Methods, apparatuses, and systems for servicing a nuclear reactor module are described. In one implementation, pressure, temperature, source range neutron count, and other operating parameters of the nuclear reactor module may be monitored while the module is in operation. In preparation for a refueling or other servicing operation, a first sensor receiver located outside of the nuclear reactor module may be decoupled from sensors located within the reactor module. The sensors within the nuclear reactor module may then be coupled to a second sensor receiver by way of an electrical, fiber-optic, or other type of bundle routed along a routing path that is attached to, or included within, an overhead crane. Upon coupling of the sensors within the nuclear reactor module to the second sensor receiver, the overhead crane may be activated to move the module from an operating bay to a servicing area.

[0022] In another implementation, decoupling and coupling of sensors within the nuclear reactor module may occur in a sensor-by-sensor manner in which an output signal level from a first sensor located within a nuclear reactor module may be recorded prior to decoupling the first sensor from a first sensor receiver. The first sensor may then be coupled to a second sensor receiver. The output signal level recorded by the first sensor receiver may then be compared with the output signal level recorded by the second sensor receiver to determine if an error condition in the first or the second sensor receiver is present. An error condition may also result from a defect in wire or fiber optic cable bundle used to couple a sensor to a sensor receiver. In the event that an error condition is not present, the comparison process may be repeated for a second sensor located

within a reactor module beginning with recording an output signal level from the second sensor, decoupling the second sensor from a first sensor receiver, and comparing the output signal level received by the first sensor receiver with the output signal level received by the second sensor receiver to determine if an error condition is present.

[0023] In an implementation, an overhead crane may include an interface panel that receives output signals from two or more sensors within the nuclear reactor module prior to movement of the module. In this implementation, an operator may decouple the two or more sensors, as a group, from a first sensor receiver and couple the group of one or more sensors to a second sensor receiver by way of the interface panel. This allows the group of two or more sensors to be decoupled nearly simultaneously from a first sensor receiver and quickly coupled to a second sensor receiver.

[0024] As used herein and as described in greater detail in subsequent sections, embodiments of the invention may include various nuclear reactor technologies. Thus, some implementations may include reactor technologies that employ pressurized water, which may include boron and/or other chemicals or compounds in addition to water, liquid metal cooling, gas cooling, molten salt cooling, and/or other cooling methods. Implementations may also include nuclear reactors that employ uranium oxides, uranium hydrides, uranium nitrides, uranium carbides, mixed oxides, and/or other types of radioactive fuel. It should be noted that embodiments are not limited to any particular type of reactor cooling mechanism, nor to any particular type of fuel employed to produce heat within or associated with a nuclear reaction.

[0025] FIG. 1 shows a crane (110) fastened to a nuclear reactor module according to an implementation. In FIG. 1, reactor core 20 is positioned at a bottom portion of a cylinder-shaped or capsule-shaped reactor vessel 70. Reactor core 20 comprises a quantity of fissile material that produces a controlled reaction that may occur over a period of perhaps several years or longer. Although not shown explicitly in FIG. 1, control rods may be employed to control the rate of fission within reactor core 20. Control rods may comprise silver, indium, cadmium, boron, cobalt, hafnium, dysprosium, gadolinium, samarium, erbium, and europium, or their alloys and compounds. However, these are merely a few of many possible control rod materials.

[0026] In implementations, a cylinder-shaped or capsule-shaped containment vessel 10 surrounds reactor vessel 70 and is partially or completely submerged in a reactor pool, such as below waterline 90, within reactor bay 5. The volume between reactor vessel 70 and containment vessel 10 may be partially or completely evacuated to reduce heat transfer from reactor vessel 70 to the reactor pool. However, in other embodiments, the volume between reactor vessel 70 and containment vessel 10 may be at least partially filled with a gas and/or a liquid that increases heat transfer between the reactor and containment vessels. Containment vessel 10 rests on skirt 100 at the base of reactor bay 5.

[0027] In a particular implementation, reactor core 20 is submerged within a liquid, such as water, which may include boron or other additive, which rises into channel 30 after making contact with a surface of the reactor core. In FIG. 1, the upward motion of heated coolant is represented by arrows 40 within channel 30. The coolant travels over the top of heat exchangers 50 and 60 and is drawn downward by way of convection along the inner walls of reactor vessel 70

thus allowing the coolant to impart heat to heat exchangers **50** and **60**. After reaching a bottom portion of the reactor vessel, contact with reactor core **20** results in heating the coolant, which again rises through channel **30**.

[0028] Although heat exchangers **50** and **60** are shown as two distinct elements in FIG. 1, heat exchangers **50** and **60** may represent any number of helical coils that wrap around at least a portion of channel **30**. In another implementation, a different number of helical coils may wrap around channel **30** in an opposite direction, in which, for example, a first helical coil wraps helically in a counterclockwise direction, while a second helical coil wraps helically in a clockwise direction. However, nothing prevents the use of differently-configured and/or differently-oriented heat exchangers and embodiments are not limited in this regard. Further, although water line **80** is shown as being positioned just above upper portions of heat exchangers **50** and **60**, in other implementations, reactor vessel **70** may include lesser or greater amounts of water.

[0029] In FIG. 1, normal operation of the nuclear reactor module proceeds in a manner wherein heated coolant rises through channel **30** and makes contact with heat exchangers **50** and **60**. After contacting heat exchangers **50** and **60**, the coolant sinks towards the bottom of reactor vessel **70** in a manner that induces a thermal siphoning process. In the example of FIG. 1, coolant within reactor vessel **70** remains at a pressure above atmospheric pressure, thus allowing the coolant to maintain a high temperature without vaporizing (i.e. boiling).

[0030] As coolant within heat exchangers **50** and **60** increases in temperature, the coolant may begin to boil. As the coolant within heat exchangers **50** and **60** boils, vaporized coolant, such as steam moving upward as indicated by arrows **51** and **61**, may be used to drive one or more turbines that convert the thermal potential energy of steam into electrical energy. After condensing, coolant is returned to locations near the base of heat exchangers **50** and **60** as shown by arrows **52** and **62**.

[0031] During normal operation of the reactor module of FIG. 1, various performance parameters of the reactor may be monitored by way of sensors positioned at various locations within the module. In the example of FIG. 1, sensors within the reactor module may measure reactor system temperatures, reactor system pressures, containment vessel pressure, reactor primary and/or secondary coolant levels, reactor core neutron flux, and/or reactor core neutron fluence. Signals that represent these measurements may be reported external to the reactor module by way of bundle **120** to reactor bay interface panel **130**. In one implementation, bundle **120** represents a multi-conductor cable. In another implementation, bundle **120** may represent a single- or multi-fiber optical transmission medium.

[0032] In the implementation of FIG. 1, crane **110** is shown as being positioned above reactor bay **5**. Crane **110** includes a cable or other device that fastens to attachment **105**, which may include a lifting lug, eyelet, or other device that couples an upper portion of containment vessel **10** to crane **110**. Thus, crane **110** operates to lift and suspend the nuclear reactor module of FIG. 1 in reactor bay **5**. In implementations, crane **110** includes a motor or other drive mechanism that enables the crane to move laterally so as to allow the nuclear reactor module to be repositioned.

[0033] Prior to the upward or lateral movement of the nuclear reactor module of FIG. 1, a connector at an end of

bundle **120** may be detached from reactor bay interface panel **130**, thereby decoupling one or more sensors operating within the reactor module from a first sensor receiver. In an implementation, bundle **120** may be attached to crane interface panel **135**, thereby coupling the one or more sensors operating within the reactor module to a second sensor receiver by way of crane interface panel **135**. In FIG. 1, crane **110** includes provisions for routing bundle **140** through, for example, conduit **137**, along an outside surface of at least a portion of the crane, or within the structure of crane **110** for connection to receptacle **115**. In an implementation, crane **110** includes a track for maintaining a minimum bend radius of bundle **140** while crane **110** moves from side to side. However, in other implementations, crane **110** may include a rack for festooning or hanging portions of bundle **140** from a surface.

[0034] In an implementation, crane interface panel **135** may include, for example, at least one set of brackets or a conduit that holds one or more signal conditioning units or other sensor receivers that function to convert electrical and/or optical signals from sensors located within the reactor module of FIG. 1. In one possible example, bundle **120** may carry low-voltage signals from a thermocouple located within reactor vessel **70**. Accordingly, crane interface panel **135** may include one or more of an amplifier, an analog to digital converter, and a multiplexer that converts an electrical signal conveyed on a conductor to an optical signal transmitted along a single-fiber or multi-fiber optical transmission medium represented by bundle **140**.

[0035] FIG. 2 is a top view showing **12** nuclear reactor modules that may be moved within a power generating station using an overhead crane according to an implementation. In FIG. 2, containment vessel **10** of a nuclear reactor module is shown within reactor bay **5**. Crane **110** moves in both an X and Y direction along track **150**, wherein X and Y represent orthogonal directions in a Cartesian coordinate system. In this manner, crane **110** may include a control capable of relocating or assisting in relocating a nuclear reactor module from reactor bay **5**, along track **150**, to servicing area **160** where the nuclear reactor module may be placed on or proximate with a lower containment vessel removal fixture. Prior to movement of a nuclear reactor module, sensors located within a reactor module may be decoupled from a first sensor receiver to a second sensor receiver by way of detaching a connector from a reactor bay interface panel to a crane interface panel, such as crane interface panel **135** of FIG. 1.

[0036] FIG. 3 is a diagram of a nuclear reactor module coupled to sensor receivers and displays according to an implementation. In FIG. 3, sensors from nuclear reactor module **200** have been decoupled from sensor receiver **220** and operator display **230**. In an implementation, operator display **230** represents one or more displays located in a reactor operator area. After such decoupling, sensors located within nuclear reactor module **200** are coupled to a second sensor receiver (**240**) by way of interface panel **235** of crane **210**.

[0037] After nuclear reactor module **200** has been coupled to sensor receiver **240**, module **200** may then be relocated from, for example, a reactor operating bay to a servicing area. While module **200** is in transit from the reactor bay to the servicing area, sensors monitoring various parameters may continue to provide output signals representing the conditions within the module. Representations of these

parameters may be displayed on servicing area display **240**, thus providing real-time monitoring of conditions within reactor module **200** to a servicing crew. Additionally, representations of output signals reflecting the conditions within reactor module **200** may be displayed on operator display **230**. These representations on operator display **230** may be accompanied by an identifier indicating that the module is “in transit” between and operating bay to a servicing area.

**[0038]** FIG. 4 is a flowchart for a method for servicing a nuclear reactor module according to an implementation. The device of FIG. 3 may be suitable for performing the method of FIG. 4, although nothing prevents performing the method of FIG. 4 using alternate arrangements of components in other embodiments. Implementations may include blocks in addition to those shown and/or described in FIG. 4, fewer blocks, blocks occurring in an order different from FIG. 4, or any combination thereof. In the method described in FIG. 4, sensors are coupled from a first receiver to a second receiver in a sensor-by-sensor manner as described below. In an implementation, at least a portion of the method of FIG. 4 may be performed by a controller or other hardware or software based processing resource.

**[0039]** FIG. 4 begins at block **300**, which includes recording a signal level from a first sensor of a nuclear reactor module received by a first sensor receiver. At **310**, the first sensor may be decoupled from the first sensor receiver. At **320**, the first sensor may be coupled to a second sensor receiver. At **330**, a signal level from the first sensor as received by the first sensor receiver is compared with the signal level from the first sensor has received by the second sensor.

**[0040]** At **340**, signal levels as received by first and second sensor receiver modules are compared. In the event that the comparison of block **340** indicates that the signal levels are within a limit, block **350** is performed in which a signal output from the next sensor received by a first sensor receiver module may be recorded. In the event that the comparison of block **340** indicates that the signal levels are outside of a limit, block **360** may be performed in which a troubleshooting routine may be performed.

**[0041]** While several examples have been illustrated and described, it will be understood by those skilled in the art that various other modifications may be made, and equivalents may be substituted, without departing from the scope of the following claims.

1. A method of servicing a nuclear reactor module, comprising:

decoupling one or more sensors of the nuclear reactor module from a first sensor receiver;

coupling the one or more sensors of the nuclear reactor module to a second sensor receiver; and

moving the nuclear reactor module from a reactor bay to a servicing area.

2. The method of claim 1, wherein the moving occurs after coupling the one or more sensors of the nuclear reactor module to the second sensor receiver.

3. The method of claim 1, additionally comprising displaying a representation of at least one signal from the one or more sensors of the nuclear reactor module on a display located within a servicing area.

4. The method of claim 3, additionally comprising displaying the representation of the at least one signal from the

one or more sensors of the nuclear reactor module on a display located in a reactor operator area.

5. The method of claim 1, wherein the coupling further comprises transmitting signals from the one or more sensors of the nuclear reactor module through a conduit located on a crane coupled to the nuclear reactor module to the second receiver.

6. The method of claim 1, wherein the decoupling and coupling occur in a sensor-by-sensor manner wherein a first sensor of two or more sensors of the nuclear reactor module is decoupled from the first sensor receiver and coupled to the second sensor receiver prior to a second sensor of the two or more sensors of the nuclear reactor module being decoupled from the first sensor receiver.

7. The method of claim 6, further comprising comparing a signal level from the first sensor received by the first sensor receiver with a signal level from the first sensor received by the second sensor receiver.

8. The method of claim 7, wherein if the signal level from the first sensor received by the first sensor receiver approximates the signal level from the first sensor received by the second sensor receiver, decoupling a second sensor from the first sensor receiver.

9. The method of claim 1, further comprising approximately continuously monitoring the nuclear reactor module during the moving using the second sensor receiver.

10. (canceled)

11. (canceled)

12. (canceled)

13. (canceled)

14. (canceled)

15. (canceled)

16. (canceled)

17. (canceled)

18. (canceled)

19. (canceled)

20. (canceled)

21. A method of servicing a nuclear reactor module, comprising:

decoupling one or more sensors of the nuclear reactor module from a first sensor receiver, the first sensor receiver being connected to a reactor bay interface panel proximate a reactor bay;

coupling the one or more sensors of the nuclear reactor module to a second sensor receiver, the second sensor receiver being connected to a crane interface panel attached to a crane for movement together with the crane; and

moving the nuclear reactor module, by using the crane, from a reactor bay to a servicing area.

22. The method of claim 21, wherein the step of decoupling comprises disconnecting a cable from the reactor bay interface panel, the cable having a connector at an end of the cable external to the nuclear reactor module, the cable operable to convey signals from the one or more sensors located within the nuclear reactor module, the cable further being selectively attachable to and detachable from the reactor bay interface panel.

23. The method of claim 21, wherein the crane interface panel is operable to accept the one or more signals from the one or more sensors within the nuclear reactor module when the one or more sensors are decoupled from the reactor bay interface panel and attached to the crane interface panel.



**24.** The method of claim **21**, wherein the step of decoupling comprises disconnecting a cable from the reactor bay interface panel, the cable having a connector at an end of the cable external to the nuclear reactor module, the cable operable to convey signals from the one or more sensors located within the nuclear reactor module, the cable further being selectively attachable to and detachable from the reactor bay interface panel, and further wherein the crane interface panel is operable to accept the one or more signals from the one or more sensors within the nuclear reactor module when the cable is disconnected from the reactor bay interface panel and attached to the crane interface panel.

**25.** The method of claim **24**, wherein when the cable is detached from the reactor bay interface panel and attached to the crane interface panel, the connector and the crane interface panel move together with the crane when the crane is operating to move the nuclear reactor module.

**26.** A method of servicing a nuclear reactor module, comprising:

terminating signal communication between one or more sensors of the nuclear reactor module and a first sensor receiver, the first sensor receiver being provided in a first interface panel positioned proximate a reactor bay; initiating signal communication between the one or more sensors of the nuclear reactor module and a second

sensor receiver, the second sensor receiver being provided in a second interface panel, the second interface panel being attached to a device operable to move the nuclear reactor module; and

moving the nuclear reactor module together with the second interface panel from a reactor bay to a servicing area.

**27.** The method of claim **26**, wherein the step of terminating comprises disconnecting a cable from the first interface panel.

**28.** The method of claim **27**, wherein the cable includes a connector at an end of the cable external to the nuclear reactor module, the cable operable to convey signals from the one or more sensors located within the nuclear reactor module, the cable further being selectively attachable to and detachable from the first interface panel.

**29.** The method of claim **28**, wherein the step of initiating comprises connecting the cable to the second interface panel.

**30.** The method of claim **29**, wherein when the cable is detached from the first interface panel and attached to the second interface panel, the connector and the second interface panel move together with the device when the device is operating to move the nuclear reactor module.

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