

What is claimed is: CLAIMS

1. ~~In combination with a~~ A subsea hydrocarbon production system which comprises a wellhead housing mounted at the upper end of a well bore, a number of concentric well casings extending from the wellhead housing through
5 the well bore, including an innermost casing through which a hydrocarbon fluid is produced, ~~and a plurality of casing annuli formed between successive ones of the wellhead housing and the well casings, the improvement comprising and a~~ monitoring system for monitoring a parameter existing in at least one of the casing annuli, ~~which comprises~~ the monitoring system comprising:

10 an interrogation package which is operable to wirelessly transmit an interrogation signal; and

at least one sensing package which is located in a corresponding casing annulus and which includes at least one sensor for sensing the parameter, the sensing package being operable to wirelessly receive the interrogation signal
15 and in response thereto wirelessly transmit a response signal to the interrogation package which is indicative of the parameter sensed by the sensor.

2. The ~~improvement~~ subsea hydrocarbon production system of claim 1, wherein the interrogation package communicates with the at least one sensing
20 package using near-field magnetic induction (NFM) signals.

3. The ~~improvement~~ subsea hydrocarbon production system of claim 1, wherein the interrogation package communicates with the at least one sensing package using inductive signals.

25 4. The ~~improvement~~ subsea hydrocarbon production system of claim 1, wherein the interrogation package is located externally of the wellhead housing.

30 5. The ~~improvement~~ subsea hydrocarbon production system of claim 4, wherein the sensing package is located in one of the casing annuli.

6. The ~~improvement~~ subsea hydrocarbon production system of claim 5, wherein the interrogation signals are transmitted directly between the interrogation package and the sensing package.

5 7. The ~~improvement~~ subsea hydrocarbon production system of claim 4, wherein the at least one sensing package comprises a plurality of sensing packages, each of which is located in a corresponding casing annulus.

10 8. ~~In combination with a~~ A subsea hydrocarbon production system which comprises a wellhead housing mounted at the upper end of a well bore, a number of concentric well casings extending from the wellhead housing through the well bore, including an innermost casing through which a hydrocarbon fluid is produced, and a plurality of casing annuli formed between successive ones of the wellhead housing and the well casings, ~~the improvement comprising and a~~
15 monitoring system for monitoring a parameter existing in at least one of the casing annuli, ~~which comprises the monitoring system comprising:~~

an interrogation package which is operable to wirelessly transmit an interrogation signal; and

20 at least one sensing package which is located in a corresponding casing annulus and which includes at least one sensor for sensing the parameter, the sensing package being operable to wirelessly receive the interrogation signal and in response thereto wirelessly transmit a response signal to the interrogation package which is indicative of the parameter sensed by the sensor;

25 wherein the interrogation package is located externally of the wellhead housing, the at least one sensing package comprises a plurality of sensing packages, each of which is located in a corresponding casing annulus, and the interrogation signals are transmitted between the interrogation package and the sensing packages using a multi-hop signal transmission technique; and

30 wherein the interrogation package communicates with a radially adjacent sensing package and the sensing packages communicate with each other using near-field magnetic induction (NFM) signals.

9. ~~In combination with a~~ A subsea hydrocarbon production system which comprises a wellhead housing mounted at the upper end of a well bore, a

number of concentric well casings extending from the wellhead housing through the well bore, including an innermost casing through which a hydrocarbon fluid is produced, and a plurality of casing annuli formed between successive ones of the wellhead housing and the well casings, ~~the improvement comprising~~ and a monitoring system for monitoring a parameter existing in at least one of the casing annuli, ~~which comprises~~ the monitoring system comprising:

an interrogation package which is operable to wirelessly transmit an interrogation signal; and

at least one sensing package which is located in a corresponding casing annulus and which includes at least one sensor for sensing the parameter, the sensing package being operable to wirelessly receive the interrogation signal and in response thereto wirelessly transmit a response signal to the interrogation package which is indicative of the parameter sensed by the sensor;

wherein the interrogation package is located within the innermost casing; and

wherein the interrogation package communicates with the at least one sensing package using near-field magnetic induction (NFM) signals.

10. ~~The improvement~~ subsea hydrocarbon production system of claim 9, wherein the sensing package is located in one of the casing annuli.

11. ~~The improvement~~ subsea hydrocarbon production system of claim 10, wherein the interrogation signals are transmitted directly between the interrogation package and the sensing package.

12. ~~The improvement~~ subsea hydrocarbon production system of claim 9, wherein the at least one sensing package comprises a plurality of sensing packages, each of which is located in a corresponding casing annulus.

13. ~~In combination with a~~ A subsea hydrocarbon production system which comprises a wellhead housing mounted at the upper end of a well bore, a number of concentric well casings extending from the wellhead housing through the well bore, including an innermost casing through which a hydrocarbon fluid is produced, and a plurality of casing annuli formed between successive ones of the

wellhead housing and the well casings, ~~the improvement comprising~~ and a monitoring system for monitoring a parameter existing in at least one of the casing annuli, ~~which comprises the monitoring system comprising:~~

an interrogation package which is operable to wirelessly transmit an
5 interrogation signal; and

at least one sensing package which is located in a corresponding casing annulus and which includes at least one sensor for sensing the parameter, the sensing package being operable to wirelessly receive the interrogation signal and in response thereto wirelessly transmit a response signal to the interrogation
10 package which is indicative of the parameter sensed by the sensor;

wherein the interrogation package is located within the innermost casing, the at least one sensing package comprises a plurality of sensing packages, each of which is located in a corresponding casing annulus, and ~~the~~ interrogation signals are transmitted between the interrogation package and the
15 sensing packages using a multi-hop signal transmission technique; and

wherein the interrogation package communicates with a radially adjacent sensing package and the sensing packages communicate with each other using near-field magnetic induction (NFM) signals.

20 14. The ~~improvement~~ subsea hydrocarbon production system of claim 1, wherein each sensing package comprises a plurality of sensors for monitoring corresponding parameters in the casing annuli.

25 15. The ~~improvement~~ subsea hydrocarbon production system of claim 1, further comprising means for powering the interrogation package.

16. The ~~improvement~~ subsea hydrocarbon production system of claim 1, further comprising means for powering the sensing package.

30 17. The ~~improvement~~ subsea hydrocarbon production system of claim 16, wherein the means for powering the sensing package comprises a transmitter for generating an AC magnetic field, a receiver which is exposed to the magnetic field and which in response thereto generates an AC current, and an energy

storage device which is charged by the current, wherein the energy storage device powers the sensing package.

18. The ~~improvement~~ subsea hydrocarbon production system of claim 5 17, wherein the transmitter is located in the interrogation package.

19. ~~In combination with a~~ A subsea hydrocarbon production system which comprises a wellhead housing mounted at the upper end of a well bore, a number of concentric well casings extending from the wellhead housing through 10 the well bore, including an innermost casing through which a hydrocarbon fluid is produced, and a plurality of casing annuli formed between successive ones of the wellhead housing and the well casings, ~~the improvement comprising and a~~ monitoring system for monitoring a parameter existing in at least one of the casing annuli, ~~which comprises~~ the monitoring system comprising:

15 an interrogation package which is operable to wirelessly transmit an interrogation signal; and

at least one sensing package which is located in a corresponding casing annulus and which includes at least one sensor for sensing the parameter, the sensing package being operable to wirelessly receive the interrogation signal 20 and in response thereto wirelessly transmit a response signal to the interrogation package which is indicative of the parameter sensed by the sensor; and

means for powering the sensing package, said means comprising a transmitter for generating an AC magnetic field, a receiver which is exposed to the magnetic field and which in response thereto generates an AC current, and 25 an energy storage device which is charged by the current, wherein the energy storage device powers the sensing package;

wherein the monitoring system comprises a plurality of sensing packages, each of which is positioned in a corresponding casing annulus, and wherein the means for powering the sensing packages comprises a plurality of 30 transmitters and receivers arranged in transmitter/receiver pairs, each transmitter/receiver pair being positioned in a corresponding casing annulus and being connected to a corresponding energy storage device which in turn is connected to a corresponding sensing package, wherein power for at least one

sensing package is transmitted to its corresponding transmitter/receiver pair by the transmitter/receiver pair of a radially adjacent sensing package.

20. The ~~improvement~~ subsea hydrocarbon production system of claim 17, wherein the energy storage device is continuously charged by the current and the power stored in the energy storage device is expended by the sensing device in a single burst.

22 21. The ~~improvement~~ subsea hydrocarbon production system of claim 1, wherein the plurality of casing annuli comprises at least an A annulus and a B annulus, and wherein the interrogation package is located in the A annulus, the sensing package is located in the B annulus and the interrogation package communicates with the sensing package using near-field magnetic induction (NFM) signals.

23 22. The ~~improvement~~ subsea hydrocarbon production system of claim 1, wherein the plurality of casing annuli comprises at least an A annulus, a B annulus and a C annulus, and wherein the interrogation package is located in the A annulus, the sensing package is located in the C annulus and the interrogation package communicates with the sensing package using near-field magnetic induction (NFM) signals.