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(54) DEVICE AND METHOD FOR NON-INVASIVE DETECTION OF HAZARDOUS MATERIALS IN THE AQUATIC ENVIRONMENT

VORRICHTUNG UND VERFAHREN ZUR NICHTINVASIVEN DETEKTION VON GEFAHRSTOFFEN IN WASSERUMGEBUNGEN

DISPOSITIF ET PROCÉDÉ DE DÉTECTION NON EFFRACTIVE DE MATIÈRES DANGEREUSES DANS L'ENVIRONNEMENT AQUATIQUE

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(56) References cited:
WO-A1-2012/089584 WO-A2-2006/067464

- **VLADIVOJ VALKOVIC ET AL: "Inspection of the objects on the sea floor by using 14 MeV tagged neutrons", ADVANCEMENTS IN NUCLEAR INSTRUMENTATION MEASUREMENT METHODS AND THEIR APPLICATIONS (ANIMMA), 2011 2ND INTERNATIONAL CONFERENCE ON, IEEE, 6 June 2011 (2011-06-06), pages 1-8, XP032153559, DOI: 10.1109/ANIMMA.2011.6172937 ISBN: 978-1-4577-0925-8**
- **CEDRIC CARASCO ET AL: "Data acquisition and analysis of the UNCOSS underwater explosive neutron sensor", ADVANCEMENTS IN NUCLEAR INSTRUMENTATION MEASUREMENT METHODS AND THEIR APPLICATIONS (ANIMMA), 2011 2ND INTERNATIONAL CONFERENCE ON, IEEE, 6 June 2011 (2011-06-06), pages 1-5, XP032153552, DOI: 10.1109/ANIMMA.2011.6172930 ISBN: 978-1-4577-0925-8**

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Description

[0001] The present disclosure relates to a device and method for non-invasive detection of hazardous substances, such as war remnants, mines, war gases, etc., in the underwater environment. The presented apparatus and method are based on neutron activation and the measurement of characteristic gamma quanta spectra of substance created after neutron beam irradiation.

[0002] Currently, the state of the art methods of detecting hazardous substances are based primarily on the use of X-rays which interact with electrons and thus, provide determination of the density distribution and the shapes of tested subjects, but do not allow for exact identification. The airport security systems also use devices for substance analysis, while the anti-terrorist units use radars and induction detectors. Unfortunately, all these methods only allow one to detect the presence of metal or determine the shape of objects under the ground. Therefore, detection of any suspicious object requires additional verification. Disadvantages of the above mentioned methods are not present with devices based on a stoichiometry analysis by irradiating the substance with neutrons and measuring the energy spectrum of gamma quanta emitted.

[0003] Remnants of war sunk at the bottom of seas, oceans and rivers are still a big problem, especially in areas of intense military operations and shallow bodies of water. Drowned munitions and mines used during World War II are a serious threat at sea and toxic substances contained in some shells, for example war gases, are a major environmental problem. By 1948 about 250000 tons of munition, including up to 65000 tons of chemical agents, had been sunk in Baltic Sea waters. The main known contaminated areas are Little Belt, Bornholm Deep (east of Bornholm) and the southwestern part of the Gotland Deep. Apart from known underwater stockyard there is an unknown amount of dangerous war remnants spread over the whole Baltic, especially along maritime convoy paths and in the vicinity of the coasts. Part of these shells have already corroded so much that they have been releasing chemical agents, mainly mustard gas, to the sea floor, causing contamination. At the bottom of the Baltic Sea the chemical agents take the form of oily liquids hardly soluble in water and thus, gas contamination reaches only a few meters in the vicinity of the corroded shell. Thus, the biggest threat to people is the consumption of fish living around the munitions landfill due to their frequent contraction of diseases and genetic defects. The sunk munitions also constitute a direct threat, e.g. for fishermen who sometimes raise the rusted shells from the bottom of the sea while fishing. Detection and identification of sunk remnants of war in the Baltic Sea is crucial in the still ongoing work of purifying it from hazardous substances.

[0004] The vast majority of dangerous substances are organic compounds or their mixtures. Therefore, they are composed mostly of oxygen, carbon, hydrogen and nitrogen. These features allow for the identification of explosives or drugs hidden among other substances by the stoichiometric analysis of suspicious objects.

[0005] In the patent applications WO 1999049311 A3 (published on 2000-01-20), US 20030165212 A1 (published on 2003-09-04) and WO 2004025245 A3 (published on 2004-05-13) one describes an apparatus and method for detecting dangerous substances hidden under ground, in buildings or vehicles based on a fast neutron beam with a well define energy of E = 14 MeV, which are produced isotropicaly by the generator. Neutrons penetrating the tested material interact with the nuclei of the atoms of an unknown substance causing their excitation. As a result, neutron irradiation leads to the emission of gamma quanta specific for each element. These quanta are registered by a detector, and determination of the number of emitted gamma quanta and their energies allows one to determine the stoichiometry of the examined substance, which as a consequence leads to its identification. US Patent application 20060227920 A1 describes a device which in addition to the fast neutron interactions also uses gamma quanta produced in the process of thermal neutrons capture produced in the test object after multiple scatterings of neutrons from the incident beam. This allows one to determine the hydrogen content and increases sensitivity of the method.

[0006] In the aquatic environment for the detection of mines and dangerous chemicals one uses primarily sonars which allow one to determine only the position and shape of the object, without giving information about the chemical composition. In the patent application WO 2012089584 A1 (Published 2012-07-05) a device and a method of detection of underwater mines using a neutron source was also described. It is based on detecting the characteristic gamma quanta from neutron capture. Neutrons are generated with a low rate and energy, and are slowed down (moderated) by the water and reach the interrogated object with very little energy as thermal neutrons. A detector mounted on the device allows for the registration and determination of energy of gamma quanta produced in the thermal neutron absorption. Also other particles produced in the interaction of neutrons with the environment are registered. Identification of a hidden mine is done by searching for anomalies in the observed spectra of gamma quanta and in multiplicity of secondary neutrons reaching the detector.

[0007] In the publication V. Valkovic et al., "An underwater system for explosive detection," Proc. SPIE 6540, Optics and Photonics in Global Homeland Security III, 654 013 (May 04, 2007), attempts to apply the fast neutron activation for underwater detection of hazardous materials were described. The neutron detector is isolated from the neutron generator and placed on the arm of a robot. The use of a special robot arm allows one to change the distance of the detector from the test object and reduces the attenuation of gamma rays moving in the water.

[0008] Further developments of similar methods and devices have been disclosed in publications: V. Valkovic et al.

"Inspections of the objects on the sea floor by using 14 MeV tagged neutrons" and C. Carasco et al. "Data acquisition and analysis of the UNCOSS underwater explosive neutron sensor", both in ANIMMA, 2011 2ND INTERNATIONAL CONFERENCE ON, IEEE, and in patent applications: WO 2006/067464 and WO 2012/089584.

[0009] Due to the relatively strong absorption of neutrons in water these methods allow only for detection of a substance located at the bottom of the sea or buried shallow beneath its surface. In addition, the water layer between the interrogated object and the device should not exceed four meters, and the strong absorption of neutrons and gamma quanta moving in water significantly increases the exposure time of the suspicious object and makes the interpretation of the obtained results more difficult.

[0010] The technical problem posed prior to the present invention is to provide such an apparatus and method for non-invasive detection of hazardous materials in an aquatic environment, which is characterized by higher sensitivity and lower noise (background reduction), and which will allow for more accurate detection of dangerous substance, also located deep in the bottom of the water reservoir, and in addition will allow determination of the dangerous substance density distribution in the tested object. Surprisingly, these technical problems were solved by the presented invention.

[0011] The first subject of the invention is a device for non-invasive detection of hazardous materials in an aquatic environment according to claim 1. In a preferred embodiment of the invention the neutrons and/or gamma quanta guides are in the form of a cylinder with closed bases, preferably telescopic. Also preferably in the neutrons and/or gamma quanta guides there is a vacuum or they are filled with a gas, preferably air, helium, argon. Preferably, the neutrons and/or gamma quanta guides are made of a material like: stainless steel, aluminum or carbon fibers. In the next preferred embodiment of the invention the neutrons and/or gamma quanta guides are covered from inside with a thin layer of neutron-reflecting material, preferably graphite. Preferably, the gamma quanta detector is a semiconductor detector system or scintillation detector. Also preferably fast neutron generator has in a position opposed to the neutron guide the α particle detector, and in a position perpendicular to the guide the α particle detectors.

[0012] The second subject of the invention is a method for non-invasive detection of hazardous materials in an aquatic environment according to claim 8. Preferably, the gamma quanta are detected in coincidence with α particles by a detector placed opposite to the guide. Also preferably, one rejects these signals of the gamma-ray detector which are in coincidence with signals from all other α particle detectors.

[0013] The device and method for non-invasive detection of hazardous materials in an aquatic environment according to the present invention, by using specially designed fast neutrons and/or gamma quanta guides which enable one to detect dangerous substances with greater precision, allows for the detection of objects hidden deep in the bottom of the water reservoir. Telescopic guide structures allow for the adjusting of its length in a wide range, thereby to perform the detection in water reservoirs of different depths. The use of moving gamma quanta guide connected to the gamma quanta detector allows for changing of the angle between the guides, and thus enables detection at different depths and variable area which makes it possible to determine the density distribution of the tested item. Measurement of gamma quanta in coincidence with signals registered by the α particle detector located just opposite to the neutron guide can significantly reduce the background and further enhance the sensitivity and resolution of the used measurement method.

[0014] Exemplary embodiments of the invention are shown in the drawing, in which Fig. 1 shows a scheme of an apparatus for non-invasive detection of hazardous materials in an aquatic environment, Fig. 2 shows a scheme of the device shown in Fig. 1 with the first settings of guides, Fig. 3 shows a diagram of the device shown in Fig. 1 with the second settings of guides, Fig. 4 shows a cross-section of the gamma quanta and/or neutrons guide, Fig. 5 shows a front view of the gamma quanta and/or neutrons guide, Fig. 6 shows a scheme of a system for changing the position of the gamma quanta and/or neutrons guide.

Example

[0015] Figure 1 shows a general scheme of an apparatus for non-invasive detection of hazardous materials in an aquatic environment 100 which is the subject of the invention. Neutron generator 101 collides deuterium ions 102 with a tritium target 103 in the reaction: $D + T \rightarrow \alpha + n$. Because of the much higher energy released in this reaction compared to the energy of deuterium, both α particle 104 and neutron 105 are produced almost isotropically in space and move almost back-to-back. The α particle 104 emerging from the neutron generation is recorded by the detector system 106a, 106b, 106c placed on the walls of the generator 101. It may consist of a silicon or scintillation detector with dimensions of a few cm. Selected neutrons move towards the interrogated item 107 within the guide 108 of specified dimensions, e.g. with a diameter of 30 cm and a maximum length of 3 m with the air pumped out. Alternatively, the guide may be filled with air or another gas, for example Helium. This prevents the absorption and slowing down of neutrons in the water. The guide 108 is a telescopic tube constructed of stainless steel with a thickness of approx. 1 mm, ending on both sides with a significantly thinner sheet, for example: 0.5 mm. Fast neutrons travelling inside the examined item are absorbed and/or scattered inelastically on atomic nuclei of the tested subject exciting them, e.g. in the following reaction: neutron + nucleus $\rightarrow$ excited nucleus + neutron $\rightarrow$ nucleus + neutron + gamma quantum.

[0016] Nuclei while deexciting to the ground state emit gamma quanta 109, which energy is specific to each nuclei.

Part of the gamma quanta emitted by the nuclei move towards the gamma quanta detector within the guide 110 of a certain size, from which the air was pumped out. As in the previous case, the guide may alternatively be filled with air or another gas, e.g. Helium. This prevents the absorption of gamma quanta and their scattering in water. The guide 110 is also made of a telescopic tube constructed of stainless steel with a thickness of approx. 1 mm and ending on both sides with a significantly thinner sheet, for example 0.5 mm. Detector 111 performs the measurement of energy of the recorded gamma quanta 109. In addition, one determines the impact position of gamma quantum 109 in the detector 111 and the time elapsed between the registration of α particle 104 and the registration of signals in the gamma quanta detector 111. The measurement of time and the location of α particle 104 and gamma quantum 109 interaction together with the known location of the target 103 and changing of the relative distance and angle of the gamma quanta guide 110 relative to the neutron guide 108 allows for the determination of the density distribution of the dangerous substance in the interrogated object. Figures 2 and 3 illustrate schematically how the reconfiguration of the guides provide determination of the depth beneath the bed (e.g. In the mud), at which gamma quanta reaching the detector have reacted. If the ratio of the diameter of the guides 208 and 210 and their length is sufficiently small (less than 0.14) the depth at which gamma quanta reacted can be determined by measuring the time Δt elapsed since α particle 204 registration until the signal is registered in the gamma quanta detector 211. It can be expressed as:

$$\Delta t - t_\alpha = t_n + t'_n + t_\gamma + t'_\gamma,$$

where tα is the time of flight of generated α particle 204 from the target 203 to the detector 206c, t'n and tn denote respectively the time of flight of neutron 205 from the target in the guide 208 over a well-known distance ln and the time of flight of neutron 205 from the end of the neutron guide 208 to the reaction site 212 in the tested object 207. Similarly, tγ is time of flight of gamma quantum 209 in the guide 210 of a known and fixed length lγ and t'γ denotes the time of flight of the gamma quantum 209 from the reaction site 212 of neutron 205 inside the tested object 207 to the entry 213 of the guide 210. These times can be expressed then by well-known particle velocities:

$$\Delta t - l_\alpha/v_\alpha = l_n/v_n + x/v_n + l_\gamma/c + y/c\,.$$

[0017] Velocities of α particle 204 and neutron 205 are fixed and determined by their known energies and gamma quanta fly at the speed of light *c*. Distance *x* of neutron 205 from the end 214 of the guide 208 to the reaction site 212 in the object 207, and the distance *y* of gamma quantum 209 from the reaction site 212 of neutron 205 to the entry 213 of the guide 210 are connected by the following relation:

$$^{x}\!/_{y} = \cos\varphi,$$

where φ is the angle between the axes of the guides 208 and 210, which can be changed. This allows one to determine at what distance from the entry 214 of guide 208 the reaction took place:

$$x = \left(\Delta t - \frac{l_\alpha}{v_\alpha} - \frac{l_n}{v_n} - \frac{l_\gamma}{c}\right)\frac{c v_n \cos\varphi}{c\cdot\cos\varphi + v_n}.$$

[0018] If the diameter to length ratio of guides 208 and 210 is large, measuring the time Δt allows one to determine the depth *x* at which the neutron 205 has interacted by looking for such a place in area 215 common for both guides 208 and 210, for which the sum of the time of flight of neutron 205 from target 203 to that point and the time of flight of the gamma quantum 209 from this place to the detector 211 is nearest to the measured time Δt.

[0019] Additional information on the depth can be obtained by changing the relative position of guides 208 and 210 and by changing the angle between them. Changing distances d_1 and d_2 (figure 2) between guides 208 and 210 allows for the registration of the gamma quanta emitted from different parts of object 207, and also at various depths. This creates the possibility to determine the density distribution of the dangerous substance in the object 207.

[0020] Neutrons and gamma quanta guides are made of telescopic tubes consisting of several segments with a length of 50 cm connected to a rubber gasket (Figure 4). Changing the length of the guides can be carried out manually, before placing the entire device in the water, or by means of a mechanical system controlled from the module 118. An example of such a system is shown in Figure 4. The guide modules 302, 303 and 304 are connected in a telescopic way so that module 302 can be put inside section 301 and module 304 can be put inside module 303. Rubber seals 305, 306 and 307 in the shape of rings, as shown in Figure 5, make the whole construction hermetic. The length of guide 300 may be adjusted by means of a system of tapped rods 310, 311 and 312 with thickness of e.g. 10 mm mounted on the support rails 314, 315, 316 and 317. Rotation of rod 310 drives another element 311, which in turn causes movement of rod 312. The system for guide 300 length adjustment may consist of e.g. four sets of rods 318, 319, 320 and 321 arranged as shown in Figure 3b. Each set is driven by a motor 309. The connection of guide 300 with engines is performed with flange 301 to seal and covers the entire system from water. Changing the angle of guide 300 with respect to the lower face 322 of the device 200 is provided by the control system 308. Each part of guide 300 is lined with a thin (approx. 1 mm) layer of material with good neutron reflective capabilities, e.g. with graphite.

[0021] The changes in relative position of the neutron guide 208 and gamma quanta guide 210 preserving the hermeticity of the device 200 may be implemented as in figure 6, where one changes only the position of gamma quanta guide 210. The guide 400 is connected to the flange 401, which in turn is connected hermetically to the bottom 402 of the device 200. It is made of a material that can be easily compressed and stretched, allowing the guide 400 to move together with the gamma quanta detector 403. This can be a thin corrugated sheet metal, corrugated plastic layer or leather. The guide 400 together with motors 404, a system for changing the angle 405 and gamma quantum detector 403 are connected to a driving system 406 based on e.g. linear traverse providing changes of position of the guide 400 and the detector 403.

[0022] Gamma quanta detector 111 shown in Figure 1 may be constructed based on known prior art solutions for gamma quanta detection, using, e.g. a scintillation crystal or a semiconductor. Inside the device 100 the position of the detector can be changed. Signals from α particle detectors 106a, 106b, 106c and gamma quanta 111 are transmitted through signal lines 112 and 113 to a signals sampling module which performs data acquisition 114. In order to remove background resulting from reactions of neutrons emitted not towards the tested object 107, all signals from the gamma quanta detector 111 recorded in coincidence with signals from α particle detectors 106a and 106b are discarded, while signals in coincidence with the detector 106c are treated as gamma quanta from the interrogated item. Next, Module 114 sends the data using a cable or radio signal to a processor module 120 located on the vessel 117, from which device 100 is controlled by the control module 118. The signals from this module are transmitted by wire 119 or radio waves to the receiving module 120 which controls modules 101, 106, 111, 114 and motor 121 which allows the device 100 movement.

[0023] Identification of the substance 107 is performed by module 117. It is performed on the basis of the number of registered characteristic gamma quanta coming from the 12C nuclei (energy 4.43 MeV), 160 (6.13 MeV energy), 14N (energies 2.31 MeV and 5.11 MeV) and other elements constituting the test substances, such as 19F (energy 1.5 MeV and 3.9 MeV), 32S (3.8 MeV energy and 35Cl (3.0 MeV energy). Taking into account different probabilities of neutron reactions with different nuclides and detection efficiency of gamma quanta with different energies the number of atoms of each of the elements that build the tested item is reconstructed and then it is compared with the known stoichiometry of hazardous substances stored in the database of module 117.

Claims

1. An apparatus for the non-invasive detection of hazardous materials in an aquatic environment comprising:

- a sealed housing, in which there is a fast neutron generator (101) surrounded by α particle detectors (106), and gamma quanta detector (111), wherein the fast neutron generator (101) is adapted to emit fast neutrons with a specific energy range from 5 MeV to 20 MeV and said fast neutrons are collimated in the direction of the tested object (107), and the gamma quanta detector (111) is adapted to detect gamma quanta emitted in the transition from the excited state to the ground state of nuclei of the tested object (107), and
- neutrons and gamma quanta guides (108), (110), connected with fast neutron generator (101) and with the gamma quanta detector (111), respectively,

characterized in that the distance between the neutrons and gamma quanta guides (108) coupled to the fast neutron generator (101) and the neutrons and gamma quanta guide (110) connected to the gamma quanta detector (111) is changeable, wherein the angle between the neutrons and gamma quanta guide (108), and neutrons and gamma quanta guide (110) is in the range from ~0 to ~90 degrees.

2. Apparatus according to claim 1, **characterized in that** the neutrons and/or gamma quanta guides (108), (110) are in the form of a cylinder with closed bases, preferably telescopic.

3. An apparatus according to claim 1 or 2, **characterized in that** inside the neutrons and/or gamma quanta guides

(108), (110) there is a vacuum or the guides are filled with a gas, preferably air, helium, argon.

4. The apparatus according to any of claims 1 to 3, **characterized in that** the neutrons and/or gamma quanta guides (108), (110) are made of a material comprising: stainless steel, aluminum, carbon fibers.

5. The apparatus according to any of claims 1 to 4, **characterized in that** the neutrons and/or gamma quanta guides (108), (110) are covered from the inside with a thin layer of neutron-reflecting material, preferably graphite.

6. The apparatus according to any of claims 1 to 5, **characterized in that** the gamma quanta detector (111) is a semiconductor or scintillator detection system.

7. The apparatus according to any of claims 1 to 6, **characterized in that** the fast neutron generator (111) has in a position opposed to the neutrons and/or gamma quanta guide (108) the α particle detector (106c) and in a position perpendicular to the guide (108) α particle detectors (106a) and (106b).

8. A method for non-invasive detection of hazardous materials in an aquatic environment, comprising the following steps:

a) generating fast neutrons with a specific energy range from 5 MeV to 20 MeV using neutron generator (101),
b) collimation of fast neutrons generated in step a) in the direction of the interrogated object (107),
c) detecting gamma quanta emitted in the transition from the excited state to the ground state of nuclei of the tested object,

wherein the generated fast neutrons and gamma quanta emitted are transmitted in the neutrons and gamma quanta guides (108), (110),
characterized in that the distance between the neutrons and gamma quanta guides (108) coupled to the fast neutron generator (101) and the neutrons and gamma quanta guide (110) connected to the gamma quanta detector (111) is changeable wherein the angle between the neutrons and gamma quanta guide (108), and neutrons and gamma quanta guide (110) is in the range from ~0 to ~90 degrees.

9. The method according to claim 8, **characterized in that** the gamma quanta are detected in coincidence with α particles detected by the detector (106c) placed opposite to the guide (108).

10. The method according to claim 8 or 9, **characterized by** rejecting signals from the gamma quanta detector (111) which are in coincidence with signals of the α particle detectors (106a, 106b).

11. The method according to any of claims 8 to 10, **characterized in that** the position of neutron and gamma quanta guides (108), (110) and the time of gamma quanta reaction in the gamma quanta detector (111) relative to the signal from the detector (106c) are measured.

Patentansprüche

1. Vorrichtung zum nicht-invasiven Nachweis von Gefahrstoffen in einer wässrigen Umgebung, umfassend:

- ein abgedichtetes Gehäuse, in dem sich ein schneller Neutronengenerator (101) befindet, der von Detektoren für α-Teilchen (106) und einem Gammaquantendetektor (111) umgeben ist,
wobei der schnelle Neutronengenerator (101) eingerichtet ist, um schnelle Neutronen mit einem spezifischen Energiebereich von 5 MeV bis 20 MeV zu emittieren, und die schnellen Neutronen werden in die Richtung des getesteten Objekts (107) kollimiert,
und der Gammaquantendetektor (111) eingerichtet ist, um Gammaquanten nachzuweisen, die beim Übergang vom angeregten Zustand in den Grundzustand der Kerne des getesteten Objekts (107) emittiert werden,
und
- Neutronen- und Gammaquantenleiter (108), (110), die jeweils mit dem schnellen Neutronengenerator (101) bzw. mit dem Gammaquantendetektor (111) verbunden sind, **dadurch gekennzeichnet, dass**

der Abstand zwischen dem Neutronen- und dem Gammaquantenleiter (108), der mit dem schnellen Neutronengenerator (101) verbunden ist, und dem Neutronen- und dem Gammaquantenleiter (110), der mit dem Gammaquan-

tendetektor (111) verbunden ist,
veränderbar ist,
wobei der Winkel zwischen dem Neutronen- und dem Gammaquantenleiter (108), und dem Neutronen- und dem Gammaquantenleiter (110) im Bereich von ~ 0 bis ~ 90 Grad liegt.

2. Vorrichtung nach Anspruch 1, **dadurch gekennzeichnet, dass** die Neutronen- und/oder die Gammaquantenleiter (108), (110) in der Form eines Zylinders mit geschlossenen Böden, vorzugsweise ausziehbar, vorliegen.

3. Vorrichtung nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** sich innerhalb der Neutronen- und/oder der Gammaquantenleiter (108), (110) ein Vakuum befindet oder die Leiter mit einem Gas, vorzugsweise Luft, Helium, Argon gefüllt sind.

4. Vorrichtung nach einem der Ansprüche 1 bis 3, **dadurch gekennzeichnet, dass** die Neutronen- und/oder die Gammaquantenleiter (108), (110) aus einem Material hergestellt sind, das umfasst: Edelstahl, Aluminium, Carbonfasern.

5. Vorrichtung nach einem der Ansprüche 1 bis 4, **dadurch gekennzeichnet, dass** die Neutronen- und/oder die Gammaquantenleiter (108), (110) von innen mit einer dünnen Schicht aus neutronenreflektierendem Material, vorzugsweise Graphit, bedeckt sind.

6. Vorrichtung nach einem der Ansprüche 1 bis 5, **dadurch gekennzeichnet, dass** der Gammaquantendetektor (111) ein Halbleiter oder ein Szintillator-Detektionssystem ist.

7. Vorrichtung nach einem der Ansprüche 1 bis 6, **dadurch gekennzeichnet, dass** der schnelle Neutronengenerator (111) in einer Position gegenüber dem Neutronen- und/oder Gammaquantenleiter (108) den Detektor für α-Teilchen (106c), und in einer Position senkrecht zu dem Leiter (108) die Detektoren für α-Teilchen (106a) und (106b) aufweist.

8. Verfahren zum nicht-invasiven Nachweis von Gefahrstoffen in einer wässrigen Umgebung, umfassend die folgenden Schritte:

   a) Erzeugen schneller Neutronen mit einem spezifischen Energiebereich von 5 MeV bis 20 MeV unter Verwendung des Neutronengenerators (101),
   b) Kollimation von schnellen Neutronen, die in Schritt a) erzeugt werden, in der Richtung des abgefragten Objekts (107),
   c) Nachweisen von Gammaquanten, die beim Übergang vom angeregten Zustand in den Grundzustand der Kerne des getesteten Objekts emittiert werden,

   wobei die erzeugten schnellen Neutronen und die Gammaquanten, die emittiert werden, in den Neutronen- und Gammaquantenleitern (108), (110) transmittiert werden, **dadurch gekennzeichnet, dass**
   der Abstand zwischen dem Neutronen- und dem Gammaquantenleiter (108), der mit dem schnellen Neutronengenerator (101) verbunden ist, und dem Neutronen- und Gammaquantenleiter (110), der mit dem Gammaquantendetektor (111) verbunden ist,
   veränderbar ist,
   wobei der Winkel zwischen dem Neutronen- und dem Gammaquantenleiter (108), und dem Neutronen- und Gammaquantenleiter (110) im Bereich von ~ 0 bis ~ 90 Grad liegt.

9. Verfahren nach Anspruch 8, **dadurch gekennzeichnet, dass** die Gammaquanten in Übereinstimmung mit den α-Teilchen nachgewiesen werden, die durch den Detektor (106c), der gegenüber dem Leiter (108) angeordnet ist, nachgewiesen werden.

10. Verfahren nach Anspruch 8 oder 9, **gekennzeichnet durch** Verwerfen von Signalen des Gammaquantendetektors (111), die mit Signalen der Detektoren für α-Teilchen (106a, 106b) übereinstimmen.

11. Verfahren nach einem der Ansprüche 8 bis 10, **dadurch gekennzeichnet, dass** die Position der Neutronen- und Gammaquantenleiter (108), (110) und der Zeitpunkt der Gammaquantenreaktion in dem Gammaquantendetektor (111) in Bezug auf das Signal des Detektors (106c) gemessen werden.

Revendications

1. Appareil de détection non invasive de matières dangereuses dans un environnement aquatique, comprenant :

    - un boîtier scellé dans lequel se trouve un générateur de neutrons rapides (101) entouré de détecteurs de particules α (106), et de détecteurs de quanta gamma (111),
    dans lequel le générateur de neutrons rapides (101) est apte à émettre des neutrons rapides avec une plage d'énergie spécifique de 5 MeV à 20 MeV et lesdits neutrons rapides sont collimatés dans le sens de l'objet testé (107),
    et le détecteur de quanta gamma (111) est apte à détecter des quanta gamma émis dans la transition de l'état excité à l'état de masse de noyaux de l'objet testé (107),
    et
    - des guides de neutrons et de quanta gamma (108), (110) reliés respectivement au générateur de neutrons rapides (101) et au détecteur de quanta gamma (111),

    caractérisé en ce que
    la distance entre les guides de neutrons et de quanta gamma (108) couplés au générateur de neutrons rapides (101) et le guide de neutrons et de quanta gamma (110)relié au détecteur de quanta gamma (111) est modifiable, dans lequel l'angle entre le guide de neutrons et de quanta gamma (108) et le guide de neutrons et de quanta gamma (110) est dans la plage de ~0 à ~90 degrés.

2. Appareil selon la revendication 1, **caractérisé en ce que** les guides de neutrons et/ou de quanta gamma (108), (110) sont sous la forme d'un cylindre avec des bases fermées, de préférence télescopique.

3. Appareil selon la revendication 1 ou 2, **caractérisé en ce que**, à l'intérieur des guides de neutrons et/ou de quanta gamma (108), (110), il y a un vide ou les guides sont remplis d'un gaz, de préférence de l'air, de l'hélium ou de l'argon.

4. Appareil selon l'une quelconque des revendications 1 à 3, **caractérisé en ce que** les guides de neutrons et/ou de quanta gamma (108), (110) sont constitués d'un matériau comprenant : acier inoxydable, aluminium, fibres de carbone.

5. Appareil selon l'une quelconque des revendications 1 à 4, **caractérisé en ce que** les guides de neutrons et/ou de quanta gamma (108), (110) sont recouverts de l'intérieur avec une couche mince de matériau réfléchissant les neutrons, de préférence de graphite.

6. Appareil selon l'une quelconque des revendications 1 à 5, **caractérisé en ce que** le détecteur de quanta gamma (111) est un système de détection à semiconducteur ou à scintillateur.

7. Appareil selon l'une quelconque des revendications 1 à 6, **caractérisé en ce que** le générateur de neutrons rapides (111) a, à une position à l'opposé du guide de neutrons et/ou de quanta gamma (108), le détecteur de particules α (106c) et, à une position perpendiculaire au guide (108), des détecteurs de particules a (106a) et (106b).

8. Procédé de détection non invasive de matières dangereuses dans un environnement aquatique, comprenant les étapes suivantes :

    a) la génération de neutrons rapides avec une plage d'énergie spécifique de 5 MeV à 20 MeV en utilisant un générateur de neutrons (101),
    b) la collimation des neutrons rapides générés à l'étape a) dans le sens de l'objet interrogé (107),
    c) la détection de quanta gamma émis dans la transition de l'état excité à l'état de masse de noyaux de l'objet testé,

    dans lequel les neutrons rapides générés et les quanta gamma émis sont transmis dans les guides de neutrons et de quanta gamma (108), (110),
    caractérisé en ce que
    la distance entre les guides de neutrons et de quanta gamma (108) couplés au générateur de neutrons rapides (101) et le guide de neutrons et de quanta gamma (110) relié au détecteur de quanta gamma (111) est modifiable, dans lequel l'angle entre le guide de neutrons et de quanta gamma (108) et le guide de neutrons et de quanta gamma (110) est dans la plage de ~0 à ~90 degrés.

9. Procédé selon la revendication 8, **caractérisé en ce que** les quanta gamma sont détectés en coïncidence avec des particules α détectées par le détecteur (106c) placé à l'opposé du guide (108).

10. Procédé selon la revendication 8 ou 9, **caractérisé par** le rejet de signaux provenant du détecteur de quanta gamma (111) qui sont en coïncidence avec des signaux des détecteurs de particules α (106a, 106b).

11. Appareil selon l'une quelconque des revendications 8 à 10, **caractérisé en ce que** la position des guides de neutrons et de quanta gamma (108), (110) et le temps de réaction de quanta gamma dans le détecteur de quanta gamma (111) par rapport au signal provenant du détecteur (106c) sont mesurés.

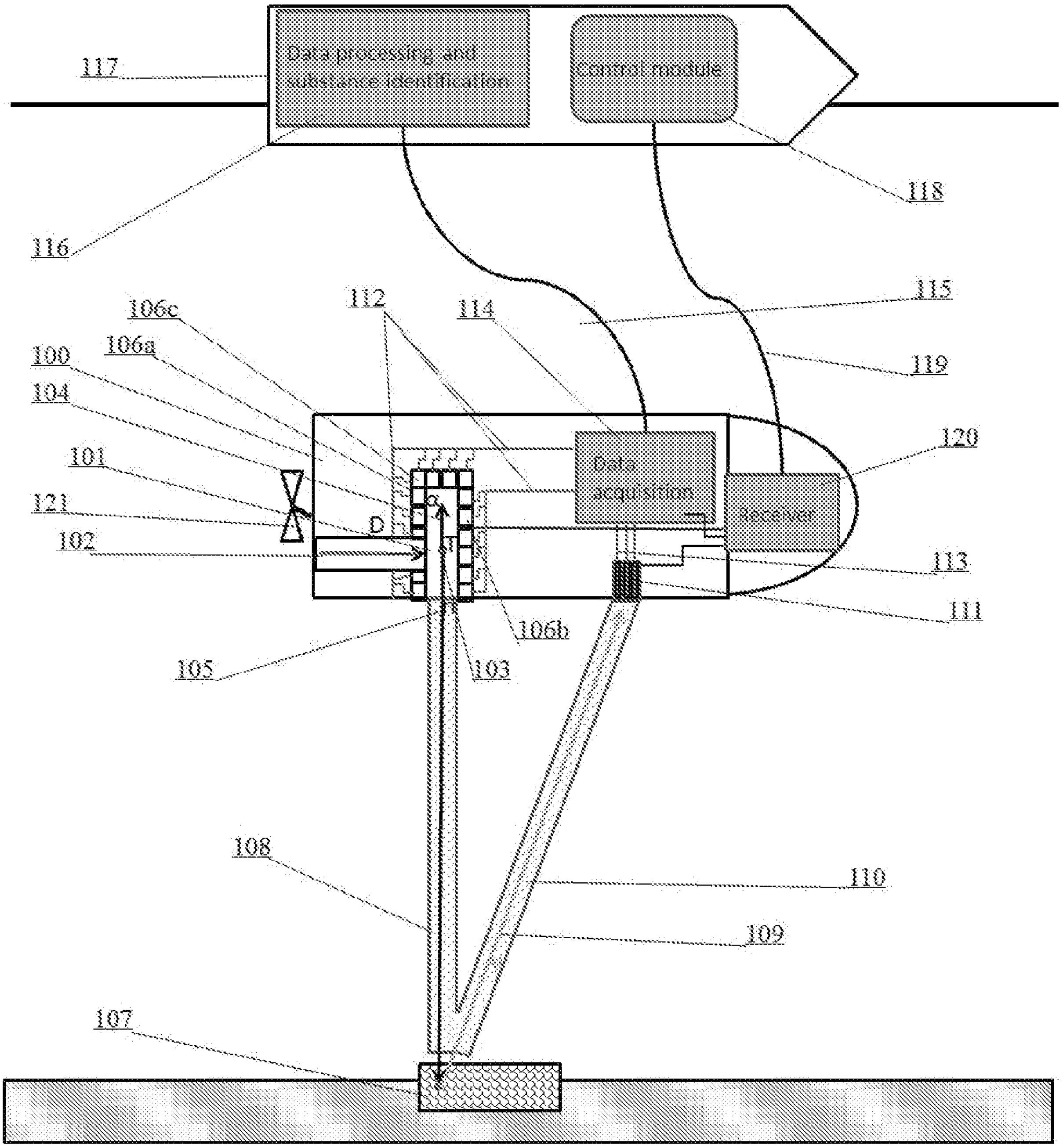

117
Data processing and substance identification
Control module
116
118
115
112
114
106c
119
106a
100
104
120
101
121
D
α
Data acquisition
Receiver
102
113
111
106b
105
103
108
110
109
107

Fig. 1

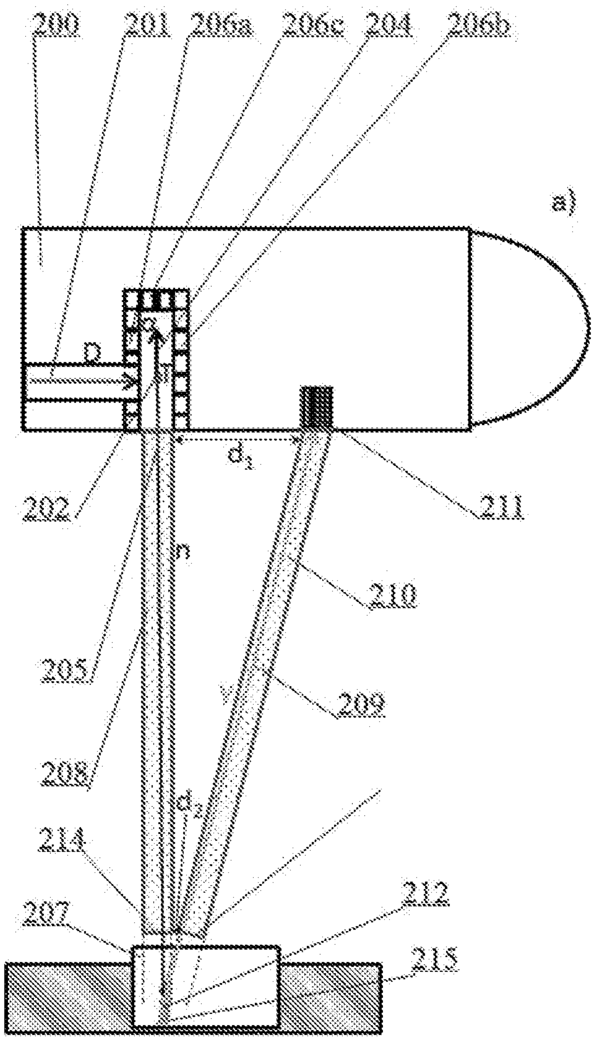

200
201
206a
206c
204
206b
a)
D
n
d1
202
211
n
210
205
v
209
208
d2
214
207
212
215

Fig. 2

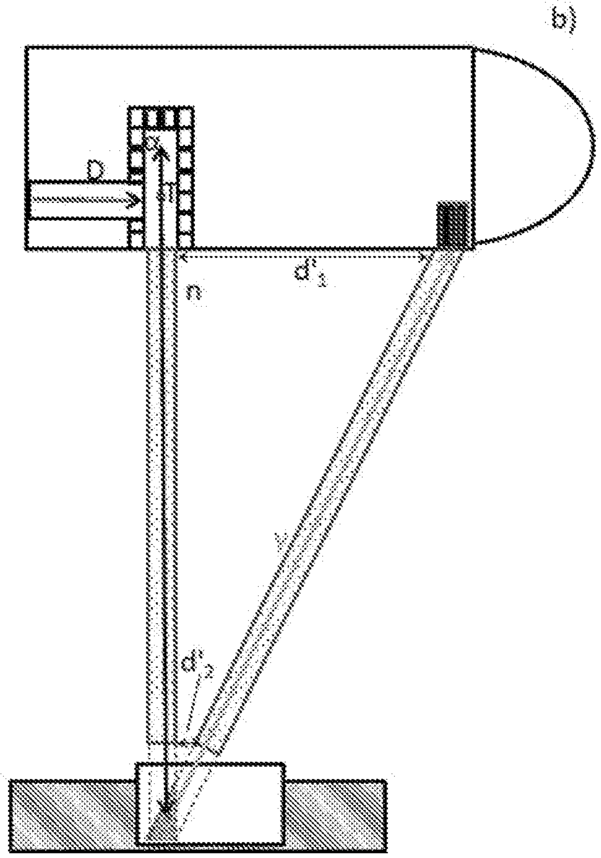
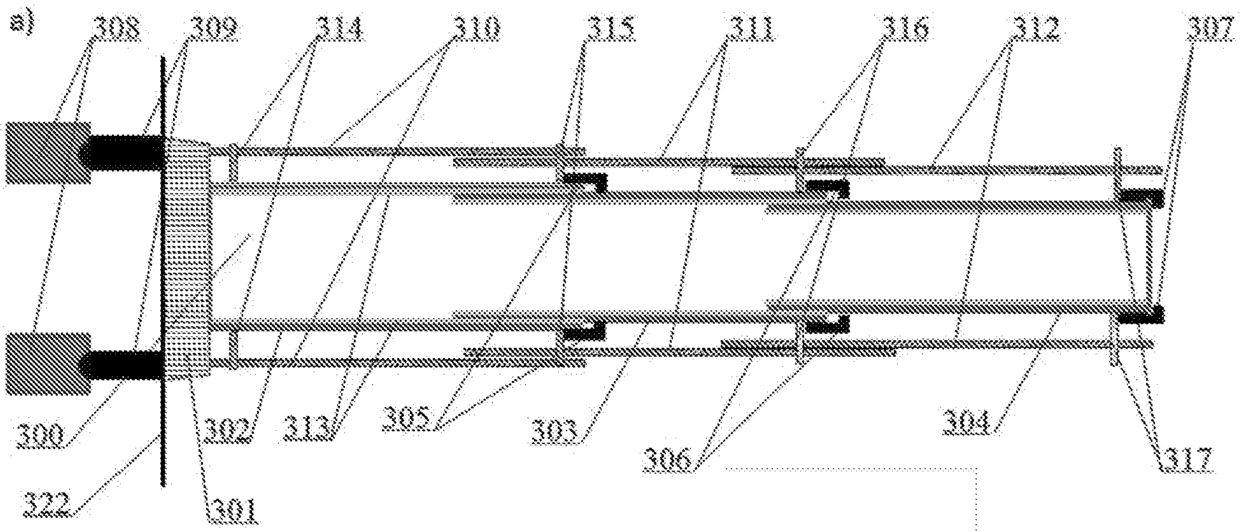

b)
D
n
d'1
n
v
d'2

Fig. 3


a)
308
309
314
310
315
311
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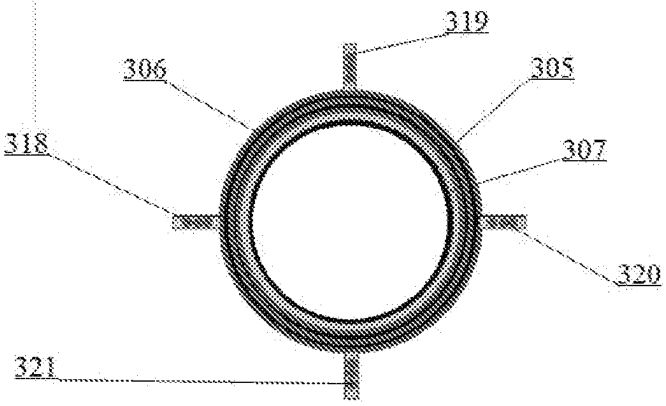
312
307
300
302
313
305
303
306
304
317
322
301

Fig. 4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321

Fig. 5

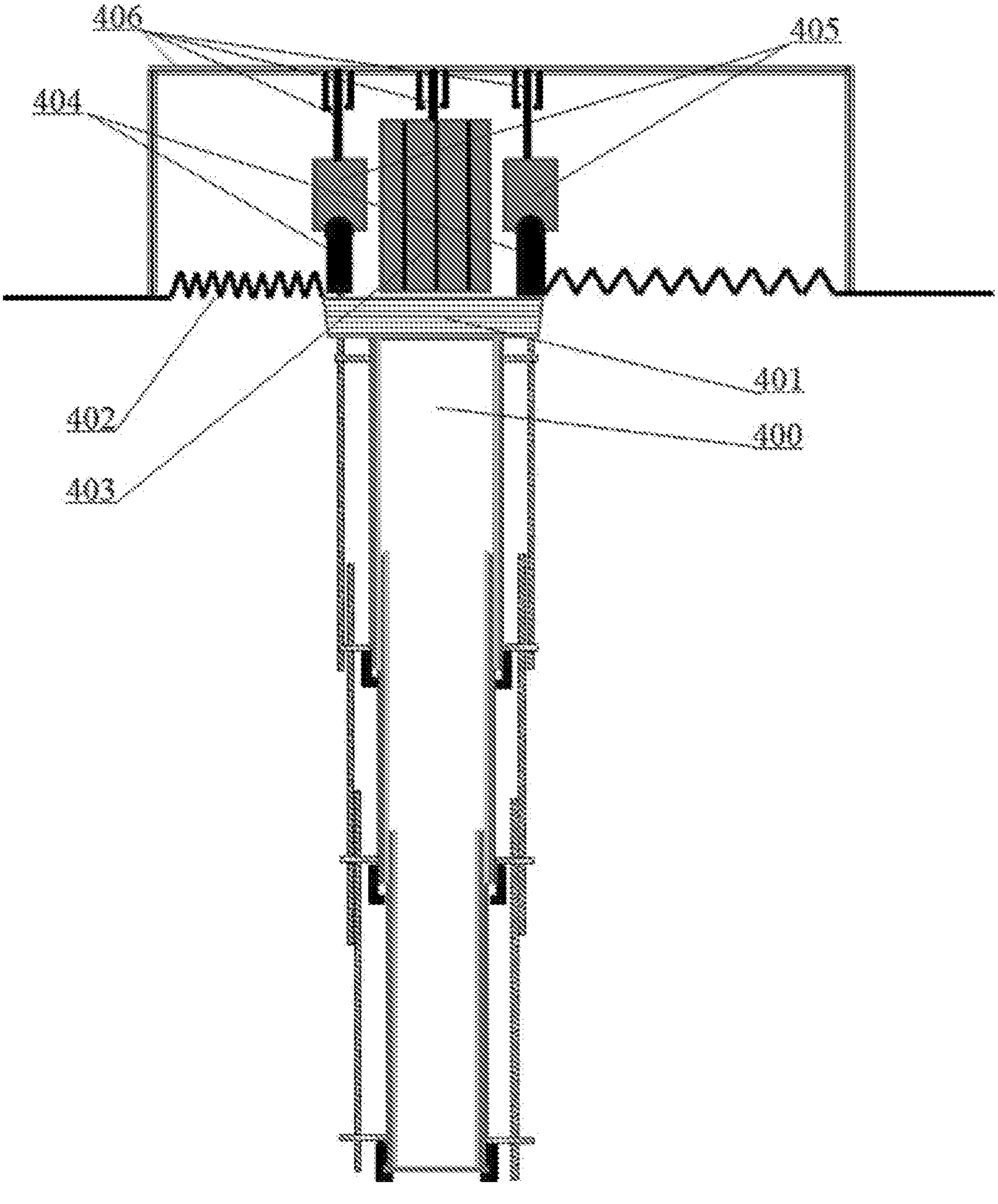

Fig. 6

REFERENCES CITED IN THE DESCRIPTION

Patent documents cited in the description

- WO 1999049311 A3 **[0005]**
- US 20030165212 A1 **[0005]**
- WO 2004025245 A3 **[0005]**
- US 20060227920 A1 **[0005]**
- WO 2012089584 A1 **[0006]**
- WO 2006067464 A **[0008]**
- WO 2012089584 A **[0008]**

Non-patent literature cited in the description

- **V. VALKOVIC et al.** An underwater system for explosive detection. *Proc. SPIE 6540, Optics and Photonics in Global Homeland Security III,* 04 May 2007, vol. 654, 013 **[0007]**
- **V. VALKOVIC et al.** Inspections of the objects on the sea floor by using 14 MeV tagged neutrons. *ANIMMA, 2011 2ND INTERNATIONAL CONFERENCE ON* **[0008]**
- Data acquisition and analysis of the UNCOSS underwater explosive neutron sensor. **C. CARASCO et al.** ANIMMA, 2011 2ND INTERNATIONAL CONFERENCE ON. IEEE **[0008]**