SEALED SOURCE DESIGN REVIEW (SSDR)

of

Radioactive Density Measurement

Clamp-on type

Single type

Integrated type

In legal terms the IHC Systems density measurements of any type could be described as an integrated and approved type A transport container complying with IAEA for the transport of radioactive materials

Document history

Revision	date	Contents	Author/Revised	Approval
0	18 May 2010	Draft		
8	10 November 2010	Preliminary version for last comments		
9	29 December 2010	Pre-final version, may be used externally		
10	8 September 2011	Final version		
11	13 July 2012	New capsule supplier added		
12	15 August 2013	Revision capsule information		
13	21 December 2015	Update documents with new Royal logo		
14	8 September 2016	General update		
15	16 December 2019	General update		
16	21 January 2021	General update		
17	21 April 2022	Update logo and responsible manager		
18	26 Jan. 24	Updates for new license request		

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Purpose of this SSDR

This SSDR is exclusively supplied within the context of an order for the delivery of a radioactive density measurement to a Customer by IHC Systems. It intends to support Customer with the application for its own licence to own, possess, handle and use IHC Systems' radioactive density measurement from the National Health Authorities of his country.

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SEALED SOURCE DESIGN REVIEW (SSDR)
of Radioactive Density Measurement

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SEALED SOURCE DESIGN REVIEW (SSDR) of Radioactive Density Measurement

1 PURPOSE OF THE MEASUREMENT

1.1 SSDR: assistance with application

A buyer of a density measurement becomes a user of radioactive materials and must apply for a licence of its national authorities. In compliance with legal requirements, IHC Systems has its own obligation to require from the buyer to apply for a licence directly after ordering and will only deliver after he offers a signed licence. The purpose of this SSDR is, to provide all information, needed at the application of a licence. It is supplied under the conditions on Intellectual Property and Copyright as stated on the 2nd page. The information is sufficient to enable National Health Authorities producing a well-informed licence and posing appropriate conditions under their national Rules and Regulations. A licence must cover import, possession, transport and operation of the device. For help with obtaining a licence: [Reference 2 (open file)].

Note: to open the reference files from the hyperlinks in this document a sub-directory has to exist in the folder were this document is placed which is called “SSDR references” in this folder all the reference pdf’s should exist.

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1.2 Generic character

This document is a generic SSDR: the information provided is valid for all types and dimensions of IHC Systems density measurements equipped with Caesium 137 or Cobalt 60 radioactive sources in the diameter range of 200-1300 mm, for the built-on types and the single density measurement types, as well as for the types which integrate one of the density measurement types with an electromagnetic mixture velocity measurement, either with or without wear-reducing liner of any available type, without exception.

2 DESCRIPTION & MEASUREMENT PRINCIPLE

The radioactive density measurement comprises two main elements:

- ✓ 1 double encapsulated, sealed radioactive source, mounted in a robust, totally steel-enveloped lead container with manually operated or (optional) spring-loaded electric shutter mechanism. In this document it is dubbed 'transmitter unit', see section 5.
- ✓ 1 robust, totally steel-and-lead-enveloped radiation detector device of the GM-tube or scintillation counter type. In this document it is called 'receiver unit', see section 5.

These type-approved units are supplied in 5 types, i.e. type 110, 150, 180, 195 and 210, the respective numbers representing the radiation shielding capacity in millimetres of lead equivalent. In every device the same type of transmitter and receiver are used for safety and total shielding purposes related to device's diameter, e.g. 110/110 or 195/195. No other combinations are made, see section 5.6.

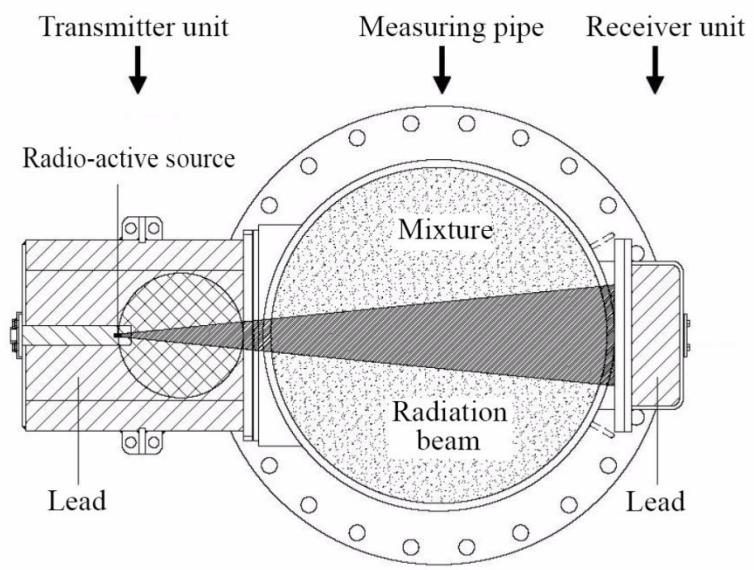

Figure 1: Typical arrangement of device

Both units are arranged to a pipe section in radial direction, either by fixed flanges or with the help of robust clamp-on brackets (Figure 1). The pipe piece may be any common dredging pipe of sufficient strength, including electromagnetic velocity measurement transmitters, and can be lined with steel, ceramic or synthetic wear-reducing liners.

The measurement principle is, that the mixture in the measuring pipe absorbs part of the radiation in relation to its density. So the radiation that reaches the receiver unit can be converted and calibrated to a density measurement unit: [kg/m^3], [metric tonnes/m^3] or [Anglo-Saxon units].

The pipe piece section as such is absolutely not relevant for the application of a licence. In a certain sense, the same can be said of the receiver box. However, as it contributes to the radiation safety of the total device it will also be considered briefly in section 5.6.

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2.1 Introduction

Operators of hydraulic dredgers have to measure the performance of their dredger, i.e. her mixture production either by weight [tons/sec] or [tons/hour] or by volume [m^3/sec] or [m^3/hr] and often must keep cumulative production records. Production is calculated by multiplying the velocity and the density of the pumped slurry in the pipeline (Figure 3, page 6). Measuring the density of an erosive slurry in a pipeline is accurately performed by a measurement mounted outside the slurry pipe, based on radioactive radiation.

Most governments consider the application of Radio Active Materials to entail a potential danger for citizens. Therefore application of radioactive materials is regulated by Rules and Regulations of the individual governments. The United Nations agree on a more or less uniform code for regulating radioactive materials, using the standards of the IAEA (International Atomic Energy Association) in Vienna.

Those regulations require from the person or entity which is to apply, possess, transport or handle radioactive materials to obtain a licence for all purposes and application of the radioactive material. These licences usually contain the conditions for any use of the material, among others:

- ✓ The appointment of an appropriately trained, responsible person: the radiation officer.
- ✓ The duty to register, record and inform the Authorities on the location of radioactive material.
- ✓ The duty to obtain a licence for any transportation of the radioactive material.

The design, production and safety performance of the final product, the IHC density measurement and the double encapsulated sealed sources locked into those devices, have been submitted to the applicable Rules and Regulations of the Government of the Netherlands (section 7). Applicable approvals have been obtained and continue to be maintained. IHC Systems has acquired governmental approval on the design and fabrication of the device as well as a licence to acquire, store, distribute and service all device models and executions [Reference 1 (open file)]. The company also applies an approved procedure for re-loading and/or disposal of decayed sources on which customers can rely, both in renewal cases and in cases they terminate their dredging activities.

3 APPLICATION AND USE OF THE DEVICE

The density measurement can be applied in the suction or discharge pipeline of any type of dredger that removes, transports and deposits the dredge slurry by means of pumping. So it can be bolted in the pipelines aboard the dredger itself, or in the discharge pipeline that supports mixture transportation onshore. In most cases the device is installed in the pump room of a trailing suction hopper dredger or in the deck pipeline of a cutter suction dredger. The exact place is considered case by case, tailored to the optimal accuracy of the measurement (Figure 2).

Figure 2: typical application of (orange-coloured) density measurement

The radiation level of the operational measurement is so low that a not-licensed human being could stay at 1 metre from its surface 4000 hours a year, not absorbing more than the legally – IAEA and national laws defined – dose equivalent of 1 milliSievert [mSv], i.e. without exceeding the said limits.

However, everyone should, according to the legislation-defined ALARA principle (As Low As Reasonably Achievable), strive for the reduction of any radiation. For that purpose IHC Systems will deliver an Instruction Manual with the delivery of each density measuring device [Reference 3 (open file)], which instructs the user – especially with respect to safety – to act as follows:

- ✓ Close the shutter mechanism when not operational, when the pipeline is internally accessible, when the pipe section liner must be refitted, in fact, when any work must be done on the device, e.g. when the detector unit must be repaired, which requires disassembly of the receiver unit.

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- ✓ Inform local authorities about the location and operation of the device.
- ✓ Call in an authorized engineer for any work to the shielding itself.
- ✓ Regularly open and close the shutter mechanism to keep it pliant, at least once a week.

In all cases, the user himself remains responsible for the proper use and operation of the device according to the conditions of his licence. In the rare case of a land-based installation, IHC Systems advises to install additional fencing to prevent unauthorised people from approaching the density measurement device.

Figure 3: the cross-point of the needles - representing mixture velocity and mixture density - indicates mixture production

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4 SEALED RADIOACTIVE SOURCES IN USE

IHC Systems uses two types of radioactive isotopes in the density measurement, Caesium 137 [Cs_{137}] and Cobalt 60 [Co_{60}]. Which of the two is used and its loaded activity depends on the internal pipeline diameter and the thickness and material of internal liners. Roughly, Cs_{137} is used in diameters of 200-650 mm. Above that dimensions Co_{60} is applied. This is caused by the specific energy of the isotopes: the specific energy of Cs_{137} is too low to penetrate large amounts of steel and mixture. Linear-logarithmic relations exist between the pipeline diameter and the required energy [$MeVs^{-1}$] of the source.

Safety considerations on the choice of an isotope are related to their half-life:

- ✓ Cs_{137} has a half-life of 30.07 years and so can remain operational during a vessel's whole life time. The risk is at the end of the vessel's life when it is possibly carried over to unlicensed and uninstructed demolition firms without removing and returning the density measurement device. In addition, its activity has only been reduced to its half in that time, so if the isotope happens to end up in the environment, it can do much harm to passers-by.
- ✓ Co_{60} has a half-life of 5.27 years and should consequently be refreshed three or four times in the vessel's lifetime. The risk is that the accompanying dismounting of the transmitter unit and its transportation will not be done according to the rules, unintentionally causing radiation exposure to people along its trajectory. The user should be very alert to stick to his licence.

4.1 Caesium 137

Cs_{137} is one of the many radioactive isotopes of Caesium, a soft and ductile alkali metal with atomic number 55. With its melting point at 28.4°C, it is liquid at nearly room temperature. The isotope decays according to Figure 4: per Giga Becquerel [GBq] of activity, 10^9 emissions of beta particles take place every second, partly turning the bereft atoms to Barium 137 [Ba_{137}] atoms, for the greater part beating them up to energetic Ba_{137m} atoms, which finally release a gamma photon with a specific energy of 0.66 Mega electron Volt [MeV] turning the concerned atoms in stable Ba_{137} yet. The specific half-life is 30.07 years.

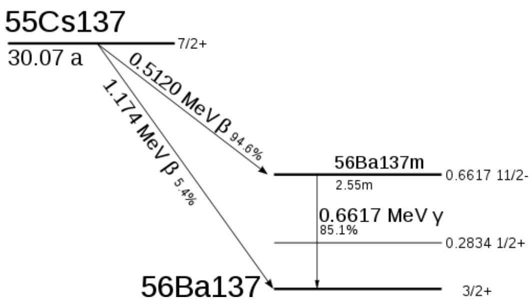

Figure 4: decay of Cs_{137}

After its production as a nuclear fission product, the required amount of Cs137 is enveloped in glazed ampoules and transported according to the rules of *IAEA TS-R-1 (Rev 1, 2008)* to a manipulator at IHC Systems' certified supplier – Eckert & Ziegler (former Nuclitec, former QSA Global), Germany and Czech Republic – in which encapsulation takes place.

4.1.1 Encapsulation and contamination tests

In the manipulator the Cs_{137}-glazed ampoules are placed under vacuum in a double-walled AISI 316L or equivalent stainless steel capsule [Reference 5 (open file), Reference 6 (open file) or Reference 23 (open file)], which is closed by robot welding, giving the double encapsulated radioactive source thermal, pressure, impact, vibration and puncture resistance according to ISO 2919/ANSI N43.6-1997 [Reference 4 (open file)]. After loading and welding, every capsule is subject to a Wipe test I, Immersion Test II and Bubble Test III according to ISO 9978: 1992 to certify that it is free of contamination above a threshold of 200 [Bq] or 5 [nCi].

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The encapsulated source has the official and legal status of sealed source. The beta-particles are easily caught in the capsule and converted to low-energy gamma photons. This means, the sealed source is a pure gamma radiation source. Then the contamination-free sealed source is mounted in IHC Systems' so-called source-stem, which gives it an additional massive fire and strength protection. More details in section 0.

4.2 Cobalt 60

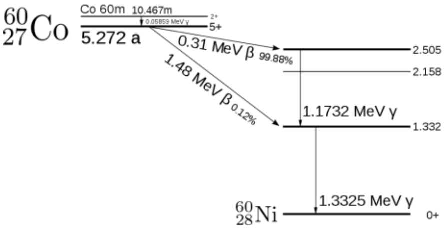


Figure 5: decay of Co_{60}

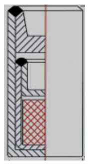
Cobalt 60 (Co_{60}) is one of the isotopes of Cobalt, a ferromagnetic metal with atomic number 27, that is a by-product of copper and nickel mining. Its melting point is 1,495°C. Co60 is generated by exposing Co_{59} grains or disks to the neutron flux in nuclear power stations. The isotope decays according to Figure 5: per Giga Becquerel [GBq] of activity, 10^9 gamma photons of 0.059 MeV per second bring the atoms' energy at about 2.8 MeV. From then simultaneous emissions of beta particles turn the bereft atoms to energetic Nickel (Ni_{28}m) atoms which release their energy in two gamma photons with a specific energy of 1.17 and 1.33 Mega electron Volt [MeV], turning the concerned atoms in stable Ni_{60} yet. The two photons bring an average energy of 1,25 MeV. For the density measurement this means that Co_{60} can penetrate pipes and mixtures with larger diameters. The specific half-life is 5.27 years.

Cobalt is usually clad with a galvanic Nickel layer and transported according to the rules of *IAEA TS-R-1 (Rev 1, 2008)* to a manipulator at IHC Systems' certified suppliers – Eckert & Ziegler (former Nuclitec, former QSAGlobal), Germany and Polatom, Poland – in which encapsulation takes place.

4.2.1 Encapsulation and contamination tests

In the manipulator the loaded Co_{60} grains or disks are placed in a double-walled AISI 316L or equivalent stainless steel capsule [Reference 7 (open file), Reference 8 (open file) or Reference 33 (open file)] which is closed by robot welding, giving the double encapsulated radioactive source thermal, pressure, impact, vibration and puncture resistance according to ISO 2919/ANSI N43.6-1997 [Reference 4 (open file)]. After loading and welding, every capsule is subject to a Wipe test I, Immersion Test II and Bubble Test III according to ISO 9978: 1992 to certify that it is free of contamination above a threshold of 200 [Bq] or 5 [nCi].

The encapsulated source has the official and legal status of sealed source. The beta-particles are easily caught in the capsule and converted to low-energy gamma photons. Which means, the sealed source is a pure gamma radiation source. At the end of this process, the contamination-free sealed source is mounted in IHC Systems' so-called source-stem, which gives it an additional massive fire and strength protection. More details in section 0.



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4.3 Overview of applied capsules and compliance with standards

Sealed Caesium sources are obtained from one, Cobalt sources from two suppliers certified in compliance with ISO 2919. Till 2017 Caesium and Cobalt sources were also obtained from NTP, Belgium. For the sake of completeness these capsules are also included in this overview. Dependent on material, supplier and activity [GBq], different capsules are used. Table 1 presents the respective standards to which any of them complies.

Iso-tope	Activity range [GBq]	Supplier	Capsule type	ISO 2919/ANSI N43.6-1997 classification	IAEA special form	US-model	Supplier's specification sheet	Special form Certificate	Tests complying to ISO 9978	Example of Certificate
Cs_{137}	0 … 185	NTP	Cs7.P04 (X9)	C66646	yes		Reference 18	CZ-1012-S-96		Reference 9
Cs_{137}	0 … 185	Eckert & Ziegler	Cs7.P04	C66646	yes		Reference 18	CZ-1012-S-96	Wipe Test I Immersion Test II Bubble Test III	Reference 24
Cs_{137}	0…66	Eckert & Ziegler	VZ-1726-001 (X.9)	C66646	yes	CDC.ZD1	Reference 19	USA-0640-S-96 ex D-0079-S-96		Reference 11
Co_{60}	0…1850	NTP	CoG10	C64445	yes, expired		Reference 20	B-018-S-96 * *		Reference 10
Co_{60}	0…200	Eckert & Ziegler	VZ-260-001	C66546	yes	CKC.P4	Reference 21	D-0091-S-96	Wipe Test I Immersion Test II Bubble Test III	Reference 12
Co_{60}	0…370	Polatom	C01HK	C66545	yes		Reference 31	PL-0023-S-96		Reference 32

Table 1: Survey of applied capsules and their compliance with standards

NB. The Special Form Certificates are presented in [Reference 18 – 19 – 20 – 21 – 31].

* Special Form Certificate B-018-S-096 [Reference 20 (open file)] has expired since 31-07-2017. As the supplier no longer exists, it is not renewed.

NB. The examples of the supplier certificates are presented in [Reference 9 – 10 – 11 – 12 – 24 - 32].

5 IHC SYSTEMS CONTAINERS & SHIELDING

5.1 Introduction

IHC Systems' suppliers place the source stem-mounted sealed source into a container, dubbed 'transmitter unit' within the dredging industry. There are five types: 110, 150, 180, 195, 210, the figures expressing the shielding capacity in millimetres of lead equivalent. Against the backdrop of a designed maximum dose equivalent rate of 10 [µSv/h] at any point of the transmitter box surface, this means that the sealed radio-active sources' activities must be limited according to the values of Table 2. The NA (Not of Application) designations in the table are explained in section 5.6.

Type	Maximum activity Cs_{137} [GBq]	Maximum activity Co_{60} [GBq]	Mass of transmitter unit [kg]	Mass of receiver unit [kg]
110	74	NA	250	135
150	222	6	600	165
180	NA	18	700	220
195	NA	55	900	240
210	NA	111	1150	275
$210_{Tungsten}$	NA	222	1150	275 or 340

Table 2: Maximum activity for each type of transmitter unit, and masses

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5.2 Generic technical description

The description in this whole section 5 is valid for all types of transmitter units, 110, 150, 180, 195 and 210. Whereas only dimensions vary per type, their design and construction is a fully identical concept. (The only exception is that the $210_{Tungsten}$ type (used only for very large diameters) includes a special source-stem, see section 5.2.2, allowing to load Co_{60} sealed sources up to 222GBq, simultaneously maintaining the maximum design dose equivalent rate over the whole surface of the transmitter unit and the isodose curve around it.)

5.2.1 Source-stem: additional strength and integrity

As stated in sections 4.1.1 and 4.2.1, the sealed source, either Cs_{137} or Co_{60}, is mounted by a licensed nuclear facility in the IHC Systems source-stem, Figure 6. Firstly the source is placed in the conical capsule holder, which is in turn placed into the foot (right in the figure) of the hollow source stem. Above it, accurately fitting Tungsten rods are placed for excellent additional radiation absorption. These rods are fixed with a stainless steel plug, that is screwed into the source-stem and finally secured with a short stainless steel welding joint, that can only be broken by destructive techniques like grinding. In this way the sealed source has been integrated in a mechanical structure, many times as large and as strong as itself, reducing the risk of loss and temperature shock of the minuscule capsule and providing total mechanical integrity under temperatures up to about 800°C.

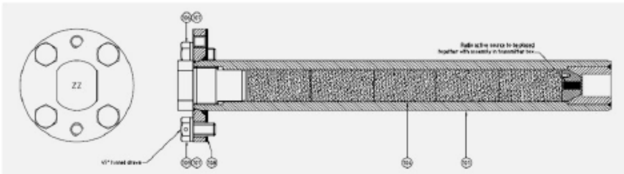

Figure 6: Stainless steel source-stem

5.2.2 Additional radiation protection of source-stem type $210_{Tungsten}$

In the $210_{Tungsten}$ type transmitter box the AISI 316L stainless steel source-stem is replaced by a Tungsten one. Tungsten with its atomic weight of 183.85, compared to the approx. 55.84 of stainless steel, and its tensile strength of 1,510MPa even at temperatures above 1,600°C, versus the 440MPa of stainless steel, absorbs more than the double amount of gamma photons than the standard source-stem. So the Tungsten source-stem allows to double the loaded activity of Co_{60} up to 222GBq at mechanical and fire protection features that can be dubbed excellent, without doing any concession to the radiation protection.

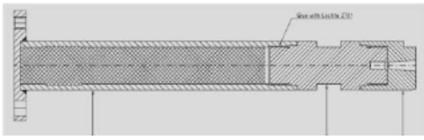

Figure 7: Tungsten source-stem

5.3 Technical description transmitter unit

Having in the source-stem an excellent means to excellently protect the sealed sources as such, it will always be mounted in IHC Systems' transmitter unit that adds the following functionality:

- ✓ Switch ability: putting through or blocking the gamma photon beam
- ✓ Fully integrated type A transport container according to *IAEA-TS-R 1*.
- ✓ Mechanical strength and robustness tailored to the operational dredging environment.
- ✓ Fire protection without radiation containment loss at persistent temperatures of 800+ °C.
- ✓ Means to fix ineradicable safety precaution tags, unique serial numbers and unique sealed source data and identification numbers according to the HASS requirements of Euratom.

To follow this description, please refer to Figure 8 and Figure 9, which are generic examples of the design and construction of the transmitter unit. More detailed (IP-protected) information on all types of transmitter units can be found in [Reference 13 (open file) – 14- 15 – 16 – Reference 17(open file)].

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5.3.1 Construction

The transmitter unit is an entirely closed all-welded mild steel (tensile strength 400MPa] construction. All weldings are made by qualified welders under ISO 9001 procedures. There is not used any depleted uranium in the design.

In radial direction a thick-walled steel cylinder-annex bearing bloc (pos 110/132) is welded-in and machined as to support the shutter drum (pos 120). This shutter drum is also a totally closed steel construction, except for a number of expansion holes in its top. It is chromium plated and carefully machined as to leave no slot between itself and the honed cylinder wall. It turns on bronze bearings (pos 110) The collimation diaphragm (shown here as a rectangular in the transmitter unit's closed position) is an all-welded AISI 304 stainless steel tubular construction.

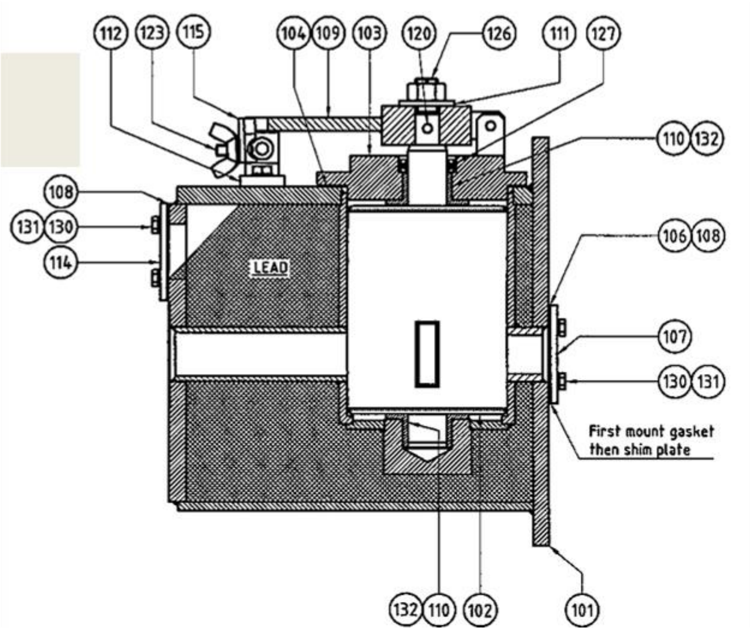

Figure 8: side view section of transmitter unit

In axial direction the shutter drum support cylinder is stiffened by a thick-walled and internally machined mild steel pipe, welded-in and running from the front-end flange to the back-end plate. In this pipe the source stem, sealed by a fireproof gasket is pushed and fixed by 4 bolts as easily can be seen in Figure 9. On the front side – where the radiation beam 'leaves' the transmitter unit – a thin brass plate with stiffening flange and fireproof gasket (pos 106/107/108) shuts the last hole in the construction, simultaneously allowing the gamma photons to pass with only little hindrance.

Figure 9: back view of transmitter unit, fix-mounted to a density measurement pipe section (old type control lever)

On top of the machined upper plate, a thick semi-circular steel plate (pos 103) with a fireproof gasket (pos 104) functions as sealing cover and as a bearing support for the shutter drum. The bronze bearing is protected against incoming water by a radial lip shaft seal according to ISO 6194/SAE J946-1989. The whole construction allows almost tolerance free turning of the shutter drum. The drum is greased in the cylinder with a special grease, drop point >220°C according to DIN/ISO 2176, kinematic viscosity 220-19 mm2/s at 40-100 °C according to DIN 51562 part 01, and a cone penetration at 25°C of 24.5 – 27.5mm according to DIN/ISO 2137. This grease will not harden under the influence of radiation.

5.3.2 Lead shielding

Both the transmitter unit and the shutter drum are filled with 100% pure lead [Pb_{206} or equivalent], the shutter drum until its top and the transmitter unit to a diagonal line as per Figure 8. The casting hole in the transmitter unit is then closed with a steel plate with fireproof gasket (pos 108/114). The space between the shutter drum (pos 120) and the sealing plate (pos 103) as well as the diagonal room function as expansion rooms for the lead in case of fire. So the lead can even melt without exerting strong forces on the transmitter unit's construction and welding joints and without leaking out of the sealed compartments. This means that no protection capacity is lost even under heavy and persistent fire exposition. The shutter mechanism also remains intact as the lead shrinks again when cooling down. See section 6.2.

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5.3.3 Shutter mechanism and radiation beam alignment

Please refer to Figure 8 and Figure 10. The shutter drum driving shaft has a squared top end over which the shutter lever (pos 109) is pressed and secured with a nut and ring. This means: the shutter lever position is an unambiguous indication of the shutter drum collimation diaphragm and consequently a sign whether the gamma photons are let through or blocked. It is indicated by a carved line in the shaft's top.

In the closed position, indicated by the visibility of a tag plate with the text **'out of circuit'** the shutter lever can be secured with a padlock – which always gives an extra safety intuition, running: 'padlock closed, source switched off, or: padlock not closed, be careful'. Note that the separate tag plate **'out of circuit'** and its counterpart '**in circuit**', barely visible in Figure 10 in the meantime have been replaced by the version of Figure 11, that inexorably prevents interchanged mounting of these indication tags.

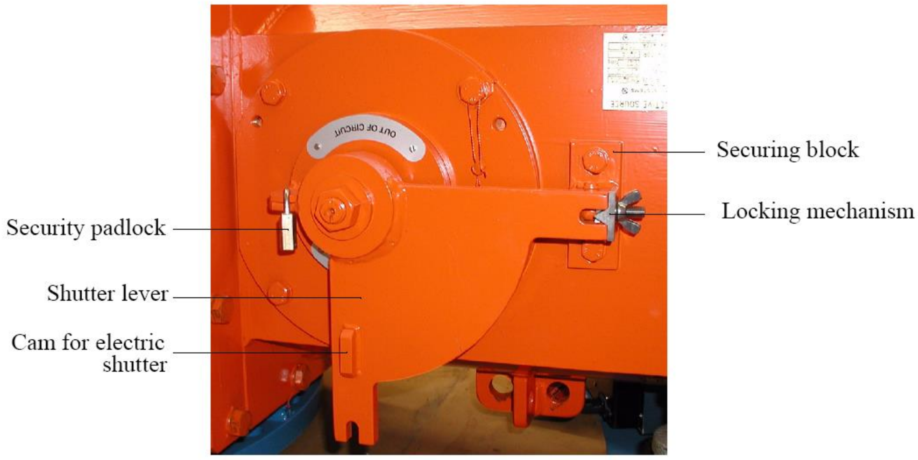

Figure 10: top view of the transmitter unit with shutter mechanism and alignment components

The shutter lever is fixed, both in the opened and closed position, by a swivelling wedge piece locking mechanism with winged nut. This also enables accurate alignment of the radiation beam: at manufacturing the securing block (pos 112) is given space to move a bit athwart along notched holes. In the calibration stage at IHC Systems' laboratory this block is shifted until the radiation detection device at the other side of the pipe section receives the maximum possible radiation dose. Then the securing block is bolted and provided with additional dowel pins to secure its alignment. The alignment guarantees that at the given radiation beam's angle the receiver box totally covers the high-radiation area at the other side of the pipe section, see section 5.6.

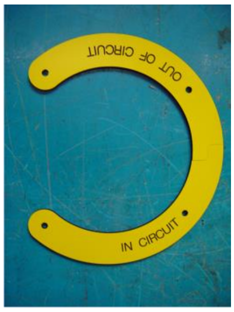

Figure 11: position of tag plates since June 2008

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5.3.4 Optional electric shutter drive

As stated in section 2.1 and in the *Instruction Manual* [Reference 3 (open file)], the standard manually operated shutter construction requires a decent and disciplined approach from the dredging vessel's crew, both for safety reasons and for keeping the shutter drum's moving mechanism elastic and pliant. Some customers therefore choose for – and some governments oblige to install – the optional automatic electric shutter mechanism, Figure 12. This mechanism acts on the cam at the shutter lever, shown in Figure 10. If not actuated, a spring load forces the shutter drum in its closed position. To bring it to the open position its electromotor must be activated. The activation can be interlocked by several conditions that are switched on the vessel's bridge or by the dredge process control system, e.g. 'dredgepump not running', or 'suction inlet valve closed' or the like, and any useful combination of those conditions. In this way two benefits are obtained:

Figure 12: electric shutter mechanism. (note also the padlock key with its emergency information tag)

- ✓ When the pipe section is empty, there is also no radiation beam, which limits any possible radiation exposure according to the known ALARA principle (as low as reasonably achievable). This basic safety principle is obtained by observing three main physical factors: (1) keep distance, (2) limit time of exposure and (3) shield radiation by sufficient mass of material.
- ✓ The shutter mechanism is moved at least one time per dredging shift: it remains elastic and pliant.

5.4 Prevention against loss of sealed source or loss of safety level

Prevention against unauthorised use and loss of functioning and safety by vibration as well as against malversation that could lead to the removal of the sealed source or the shutter drum – which would radically spoil the radiation containment features – is realised by a number of measures:

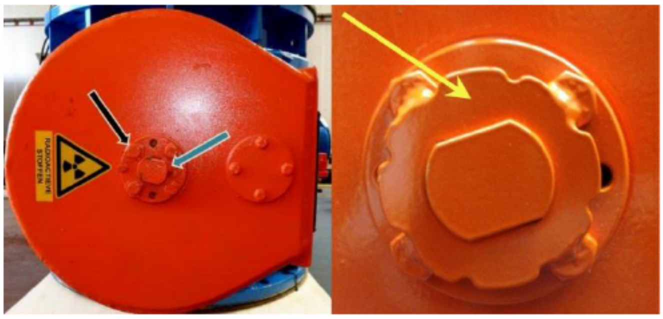

Figure 13: sealing of source stem and additional closure disk

- ✓ The plug that locks up the sealed source and the Tungsten rods of the source stem (item marked 'ZZ' in Figure 6) is secured by a stainless steel welding joint after fastening it (blue arrow in Figure 13). This welding joint can only be removed by grinding – which the *Instruction Manual* [Reference 3 (open file)] explicitly forbids to unauthorised people.
- ✓ 2 out of the 4 bolts that fix the source-stem into the transmitter unit are secured against vibration by locking plates. In addition these two bolts are also secured to each other and put under seal against accidental removal by a locking wire with lead seal (black arrow in Figure 13).
- ✓ The same measures have been taken to prevent loosening of the sealing cover (Figure 8, pos 103) of the shutter drum, Figure 14.
- ✓ Since start 2015 an additional security measure is applied to prevent easy removal of the source-stem by people with malicious intent. Around the plug (item marked 'ZZ' in Figure 6) a closure disk is mounted and welded to the four bolt heads (yellow arrow in Figure 13)
- ✓ The padlock prevents the transmitter unit to be switched 'in circuit' by unauthorised persons.

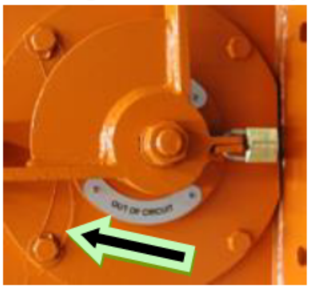

Figure 14: securing 2 out of 4 bolts and putting them under seal

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5.5 Precaution tags and inscriptions for compliance to legislation

The authorities of the Netherlands rule the possession and handling of sealed radioactive sources in the Kernenergiewet (1963) and the Dutch **B**esluit **b**asisveiligheidsnormen **s**tralingsbescherming (Bbs 2018), (former **B**esluit **S**tralingsbescherming (BS 2001), including the rules for “High Activity Sealed Sources” (HASS), implementing also the regulations of 96/97, 97/43 and 2003/122 Euratom. This legislation pre-scribes that any radioactive device must be provided with inerasable indications of the sealed source, a unique serial number and supplier’s ID. IHC Systems’ density measurements comply with this regulations, maintaining the indications in case of fire:

- ✓ Punched symbols in the edge of the transmitter unit topplate state the shielding capacity in millimeters of lead equivalent and the unique supplier’s ID. Example:
- ✓ CON 180-000 NL-L01 in a type 180 transmitter unit (Figure 15).
- ✓ Punched symbols in the opposing edge state the unique serial number 584-422A-xxxx, in which xxxx represents the actual serial number in the reserved range for density measurement devices.
- ✓ A brass indication plate with punched symbols repeats the above indicated data and also includes the unique identification number of the sealed source (e.g. NL-L01-PR-273), its material and activity.

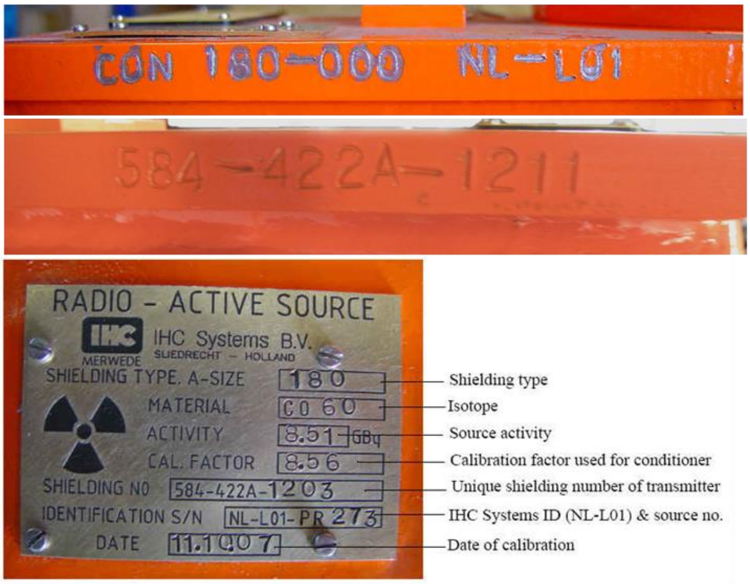


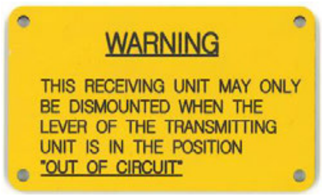
Figure 15: Punched identifications

- ✓ The radiation symbol is engraved in the same brass plate, stickered on three other sides of the transmitter unit and also engraved in the padlock’s key tag with emergency information.

In addition to these indications, seawater proof aluminium or acrylic general precaution tags are fixed on both the transmitter unit and the receiver unit, instructing people not to manipulate with either of them if the transmitter unit is not closed, and urging them to warn health authorities in any case of emergency – which includes radiation-accidents.

Tag on transmitter:

tag on receiver:



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5.6 Combined radiation safety features of transmitter and receiver unit

In principle the receiver unit has nothing to do with the safety of the sealed source as such. It plays however its role in the total radiation safety of the radioactive density measurement, especially if the pipe section is not filled with water. The reason is: any type of shutter cylinder has its own specific radial and axial collimation angle (Figure 1 and Figure 16), resulting in a defined pyramidal outgoing radiation beam.

Consequently, when a too large transmitter- too small receiver combination is used in relation to a too small pipe diameter, the collimated radiation beam will overdraw the receiver box area. This results in a too high dose equivalent rate at the pipe section surface just near the receiver unit, as is illustrated in Figure 17.

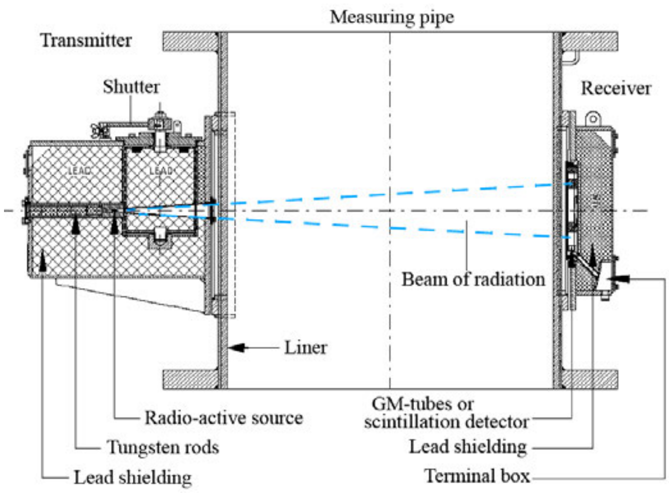

Figure 16: axial collimation of radiation beam

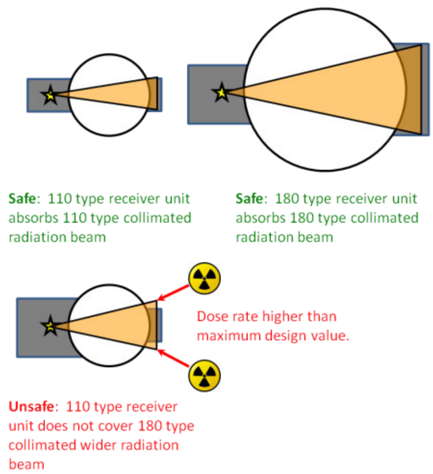

Figure 17: safety only by the same type of transmitter and receiver unit

To prevent that, IHC Systems always applies the same type of transmitter and receiver unit in one specific density measurement, correctly fit to the pipe section diameter. No exception is ever made on this principle, which is secured in the drawing package and in the ISO 9001-2015 Quality Management System. This also explains the NA boxes in Table 2, page 10: certain diameter and collimation angle combinations simply do not match. Consequently Co_{60} sealed sources cannot be applied for smaller diameters. Radiation safety considerations prohibit this theoretical application in practice, as the 150+ types of transmitter units, required for Co_{60}, allow the radiation beam to be too wide.

Finally, the receiver unit shields the applied electronic radiation detector of either the GM-tube or the scintillation counter principle and protects it against mechanical and climatologic hazards. As for the mechanical strength, it was designed mechanically following the same standards as the transmitter unit. Its lead mass is also entirely enveloped by steel and has expansion rooms. This means: both transmitter and receiver unit maintain 99,9% of their radiation absorption capacity even after fire, flooding or exposition to the common mechanical influences on board dredging vessels, but should be overhauled after such an incident in order to make them again fully complying with the as-new specifications.

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5.7 Radiation maximum level guarantee

IHC Systems' density measurements have especially been designed for application in the dredging industry. The criteria taken into account are: Safety, Reliability, Accuracy, Humidity, Vibrations and Wear and Tear. With regard to radiation safety, they have been constructed in such a way that even people who are not classified as radiological workers, are allowed to work in the vicinity of the transmitter during all working hours without the need for special protection, because:

- ✓ The sealed (or: encapsulated) sources fulfil the international requirements for identification as "special form" under "dangerous goods, class 7, schedule 9".
- ✓ The dose equivalent rate at any point of the surface does not exceed 10 μSv/hr (or 1 mR/hr), and in general remains below 5 μS/hr, complying with *IAEA TS-R-1* type A container Transport Index category "I-White".
- ✓ At one meter distance the dose equivalent rate is less than 0.25 μSv/h.

Isodose curves supporting the above statements for all types of transmitter units are available as per [Reference 25 (25, 26, 27, 28, 29 open file) – Reference 30 (open file)]. They were recorded and verified by two of certified IHC Systems' radiation officers in September 2010 with all types of transmitter units, loaded with a sealed source of specific activity. The actual measurements were linearly extrapolated to the values that would prevail if these transmitter units were loaded with their maximum allowed activity.

The radiation indicator, used at these measurements was the FH40F2 type of Thermo Electron RM&P, serial number 42482, calibrated and inspected by the Nuclear Research and consultancy Group (NRG) Petten, the Netherlands on 26 March 2010. Calibration is performed yearly.

5.8 IHC Systems procedures complying with legislation

IHC Systems' internal procedures comply with the Dutch **B**esluit **b**asisveiligheidsnormen **s**tralingsbescherming (Bbs 2018), (former **B**esluit **S**tralingsbescherming (BS 2001), including the rules for High Activity Sealed Sources (HASS), which implement the regulations of 96/97, 97/43 and 2003/122 Euratom. This includes:

- ✓ Registration of any movement of sealed sources within IHC Systems premises;
- ✓ If not worked-on, transmitter units are stored in a dedicated, separate and closed storage hangar;
- ✓ Two-weekly registration and report to the authorities of any transfer of ownership of a HASS source;
- ✓ Statement of unique supplier identification (NL-L01) and unique serial number(584-422A-xxxx) in documentation and at every transmitter unit;
- ✓ Statement of unique serial number of the sealed source in documentation and at every transmitter unit;
- ✓ Colour photograph of any sealed source with visible coding in documentation;
- ✓ Three-monthly visual monitoring on presence of stored sealed sources in transmitter units in storage;
- ✓ Yearly HASS report to authorities on full identification and licence for the possession of any sealed source;
- ✓ Yearly visual inspection and certified contamination (wipe) test of any transmitter unit in store;
- ✓ Workers on radioactive measurements wear electronic personal dose trackers which, track and log the dose with thresholds settings for dose and dose rates and have a real time alarm function. The log data of the used trackers is loaded into a database every month;
- ✓ No deliveries to unlicensed clients, persons and/or entities;
- ✓ Financial warranty for storage or destruction of returned sealed sources in case of bankruptcy;

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5.9 QMS Safety procedures at IHC Systems

Additional to the legislation-induced procedures, IHC Systems keeps the following procedures with respect to radioactive density measurements, according to the ISO 9001-2015 Quality Management System:

- ✓ Verification of the licence of the receiving client and the receipt of a statement of the client that his licence is valid for the ordered source. If not, the client is urged to apply for a licence by his local health authorities. The purpose of this SSDR is to seriously assist the client with the application.
- ✓ Use of only one, instructed and licensed transport firm for road transport of transmitter boxes, returned empty source stems and complete density measurements.
- ✓ Computerised and radiation officer verified calculation and ordering procedure of sealed sources for each individual density measurement, tailored to the specific dredging vessel and application.
- ✓ Testified visual inspection, checklist-processing and dose equivalent measurement of loaded or returned empty transmitter units, returned empty source stems or complete density measurements and lorry or truck on arrival at IHC Systems location.
- ✓ Mounting and dismounting according to prescribed QMS procedure.
- ✓ Continuous workshop and storage hangar radiation monitoring with visual and acoustic radiation alarm signals, permanently displayed on the computers of the company's safety officers.
- ✓ Computer supported calibration of the density measurements.
- ✓ Testified visual inspection, checklist-processing and dose equivalent measurement before any transmitter box, empty source stem or complete density measurements leaves the workshop.
- ✓ Closed storage area with visual radiation symbols at the door for loaded transmitter units and in some cases a complete measurement. The local firefighting department is informed about the storage of the radioactive sources. The alarm system of the storage is 24/7 in operation. Legal dose equivalent rates are complied with. Terrain is subject to security patrol and fenced at night.

5.10 Transportation categories

IHC Systems transmitter units fully comply with The Dutch Besluit Vervoer splijtstoffen, ertsen en radioactieve stoffen, which is in fact the implementation of the IAEA TS-R-1 (Rev 1, 2008). According to this legislation IHC Systems transmitter units and complete density measurements are to be considered a type A packaging. This means they may be transported in the open air. The prescribed Category I-White or II-Yellow stickers with the appropriate isotope, activity – and in the case of II-Yellow also the Transport Index – are filled-in and stuck at a good visible place on the unit's surface.

Figure 18: category I-White sticker, also indicating the Hazardous Materials, Class 7 status.

For Road transport, IHC Systems always recruits only one, instructed and licensed transport firm for any transport of transmitter units, returned empty source stems and complete density measurements. This transport firm transports the concerned unit to the client's premises, shipyards or to the concerned vessel or to the airport.

Under the Accord européen relatif au transport international des marchandises Dangereuses par Route (ADR), IHC Systems' transmitter units density measurements and adjacent equipment are identified as Special Form under Dangerous Goods (or: Hazardous Materials), Class 7, Schedule 9. All European ADR-licensed drivers have been trained to handle such cargo adequately, during transportation as well as in emergency cases. The units comply with ADR's European Agreement Concerning the International Carriage of Dangerous Goods by Road.

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In the case of Air transport, the unit is packed in an additional and sturdy wooden crate, provided with the appropriately filled-in Category I-White 1 stickers. For air transport the unit complies with the rules laid down in the ICAO/IATA document: "Technical instructions for safe transport of dangerous goods by air".

For Sea transport – which has happened never in the current decade because of the awkward paperwork the transporter has to do for any port visited – the unit complies with the document: IMO International Maritime Dangerous Goods (IMDG).

Customers who are returning a transmitter unit to IHC Systems e.g. for reloading the sealed source, should carefully verify the shutter mechanism and the padlock to ensure the shutter mechanism is closed before transportation. In addition they should correctly package and label the freight and make sure they inform the authorities and IHC Systems on the transport as well as take all other measures their specific licence requires from them.

6 TESTS AND APPROVALS

6.1 Type A packaging for transport

In 2010, TNO certification BV tested the transmitter unit for compliance with the rules concerning a type A package for the transport of radioactive substances. They presented the results in TNO certification report 14698-E.10.26674 [Reference 22(open file)]. The relevant rules applied were:

- ✓ *IAEA TS-R-1* (2009) section VI
- ✓ For Sea transport: IMO, International Maritime Dangerous Goods (IMDG) code 2008
- ✓ For Road transport: ADR, European Agreement Concerning the International Carriage of Dangerous Goods by Road, 2009. Paragraphs 6.4.2 and 6.4.7, including relevant subparagraphs.
- ✓ ICAO, "Technical instructions for safe transport of dangerous goods by air" 2009/2010. Paragraphs 7.2.1/ 7.2.2 and 7.2.3.

TNO's working method was a thorough screening of any and every aspect of the transmitter unit against any paragraph of the mentioned rules. If they could theoretically clarify performance against a specific rule they did no additional test. If not, a real test was performed.

The main aspects covered were:

- ✓ Strength of facilities for safe lifting and the prevention of being lifted at unintended parts;
- ✓ Sensitivity for absorption of rainwater (spray test equivalent to approx. 5cm/h during 1hour);
- ✓ Effects of acceleration, vibration or resonance under routine conditions of carriage;
- ✓ Effects of temperatures between -40°C and +70°C;
- ✓ Minimum prescribed dimensions;
- ✓ Special form radioactive material as a component of the containment system;
- ✓ Availability of positive fastening devices and the prevention of unintended loosening of them;
- ✓ Reaction of containment system on reduction of ambient pressure to 60 kPa;
- ✓ Reaction of containment system on internal pressure increase, producing a pressure differential of not less than maximum operating pressure plus 95kPa.
- ✓ Drop test of type 110 at 1.2m, repeated for the interpolation to other types to a height of 5m, for causing maximum damage dropped in diagonal direction at the edge front/shutter mechanism;
- ✓ Stacking test by means of calculation;
- ✓ Penetration test by means of calculation.

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6.1.1 Conclusions

As a result of the investigation, TNO certifies that IHC transmitter units of all types mentioned fully comply with the requirements of type A packaging for the transport of radioactive substances, without loss of containment for any of the investigated aspects.

6.2 The use on seagoing dredgers under classification

IHC Systems density measurements have been used for more than four decennia on seagoing dredgers under Bureau VERITAS or Lloyds Register classification without any problem. Other classifications have also accepted the measurement without problems.

There is plural evidence from the history that the lead shielding will keep its containment capacity under and after exposition to fire. See also section 5.3.2.

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7 CONFIRMATION BY THE AUTHORITIES OF THE NETHERLANDS

Agentschap NL
Ministerie van Economische Zaken, Landbouw en Innovatie

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[redacted]

Ons kenmerk
2011/IHC/10472/GH
Uw kenmerk

Datum 15 augustus 2011

Betreft License radioactive materials

To whom it may concern,

The Netherlands' Agentschap NL, which is an agency of the nation's ministry of Economic Affairs, Agriculture and Innovation, and the executive body for laws and regulations on behave of the authorized parties in the Netherlands, including those on radioactive materials, confirms that IHC Systems B.V. has a valid license for handling with radioactive materials and complies with the regulations, such as: registrations, duty to yearly and periodically reports, financial guarantee, as per:

- The Dutch Kernenergiewet (1963 with amendments up to 1996);
- The Dutch Besluit stralingsbescherming (2001), including the rules for highly active sealed sources of Staatsblad 260, 12 May 2006 (HASS), implementing also the regulations of 96/97, 97/43 and 2003/122 Euratom.

the Minister of Economic Affairs, Agriculture and Innovation,
on behave of:

[redacted]

Unitmanager Radiation Protection and Society

>> Als het gaat om duurzaamheid, innovatie en internationaal

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8 LIST OF REFERENCES

Reference 1	Licence of IHC Systems Nr. 2009/2656-05 [8 pages]
Reference 2	How to apply for a Licence? IHC Systems, October 2010 [2 pg.]
Reference 3	Instruction Manual Radioactive Density Transducer 5881256K_RA_Manual [53 pg.]
Reference 4	Information sheet Explanations for Certificates (Page 2 of Certificates) [1 pg.]
Reference 5	NTP (former Best Medical, former MDS Nordion) data sheet X9 capsule for Cs137 sealed sources [1pg.]
Reference 6	Eckert & Ziegler (former Nuclitec, former QSA Global) data sheet VZ 1726/1 capsule for Cs137 sealed sources [1 pg.]
Reference 7	NTP (former Best Medical, former MDS Nordion) datasheet CoG10 capsule for Co60 sealed sources [1 pg.]
Reference 8	Eckert & Ziegler (former Nuclitec, former QSA Global) data sheet VZ-260/2 capsule for Co60 sealed sources [1 pg.]
Reference 9	Supplier certificate NTP (former Best Medical, former MDS Nordion) Cs7P04 capsule [1 pg.]
Reference 10	Supplier certificate NTP (former Best Medical, former MDS Nordion) CoG10 capsule [1 pg.]
Reference 11	Supplier certificate Eckert & Ziegler (former Nuclitec, former QSA Global) VZ1726-001
Reference 12	Supplier certificate Eckert & Ziegler (former Nuclitec, former QSA Global) VZ-260-001 capsule [3 pg.]
Reference 13	Construction and arrangement drawing transmitter unit type 110 [4 pg.]
Reference 14	Construction and arrangement drawing transmitter unit type 150 [4 pg.]
Reference 15	Construction and arrangement drawing transmitter unit type 180 [4 pg.]
Reference 16	Construction and arrangement drawing transmitter unit type 195 [4 pg.]
Reference 17	Construction and arrangement drawing transmitter unit type 210 [4 pg.]
Reference 18	Special form certificate CZ-1012-S-96 (Cs7.P04) [12 pg.]
Reference 19	Special form certificate USA/0640/S-96 (ex D/0079/S-96) (VZ-1726-001 X.9) [4 pg.]
Reference 20	Special form certificate B-018-S-96 (CoG10) [5 pg.]
Reference 21	Special form certificate D-0091-S-96_Rev4 (VZ-260-001) [6 pg.]
Reference 22	TNO certification report 14698-E10.26674 on packaging type A compliance [19 pg.]
Reference 23	Eckert & Ziegler data sheet Cs7.P04 capsule [1 pg.]
Reference 24	Supplier certificate. Eckert & Ziegler Cs7.P04 capsule [3 pg.]
Reference 25	Isodose curve transmitter unit type 110 [3 pg.]
Reference 26	Isodose curve transmitter unit type 150 [3 pg.] not available yet
Reference 27	Isodose curve transmitter unit type 180 [3 pg.]
Reference 28	Isodose curve transmitter unit type 195 [3 pg.]
Reference 29	Isodose curve transmitter unit type 210 AISI [3 pg.]

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Reference 30	Isodose curve transmitter unit type 210Tungsten [3 pg.]
Reference 31	Special form certificate Polatom PL-0023-S-96 (C01HK) [3 pg]
Reference 32	Supplier certificate Polatom C01HK capsule [1 pg.]
Reference 33	Polatom datasheet CO1HK capsule [1 pg.]

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