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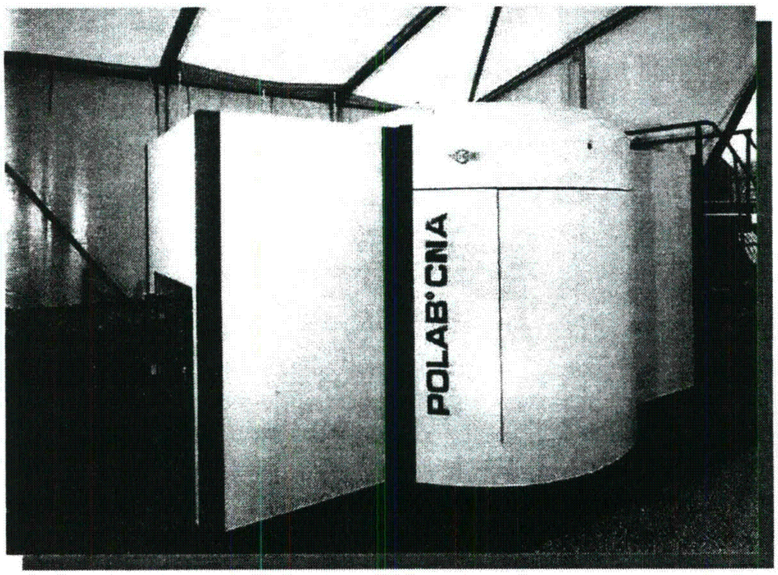
POLAB® CNA

Continuous Neutron Analyser



Technical Information about
POLAB® CNA
incl.
Neutron Generator and Neutron Emitting Module
Safety evaluation of device – safety review

Version 4.0

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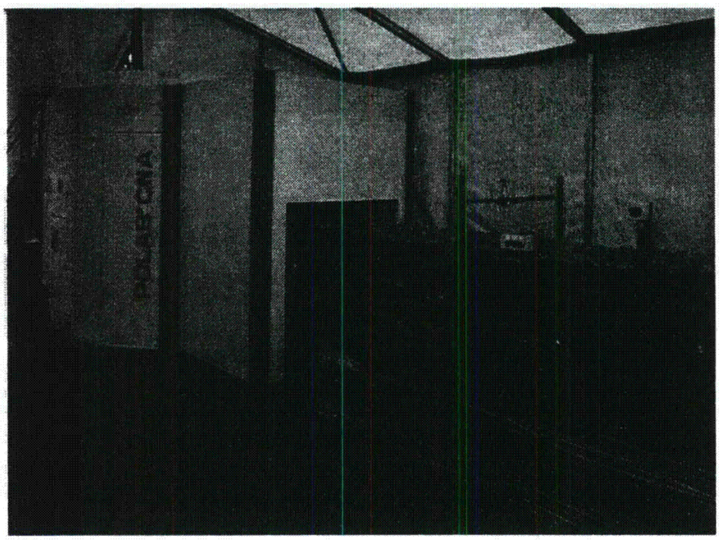
1. Introduction

This document contains information on the POLAB®CNA and its principal components. The information has been compiled to provide the licensing authorities with detailed answers to numerous technical questions, which may arise in connection with the licensing procedures. This document is intended to cover questions related to radiation protection of the POLAB®CNA and might be used as part of customer application procedures. It does not replace the operating and radiation safety chapters of the users manual.

Since the following text is considering questions concerning radiation safety and also details concerning export and import procedures, not all parts are equally relevant for the different parties concerned. Nevertheless we have tried to clarify the possible questions arising from the various aspects as comprehensively as possible. It has to be stressed however, that the system safety responsibility lies only with the user (especially the radiation protection).

2. Product description POLAB®CNA (Continuos Neutron Analyser)

The POLAB® CNA is an instrument for measuring the elemental composition of raw materials typically used in the manufacture of cement and comparable building material *continuously* and *on-line*.



The material passes through the analyser on a conveyor belt. Material types can be either individual materials such as limestone, marl or clay or blended material of raw mix or blending bed composition.

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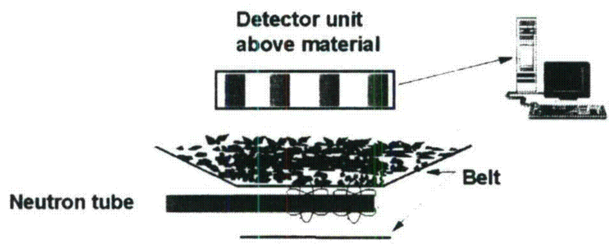
The measuring principle is based on the analysis of the gamma spectrum emitted by the material after its irradiation with neutrons. This method is usually called PGNAA, short for "**P**rompt-**G**amma-**N**eutron-**Ac**tivation **A**nalysis."

The neutron source used is situated under the belt conveyor transporting the rock material. The detectors for the gamma radiation analysis are arranged above the conveyor belt.

Numerous systems of comparable design are already being used in the coal and cement industries. However, in contrast to the other systems available on the market, the system named POLAB®CNA does not have a continuously active radioactive source of artificial radioisotopes such as ^{252}Cf but a neutron generator, which can be turned off.

Schematic sketch of the analyser principle



Neutron tube installed directly underneath the belt!
Minimum interference with belt geometry.

So operation of the GENIE16R neutron generator is an integral part of this analysing system which is intended for the chemical analysis of materials on belt conveyors.

When material is irradiated by neutron radiation of a certain energy range, several reactions take place on an atomic level, which can be used to extract useful chemical information.

The most prominent reaction has also given the name to this analysis principle (**P**rompt **G**amma **N**eutron **A**ctivation **A**nalysis). The analysis method is based upon the fact that the capture of a neutron by a nucleus leads to the formation of a highly excited compound nucleus, which decays, by the emission of gamma rays.

It is thus the secondary radiation, the gamma rays that actually hold the useful spectral information such as oxide concentrations. PGNAA contains the word **prompt**, because the emission of the gamma rays, after the atom has captured a neutron, is a very fast process indeed. Within 10^{-9} seconds (Nano seconds) the gamma radiation is emitted. And this nearly instantaneous reaction makes true on-line analysis possible. The emission of the gamma rays is so fast that irradiation and analysis can be performed simultaneously.

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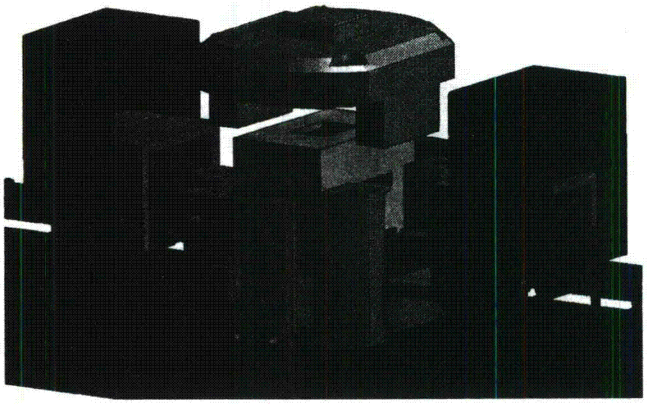
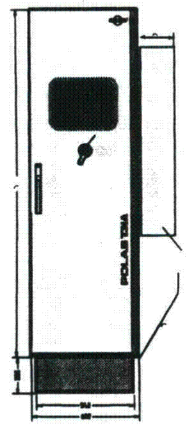
2.1 Design description

The actual POLAB®CNA consists of three main design components:

- measuring unit comprising radiation source, detector unit, moderation and reflector material (yellow)
- radiation shielding of special concrete (grey)
- electronic control and evaluation unit in a separate control cabinet including all necessary interlocking circuits for operator safety.





2.1.1 Measuring unit

The so-called measuring unit carries the neutron emitting module (MEN), the detector unit (SED) and the necessary moderation and reflection material needed to slow down the neutrons and reflect them back into the material. The inner measuring unit consists of numerous polyethylenes (density 1.7 g cm^{-3}), lead (density 11,4 g cm^{-3}) and graphite (1.7 g cm^{-3}) blocks, which are arranged around the conveyor belt. There are two subunits to be distinguished, a lower assembly, which carries the neutron emitting module (MEN) and an upper assembly holding the detectors. The whole part is coloured yellow in the figure given above. The total material mass is approximately 1,800 kg.

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2.1.2 Electronic cabinet

A high voltage- and a detector cable to an electronic cabinet connect the measuring unit. This electronic cabinet contains all measuring and control electronics, air conditioning and all necessary equipment needed to run the neutron generator, control the detectors and perform the data acquisition using high-speed data processing. Also included are all safety loops to stop the analyser e.g. in case of an incident. This cabinet can be positioned in a distance of up to 12 m away from the analyser.

2.1.3 Radiation shielding

Around the measuring unit a special, borated concrete shielding is used in order to assure, that radiation levels at the surface of the shielding (5cm distance) do not exceed the values of 2.5 μSv/h.

The components of the radiation shielding consist of modular pre-assembled parts of this special concrete (density 2.5 g cm^{-3}) and are assembled in a modular way with tongue-and-groove joints and no direct joints. The total material mass is 25,000 kg. The wall thickness lies between 30 and 54 cm. The thickest wall of 54 cm is located directly above the detectors. At certain positions (e.g. directly above the detectors) high density polyethylene plates are used on the inside to provide additional shielding. Concrete has the advantage of beeing fireproof, waterproof and non-corrosive.

3. Description of the neutron emission module

The POLAB®CNA is using a small particle accelerator for the production of the neutron radiation. The generator is a GENIE 16R developed by Messrs. SODERN. It consists of three main components, a neutron emitting module, a high voltage generator and rack with control electronics.

3.1 MEN (Module Emission Neutronique)

The Neutron Emitting Module (MEN) is a tube of polyurethane resin with a copper skin. This tube has a length of approximately 700 mm and a diameter of 100 mm and is called "**MEN**" after the French **M**odule **E**mission **N**eutronique. The schematic build-up is shown below

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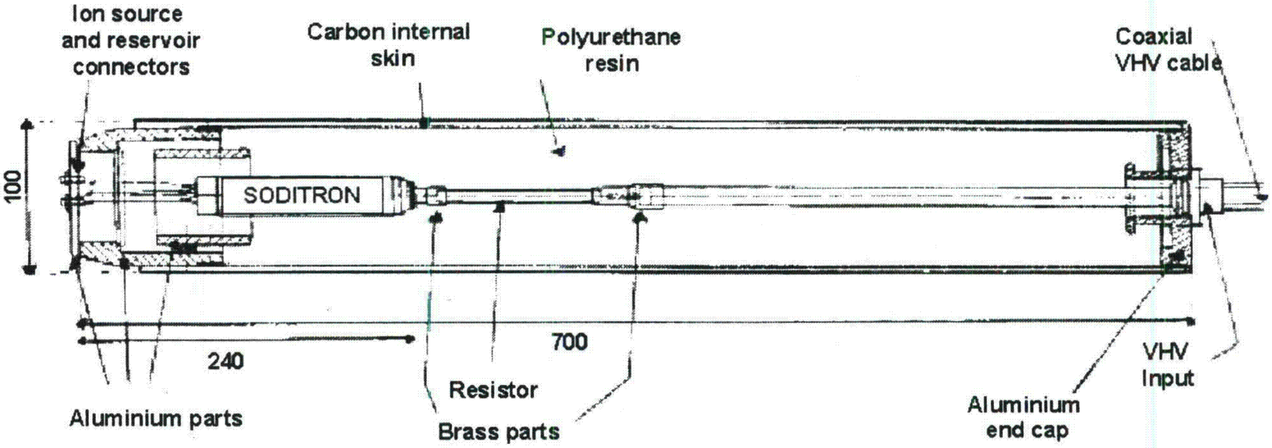


The total weight of the MEN is approximately 9 kg. Together with the high-voltage supply unit and the electronic control equipment, the MEN forms the actual neutron generator. For sake of clarity the designation MEN will be used for the black, cylindrical building part shown in the picture below for the rest of this document.

MEN envelop skin:

The MEN has a skin of copper sheet with a thickness of 0.3 mm. The end caps are made of aluminium.

Radiation emission window:

The SODITRON tube has no radiation emission window.

Type of sealing:

The MEN envelope consists of welded and polymerised polyurethane resin.

Type and thickness of the protection:

The actual SODITRON tube is embedded in welded polyurethane material with a thickness of 40 mm. This plastic material serves for moderation and protection.

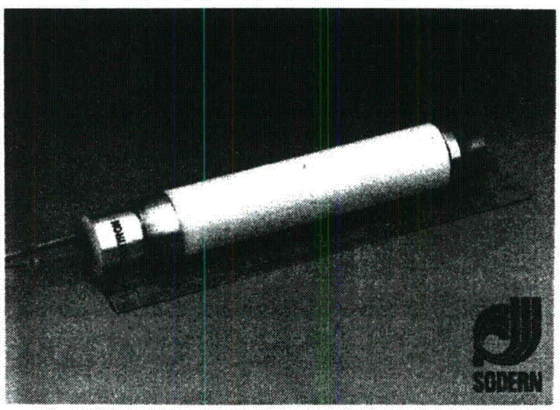
Mechanical, thermal and chemical influences

The polyurethane resin envelope with the copper skin provides a good protection for the tritium-containing tube against mechanical and chemical influences.

3.2 Neutron tube

Inside the MEN, embedded within the resin, we find the sealed neutron tube "SODITRON" which is the active component.

The SODITRON neutron tube is a sealed, metal-ceramic vacuum tube ($1.3 \cdot 10^{-3}$ Pa (10^{-5} Torr).



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The tube is the key component of the neutron generator. With electronic equipment and high-voltage supply, the tube inside the MEN is capable of generating an either pulsed or continuous radiation flux of almost monochromatic, high-energy 14 MeV neutrons. Maximum emission is 2×10^8 [n/s 4π sr]. For the present application the tube is run at 5×10^7 [n/s 4π sr]. The tube is only 155 mm long. Special cooling necessary for X-ray tubes is not required for the SODITRON neutron tube.

3.2.1 SODITRON chemical/physical characteristics

The SODITRON tube contains radionuclide (^3H) tritium in form of a titan-hydride layer of 1 to 5 µm thickness on ceramic base material and, in addition, tritium in the form of hydride bound in Al_2O_3-ceramic. The neutron tubes manufactured by Messrs. SODERN are acknowledged as sealed radioactive source; *„....considérés comme des sources scelles conformément aux „Conditions Particulières d´Emploi (CPE) des sources de Tritium absorbées“.*

One tube contains approximately 3.3 Ci Tritium (^3H). 3.3 Ci corresponds to $3.3\cdot(3.7\cdot10^{10})$Bq = $122\cdot10^9$ Bq. The total tritium mass contained in one tube is 0.34 mg.

Tritium is an emitter of ß-radiation. The maximum energy of the emitted electrons is around 18 keV. The penetration depth of these electrons and the X-ray radiation induced is so weak, that no radiation from the tritium is measurable as long as the tube remains sealed. The tube is regarded as an “encased radioactive source” because it is surrounded by a “solid, inactive envelope, i.e. permanently embedded in solid, inactive material, which ensure that a radioactive emission during foreseen normal application is prevented.” So the MEN, holding the tube, can be handled without special protection. Wipe tests have not shown any contamination on the tube surface.

According to the EURATOM (European Atomic Energy Community) standards, tritium is in the lowest group of radiotoxicity (group 4).

3.3 Electronic cabinet

The electronic cabinet holds all electric and electronic equipment to run and completely control the analyser. It is equipped with several safety loops assuring that no neutron radiation is emitted in case of several scenarios which might make it necessary to shut down the installation.
It´s main parts are
- the command rack for the generator and the VHV module
- the electronics for a ^3He counter continuously monitoring the neutron flux
- data acquisition electronics
- industrial PC and interfaces

The whole rack is according to IP55 and in accordance to EC EMC-regulations.

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3.3.1 Description

The set-up of the cabinet is schematically drawn up in the following drawing:

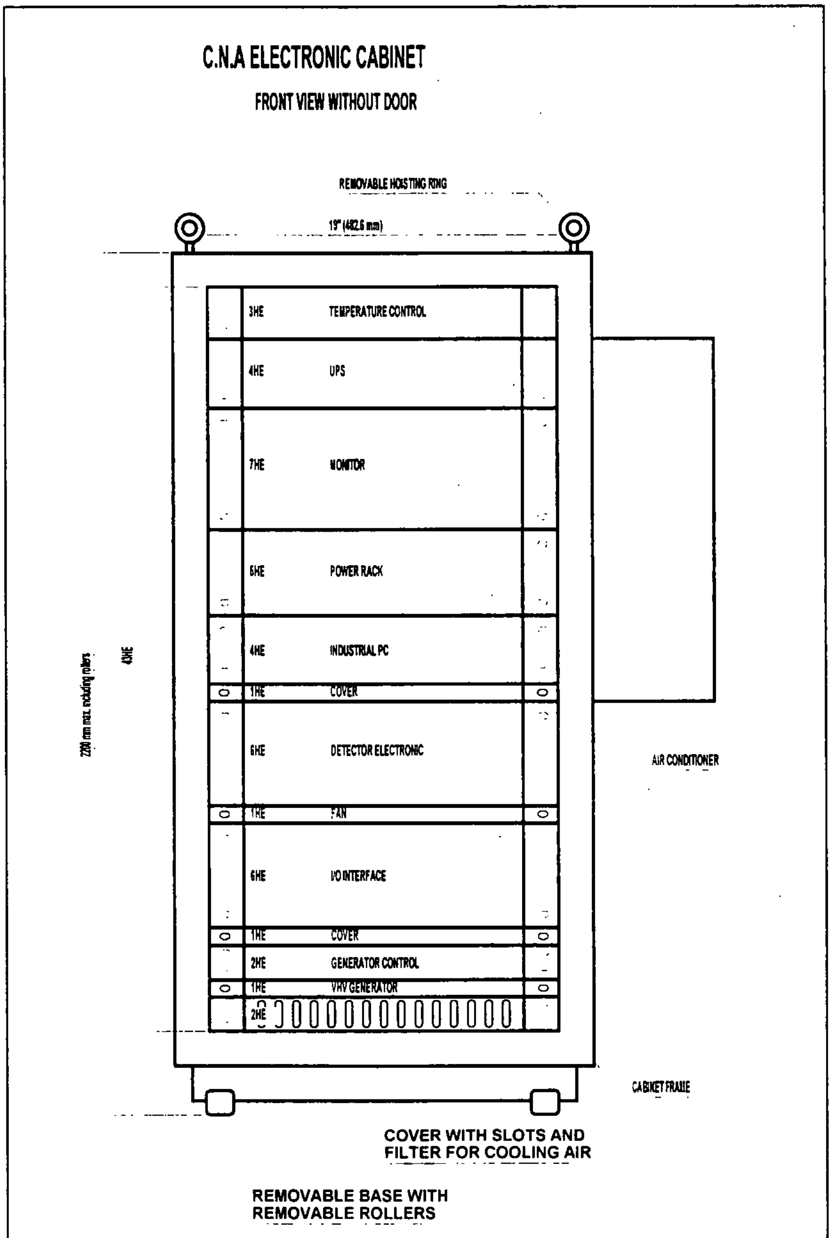

FIGURE 1

The industrial PC used can be completely controlled by remote access thus allowing to switch on/off the neutron radiation either on site or from a centralised control room. Status, error messages and commands can be exchanged in order to allow control of the equipment according to the different access levels.

3.3.2 Safety circuits

Different safety loops are connected to the power rack and the neutron generator. In case that any of the external emergency stop buttons is triggered, or the main switch is used, the complete POLAB®CNA is turned powerless. Safety loops are used to stop neutron emission immediately in case the access hatch to the MEN is not properly closed or opened while the generator is running.

3.3.3 Emission control

Neutron emission is continuously monitored by the generator control electronics. If the ^{3}He detector near the MEN detects any abnormal behaviour leading to neutron flux levels other than within the desired range, this will result in a shut down by the respective security loop.
Additionally the generator control electronics constantly monitor the high voltage and current of the neutron generator so that any abnormal behaviour is detected and closes yet another safety loop.

4. Radiation safety - general precautions

When it is operating the neutron-emitting module in the measuring unit produces
- fast and thermalised neutrons,
- gamma rays and X-rays,
- alpha and ß- radiation of such low energy that they do not even leave the inner parts of the tube itself.

Especially the neutron radiation can be extremely dangerous if the necessary security prescriptions concerning the use are not observed. So a radiation shielding is mandatory in any case. In a general manner some minimum precautions are imposed such as:

- the operator in charge of the installation is responsible for the observation and respect of standing rules and regulations

- deliberate destruction or opening of the neutron emitting module is forbidden. Handle the MEN with care to prevent breakage

- no unauthorised personnel should be able to switch on the generator

- the security systems of the analyser must be neither disconnected nor modified

4.1 Regular operation

During regular operation, all the control circuits, material transport preconditions and other boundary conditions are within the demanded operating specifications.

Three main modes are relevant now for radiation safety aspects:

Standby mode

In standby mode all systems are operational only the neutron generator is in idle mode.
Preconditions for the start of the analyser are:

Safety circuit is closed
No fault is signalled in the CNA status

When in standby mode, no neutron radiation is produced but the system is ready to be switched to neutron production at any desired moment.

Measuring mode

The system is running and neutron flux is nominal. Measurements can be performed.

When the system is switched off by remote, the analyser goes back to the above-mentioned standby mode. The command for this comes from the control system. So in standby mode, only the high-voltage generator is run down whilst the constant temperature of the detectors continue to be maintained by the control circuit.

The responsible operator in a dedicated routine running down all electrical systems performs a shutdown for a longer period of time (e.g. long weekend).

Irregular operation

"Irregular operation" is sub-divided into system failures which make a chemical analysis of the material in the analyser impossible or pointless and operational states in which analysis can be continued with limitations.

If a warning happens the measurement continues but the results may not match the warranties .
The POLAB®CNA supervisor should decide if the measurement continues.
Error : If an error happens, the measurement stops and the SODISCAN goes back to the standby mode except for fatal errors which completely switch off the entire system.

4.1.1 Dose around the installation

Due to the analyser design the maximum dose around the analyser is minimised as given for the example from the prototype installation (cf. annex).

Calculations and measurements show that in this equipment the induced dose of gamma radiation is by two powers-of-ten lower than that of the neutrons and therefore negligible. The shielding has been so dimensioned that a dose equivalent of 2.5 µSv/h at the concrete surface is not exceeded in full-load operation. Only directly at the inlet and outlet openings for the conveyor belt, a maximum dose equivalent of about 15 –25 µSv/h is measured when the belt is not loaded with material. When the conveyor belt is loaded with material, the dose equivalent is lower, i.e. as low as 2 to 4 µSv/h depending on the material load transported on the conveyor belt. Owing to the distance principle, a maximum dose of 2.5 µSv/h at a distance of 100 cm from the belt inlet and outlet openings is not exceeded during operation.

4.1.2 Activation phenomena

Material activation phenomena other than those used for the material analysis itself are a mayor concern to many users. Therefore some general explanations shall be given on this subject. The analyser design is such, that activation phenomena are minimised. As the production of neutrons can be stopped at any moment by turning off the generator, there is always enough time to assure that activation phenomena play no role if inner parts have to be accessed.

4.1.2.1 Activation of the installation

After operating the POLAB CNA for a long time, some inner parts of the measuring chamber and the interior of the shielding may become slightly activated. The choice of material for construction (C,H, concrete) is however such, that after some minutes decay time no relevant activation is measurable. This is especially important at the end of the service time of the analyser when the shielding etc. have to be disposed. Apart from mere radiation safety considerations, long term activation phenomena would decrease analytical performance of the analyser as the spectra would superimpose those needed for analysis.

4.1.2.2 Activation of the material

Due to the moderate neutron flux and the short dwell time in the analyser (belt speeds up to 4m/s), the activation of the rock material situated on the conveyor belt is smaller by orders of magnitude than what is allowed by international standards. Even with the radiation times of up to 60 minutes necessary for calibration measurements at a stopped conveyor belt, the activation of sample material is inferior to 2.5 µSv/h.. Radioactive waste is therefore not produced during the operation of the POLAB®CNA .

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4.1.2.3 Activation of the belt

The conveyor belts used consist of rubber and are irradiated together with the material. The main elements C, N, O, H contained in the conveyor belts show merely an activation of negligible half-life values. Even belt material measurements taken after the stopped belt had been radiated for several hours showed no relevant activation phenomenon with regard to radiation safety. Theoretically, normal belt material deactivates with the factor 1000 in approximately 1 minute.

4.1.2.4 Release of radioactive materials into air or water

The operation of the neutron generator causes no release of radioactive materials into air or water. The sealed neutron tube is to be returned to the manufacturer at the end of its service life or at the latest ten years after the purchase date.

4.2 Irregular operation

Irregular operation is considered situations were, despite a failure/error in a subsystem, the analyser can still be operated without danger. So if for example some piece of detector electronics is not working properly this might detoriate analysing efficiency but is not vital for the security loops or the overall functioning of the system. Another situation would be that a piece of plant process equipment is not working properly and therefore affecting the overall performance of the system. A misalign belt, a defect in the weight scale or oversize material on the belt might lead to a stoppage of the analysing system, but have no effect as far as radiation or operation safety are concerned.

4.2.1 Stop of the conveyor belt

In order to avoid unnecessary material irradiation in case the material transport system is not working for a longer time, the POLAB®CNA should be switched to “standby mode”. This is in accordance with the so ALARA (As Low As Reasonably Achievable) principle to be followed in radiation safety.

4.2.2 General power failure

In case of a general power failure the system will be buffered for a transitional period of some minutes by the UPS-system. But as high tension will be cut, neutron radiation will be stopped accordingly.

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4.2.3 In case of an accident

One of the big advantages of using a neutron generator instead of isotopic sources is that in the event of a mayor accident (plane crash, earth quake, etc.) leading to the complete destruction of the installation, no more neutron radiation is produced. Despite of the low tritium content a contamination by tritium is however possible if also the MEN is completely destroyed.

In case of fire or breaking of the tube due to a mayor incident, the MEN may be destroyed and can release a tritium quantity up to 1.2 10^{11} Bq. If ventilation is assured (an open door is sufficient), it can be shown that even the release of the total quantity of tritium would result in such a high dilution factor, that maximum permitted concentrations in air are not exceeded.

In case of breaking only a smaller quantity will be released if the temperature is still below 120°C but broken parts may be tritiated. As a consequence all parts of the broken MEN should then be placed in a double plastic envelope using gloves. The envelopes and the gloves shall be send back to SODERN for disposal.

Among other security tests one was performed were the complete MEN, that is the neutron tube embedded in the resin, was subjected to 400°C for 1h in a muffle furnace. After inspection the SODITRON tube showed to be still intact inside the MEN.

4.3 Normal shut down

In many applications it might not be necessary to run the analyser on a 24h basis. In this case, e.g. if the quarry operation is stopped overnight, the analyser should return to standby mode thus stopping the emission of radiation. For service or maintenance it is necessary to put the whole system powerless. So a complete shut down including tuning down the detector electronics and the other control electronics and secondary equipment (climatisation, IPC, thermal control etc.) is necessary.

5 Maintenance

The radiation source, namely the MEN, is virtually maintenance free. No manipulations are allowed. Attempts to open the MEN will have the result that the MEN is not operational any more. By signing the end user certificate the end user is also bound not to destroy the equipment.

5.1 Access to equipment other than the radiation source

When accessing the detector unit or when replacing the wear protection plates in the interior of the measuring unit, the analyser is completely turned off and powerless. All other key components are found in the electronic rack and can be accessed without any danger of irradiation.

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5.2 Change of the neutron emitting module

At the end of its lifetime the MEN has to be replaced. For this the access hatch in the radiation shielding needs to be opened. To access to the neutron-emitting module the system is completely turned off by the main power switch. Replacement can be performed by the operator himself. The installation procedures as described in the manuals have to be followed.

5.2.1 Residual activation

Before withdrawing the MEN from its position underneath the belt a waiting time of 45 minutes is recommended. Due to some short time activation phenomena of metallic parts within the MEN this time is needed to allow for deactivation.

5.2.2 Electrical hazards

In case of service procedures of whatever nature or any kind of operation concerning the neutron emitting module or the detectors, it is imperative that the main power plugs are disconnected and that the capacitors of the high voltage section are discharged. All safety rules in force concerning high voltage are applicable, while high voltage applied to the tube may reach 110 kV in nominal use.

When power is switched off or is accidentally interrupted, the capacitors are discharged, but discharge time may take a few seconds.

5.2.3 Storage of MEN

Spare MEN units should be stored in a secure place protected against fire and theft. They should only be accessible to authorised persons. The storage place must be adequately ventilated. Spare tubes are to be stored in the original MEN packing. The design of the neutron tube prevents misuse of the tube. Any attempt to use the tube with more than the rated capacity renders the tube inoperable.

5.2.4 Delivery of a new MEN

The neutron-emitting module is delivered in a dedicated transport enclosure. The user should keep this transport enclosure as it is used to send the MEN back to the manufacturer at the end of the lifetime. As the MEN is considered as a closed radioactive source of the lowest radiation safety level (EURATOM group 4), any authorised carrier can transport it if duly marked as containing radioactive material. Within the European Union the dispatch has only to be announced using EURATOM-form No. L148/4.

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6. Dismounting the analyser

At the end of its service life the analyser may be dismounted. For this the MEN needs to be withdrawn. Mechanical dismounting the analyser can be performed without special precautions as far as radiation safety is concerned.

6.1 Disposal of neutron emitting modules

The buyer of a SODITRON neutron tube must oblige himself to return the tube to the manufacturer as soon as the tube's service life has expired, or at the latest ten (10) years after its delivery date. The tube has to be returned to the following address:

SODERN
20, Avenue Descartes
F-94451 - LIMEIL BREVANNES Cédex
FRANCE
Tel.: (33) 1 45 95 70 00
Fax.: (33) 1 45 95 71 77

6.2 Loss or theft

In case of lost or theft of the neutron emitting module the user shall advise POLYSIUS as the supplier is responsible to declare to final destination of the equipment to the CIREA in France.

7. Administrative aspects

As a source of radiation, all neutron tubes are subject to the export regulations for nuclear equipment of the exporting country concerned (nuclear non-proliferation rules).

7.1 Export of a POLAB CNA

For the issue of an export licence the buyer has to present a number of documents to the seller, such as:

- copy of a handling licence for tritium, or an official authorisation to receive, store, own and handle the materials present in the MEN; or a MEN respectively;
- buyer's declaration (see enclosed standard declaration) in which the end user commits himself to employ the MEN bought by him exclusively for the intended use;

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- END USER CERTIFICATE completed by the end user for every MEN and POLAB CNA ordered by him;

- depending on the country to which the equipment is exported, an international import certificate may be required;

Only when the aforementioned documents have been submitted to the manufacturer the manufacturer can obtain an export licence.

Since only the buyer himself can apply for the handling licence, and since the licensing procedures vary considerably depending on the importing country, the applications should be made early enough before the planned date of commissioning

7.2 Transport of MEN

For the transport of the MEN the international regulations for the transport of said equipment (closed radioactive sources) apply. The MEN is delivered with all necessary documentation and should only be send back in the dedicated transport box. Handling of the MEN and replacement can be performed by the user himself. When not under high tension no emission of neutron radiation is possible.

7.3 Radiation signs and warning plates

The customer is responsible to properly attach the typical radiation warning signs (black wiriting on a yellow background) in such a way, that by approaching the analyser they are clearly visible. As the analyser can be operating in conditions ranging from indoor operation within a building to nearly outdoor operation in a sampling tower, the final placing of signs and warning signals such as flash lights, depends on the local conditions.

8. Summary

Maximum safety has been a main target in the development of the POLAB CNA both with regard to the neutron generation technology and the constructional concept for protection against radiation. In combination with the modular design of the concrete housing, the possibility to switch off radiation electronically provides a unique safety concept for this piece of analytical equipment. Easy transport, manipulation and use of the neutron emitting module allow for safe operation in everyday industrial operation.

Annex:

Annex1: Data sheet showing some general characteristics of tritium

Annex2: Example for buyer's commitment for use of the neutron generator

Annex3: Dose equivalents (radiation survey) measured at the shielding surface of the CNA prototype installation in Germany. The measurements were performed under the most unfavourable conditions that is with empty belt and maximum tunnel opening (320 mm). At those positions on the shielding surface were the prototype showed higher doses than the desired 2.5μSv/h (0.25mRem/h) ($n+\gamma$), the shielding of the final versions was improved accordingly.

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Data sheet
General characteristics of tritium:

Tritium element ^3H:

Emission:	ß-radiation
Half-life value	12.35 years
Maximum energy of ß- emission:	18.6 keV
Medium energy of ß-emission:	electrons with 5.685 keV
Penetration depths	
maximum in water	6 µm
average in water	0.56 µm
maximum in air	5 mm
Activity per gram tritium (T2)	359 TBq (9.7 kCi)
1 tritium unit (TU)	# 1 tritium atom / E+18 hydrogen atoms # 0.118 Bq HTO/L # 3.2 pCi HTO/L
1 mCi HTO/g water	37 GBq/g water 3,4 E11 TU 0.1214 Gy/h
Toxicity group	group 4
Effective dose per incorporation unit for water containing tritium (adults)	
- ingestion	1.8 E-11 Sv/Bq
- inhalation	1.8 E-11 Sv/Bq
- inhalation + absorption by skin	2.7 E-11 Sv/Bq

Tritium in SODITRON respectively MEN

Total activity :	120 GBq (3.24 Ci)
State	absorbed as hydride in a target and a replenisher (Ti or Zr)
Thickness of target	# 5 µm
Target substrate	copper
Housing:	sealed ceramic tube
Outer skin of MEN	polyurethane resin
Tritium emission	none
Tritium contamination of the outside	none

Example for buyer's commitment in writing:

KRUPP POLYSIUS

SODERN NEUTRON TUBES AND NEUTRON GENERATORS: PARTICULAR COMMITMENTS OF THE END USER OUTSIDE FRANCE

First commitment:

As the neutron tube is listed as equipment subject to authorisation under the Nuclear Non-Proliferation Act as well as to a verification of final destination, the sale of the neutron tube is subject to the issue of an export licence and the buyer's obligation not to re-export the tube to any third country. Furthermore, it is forbidden to remit a tube to any third party whether the tube charged or not.

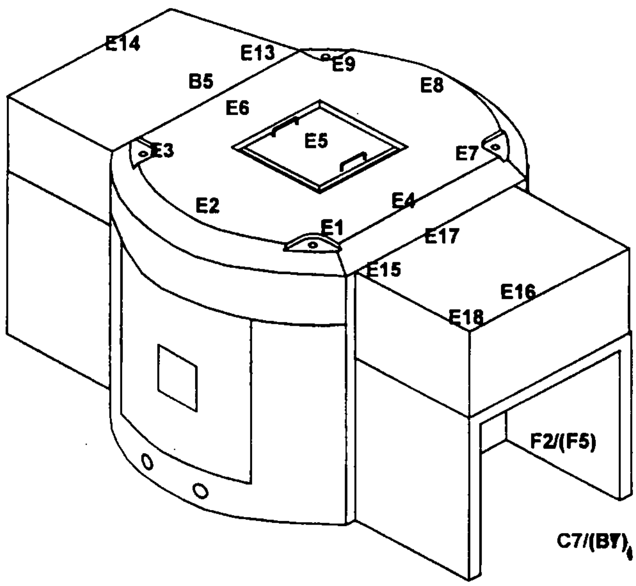
Second commitment:

The buyer herewith obliges himself to return the tube or the MEN (neutron-emitting module) with the tube to the manufacturer at the end of the tube's service life or at the latest ten (10) years after the date of delivery. The manufacturer's address is:

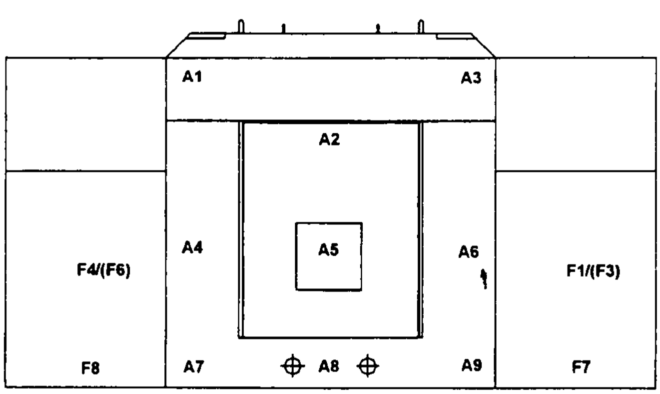
SODERN
20, Avenue Descartes
F- 94451 – LIMEIL BREVANNES Cédex
FRANCE
Phone: (33).1.45.95.70.00
Fax: (33).1.45.95.71.77

Read and approved by customer:

KRUPP POLYSIUS



Symmetrical points are in parantheses!
F2, F5 on the belt; **C7, B7** under the belt



Dose rates of neutrons + γ rays at 5 cm from shielding surface. Belt empty, generator on, tunnel 320 mm

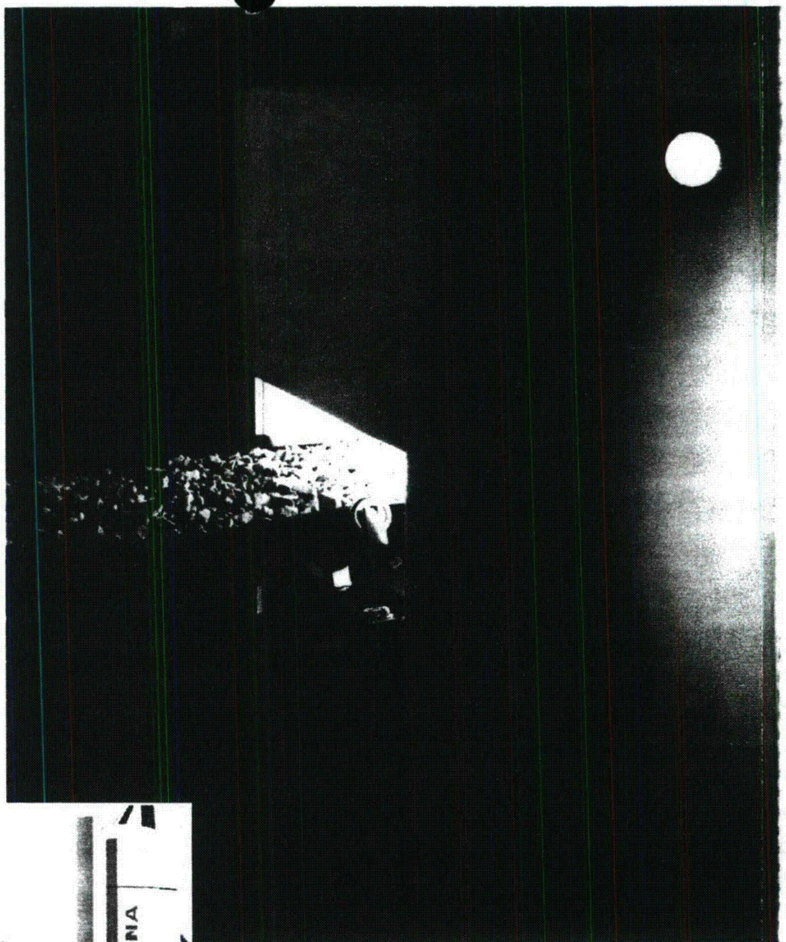
point	total µSv/h
A1	2,70
A3	1,46
A4	3,20
A5	4,40
A6	3,80
A7	1,41
A8	2,44
A9	1,55
B5	2,57
B7	8,10
C7	3,60
D6	4,80
D7	1,45
D8	1,83
D9	1,30
E1	0,76
E2	0,55
E3	0,58
E4	1,13
E5	3,70
E6	1,15
E7	0,75
E8	0,65
E9	0,62
E13	2,77
E14	2,90
E15	1,78
E16	2,74
E17	2,40
E18	2,02
F1	3,00
F2	15,60
F4	2,90
F5	30,60
F6	3,90
F7	1,55
F8	1,45

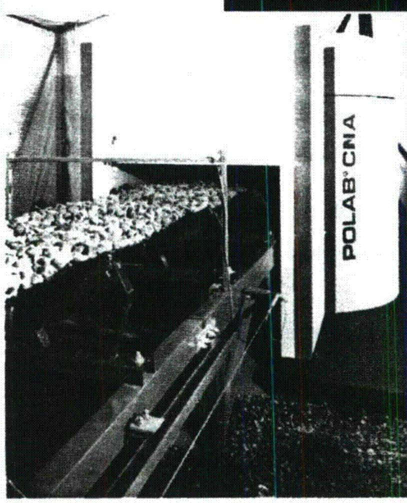
KRUPP POLYSIUS

POLAB® CNA
raw material analyser.

KRUPP

Long-term precision and safety: POLAB® CNA raw material analyser.





POLAB® CNA: highly effective and radiation proof – due to a totally new method of generating the neutron rays required for the material analysis

Outstanding effectiveness and maximum radiation safety. These were the requirements placed by Krupp Polysius on the development of a new raw material analyser. The result is our POLAB® CNA (Continuous Neutron Analyser) – a measuring device for continuous online analysis of material on a conveyor belt.

The analyser determines the chemical composition of the entire flow of material, which can be individual components like limestone, marl and clay, or mixtures of different components. It provides the weight percentages of silicon (SiO_2), aluminium (Al_2O_3), iron (Fe_2O_3), calcium (CaO), magnesium (MgO), sodium (Na_2O), potassium (K_2O), titanium (TiO_2), sulphur (SO_3), chlorine (Cl) ad manganese (Mn_2O_3), all of which are important parameters for controlling the raw material preparation. The advantage: thanks to POLAB® CNA, continuous regulation is made possible and raw material preparation and blending processes are substantially improved.

The main POLAB® CNA components are:

- measuring unit,
- radiation protection enclosure and
- electronic cabinet.

POLAB® CNA is of modular design, enabling rapid installation, including retrofitting into existing conveying equipment.

Windows NT based software is used for all analysis control, monitoring and evaluation procedures and also ensures easy data exchange with other automation systems, such as POLAB® AMT, POLCID® NT and POLEXPERT®...).

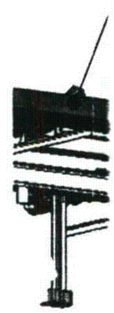
Measuring unit

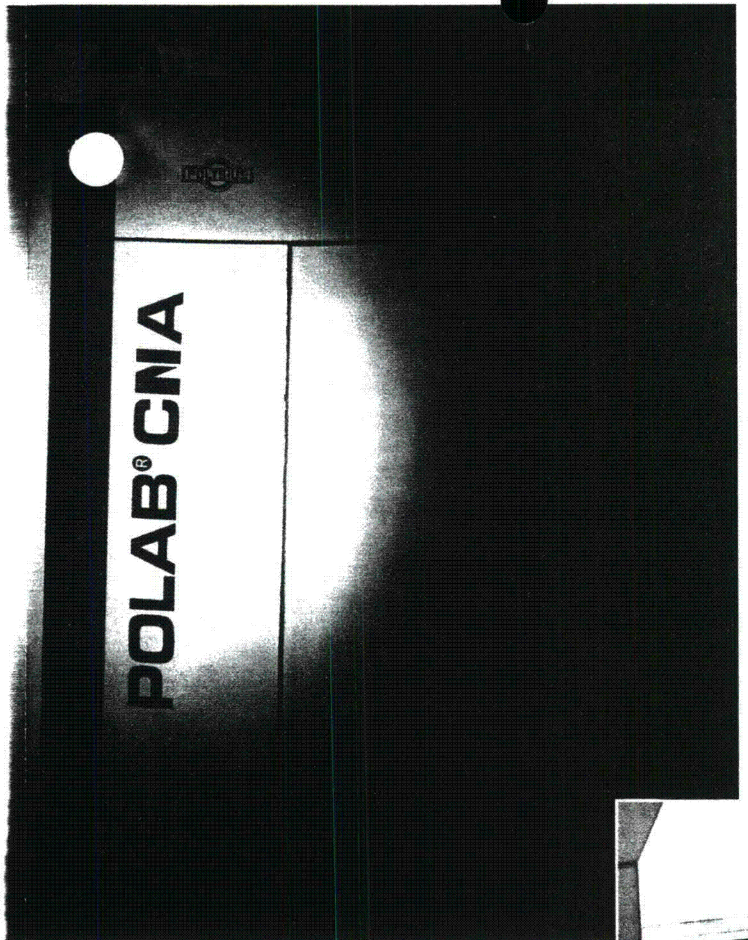
The measuring unit, whose modules are grouped around the conveyor belt, includes the neutron tube, the moderation material and the detector module.

The **neutron tube,** which is located beneath the conveyor belt, emits the neutrons which are required for the analysis. The advantages of this high-tech product are: it is easy to handle, can be switched on and off and, above all, it delivers pure neutron rays of the same intensity over its entire lifetime. POLAB® CNA the system thus supplies consistently high-precision measurement results. The neutron tube requires no cooling and is ready for operation directly after connection to the high-voltage supply. Control of the neutron flow is fully automatic.

The **moderation material** slows down the fast neutrons emitted by the tube. It is so arranged that the moderated neutrons are uniformly distributed over the flow of material to be analysed – a further crucial prerequisite for high-quality analysis results.

The **detector module** consists of gamma detectors positioned above the conveyor belt. The specific gamma ray spectrum emitted as a result of the neutron irradiation of the materials is recorded by the detectors with a precision which is not even affected by fluctuating material load on the conveyor belt!



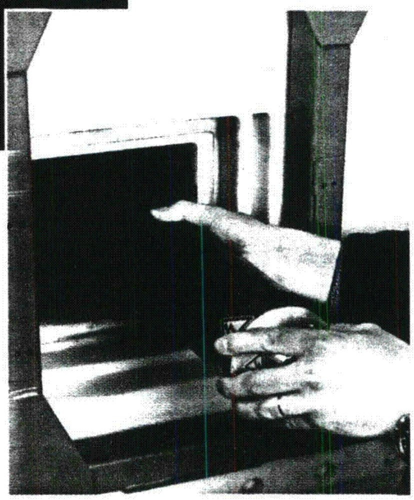


POLAB® CNA advantages at a glance:

Maximum precision:
- pure neutron radiation
- constant neutron radiation intensity
- multispectral evaluation (100 ms pulse length)
- analysis of the entire flow of material – instead of random sample analysis
- online analysis of the mass flows

Reliable radiation protection:
- safe radiation shielding enclosure
- disconnectable neutron tube

Minimum installation and maintenance work:
- modular construction
- on/off neutron tube ensures simple handling and transportation



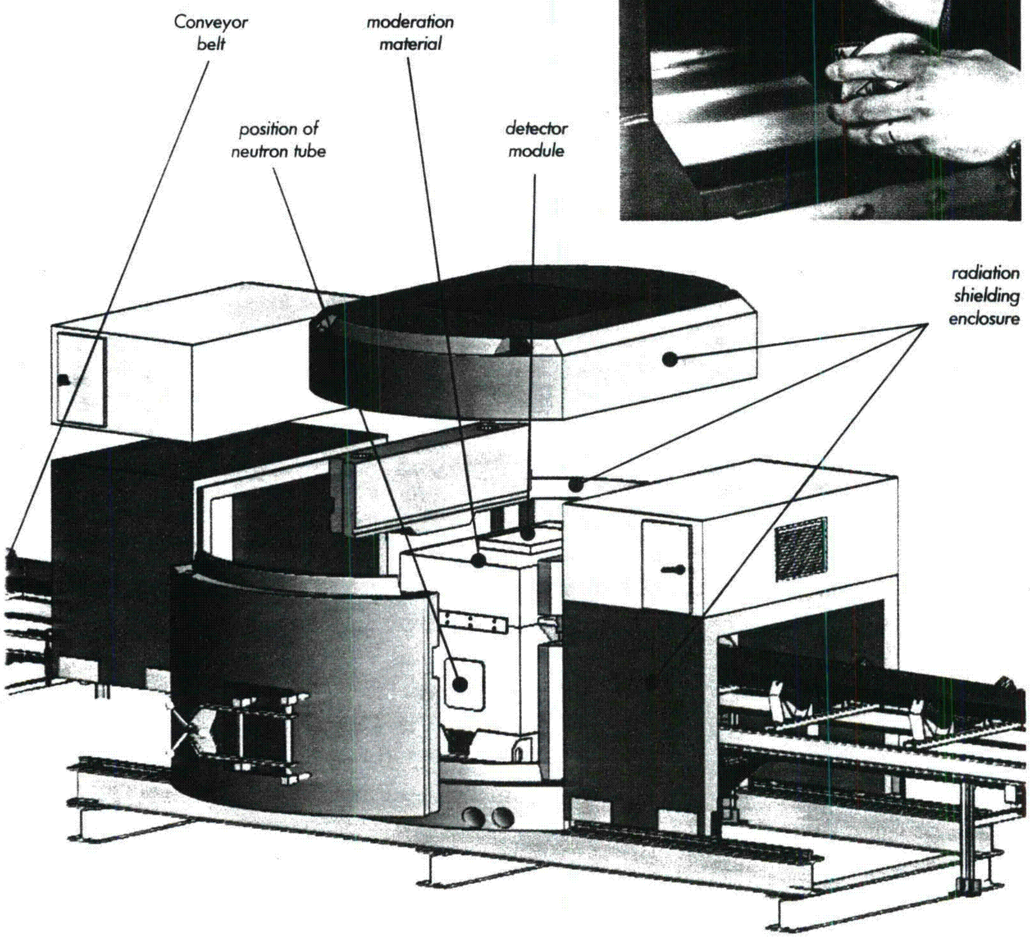
Straightforward installation and removal of the neutron tube

Radiation shielding

Reliable radiation protection is provided by the combination of radiation shielding enclosure and on-off neutron source. Even when the analyser is in operation it is perfectly safe to stand nearby. Access to the detectors and the neutron tube is provided by specially secured doors. Apart from the safety aspect, the modular design of the screening equipment ensures straightforward maintenance and installation.

Control cabinet

The control cabinet contains the measuring and control electronics, the cooling system and other equipment for controlling the neutron generator and detectors, as well as the spectral data acquisition and processing units.



The modular design ensures rapid installation (even in existing conveying equipment)

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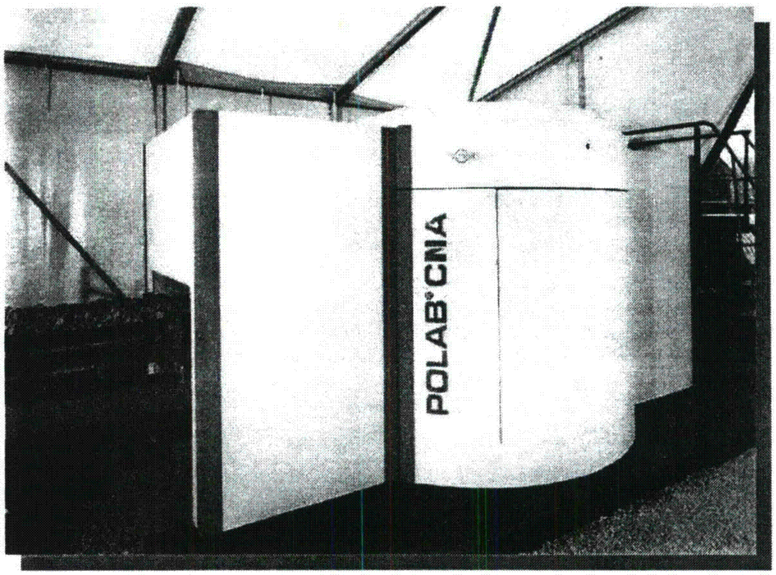
POLAB® CNA

The

Continuous Neutron Analyser

for

cement plants



Short description

Revision 1.0, May 1998

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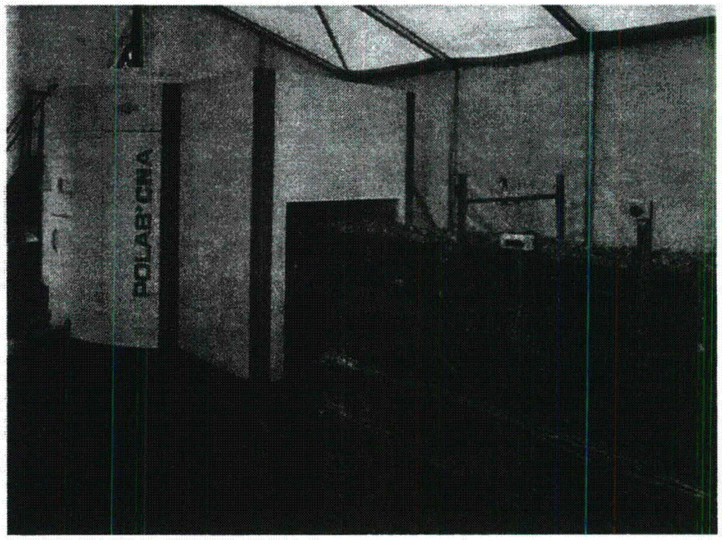
POLAB®CNA, The Continuous Neutron Analyser

Introduction

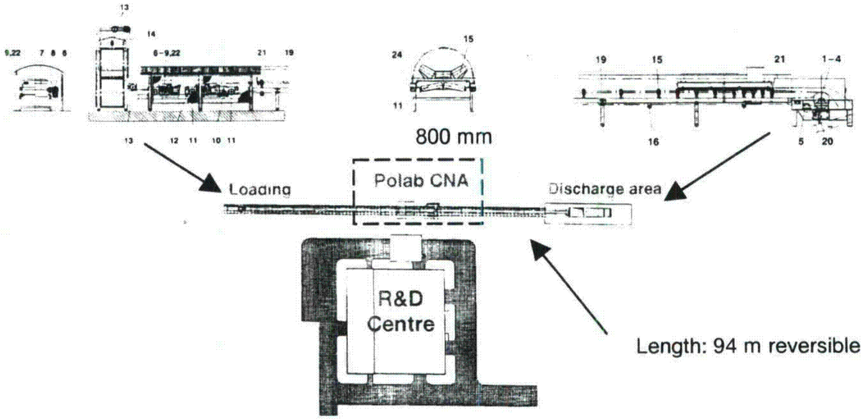
The POLAB® CNA is an instrument for measuring the elemental composition of raw materials typically used in the manufacture of cement and comparable building material *continuously* and *on-line.*



The material passes through the analyser on a conveyor belt. Material types can be either individual materials such as limestone, marl or clay or blended material of raw mix or blending bed composition. The physical principles used for analysis allow to real determination of the chemical composition of the ***total amount of material*** (bulk) which has moved through the analyser. The analysis is thus not only of a subset or only of the material's surface, as is typically the case if a sampling station is used.

The main idea which prompted the development of the POLAB® CNA is that radiation safety considerations will become more and more important for this kind of equipment in the future. A new approach concerning the production of neutrons for material analysis was therefore chosen.

But apart from this, the POLAB® CNA also shows significant technical advantages over existing systems. A first system is actually in operation in the POLYSIUS R&D centre at Beckum where a 94m industrial conveyor belt was installed in order to have the possibility to test the equipment in true dynamic mode. The test site is unique in the sense that it allows variation under exactly controllable conditions of all parameters that influence the analysis results and provide operational benefits. Tests can be performed on an industrial scale with several tons of material in dynamic mode.



Many tests, both in static and dynamic mode, have been performed with local and customer material in order to assess the performance and reliability of the equipment. The POLAB® CNA was first presented at the Hanover fair in April 1998 and is now offered to our clients as a new component of the POLAB laboratory automation line. It is able to significantly improve the raw material preparation and blending part of the cement production process, as it provides full control over aspects related to raw material composition.

Product description

The POLAB® CNA with computer controlled stockpiling assures that:

- the chemical composition of the stockpile content is known,
- fluctuations of feed material are quickly recognised and can be compensated during the building up of the stockpile,
- the setpoint values (e.g. LSF) can be consistently obtained at a given stockpile level,
- the quarrying operations can be planned for long-term exploitation.

Analysis principles

When material is irradiated by neutron radiation of a certain energy range, several reactions take place on an atomic level which can be used to extract useful chemical information.

The most prominent reaction has also given the name to this analysis principle which is often referred to as **P**rompt **G**amma **N**eutron **A**ctivation **A**nalysis (PGNAA). The analysis method is based upon the fact that the capture of a neutron by a nucleus leads to the formation of a highly excited compound nucleus which decays by the emission of gamma rays.

It is thus the secondary radiation, the gamma rays, that actually hold the useful spectral information such as oxide concentrations. PGNAA contains the word **prompt**, because the emission of the gamma rays, after the atom has captured a neutron, is a very fast process indeed. Within 10^{-9} seconds (Nano seconds) the gamma radiation is emitted. And this nearly instantaneous reaction makes true on-line analysis possible. The emission of the gamma rays is so fast that irradiation and analysis can be performed simultaneously.

Upon neutron irradiation, each element emits a unique set of gamma rays with known probability. Calcium, for example, emits gamma rays with several energies, the most prominent energies being 4.4 MeV and 6.4 MeV. The emitted gamma ray spectrum has to be detected and the gamma rays have to be identified according to their energy. This is achieved by using scintillation detectors. These detectors are installed across the belt, right above the material.

With additional signal processing equipment, a gamma ray spectrum can be created. Especially designed high speed electronic circuits amplify and process the detector pulses yielding a composite gamma ray spectrum. The spectrum, in turn, can be decomposed into its constituent parts (elements) by using a microprocessor and sophisticated analytical software especially developed for this application.

The physics of **P**rompt **G**amma **N**eutron **A**ctivation (PGNAA) makes it necessary that the neutrons emitted from the neutron source have to be slowed down (thermalised) and reflected into the material so that the reaction probability of a neutron with a nucleus of any atom in the material to be analysed is enhanced.

Neutrons are best reflected and slowed down by hitting against atoms of comparable mass. Hydrogen is very effective in this respect, as neutron and hydrogen masses are nearly equal. So if effective thermalisation and reflection of neutrons is to be performed, the neutron source should be surrounded by material with high concentrations of hydrogen and other light atoms. Therefore special plastic material with high hydrogen concentrations is arranged around the neutron source and the conveyor belt.

The arrangement of the reflection (or moderation) material surrounding the neutron source has to be very well designed, however, as it has to be assured that the material volume to be analysed is homogeneously illuminated by the reflected neutron radiation. What is happening while reflecting the neutrons into the material mass to be analysed on the belt might be called "neutron billiards". The so called moderation material has to be designed in such a way that statistically, even after multiple reflections, the distribution of slowed down neutrons is homogeneous over the material on the belt. Very time consuming and extremely complicated calculations therefore have to be performed for the design of a PGNAA system.

The POLAB CNA uses spectral information from prompt and capture gamma radiation induced in the material by irradiation with neutrons coming from a *pulsed neutron generator* and not from the traditionally used isotope source. The unique feature of a neutron generator, as

used in the POLAB CNA, is that it produces neutron bursts of adjustable length (1/1000 second scale) that allow differentiation of several energy transfer effects on an atomic level. Thus, the spectral information from prompt gamma neutron activation (PGNA) and other activation phenomena can be used to perform non-destructive, true elemental analyses of material passing through the analyser on a conveyer belt.

The POLAB®CNA thus uses a combination of spectral information emitted during irradiation of a sample with fast neutrons from a neutron tube in so called pulsed mode. This is very different from systems operated by isotope sources, which of course cannot use these effects, as pulsing is impossible. Another technical advantage lies the fact that by using a neutron generator producing pure neutron radiation, no disturbing gamma rays enter the detectors from the neutron source itself. Neutrons generated in the POLAB®CNA are all of equal energy and are not mixed with gamma rays to be accounted for in spectra deconvolution.
A ^{3}He detector is used to measure the amount of total hydrogen and infer the moisture of the material. Together with a customer-supplied belt scale and tachometer information from upstream of the analyser, this enables calculation of the true stockpile composition on a dry basis.

Neutron generation

The neutrons needed for the PGNAA technology applied within the POLAB CNA are emitted by a so called neutron tube, a small metal-ceramic device which is connected to a high voltage generator. The unit of high voltage generation and control, together with the neutron tube, is called a neutron generator.

The neutron tube (length = 155 mm, Diameter = 25 mm) is the key component of the neutron emitting unit. The use of a neutron generator makes it possible to keep the flux of neutrons constant over the whole lifetime of the tube. The control of the neutron flux is completely automatic and self adjusting; no intervention by the operator is necessary to monitor the right neutron flux. This is another key difference to the ever decreasing neutron flux emitted by an isotopic source. So operation of the POLAB CNA at ***constant accuracy and precision levels over its entire service life*** is assured not only by the production of pure neutron radiation, but also by the fact that neutron intensity is kept constant over the complete tube lifetime. The

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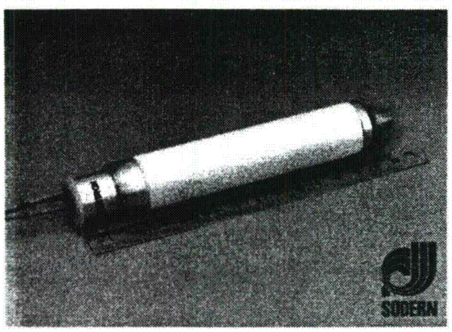

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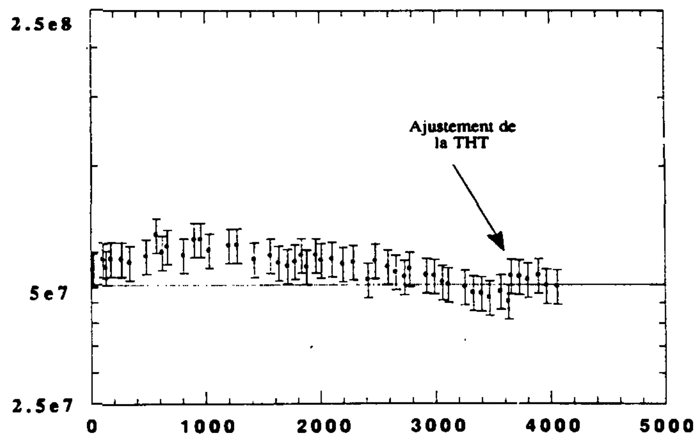
neutron tube needs no cooling device and is operational directly after high voltage has been switched on, so there is no warm-up phase as known from e.g. XRF systems.

In the case of a neutron tube, the lifetime is identical to the operation time. So if the tube is used for e.g. ten hours a day in a quarry, a possible "lifetime" of around 7000 h would correspond to approximately two years' operation time. If for any reason the POLAB CNA is not used for a longer period, the generator is simply switched off.



The figure shows the constant neutron flux of the neutron tube (approximately 5e7 n/s) over a long time period (example for 4000 h continuous operation).

Function

The analysis results are available as often as once per minute and are in the form of weight percents of oxides such as CaO, Fe_2O_3, Al_2O_3 and SiO_2. Quality parameters such as C_3S and LSF are calculated from the oxide analyses and are available from the operator's PC. For process control purposes however, average intervals of ten or fifteen minutes are normally used. Integrated analysis data are calculated together with the data from a belt scale.

Dedicated software controls the analyser, performs statistical evaluation of the data and provides communication with nearly all plant control systems, due to its very open structure.

Belt speed

As with other analysis systems on the market, the intensity of secondary gamma rays depends on the sample mass under investigation, so that there is a direct correlation between the achievable accuracy and precision and the belt load. Underloading reduces the number of emitted gamma rays, while a lower gamma ray count rate results is reduced repeatability.

The POLAB CNA is, however, ***not affected by irregular belt loading***, due to its use of pure neutron radiation from a neutron tube. If, during operation, an empty belt moves through the measuring chamber, no pulse pile-ups occur in the detectors etc. and the analysis capabilities are not affected. Constant belt loads and nominal mass are nevertheless, favourable, in order to obtain consistently good analytical results. Overloading should be avoided to prevent physical damage of the analyser and to avoid stoppages due to oversize material exceeding the possible tunnel height.

Elements to be analysed

The POLAB CNA measures the chemical composition of the material, expressed in terms of the cement chemist's notation, that is in oxides such as CaO, SiO_2 etc.

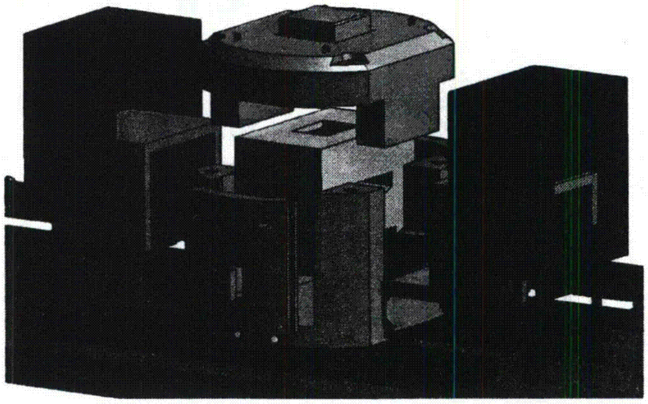
Elements		
Principle Elements	*Minor Elements*	*Calculated Moduli*
Silicon, SiO_2 Aluminium (Al_2O_3) Iron (Fe_2O_3) Calcium (CaO)	Magnesium (MgO) Sodium (Na_2O) Potassium (K_2O) Titanium (TiO_2) Sulphur (SO_3 Chlorine, Cl	Lime Saturation Factor Silica Modulus Aluminium / Iron Ratio C_3S C_2S C_3A C_2F C_4AF

The above-mentioned principal elements are those needed for stockpile control. They determine the functional scope of the analyser. The accuracy and precision of their determination is in the same order of magnitude as given by other PGNAA based on-line analysis systems and depends on the application. Other ratios and quality control parameters based on the knowledge of the elements quantified by the analyser can also be specified on customer demand and can be included in the software.

Typical performances for static <u>**and dynamic**</u> repeatabilities and accuracy are given in a special paper dealing with the results of the tests performed in the POLYSIUS R&D centre on customer material.

Analyser design

The analyser consists of two main subassemblies. A so-called measuring unit and radiation shielding.



The POLAB CNA is designed in very modular way to make installation as easy as possible and to minimise interference with existing equipment. It is not necessary to cut the belt for installation. Minor modifications of the steel structure have to be performed directly before and after the analyser, as the return belt passes underneath the analyser.

Measuring Unit

The measuring unit (yellow) is installed around the belt conveyor and comprises the neutron tube, a detector assembly and all the moderating material for thermalisation and reflection of the fast neutrons emitted by the tube.

The neutrons are emitted by a neutron tube situated underneath the conveyor belt, while the detector unit consists of scintillation detectors located above the conveyor belt. The belt slides through the measuring unit on a wear protection element, assuring that the belt is guided safely through the analyser.

Radiation Shielding

Around the measuring unit, a special concrete shielding is used, in order to assure that radiation levels in the proximity of the analyser do not exceed the values allowed by international radiation safety rules.

It designed for optimal radiation safety and has a modular structure providing easy access to neutron tube and detector unit. It can be easily imagined that the concrete used for this application is not at all of normal composition. It has to be assured that no signal coming from the shielding interferes with the measuring signal. Besides its radiation protection properties, concrete is a very effective insulator against heat and therefore helps to minimise temperature

variations in the interior of the analyser. POLYSIUS has given priority to radiation safety over total mass considerations. With a total mass of around 18t, most of it due to the design of the shielding, the POLAB CNA is no light-weight. But, together with the concept of an ON/OFF neutron source, it offers unprecedented radiation safety for this kind of technology.

Measuring Electronics

The measuring and control electronics, air conditioning and all necessary equipment needed to run the neutron generator, control the detectors, perform the data acquisition and high speed processing of spectral data are included on a dedicated electronic rack. This can be positioned in a distance of up to 12 m from the analyser. It is connected to the measuring unit by a flexible cable connection for power supply and data transfer. The rack protects the internal equipment from environmental influences such as dust, humidity or rain. The intention is to have an optimised environment for inspection and servicing of the components.

Software

A PC based software package is provided allowing full control of the analyser, diagnostics and monitoring of the measured oxide concentrations. The software consists of several access levels with interaction privileges allocated by the system administrator.

Advantages of POLAB® CNA

In comparison to other analysing systems on the market, POLAB®CNA has the following advantages:

- On/ Off source of neutron radiation (neutrons on demand!),
- Constant and controllable neutron radiation intensity over tube lifetime. Accuracy and precision independent of source age,
- Emission of pure monoenergetic neutron radiation. No spectral impurities from additional gamma rays produced by the neutron source itself,
- Follows highest radiation safety standards during operation,
- Very robust analysis technique, high quality equipment,
- Simple handling and transport of neutron tube,
- Simplified radiation safety licences in most countries,
- Analysis of the total material flow through the analyser not of subsamples,
- Real online analysis technique for bulk materials,
- System delivered by an experienced supplier of technology for the cement and minerals industry.

Table of contents of the POLAB®CNA radiation safety training for customers

Certified to ISO 9001

Member of
Krupp Engineering Group

Krupp Polysius Aktiengesellschaft
Registered Office: Beckum-Neubeckum
Trade Register: Amtsgericht Beckum, HRB-Nr. 1145
Chairman of Supervisory Board: Tyark Allers
Executive Board: Jürgen Bauer, Chairman
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180 Interstate North Parkway, NW.
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11. WASTE MANAGEMENT

Please refer the Technical Information about POLAB CNA located at the beginning of the Application documents. Section 5.2.3 on page 16 through Section 7.3 on page 18 deal specifically with waste management and device handling and storage.

KRUPP POLYSIUS CORP.

Coesfeld State Office for Workplace Safety

Responsible for the Area of the County of the City of Muenster,
and the Counties of Coesfeld, Steinfurt and Warendorf
Cottage Industry Work in the Muenster Administrative District

Addressed to:

Krupp Polysius
Graf Galen Str. 17
59267 Beckum

Processed by: Mr. Gewers

Phone No.: 771

Received by Krupp Polysius on April 13, 1999

Dated April 9, 1999

Hazardous Material Regulations, Road Traffic (GGVS);
Here: Transporting of Neutron Pipes with Radioactive Material

Dear Ms. Reyman:

The SODITRON tubes contained as a radioactive material, the Radionuklid Tritium (^3H) in the form of a 1.5 micron thick layer of Titanium Hydride on a ceramic bearing material, as well as additional Tritium in the form of a hydride bound in a Al_2O_3 ceramic. The specific activity is $122x10^6$ Bq. The total amount of Tritium in the tubes is 0.34 mg. Tritium is a better ray emitter.

Evaluation

In accordance with Section 1, Table 1, of Appendix A7, Edge No. 3700, the A1 value for the Radionuklid Tritium is set at 40 TBq ($40 \times 10_2$).

In accordance with Edge No. 2704, Page 2, Table 2, the limit value per instrument/make for Tritium as a solid material in special form 10^2 minus 2xA1 ($40x10^{10}$ Bq) = 400 GBq.

Since the activity of the material in the pipes is only 122 GBq, this limit value is not exceeded. Therefore, these tubes can be considered as items which can freely be shipped.

Though we are here dealing with material which can be shipped, Items 1-13 of Edge No. 2704, Page 2 are to be observed. For example, the shipping documentation in accordance with Item 10 must have the following notation: "2910 radioactive material, release for shipment, instruments or products, 7, Page 2, ADR".

In accordance with No. 1, Page 2, of Edge No. 2704, the dosage output at a distance of 10 cm from the surface of each unpacked instrument or product cannot be greater than 0.1 MSV/hour. In accordance with Edge No. 2704, No. 3, in conjunction with Edge No. 2702, No. 3, the highest permissible dosage output on the outer side of the shipping item cannot be greater than 5 micro SV per hour.

In sum, one can state that the pipes with their activity level of 122 GBq is to be classified as items free for shipment in accordance with GGVS Page 2, and thus in terms of shipment does not fall under any special regulation.

Should you have any further questions in the matter, I am available to provide you with what you need.

With best regards,

Ing. Gewers

Staatliches Amt für Arbeitsschutz Coesfeld
zuständig für das Gebiet der kreisfreien Stadt Münster und der Kreise Coesfeld, Steinfurt und Warendorf
Heimarbeitsschutz im Regierungsbezirk Münster

Staatliches Amt für Arbeitsschutz · Postfach 18 42 · 48638 Coesfeld

Firma
Krupp Polysius
Graf Galen Str. 17

59267 Beckum

Eingegangen
KRUPP POLYSIUS
am 13. APR. 1999
Erledigt: ....
Danach an 891

Bearbeiter: Herr Gewers

Durchwahl: (02541) 911- 771

Bitte mein Zeichen in der Antwort angeben

Ihr Zeichen und Tag	Mein Zeichen	Datum
	2.1-gw/bo	1999-04-09

Gefahrgutverordnung Straße (GGVS);
hier: Transport einer Neutronenröhre mit radioaktivem Material

Sehr geehrte Frau Reymann,

die SODITRON-Röhre enthält als radioaktives Material das Radionuklid (^3H) Tritium in Form einer 1-5 µm dicken Schicht von Titanhydrid auf einem keramischen Trägermaterial sowie zusätzlichen Tritium in Form von Hydrid in einer Al_2O_3-Keramik gebunden. Die spezifische Aktivität beträgt $122x10^9$ Bq. Die Gesamtmasse Tritium in der Röhre beträgt 0,34 mg. Bei Tritium handelt es sich um einen Betastrahler.

Beurteilung

Gemäß Abschnitt 1 Tabelle 1 des Anhanges A 7 Randnummer 3700 ist der A 1 Wert für das Radionuklid Tritium mit 40 TBq ($40x10_{12}$) festgelegt.

Gemäß Randnummer 2704 Blatt 2, Tabelle 2 beträgt der Grenzwert je Instrument/Fabrikat für Tritium als fester Stoff in besonderer Form 10^2 minus 2xA1 ($40x10^{10}$ Bq) = 400 GBq.

Da die Aktivität des Materials in der Röhre lediglich 122 GBq beträgt, wird der Grenzwert unterschritten. Es handelt sich demnach bei der Röhre um ein freigestelltes Versandstück.

Obwohl es sich um ein freigestelltes Versandstück handelt, sind die Punkte 1 - 13 der Randnummer 2704, Blatt 2 zu beachten. Beispielsweise muß das Beförderungspapier nach Nr. 10 folgende Eintragung enthalten "2910 radioaktiver Stoff, freigestelltes Versandstück, Instrumente oder Fabrikate, 7, Blatt 2, ADR".

Dienstgebäude: Leisweg 12 • 48653 Coesfeld • Telefon: (02541) 911-0 • Telefax (02541) 911 - 644
e-mail (internet) poststelle@stafa-co.nrw.de e-mail (X400) S=poststelle, O=stafa-co, P=dvs nrw, A=dbp, C=de

Gemäß Nr. 1 Blatt 2 der Randnummer 2704 darf die Dosisleistung in einer Entfernung von 10 cm von der Oberfläche jedes unverpackten Instruments oder Fabrikats nicht größer als 0,1 mSv/Std. sein. Gemäß Randnummer 2704 Nr. 3 in Verbindung mit Randnummer 2702 Nr. 3 darf die höchstzulässige Dosisleistung an der Außenseite des Versandstückes nicht größer als 5 µSv/Std. sein.

Zusammenfassend kann gesagt werden, daß die Röhre bei einer Aktivität von 122 GBq als freigestelltes Versandstück nach GGVS Blatt 2 einzustufen ist und somit bezüglich der Beförderung keiner besonderen Bestimmung unterliegt.

Sollen Sie hierzu noch Fragen haben, bin ich zu weitern Auskünften gerne bereit.

Freundliche Grüße
i. A.

Dipl.-Ing. Gewers

Dienstgebäude: Leisweg 12 • 48653 Coesfeld • Telefon: (02541) 911-0 • Telefax (02541) 911 - 644
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