UNIVERSITY *of* MISSOURI

RESEARCH REACTOR CENTER

July 20, 2015

U.S. Nuclear Regulatory Commission
Attention: Document Control Desk
Mail Station P1-37
Washington, DC 20555-0001

REFERENCE: Docket 50-186
University of Missouri – Columbia Research Reactor
Amended Facility License No. R-103

SUBJECT: Written communication as specified by 10 CFR 50.4(b)(1) requesting U.S. Nuclear Regulatory Commission approval to amend the Technical Specifications appended to Amended Facility License No. R-103 pursuant to 10 CFR 50.59(c) and 10 CFR 50.90

1.0 Introduction

The University of Missouri Research Reactor (MURR) is requesting a change to the facility Technical Specifications (TSs) in order to produce the radiochemical sodium iodide (I-131). There are currently no competing modalities for its use as a therapy for thyroid dysfunctions and no current supplier within the U.S. This Amendment would allow MURR to continue to perform a key role in the supply of critical medical radioisotopes, both domestically and internationally.

2.0 General Description of Proposed Experiment

The proposed I-131 experiment will include target irradiation; target disassembly; I-131 separation; and Quality Control (QC) testing of the product.

A double encapsulated [redacted] target will be placed in a predetermined graphite reflector region irradiation position. MURR Reactor Utilization Request (RUR) 440, "[redacted] – To Produce I-131" (Ref. 1), documents the safety evaluation performed for this target, which includes satisfying all of the applicable experimental specifications of Section 3.6 of the MURR TSs (Ref. 2). The RUR has been reviewed and recommended for approval by the Reactor Safety Subcommittee (RSSC), a subcommittee of MURR's Reactor Advisory Committee (RAC) (TS 6.1.c). The mass of the target is limited to [redacted] which can theoretically produce [redacted] of I-131 at a peak flux of [redacted]. In actuality, [redacted] of I-131 is a conservative overestimation of activity based on a maximum value for flux, greater than normal irradiation time

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(typical weekly reactor run time is 150 hours or less), and the discounting of any self-shielding effects of the target material. Based on the typical values of flux and irradiation time, and data from low activity experimental testing, a [redacted] target will produce approximately [redacted] of I-131 at the end of a typical [redacted] irradiation.

The following is a basic description of the overall process for producing I-131:

a. An irradiated [redacted] target will be delivered to the Handling Hot Cell (also designated as HHC or HC-11A) where the target will have its encapsulation removed. The target material will then be placed in [redacted] and transferred to the Processing Hot Cell (also designated as PHC or HC-11B) via a pass-through between the cells.

b. [redacted] is contained in a sealed casing, or containment vessel, with a filtered exhaust as described below. This provides the first barrier against a release of I-131 to the hot cell.

c. The bulk product solution will be sealed in a suitable transfer vial and transferred via a pass-through from the PHC to the Dispensing Hot Cell (also designated as DHC or HC-11C) for formulation into final product solution. It will then be dispensed according to customer requirements into vials suitable for shipping. An aliquot will be taken from the bulk solution and removed from the DHC for QC analysis.

The [redacted] time to release I-131 gas from the target matrix is [redacted]. The expended target material (waste) will be sealed in a can within the PHC for interim storage and eventual processing as radioactive waste. After multiple processes, and when the can is full, it will be allowed to decay for a sufficient time and then it will be moved via the pass-through to the HHC for additional decay and storage.

Figure 1 is a vendor drawing of the basic components designed for the [redacted] to produce I-131 from irradiated [redacted]. The irradiated [redacted] is placed in [redacted] which are then [redacted]. [redacted] described in IAEA-TECDOC-1340, "Manual for Reactor Produced Radioistopes" (Ref. 3).

[redacted]

[redacted]

[redacted]

Figure 1 – Vendor Drawing of [redacted] Processing Equipment

Processing within the hot cells will be performed under MURR Project Authorization RL-76, "Production of I-131 Radiochemical Sodium Iodide Solution" (Ref. 4). The Project Authorization has been reviewed and recommended for approval by the Isotope Use Subcommittee (IUS), a subcommittee of the RAC.

3.0 Hot Cell Design Considerations

The I-131 processing facility contains three adjoined and inter-connected hot cells which are located on the building grade level (see Figure 2). The HHC and the PHC have 200 mm (7.9 inches) of vertical lead shielding and the DHC has 100 mm (3.9 inches) of vertical lead shielding. The area to the rear of the cells, labeled the cask loading area (Room 299U), is where cell support facilities and equipment are located and where most cell inputs and outputs of targets, equipment and supplies occurs. Table 1 provides the lead dimensions of all of the hot cell components in millimeters. The area in front of the hot cells, labeled the operator area (299T), is where the cell windows, manipulators and controls are located.

[redacted]

Figure 2 – Iodine-131 Processing Area

The design philosophy for the hot cells is to provide adequate personnel shielding and containment of the I-131, precluding or minimizing any potential release from the individual cells to the reactor facility or to any unrestricted area. The design of the hot cell shielding and filtration is based upon a 200 Curie I-131 process; however, the proposed TSs will only request a limit of 150 Curies. This is consistent with our current fueled experiment TS limit (TS 3.6.a) on the inventory of iodine-131 through -135 per experiment. As explained above, a [redacted] target can theoretically produce [redacted] of I-131 (conservative overestimation of activity based on a maximum value for flux, greater than normal irradiation time, and the discounting of any self-shielding effects of the target material). Based on the typical values of flux and irradiation time, and low activity testing, a [redacted] target will produce approximately [redacted] of I-131 at the end of a typical [redacted] irradiation.

Table 1 – Hot Cell Lead Shielding
(in millimeters)

<table>
<tr><th></th><th>HC-11A</th><th>HC-11B</th><th>HC-11C</th></tr>
<tr><td>**Front, Rear Walls**</td><td>200</td><td>200</td><td>100</td></tr>
<tr><td>**Ceiling**</td><td>150</td><td>150</td><td>100</td></tr>
<tr><td>**Bottom (Table)**</td><td>100</td><td>100</td><td>100</td></tr>
<tr><td>**Side Wall**</td><td>200</td><td>N/A</td><td>100</td></tr>
<tr><td>**Partition**</td><td colspan="2">100</td><td>N/A</td></tr>
<tr><td>**Partition**</td><td>N/A</td><td colspan="2">100</td></tr>
<tr><td>**Bottom Channel (U-Shaped)**</td><td colspan="2">100</td><td>N/A</td></tr>
<tr><td>**Exhaust Air**</td><td colspan="3">100</td></tr>
<tr><td>**Inlet Air**</td><td colspan="3">50</td></tr>
<tr><td>**Material Lock (HSB to HC-11A)**</td><td>150</td><td colspan="2">N/A</td></tr>
<tr><td>**Material Lock (HC-11C to HSB)**</td><td colspan="2">N/A</td><td>50</td></tr>
</table>

The three (3) cell hot cell processing system also incorporates a six (6) detector radiation monitoring system (ALMO-6) designed to provide radiation dose level information to the process operators (Ref. 5 and Attachment 1). Three of the detectors (G-M) are located at the operator's work station where the hot cell manipulators are located and used during the process. These detectors provide real time dose rate information to the operators when they are performing a process. The remaining three detectors (G-M) are situated next to the first in a series of charcoal filters located in each of the bays above the three (3) hot cells. These are designed to give the process operators real time information related to the capture and loading of I-131onto the first charcoal filter in each external bank of the individual cells. This allows the process operators to monitor the condition of the charcoal filters and will alert them of the need to change to a bank of alternately available filters.

3.1 Handling Hot Cell – Design Features

The Handling Hot Cell (HHC or HC-11A) is designed for two principal purposes: (1) to receive irradiated targets and house support equipment to remove the target encapsulation, and (2) to store process waste for

an interim period of time. This cell has a floor access port to allow entry of irradiated targets from a target transfer cask designed to seal with the cell floor port. Within this cell the target encapsulation is removed and the irradiated [redacted] material is placed in crucibles and transferred via a pass-through to the PHC.

The cell is designed to have process waste materials from the PHC returned via a pass-through chamber for interim storage. The pass-through has a door at each side and is sized to hold any object that will be moved to and from the PHC. The waste material from the PHC (e.g., expended target material, contaminated used equipment) will be placed in containers with press-seal lids.

The volume of the cell is designed to hold the process waste for approximately 10 half-lives of the I-131 (about 80 days) after which time the cans may be moved to longer term shielded storage. As noted above, the cell has 200 mm (7.9 inches) thick vertical lead shielding with a stainless steel liner and two master-slave-manipulators (MSM) penetrating the cell from the operator side. This cell also has a sealable glove box for entry of items such as product vials and processing equipment.

3.2 Processing Hot Cell – Design Features

The Processing Hot Cell (PHC or HC-11B) is where the [redacted] processing of the [redacted] targets is performed. This cell has 200 mm (7.9 inches) thick vertical lead shielding with a stainless steel liner and two MSM which penetrate the cell from the operator side of the cells. The sodium iodide product solution will be moved from the PHC to the DHC in a sealed vial through a pass-through. Note: The system is also designed where the sealed vial may be passed back into the HHC through the pass-through for transfer from the HHC to the DHC via a shielded cask.

The PHC, during processing, provides three barriers to prevent the release of radioactive material to the environment: (1) the processing equipment itself, (2) an additional inner containment for the separation furnace within the PHC with a dedicated filtration system (as described in Section 2.0), and (3) the PHC containment provided by an exhaust system that includes high efficiency charcoal filters. The process is designed to contain I-131 within the process equipment; therefore, there should be minimal, if any, release of airborne radioactivity to the hot cell.

3.3 Dispensing Hot Cell – Design Features

The Dispensing Hot Cell (DHC or HC-11C) is designed to receive the bulk I-131 in solution from the PHC via a pass-through. The bulk sodium iodide radiochemical will then be dispensed in quantities to meet customer order requirements. This cell will also have a sealable glove box for entry of items such as product vials, lead pigs, and dispensing equipment.

The dispensing cell has 100 mm (3.9 inches) thick of vertical lead shielding and two MSM penetrating the cell from the operator side.

4.0 Facility and Hot Cell Ventilation Systems

4.1 Facility Ventilation Supply System

Fresh air is supplied to both the laboratory and reactor containment buildings through louver dampers on the north and south facades of the reactor building east tower. Most of the supply air entering the east tower is diverted to the laboratory building; a smaller portion is for make-up air to the containment building.

Outside air is preheated, as necessary, by a steam coil and then filtered before entering the laboratory building via the laboratory building supply fan (SF-1). The supply air is then directed to two receiving plenums (hot and cold decks), each containing an independent coil system. Steam is supplied to the hot deck to heat the supply air; chill water from the air-conditioning system is supplied to the cold deck to cool the air. The heated and conditioned air from these plenums is then circulated throughout the laboratory building via a double duct air distribution system. A ceiling register and mixing box in each laboratory and office allows the hot and cold air from the distribution system to be combined and circulated within that space to create a suitable environment for personnel comfort and equipment cooling.

Additional fresh air is supplied to the laboratory building (also to the laboratory building expansion, known as the MURR industrial building) through roof top air handlers (RTAH). Each RTAH has a heating and a cooling coil to heat and/or condition the supply air before its discharge into the laboratory building through registers in the ceilings of these corridors.

4.2 Facility Ventilation Exhaust System

Exhaust air from both the laboratory and reactor containment buildings is combined in an exhaust plenum prior to being discharged to the atmosphere. Since air from both buildings is never mixed until this point, potentially contaminated air is diluted by mixing with uncontaminated air, resulting in minimum concentrations of radioactive gases being released to the environment.

The ventilation exhaust system for the laboratory building is divided into four quadrants, each servicing approximately one quarter of the building. The ventilation exhaust system also services the MURR industrial building and mechanical equipment room 114. Each quadrant consists of a stainless steel filter housing containing a bank of pre-filters and a bank of high efficiency particulate air (HEPA) filters. Air is ducted from the quadrants to an exhaust plenum located in the reactor building west tower. Facility ventilation exhaust fans EF-13 and EF-14, located within the exhaust plenum, discharge the air through the facility exhaust stack to the atmosphere. The top of the exhaust stack is approximately 70 feet (21 m) above grade level of the containment building. One exhaust fan is always in operation while the other is in standby. This condition is indicated by a green light on the fan failure alarm panel located in the reactor Control Room. Any condition other than one fan in "fast speed" and the other in "stand-by" will de-energize the green light and indicate an abnormal condition. Malfunction of the operating fan will automatically start the standby fan and de-energize the green light indicating a loss of the operating fan. Failure of both exhaust fans, or significantly degraded flow, actuates a pressure switch which initiates an

audible alarm in the reactor Control Room. EF-13 and EF-14 are powered from the Emergency Electrical Power System; therefore, on a loss of normal electrical power, the operating fan will continue to operate. It should be noted that a facility ventilation exhaust fan is always in operation, whether the reactor is operating or not. The standby feature is checked every week during the normally scheduled maintenance day and the fans are swapped to even runtime. EF-13 or EF-14 shall be in operation when processing, as required by the proposed TSs.

Figures 3 through 7 depict the facility ventilation system (8.5-inch x 14-inch versions are also included as Attachments 2 through 6). Specifically, Figure 7 shows the ventilation system for the iodine-131 hot cells including the filtration systems. The I-131 hot cell filtration system is described in greater detail below.

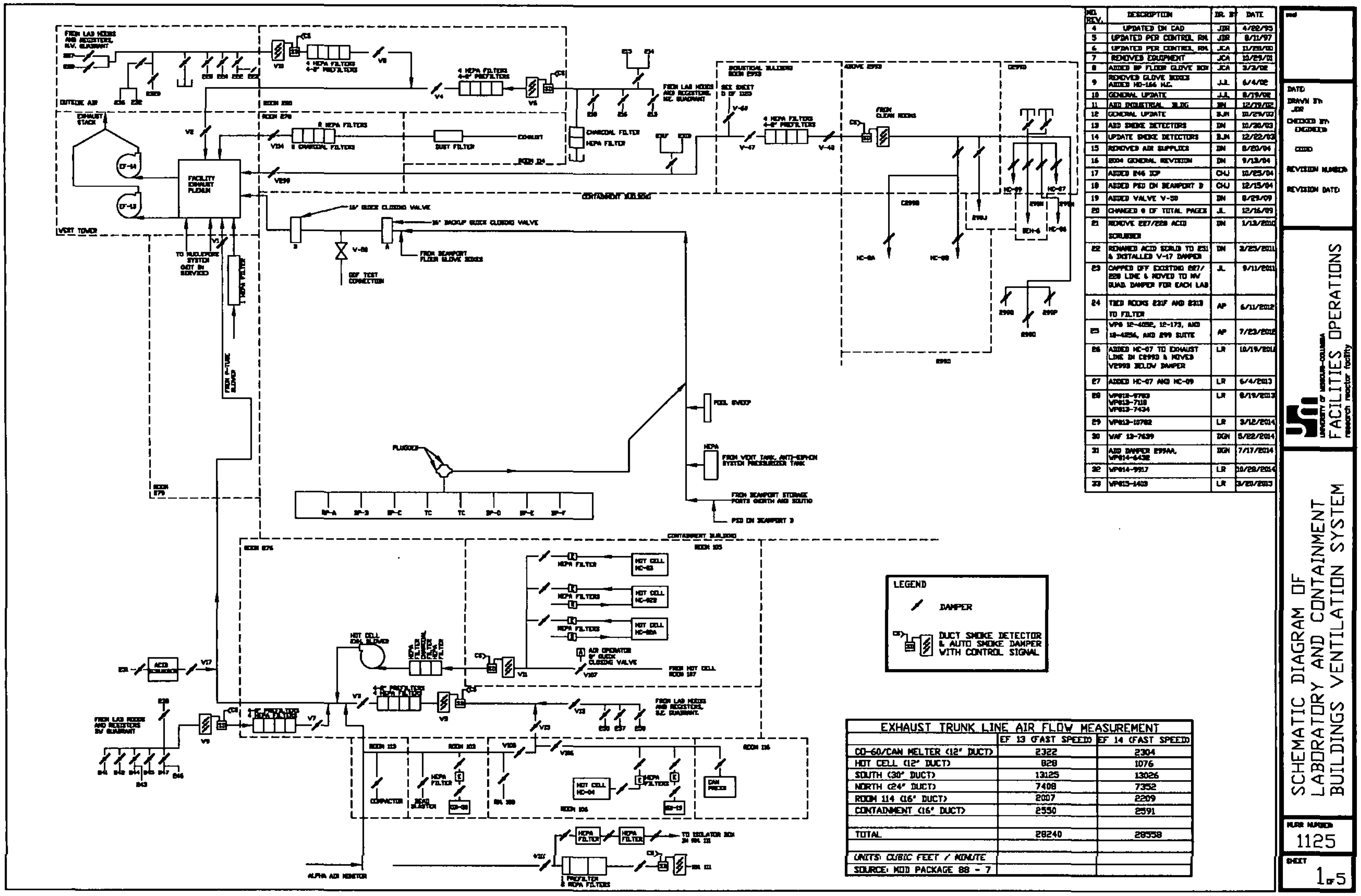
4.3 Hot Cell Ventilation and Filtration Systems

The ventilation supply and exhaust system for hot cells HC-11A, HC-11B and HC-11C consists of a combination of HEPA and charcoal filtration systems. The supply and exhaust systems for each cell combine to form a common header, but each hot cell has its own independent filtration system. Air is supplied to each hot cell from a common header (suction located in an area above room 299T) through a HEPA and charcoal filter at a rate of approximately 17 cubic feet per minute (cfm). Air is exhausted from each hot cell through an internal parallel set of charcoal filters (Bank No. 1) (Ref. 6 and Attachment 7), then through a (selected) external parallel charcoal filtration bank (Bank No. 2: one set of two in service – the other set in standby) (Ref. 6 and Attachment 7), a second (selected) external parallel charcoal filter bank (Bank No. 3: one set of two in service – the other set in standby) (Ref. 6 and Attachment 7), and then through a (selected) parallel charcoal filter (Bank No. 4: one filter on service – one in standby) (Ref. 7 and Attachment 8) into the facility main ventilation exhaust system at a flow rate of approximately 50 cfm. Air is removed from the hot cells at a rate of approximately 10 air changes per hour (ACPH).

There are two glove boxes mounted to the hot cells; one on the north end of HC-11A and one on the south end of HC-11C. These gloves boxes provide the means of introducing or removing items from the hot cells. Each glove box also has its own independent supply and exhaust system. Air is supplied to each glove box at a rate of approximately 1.7 cfm through a combination HEPA/charcoal filter. Air is exhausted from each glove box through a charcoal filter and then a HEPA filter. The exhaust ducting for each glove box connects to the hot cell common exhaust header downstream of the hot cell filtration systems.

As described in Section 3.0 above, a six (6) detector radiation monitoring system (ALMO-6) designed to provide radiation dose level information to the process operators is incorporated into the three (3) cell hot cell processing system (Ref. 5 and Attachment 1). Three of the detectors (G-M) are positioned next to charcoal filter Bank No. 2 in each bay of the three (3) hot cells. These are designed to give the process operators real time information related to the capture and loading of I-131onto the first charcoal filter in each bank of the individual cells. This allows the process operators to monitor the condition of the charcoal filters and will alert them of the need to change to a bank of alternately available filters.

Figure 3 – MURR Ventilation System



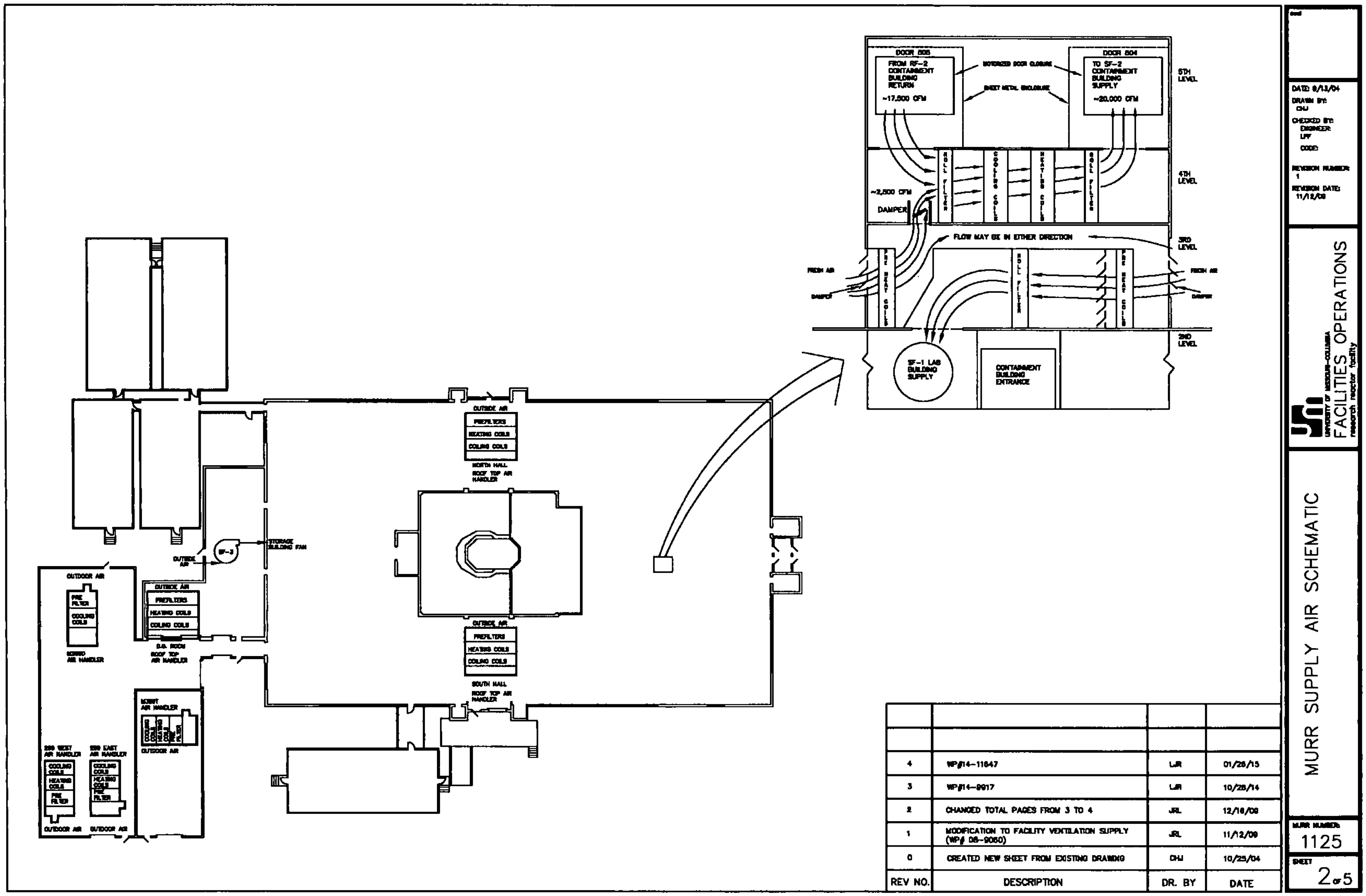


Figure 4 – MURR Ventilation System (Supply)

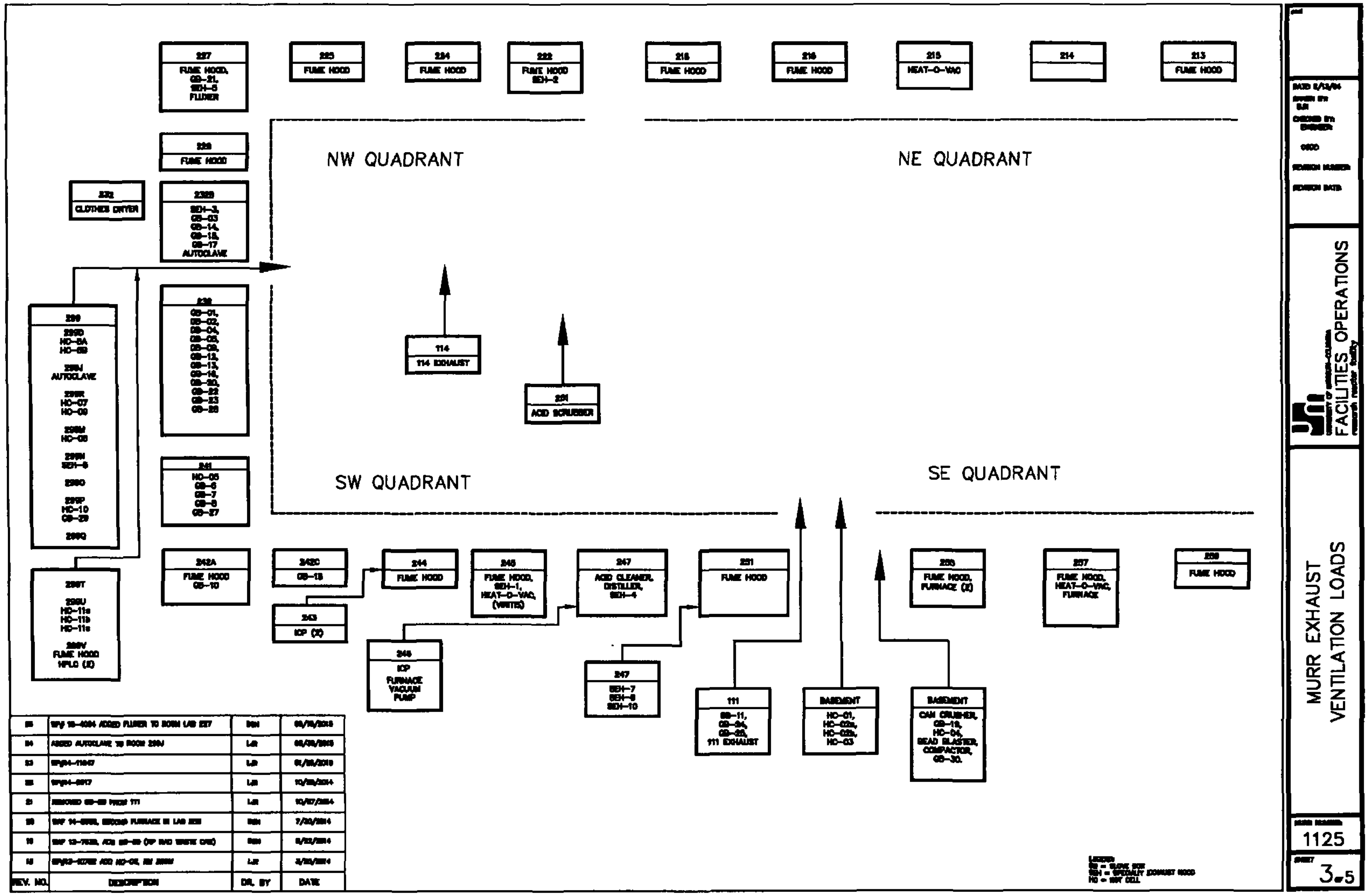


Figure 5 – MURR Ventilation System (System Loads)

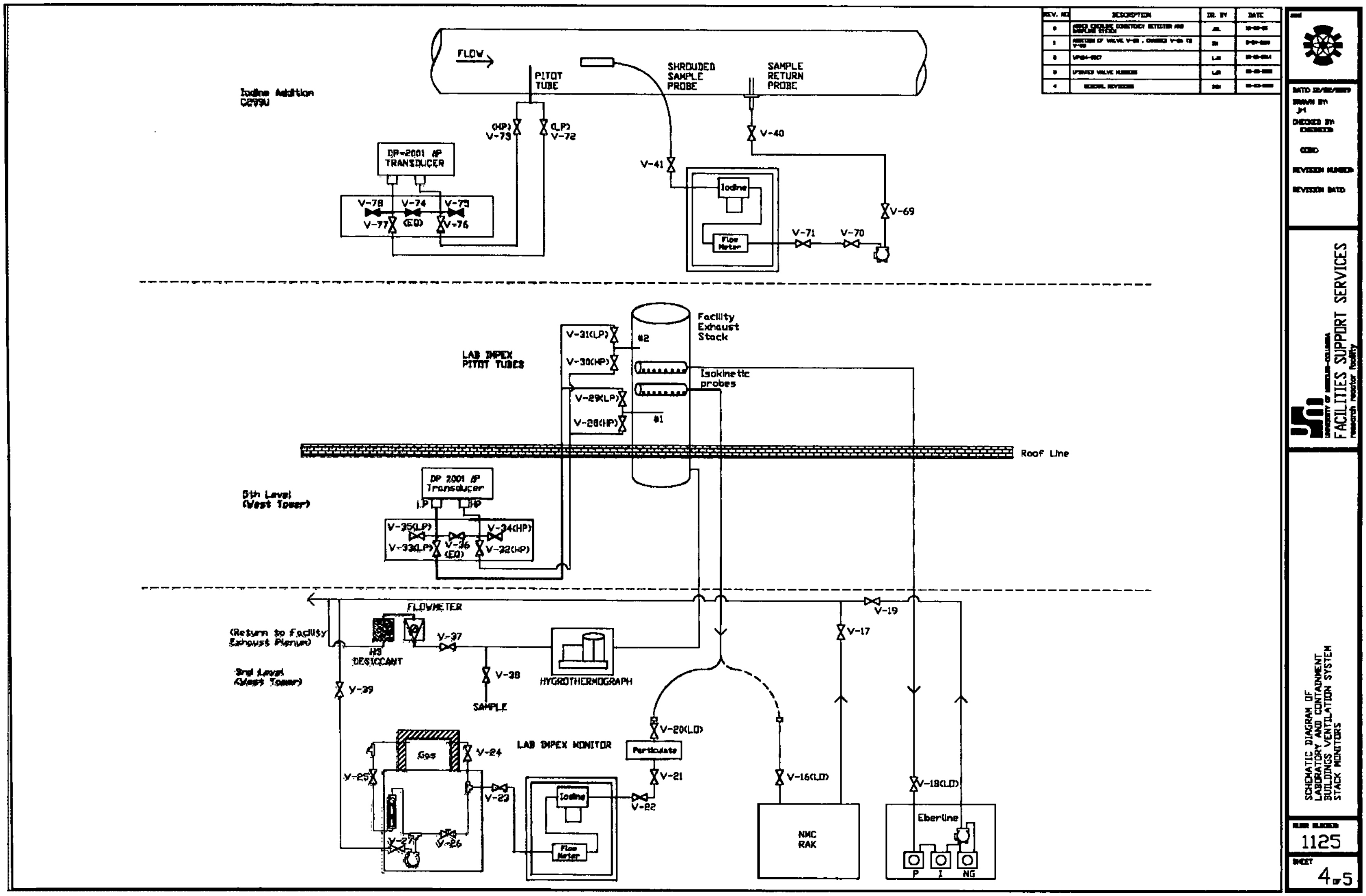
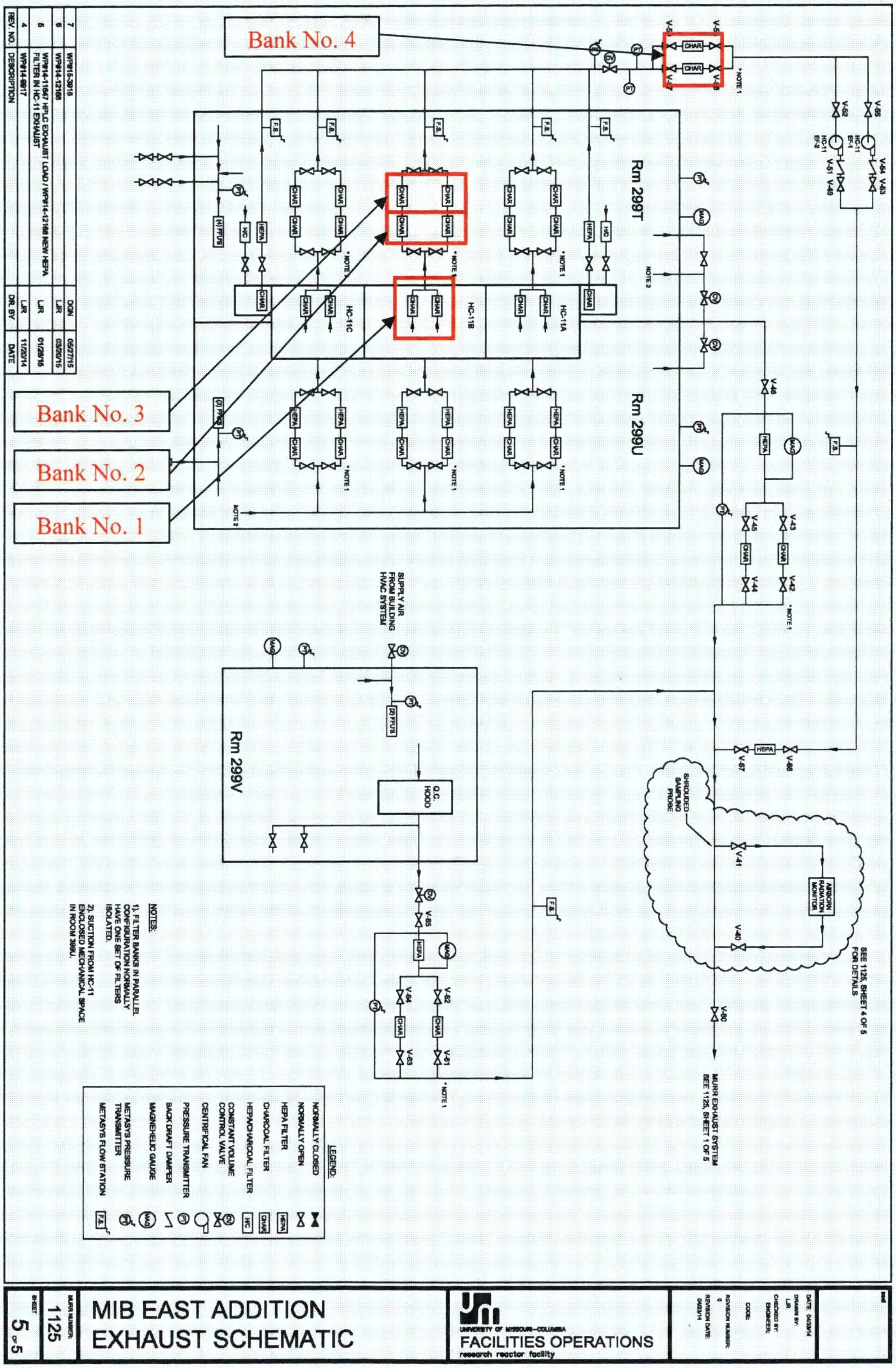


Figure 6 – MURR Ventilation System (Instrumentation)

Figure 7 – MURR Ventilation System (I-131 Processing Area)



5.0 Radiation Monitoring Equipment

There are three (3) separate radiation monitoring systems that can monitor the effluents from the I-131 processing hot cells: (1) the facility Off-Gas Radiation Monitoring System, (2) the I-131 Processing Laboratory Exhaust Duct Monitor, and (3) the ALMO-6 Hot Cell Dose Rate Radiation Monitor.

Air exiting the MURR facility through the ventilation system exhaust stack is continuously-monitored for airborne radioactivity by the Off-Gas Radiation Monitoring System (TS 3.4.a – Stack Radiation Monitor). The monitoring equipment of this system consists of a three (3) detector radiation detection system designed to measure the airborne concentrations of radioactive particulate, iodine, and noble gas in the facility exhaust air which is sampled by an isokinetic probe located in the ventilation exhaust plenum. The radiation detection equipment is a self-contained unit consisting of a fixed filter monitored by a beta scintillation detector, a charcoal cartridge monitored by a gamma scintillation detector, and a gas chamber monitored by a beta scintillation detector. The output from each radiation detector is displayed on a local meter in counts per minute (cpm) and on a strip-chart, three-pen recorder mounted on the instrument panel in the reactor Control Room. An audible and visual alarm alerts the operator to high activity or abnormal air flow through the radiation detection equipment. As can be seen by Figure 6 (lower section of drawing), two (2) of these systems are installed for redundancy; however, only one is required by the TSs. The facility Stack Radiation Monitor shall be in operation when processing, as required by the proposed TSs.

The I-131 Processing Laboratory Exhaust Duct Monitor consists of a radiation detection system designed to measure airborne concentrations of radioactive iodine in the exhaust air that is sampled by a shrouded probe in the ventilation ducting immediately downstream of all of the I-131 hot cell and room filtration systems. The system is capable of measuring real-time exhaust flow rate as its basis for release concentrations. A pitot tube measurement device and flow transmitter provides input to the system. The radiation monitor can be seen in the upper section of Figure 6.

The ALMO-6 Hot Cell Dose Rate Radiation Monitor, as described in Section 3.0, consists of a six (6) detector radiation monitoring system designed to provide radiation dose level information to the process operators (Ref. 5 and Attachment 1). Three of the detectors (G-M) are located at the operator's work station where the hot cell manipulators are located. These detectors provide real time dose rate information to the operators when they are performing a process. The remaining three detectors (G-M) are located next to the first in a series of charcoal filters (Bank No. 2 and No. 3) located in each of the bays above the three (3) hot cells. These are designed to give the process operators real time information related to the capture and loading of I-131 onto the first charcoal filter in each external bank of the individual cells. This allows the process operators to monitor the condition of the charcoal filters and will alert them of the need to change to a bank of alternately available filters. The ALMO-6 radiation monitor shall be in operation when processing, as required by the proposed TSs. It is referred to as the "Iodine-131 Processing Hot Cells Radiation Monitor" in the TSs.

6.0 Evaluation of an I-131 release in the Processing Hot cell

The PHC will have the highest possible content of volatile I-131. This peak content would occur during the approximately [redacted] when the [redacted] targets are [redacted]

[redacted]. The I-131 evolved during this [redacted]. For this conservative evaluation of a potential release during processing it will be assumed that 150 Curies of I-131 are released within the PHC. This is a very conservative assumption for the following reasons:

1. The I-131 is evolved over about a [redacted]. Any indication of leakage from the process equipment into the hot cell (e.g., malfunction of the process equipment) would cause staff to immediately secure the furnace resulting in the I-131 evolution to be reduced and then to cease, evolving only a small fraction of the total target inventory;

2. [redacted] and

3. Theoretical I-131 yield from a [redacted] is [redacted] based on a conservative overestimation of flux, greater than normal irradiation time, and the discounting of any self-shielding effects of the target material. Based on the typical values of flux and irradiation time, and data from low activity testing of target material, a [redacted] target will produce approximately [redacted] of I-131 at the end of a typical [redacted] irradiation.

In addition to the dose consequences from a 150 Curie target that are provided below, dose consequences from a release of [redacted] of I-131 are also provided for a more realistic comparison.

5.1 Dose Consequences in the Restricted Area

The following analysis is specific to determining exposure rates from the ventilation exhaust system to a worker assuming a non-credible, total loss of the I-131 inventory within the PHC (the same filtration mitigation features exist on all three (3) hot cells; therefore, the analysis applies to any of the three cells).

The analysis assumes the following three (3) separate quantities of I-131 activity: [redacted] and 150 Curies. As stated previously, 150 Curies represents the maximum allowable iodine inventory for any fueled experiment conducted at MURR (TS 3.6.a) and was chosen as the starting point for analysis of offsite dose consequences for I-131 release, [redacted] represents an overestimated theoretical yield, and [redacted] represents the typical processing yield.

No credit was taken for the plating of iodine within the hot cells and ventilation ducting. Radiation exposure calculations are broken down into two scenarios: (1) exposure rates from the installed charcoal filters, and (2) exposure rates from the ventilation ductwork assuming complete filter failure. While calculating exposure rates from the installed filters several adjunct calculations were also performed. The

below sequence illustrates the calculation methodology of radiation exposure rates from a loaded charcoal filter.

In order to calculate the activity deposited on a filter and subsequent filters in a series, the following equation was used:

(Eq.1) $$A(x) = (A(e)/D^{x-1}) - (A(e)/(DF)^{x})$$

Where:

A(x) = Activity deposited on filter "x";
A(e) = Activity entering the first filter of the series;
DF = Decontamination Factor (must be common between all filters); and
X = The sequential number of the filter bank in a series starting with 1.

Using Equation 1, Tables 2, 3 and 4 present activities that were determined to be deposited on each of the four (4) installed charcoal filter banks using a Decontamination Factor (DF) of both 100 (99.0% efficiency) and 1000 (99.9% efficiency) for all three (3) processing activity amounts and assuming a failure of one (1) of the installed filters. To model the greatest potential for worker exposures, Filter Bank No. 1 was assumed to fail. The failure of Filter Bank No. 1 represents a greater exposure to workers because this filter is housed within the PHC and shielded with the greatest amount of lead. Filter Bank No. 1 failure would create the largest magnitude of activities external to the PHC and the largest potential of exposure to workers.

Table 2 – 150 Curies of I-131

Activity on Filters Post Release (Ci)				
	Bank No. 1	**Bank No. 2**	**Bank No. 3**	**Bank No. 4**
Mitigated (4 of 4 filters - DF 1000)	1.4985E+02	1.4985E-01	1.4985E-04	1.4985E-07
Mitigated (3 of 4 filters - DF 1000)	0.0000E+00	1.4985E+02	1.4985E-01	1.4985E-04
Mitigated (4 of 4 filters - DF 100)	1.4850E+02	1.4850E+00	1.4850E-02	1.4850E-04
Mitigated (3 of 4 filters - DF 100)	0.0000E+00	1.4850E+02	1.4850E+00	1.4850E-02
Unmitigated	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Table 3 – [redacted] of I-131

Activity on Filters Post Release (Ci)				
	Bank No. 1	**Bank No. 2**	**Bank No. 3**	**Bank No. 4**
Mitigated (4 of 4 filters - DF 1000)	8.7912E+01	8.7912E-02	8.7912E-05	8.7912E-08
Mitigated (3 of 4 filters - DF 1000)	0.0000E+00	8.7912E+01	8.7912E-02	8.7912E-05
Mitigated (4 of 4 filters - DF 100)	8.7120E+01	8.7120E-01	8.7120E-03	8.7120E-05
Mitigated (3 of 4 filters - DF 100)	0.0000E+00	8.7120E+01	8.7120E-01	8.7120E-03
Unmitigated	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Table 4 – [redacted] of I-131

Activity on Filters Post Release (Ci)				
	Bank No. 1	**Bank No. 2**	**Bank No. 3**	**Bank No. 4**
Mitigated (4 of 4 filters - DF 1000)	5.4945E+01	5.4945E-02	5.4945E-05	5.4945E-08
Mitigated (3 of 4 filters - DF 1000)	0.0000E+00	5.4945E+01	5.4945E-02	5.4945E-05
Mitigated (4 of 4 filters - DF 100)	5.4450E+01	5.4450E-01	5.4450E-03	5.4450E-05
Mitigated (3 of 4 filters - DF 100)	0.0000E+00	5.4450E+01	5.4450E-01	5.4450E-03
Unmitigated	0.0000E+00	0.0000E+00	0.0000E+00	0.0000E+00

Calculation of exposure rates for each of the filters was performed using the computer program MicroShield 8.02 (Ref. 8 and Attachment 9) with an Annular Cylinder – External Dose Point geometry for Filter Bank No. 1 through 3 and a Rectangular Volume geometry for Filter Bank No. 4. These geometries most accurately represent the designs of each filter according to the manufacture specification sheets. Also, each filter is designed with surrounding lead shielding. This shielding was included in the geometry model and used in the exposure rate calculations for each filter. Filter shielding thicknesses are described in Table 5.

MicroShield 8.02 is a product of Grove Software and is a comprehensive photon/gamma ray shielding and dose assessment program that is widely used in the industry for designing shields.

Table 5 – Filter Shielding Thickness
(in centimeters)

Filter Bank	**Lead Thickness**
No. 1	10
No. 2	10
No. 3	10
No. 4	0.635

An exposure rate calculation for each case as seen in Tables 2, 3 and 4 was performed in MicroShield and resulted in the associated exposure rates in Tables 6, 7 and 8 below. A summary of each MicroShield calculation is attached for review; however, in some cases the calculated exposure rates were scaled from a previous calculation by a ratio of the activities. To be conservative, a one (1) foot distance from each filter was selected as the dose point distance. Workers are not expected to come within four (4) feet of a filter during normal work activities.

Table 6 – **150 Curie** Target Exposure Rates Due to Shine from Filters at 1 Foot (in mR/hr)

	Bank No. 1	Bank No. 2	Bank No. 3	Bank No. 4
Mitigated (4 of 4 filters - DF 1000)	5.15E-03	9.72E-06	9.72E-09	1.42E-05
Mitigated (3 of 4 filters - DF 1000)	0.00E+00	9.72E-03	9.72E-06	1.42E-02
Mitigated (4 of 4 filters - DF 100)	5.10E-03	9.64E-05	9.64E-07	1.41E-02
Mitigated (3 of 4 filters - DF 100)	0.00E+00	9.64E-03	9.64E-05	1.41E+00

Table 7 – [redacted] Target Exposure Rates Due to Shine from Filters at 1 Foot (in mR/hr)

	Bank No. 1	Bank No. 2	Bank No. 3	Bank No. 4
Mitigated (4 of 4 filters - DF 1000)	3.02E-03	5.71E-06	5.71E-09	8.34E-06
Mitigated (3 of 4 filters - DF 1000)	0.00E+00	5.71E-03	5.71E-06	8.34E-03
Mitigated (4 of 4 filters - DF 100)	2.99E-03	5.66E-05	5.66E-07	8.26E-03
Mitigated (3 of 4 filters - DF 100)	0.00E+00	5.66E-03	5.66E-05	8.26E-01

Table 8 – [redacted] Target Exposure Rates Due to Shine from Filters at 1 Foot (in mR/hr)

	Bank No. 1	Bank No. 2	Bank No. 3	Bank No. 4
Mitigated (4 of 4 filters - DF 1000)	1.89E-03	3.57E-06	3.57E-09	5.21E-06
Mitigated (3 of 4 filters - DF 1000)	0.00E+00	3.57E-03	3.57E-06	5.21E-03
Mitigated (4 of 4 filters - DF 100)	1.87E-03	3.54E-05	3.54E-07	5.17E-03
Mitigated (3 of 4 filters - DF 100)	0.00E+00	3.54E-03	3.54E-05	5.17E-01

Tables 6, 7 and 8 indicate that the highest exposure rate is expected to be from Filter Bank No. 4 at 1.41 mR/hr with three (3) of four (4) filter banks in service during a 150 Curie process and filter DFs of 100. The reason for the highest exposure rates being seen on Filter Bank No. 4 is due to the substantially thinner lead shielding thickness installed around this filter as compared to Filter Bank No. 1 through 3.

A second potential scenario for the ventilation exhaust system to create exposure rates near a worker is that of an unmitigated release resulting in a high activity concentration volume of air moving through the ventilation system. In order to calculate the activity concentration of the air within the facility ventilation exhaust system, the following assumptions were made:

1. 100% of the available iodine inventory is instantaneously released into the hot cell volume free space. In reality it is expected the iodine activity would be released from a target over one (1) hour allowing for greater dilution than is considered by this assumption;

2. 50% of the entire hot cell volume is considered as free space. 50% is a large underestimation of the available free space within a hot cell; however, this results in a conservative determination of airborne activity concentrations and increases the calculated exposure rates; and

3. 100% efficiency of the air to be turned over in the hot cell in the minimum time possible. In reality it is not expected that 100% air turn over efficiency will be achieved; however, for the purposes of calculating exposure rates this assumption will result in a conservative determination of air activity concentrations within the facility ventilation exhaust ducting.

Also, the following parameters were used to calculate the activity concentration of the air within the facility ventilation exhaust system:

1. Hot cell dimensions of 152.5 cm x 152.5 cm x 122 cm (H x W x D); and

2. Hot cell flow rates of: HC-11A = 15 cfm; HC-11B = 11 cfm; and HC-11C = 10 cfm (determined by flow measurements documented in Work Package No. 15-3918, May 4, 2015).

In order to calculate the activity concentration of the air entering the facility ventilation exhaust ducting, a determination must first be made of the hot cell air volume turnover time. Equation 2 was used to determine hot cell air volume turn over time.

(Eqn. 2) $$T(x) = V(x)/F(x)$$

Where:

$T(x)$ = Air volume turn over time for hot cell "x" in minutes;
$V(x)$ = Volume of hot cell "x" in cubic feet; and
$F(x)$ = Flow of air exiting hot cell "x" in cfm.

Using Equation 2, the following turn over times listed in Table 9 were calculated for the I-131 processing hot cells.

Table 9 – Hot Cell Turnover Time
(in minutes)

Hot Cell	Turnover Time
HC-11A	3.34
HC-11B	4.55
HC-11C	5.01

Next a calculation was performed to determine the concentration of activity within the hot cell. The below equation was used to calculate the activity concentrations listed in Table 10.

(Eqn. 3) $$C(x) = A(x)/V(x)$$

Where:

$C(x)$ = Concentration of airborne activity in hot cell "x";
$A(x)$ = Activity instantaneously entering hot cell "x"; and
$V(x)$ = Volume of hot cell "x".

Table 10 – Hot Cell Air Concentrations
(in μCi/ml)

Process Activity	Air Concentration
150 Ci	105.74
[redacted]	62.03
[redacted]	38.77

From the hot cell, a conservative assumption is made that all of the activity instantaneously introduced into the PHC escapes the hot cell and enters the ventilation exhaust system within approximately five (5) minutes. As stated previously, this assumption will conservatively calculate activity concentrations of the air and hence result in conservative exposure rate values.

In order to calculate expected activity concentrations throughout the facility ventilation exhaust system a ratio of ventilation flow rates was determined and used to ratio the expected activity concentrations. Table 11 lists the flow rates used for the activity determinations and Equation 4 describes the method used to ratio the activity concentrations.

Table 11 – Ventilation exhaust Flow Rate
(in cfm)

Location	Flow Rate
HC-11B	11
6-inch Ductwork	47
16-inch Ductwork	1000

(Eqn. 4) $$A(x) = C[F_o/F(x)]$$

Where:

$A(x)$ = Activity concentration at location "x";
C = Activity concentration in the hot cell;
F_o = Flow rate from the hot cell; and
$F(x)$ = Flow rate at location "x".

Using Equation 4, the following activity concentrations listed in Tables 12, 13 and 14 were determined at various locations of the ventilation exhaust system. Also, in the tables are the calculated exposure rates

resulting from the associated activity concentrations. The exposure rate calculations were performed in Microshield 8.02 using a 100 cm line source geometry with a dose point at a distance of one (1) foot from the source. A summary of each MicroShield calculation is attached to this document (Attachment 9).

Table 12 – **150 Curie** Target Exposure Rates Due to Shine from Ventilation at 1 Foot

	Hot Cell Ductwork	**6-inch Ductwork**	**16-inch Ductwork**
Activity Concentration (μCi/ml)	1.0574E+02	2.4762E+01	1.1632E+00
Unmitigated Exposure Rate (mR/hr)	1.6330E+01	3.8230E+00	1.7960E-01

Table 13 – [redacted] Target Exposure Rates Due to Shine from Ventilation at 1 Foot

	Hot Cell Ductwork	**6-inch Ductwork**	**16-inch Ductwork**
Activity Concentration (μCi/ml)	6.2032E+01	1.4527E+01	6.8242E-01
Unmitigated Exposure Rate (mR/hr)	9.5770E+00	2.2430E+00	1.0540E-01

Table 14 – [redacted] Target Exposure Rates Due to Shine from Ventilation at 1 Foot

	Hot Cell Ductwork	**6-inch Ductwork**	**16-inch Ductwork**
Activity Concentration (μCi/ml)	3.8770E+01	9.0796E+00	4.2651E-01
Unmitigated Exposure Rate (mR/hr)	5.9860E+00	1.4020E+00	6.5850E-02

As expected, the highest exposure rate from an unmitigated release is from the hot cell ductwork at 16.33 mR/hr assuming the 150 Curie process activity is instantaneously released into the hot cell.

After review of the expected exposure rates from an unmitigated and mitigated release, external dose hazards to personnel are minimal and within regulatory compliance for process activities up to 150 Curies.

5.2 Dose Consequences in the Unrestricted Area

Two analyses were performed for potential offsite dose consequences of a failed [redacted] target and subsequent release of I-131 to the surrounding environment that was produced in the target during irradiation. The first analysis was performed using the Environmental Protection Agency (EPA) and U.S. Nuclear Regulatory Commission (NRC) accepted computer code COMPLY – a computerized screening tool for evaluating radiation exposure from atmospheric releases of radionuclides for calculating doses to the public for offsite air effluent radionuclide releases (Ref. 9). In fact, MURR currently uses this code for determination of air effluent offsite dose consequences on an annual basis for regulatory compliance. Updated wind rose data used for this analysis was obtained from the Columbia Regional Airport (CRA) for the time period of 1984 to 1992. The doses calculated are based on the dose to the nearest permanent resident located approximately 760 meters north of MURR in a residential neighborhood and uses the frequency distribution of wind directions around MURR. CRA is located approximately 13 miles SE of

MURR and the wind data used as noted above is the most readily available and recent wind rose data found published in the available literature.

As previously stated, the following three (3) activities of I-131 were used in the analysis: (1) 150 Curies represents the maximum allowable iodine inventory for any fueled experiment conducted at MURR (TS 3.6.a), (2) [redacted] represents an overestimated theoretical yield, and (3) [redacted] represents the typical processing yield.

The second analysis utilized the Pasquill-Guifford (P-G) dispersion model methodology for atmospheric dispersion of contaminants. This model has been used for years in the nuclear industry and is the basis for subsequent atmospheric modeling methods developed throughout the late 20th century. The "D" stability class and a southern wind direction was chosen for this analysis as they provide the most conservative (highest) concentrations of effluents at the point of interest with regards to offsite dose calculations and is the most prominent wind direction in central Missouri, respectively. Additionally, the wind direction is assumed to come from the southerly direction the entire two (2) hours of the release event. The above stated three (3) activity amounts were also used in this analysis.

Table 15 presents the dose consequences of the three (3) I-131 unmitigated (no filtration or plating) release scenarios to the environment whereas Tables 16, 17 and 18 show the expected offsite dose consequences, presented in a matrix of four separate filter status scenarios, for a mitigated release. This calculation is repeated three times to reflect the COMPLY code output and two separate calculations for whole body (WB) and thyroid dose utilizing the P-G methodology.

Table 15 – Offsite Dose Consequences – Unmitigated (no Filtration)

Activity Released (Ci)	COMPLY[1] (Whole Body)	Pasquill-Guifford Model[2,3] (Whole Body)	Pasquill-Guifford Model[2,3] (Thyroid)
	(mrem)		
	Nearest Residence	Emergency Planning Zone – 150 meters	
150	124	13.1	7616
[redacted]	73	7.7	4468
[redacted]	45	4.8	2793

Table 16 – Offsite Dose Consequences – Mitigated (Filtration)
(COMPLY Model – Nearest Residence)

Activity Released (Ci)	Method	1 Filter Bank	2 Filter Banks	3 Filter Banks	4 Filter Banks
		(mrem)			
150	COMPLY[1] (WB – Nearest Residence)	1.24	0.01	1.24E-04	1.24E-06
[redacted]		0.73	0.01	7.27E-05	7.27E-07
[redacted]		0.45	0.01	4.55E-05	4.55E-07

Table 17 – Offsite Dose Consequences – Mitigated (Filtration)
(P-G Model[2,3] – Whole Body at Emergency Planning Zone)

Activity Released (Ci)	Method	1 Filter Bank	2 Filter Banks	3 Filter Banks	4 Filter Banks
		(mrem)			
150	P-G Model[2,3] (WB – EPZ)	0.13	0.01	1.31E-05	1.31E-07
[redacted]		0.08	0.01	7.70E-06	7.70E-08
[redacted]		0.05	0.01	4.80E-06	4.80E-08

Table 18 – Offsite Dose Consequences – Mitigated (Filtration)
(P-G Model[2,3] – Thyroid at Emergency Planning Zone)

Activity Released (Ci)	Method	1 Filter Bank	2 Filter Banks	3 Filter Banks	4 Filter Banks
		(mrem)			
150	P-G Model[2,3] (Thyroid – EPZ)	76.16	0.76	7.62E-03	7.62E-05
[redacted]		44.68	0.45	4.47E-03	4.47E-05
[redacted]		27.93	0.28	2.79E-03	2.79E-05

[1]Dose from COMPLY is to the nearest residence, 760 meters north.
[2]Dose conversion factors for the two P-G Models are from NRC Regulatory Guide 1.109, "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR 50, Appendix I" (Ref. 10).
[3]Doses for the two P-G models are assumed to be received at the EPZ, 150 meters north over a two (2) hour period. No correction for dispersion of the cloud is made at the site of the recipient, i.e. the cloud is assumed to be uniform over the entire two (2) hour scenario post release.

The initial offsite doses were calculated assuming a total release of the available iodine inventory with no filtration or capture used (unmitigated) and were generated using the COMPLY code. The second and third scenarios were calculated using the P-G model and assumed the dose would be received by a person situated at the Emergency Planning Zone (EPZ) boundary of 150 meters due north of MURR (also highest dose location). The first set of dose calculations are for WB doses due to exposure of I-131 at the EPZ boundary. The second set of dose calculations are doses to the thyroid at the same point. Both sets of calculations show the effects of 1 through 4 banks of charcoal filters, assuming a 99% collection efficiency (DF 100) for I-131, used to mitigate offsite dose. Again, the scenario assumes that no I-131 would plate out in the hot cell or ductwork prior to being released from the facility. Furthermore, the dose calculations assume that a person is located at the EPZ for the entire two (2) hour post-accident period prior to being evacuated from that area (Ref. 11). This assumes that the air concentration is constant at the calculated values during the accident and that no credit is taken for the prevailing wind to disperse the I-131 laden air.

MURR is situated on a 7.5-acre lot in the central portion of Research Commons, an 84-acre tract of land approximately one mile southwest of the University's main campus (Figure 8). Approximate distances to the University property lines (site boundary) from the reactor facility are 2,400 feet (732 m) to the north (Stadium Boulevard); 4,800 feet (1,463 m) to the east of Providence Road; 2,400 feet (732 m) to the south

(MU Recreational Trail); and 3,600 feet (1,097 m) to the west (MKT Nature and Fitness Trail). MURR's EPZ lies completely within the site boundary and individuals can easily be evacuated from within this area in two (2) hours. The area within the site boundary is owned and controlled by MU and may be frequented by people unacquainted with the operation of the reactor. The Reactor Facility Director has authority to initiate emergency actions in this area, if required (Ref. 12 and 13).

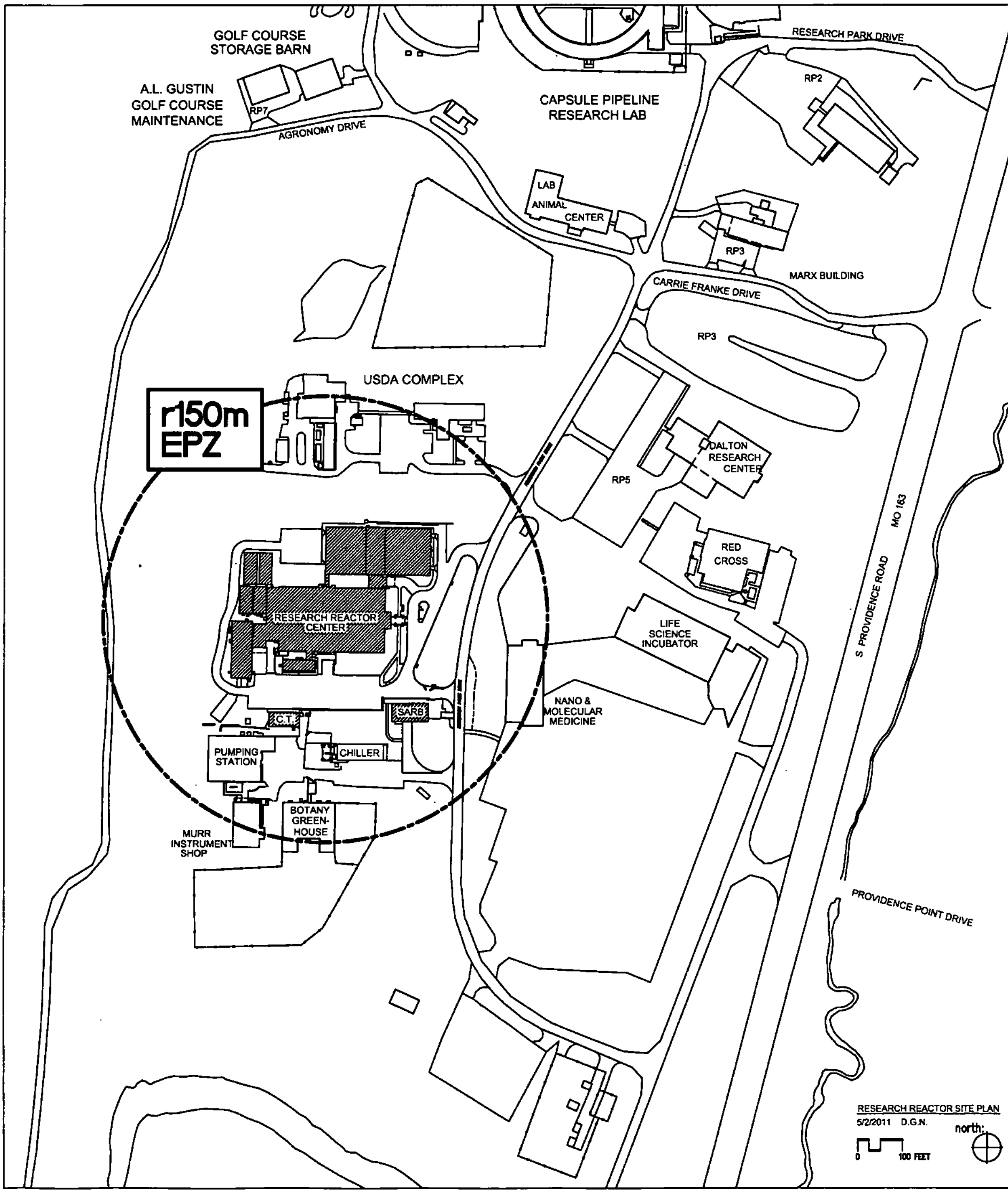


Figure 8 – MURR Emergency Planning Zone and Surrounding Site Area

Providence Road crosses MU property separating University Research Commons from another MU-owned tract of land lying to the east. The road runs north and south with the closest point of approach being approximately 400 meters east of the facility. MU has the authority to determine all activities including the exclusion or removal of personnel and property and to temporarily secure the flow of traffic on this road during an emergency.

For comparison purposes, the dose consequence matrix calculates offsite doses for scenarios where one, two, three and four banks of activated charcoal filters are available to capture released I-131 gases. The filters are assumed to be 99% efficient in capturing elemental iodine, which is a factor of 10x lower than stated values provided by the filter manufacturers. Thus the offsite doses can be easily compared using a variety of scenarios ranging from having no filtration up to the maximum amount designed into the system of four (4) separated banks of activated charcoal filters.

In conclusion, the above analysis demonstrates that only one (1) in four (4) filter banks is required to be functional in order to keep offsite dose below the 10 CFR 20 limit for occupationally exposed workers that require monitoring and two sets of functioning filters would keep doses below 10 mrem to the thyroid and thus below any dose limits applicable to the general public.

6.0 Comparison to Current Fueled Experiment Technical Specifications

There are currently two specifications regarding radioisotope limits for conducting fueled experiments at MURR. Both are based on the total inventory of iodine-131 through iodine-135 and strontium-90 produced by the experiment:

3.6.a "*Each fueled experiment shall be limited such that the total inventory of iodine isotopes 131 through 135 in the experiment is not greater than 150 Curies and the maximum strontium-90 inventory is no greater than 300 Millicuries.*"

3.6.o "*Fueled experiments containing inventories of Iodine 131 through 135 greater than 1.5 Curies or Strontium 90 greater than 5 millicuries shall be in irradiation containers that satisfy the requirements of specification 3.6.i or be vented to the exhaust stack system through HEPA and charcoal filters which are continuously monitored for an increase in radiation levels.*"

TS 3.6.a was proposed by MURR in a letter to the NRC dated February 15, 1977, specifically to support an experiment in the reactor thermal column which utilized "unclad" fission plates to irradiate large rolls of thin polycarbonate film material (Ref. 14).

TS 3.6.o was proposed by MURR in its September 23, 1977 letter to the NRC (Ref. 15). This letter was one in a series of letters in support of an Amendment request to allow TS 3.6.a fueled experiment limits to be increased from 1.5 Curies of I-131 through -135 and 5 millicuries of Sr-90 to 150 Curies of I-131 through -135 and 300 millicuries of Sr-90, which are currently the radioisotope limits for fueled experiments stated in TS 3.6.a. This increase was requested in order for the MURR to perform the specific fueled experiment described above. The nature of the experiment, "unclad" uranium fission

plates located outside of the reactor pool, required it to be vented to the facility ventilation exhaust system through continuously monitored HEPA and charcoal filters.

Additionally, TS 3.6.o provided assurance that any experiment exceeding the limits of TS 3.6.o, and up to the limits of TS 3.6.a, would be vented to the ventilation exhaust system through continuously monitored HEPA and charcoal filters, and it specifically applied to the experiment described in MURR letters to the NRC dated February 15, 1977; September 23, 1977; and January 20, 1978 (Ref. 16).

By letter dated February 24, 1978, the NRC issued Amendment No. 8 to MURR facility license No. R-103 to change the limitations on fueled experiments (Ref. 17). Table 1 of that letter provides the potential dose consequences in the unrestricted area due to a failed fueled experiment as calculated by the NRC. These are the following NRC dose calculations and assumptions directly taken from that table:

TABLE 1
POTENTIAL CONSEQUENCES OF THE
POSTULATED MURR FUELED EXPERIMENT ACCIDENT

		Dose (Rem)	
Exposure	Location	Thyroid	Whole Body
2 Hours	Exclusion Boundary (500 feet)	77	0.5
	Low Population Zone (1500 feet)	20	<0.2

Assumptions:

Meteorology: Regulatory Guide 1.4 Ground Level Release
Building Wake Effect (1.6)
1.0×10^{-2} sec/m (Exclusion Boundary 0 – 2 hours)
2.5×10^{-3} sec/m (Low Population Zone, 0 – 8 hours)

Puff Release
No credit for filter
No credit for plateout
Equilibrium quantities of fission products
150 curies radioiodines 131 to 135
300 mcuries Strontium-90

The above NRC-calculated (and accepted) doses from an unmitigated release of 150 Curies of I-131 through -135 is the basis for our current MURR facility license and TSs for a fueled experiment. For comparison, the unmitigated dose calculations for the requested license amendment in support of producing the radiochemical sodium iodide for approximately the same distances from the MURR ventilation exhaust stack are provided in Table 19.

Table 19 – Comparison of Doses from an Unmitigated Release of 150 Curies of Iodine

NRC-calculated Doses[1] (Rem)			MURR-calculated Doses[2] (Rem)		
Location	Whole Body	Thyroid	Location	Whole Body	Thyroid
500 ft (152.4 m)	0.5	77	150 m (492.1 ft)	0.013	7.616
1500 ft (457.2 m)	< 0.2	20	457 m (1499.3 ft)	0.002	1.066

[1]Doses as calculated for a ground release by the NRC for failure of a fueled experiment in support of License Amendment No. 8, dated February 24, 1978.
[2]Doses as calculated for an elevated release by MURR for a complete release of 150 Curies of I-131 in support of request to amend facility operating license R-103 to produce radiochemical sodium iodide.

Therefore, the scale of the I-131 experiment proposed by MURR in this request is well within the current safety analysis for fueled experiment TSs 3.6.a and 3.6.o that was approved by the NRC in 1978 for an "unclad" experiment using uranium material.

8.0 Proposed Technical Specifications

Attached are the proposed TS pages (revised and new) that will allow MURR to safely produce the radiochemical sodium iodide (Attachment 10).

New Specifications 3.6.p and 3.6.q are based on, and worded very similar to, the current fueled experiment TSs 3.6.a and 3.6.o – a 150 Curie limit on I-131 and requiring the experiment to be vented to the exhaust stack through charcoal filtration which is continuously monitored for radiation levels.

New Specification 3.11 provides the Limiting Conditions for Operations (LCO) for the ventilation exhaust, charcoal filtration and radiation monitoring equipment needed to safely produce I-131. American National Standard ANSI/ANS-15.1-2007, "The Development of Technical Specifications for Research Reactors" (Ref. 18), specifically Sections 3.5 and 3.7, was used to determine the LCOs for this experiment.

New Specification 5.7 provides the surveillance requirements for the new LCOs. Once again, Reference 18, specifically Sections 4.4 and 4.7, were used to establish these requirements. Based on the vendor recommendation of three (3) years for both the Camfil and Flanders charcoal filters, filter efficiency measurements will be performed biennially. Regulatory Guide 1.52, "Design, Inspection, and Testing Criteria for Air Filtration and Adsorption Units of Post-Accident Engineered-Safety-Feature Atmosphere Cleanup Systems in Light-Water-Cooled Nuclear Power Plants" (Ref. 19), will be used as guidance to meet this specification. Additionally, based on the installed radiation monitoring equipment, filters maybe replaced at shorter intervals should an increase in radiation levels or activities be detected.

9.0 Conclusion

Based on the onsite and offsite dose calculations for unmitigated and mitigated I-131releases and the proposed changes to the TSs, MURR can safely produce the radiochemical sodium iodide. Since there

are currently no competing modalities for its use as a therapy for thyroid dysfunctions and no current supplier within the U.S., this Amendment would allow MURR to continue to perform a key role in the supply of critical medical radioisotopes, both domestically and internationally.

Additionally, as discussed in Section 6.0, the unmitigated MURR-calculated dose consequences for this experiment are much lower than the NRC-calculated dose consequences of a fueled experiment containing 150 Curies of I-131 through -135 and 300 millicuries of Strontium-90. The same safety equipment and instrumentation – exhaust ventilation, charcoal filtration and radiation monitoring – will be used for this experiment that is currently required for fueled experiments (TS. 3.6.o), as was always the intent.

If there are questions regarding this request, please contact me at (573) 882-5319. I declare under penalty of perjury that the foregoing is true and correct.

Sincerely,

John L. Fruits
Reactor Manager

ENDORSEMENT:
Reviewed and Approved

Ralph A. Butler, P.E.
Director

xc: Reactor Advisory Committee
Reactor Safety Subcommittee
Dr. Garnett S. Stokes, Provost
Dr. Henry C. Foley, Senior Vice Chancellor for Research
Mr. Alexander Adams, U.S. Nuclear Regulatory Commission
Mr. Geoffrey Wertz, U.S. Nuclear Regulatory Commission
Mr. Johnny Eads, U.S. Nuclear Regulatory Commission

References:

1. MURR Reactor Utilization Request 440, "[redacted] – To Produce I-131"
2. MURR Technical Specifications
3. IAEA-TECDOC-1340, "Manual for Reactor Produced Radioistopes"
4. MURR Project Authorization RL-76, "Production of I-131 Radiochemical Sodium Iodide Solution"
5. ALMO 6 Operating Manual (G-M Radiation Monitoring System)
6. Camfil Activated Carbon Filters
7. Flanders High Efficiency Gas Adsorber (HEGA) Filters
8. MicroShield 8.02 – Computer program used to estimate dose rates due to a specific external radiation source

9. Comply – Computerized screening tool for evaluating radiation exposure from atmospheric releases of radionuclides
10. Regulatory Guide 1.109, "Calculation of Annual Doses to Man from Routine Releases of Reactor Effluents for the Purpose of Evaluating Compliance with 10 CFR 50, Appendix I."
11. Regulatory Guide 2.2, "Development of Technical Specifications for Experiments in Research Reactors" (November 1973)
12. MURR Emergency Plan
13. MURR Emergency Plan Implementing Procedures (TOC-107)
14. Letter from MURR to the NRC, dated February 15, 1977, requesting a change to the Technical Specifications in order to increase the iodine inventory limit in a fueled experiment
15. Letter from MURR to the NRC, dated September, 1977, responding to request for additional information in support of the February 15, 1977 request to change the Technical Specifications
16. Letter from MURR to the NRC, dated January 20, 1978, in support of the February 15, 1977 request to change the Technical Specifications
17. Letter from the NRC to MURR, dated February 24, 1978, issuing Amendment No. 8 to facility operating license R-103
18. American National Standard ANSI/ANS-15.1-2007, "The Development of Technical Specifications for Research Reactors"
19. Regulatory Guide 1.52, "Design, Inspection, and Testing Criteria for Air Filtration and Adsorption Units of Post-Accident Engineered-Safety-Feature Atmosphere Cleanup Systems in Light-Water-Cooled Nuclear Power Plants" (September 2012, Rev. 4)

Attachments:

1. ALMO 6 Operating Manual (G-M Radiation Monitoring System)
2. MURR Drawing No. 1125 (Sheet 1 of 5), "Schematic Diagram of Laboratory and Containment Buildings Ventilation System"
3. MURR Drawing No. 1125 (Sheet 2 of 5), "MURR Supply Air Schematic"
4. MURR Drawing No. 1125 (Sheet 3 of 5), "MURR Exhaust Ventilation Loads"
5. MURR Drawing No. 1125 (Sheet 4 of 5), "Schematic Diagram of Laboratory and Containment Buildings Ventilation System Stack Monitors"
6. MURR Drawing No. 1125 (Sheet 5 of 5), "MIB East Addition Exhaust Schematic"
7. Camfil Activated Carbon Filters
8. Flanders High Efficiency Gas Adsorber (HEGA) Filters
9. MicroShield 8.02 Analysis for MURR I-131 Experiment
10. New and Revised Technical Specification Pages

ATTACHMENT 1

ALMO 6

Operating Manual

MED

Nuklear-Medizintechnik Dresden GmbH

ATTACHMENT 1

Contents

1. Description and Definition of Project

Stationary dose rate measuring system

The ALMO 6 measuring system can work with up to 6 detectors e.g. Geiger-Müller or NaI-detector to determine the local dose rate.

Measuring electronics and display unit are integrated in a plastic housing. A large LC display is incorporated into the front panel of the housing. The values currently measured by the connected detectors are displayed on this LC display (240 x 128 pixels).
Two freely parameterizable alarm thresholds can be defined for each probe. Parameters are set on various menus. A visual / acoustic alarm is triggered whenever an alarm threshold is exceeded.
Optionally the device can be equipped with an emergency power supply. Depending on the connected components (LED traffic light), the ALMO 6 will continue to work for up to 3 hours after power failure.

Fields of application

- workplace and room monitoring, e.g. in hot cells
- system monitoring, e.g. in isotope production
- ward and/or patient monitoring in nuclear medicine/radiation therapy
- monitoring and selection in sorting boxes for radioactive waste
- exhaust air monitoring
- monitoring of test facilities in nondestructive material testing
- warehouse monitoring, e.g. collection sites for radioactive waste

Performance features

- μ-controller-based measurement electronics
- digital measurement value information on large-area, illuminated LC display
- measurement value display of dose rate in n/μ/mSv/h with autoranging function
- membrane keyboard with indication of the switching status of the traffic light relays
- externally connectable detector (GM counter tube, NaI detectors) with integrated high voltage generation and electronics
- automatic detector identification, calibration data are read out by the measurement electronics, allowing simple replacement of the detector
- detector can be set up in a distance of 100 m from measurement electronics via cable
- 2 freely definable alarm thresholds per probe
- easy-to-operate measurement system with user guidance
- ergonomically shaped housing, desktop or wall version
- 8 x 2 switch outputs, 8 x potential-free and 8 x potential-free or 24 Volt supply (can be set via menu)
- 2 (3) interfaces:
    - Interface A: USB, RS-232, RS-422 or RS-485 can be selected via menu.
    - Interface B: RS-232, RS-422 or RS-485 can be selected via menu.
    - Ethernet (in preparation)
- four languages can be selected: English, German, French and Russian
- data storage of the last 100 alarms
- opional accessory (see chapter 9), options:
  - various optical/acoustic alarm units can be connected
  - emergency power supply
  - software for continuous dose rate measurement, incl. data storage

2. Operation of the Alarm Monitor

The alarm monitor has a clear structure and the operating elements are clearly and logically arranged.

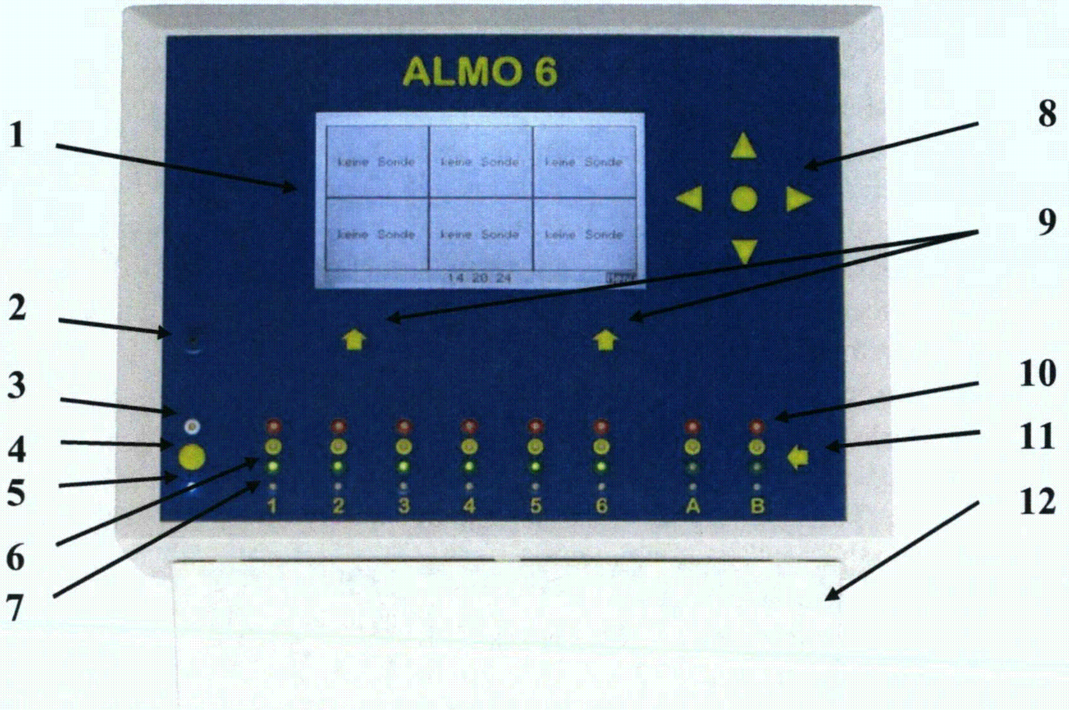


Figure 1: ALMO 6 operating components

1. LC display with 240x128 pixels
2. LDR sensor for the backlight
3. Charge control light
4. On/Off switch
5. Indicator light: Device on / ok
6. Three-stage display of the LED status per probe (channel 1 to 6)
7. Blue signal LED's (e.g. indicating malfunctions)
8. Operating keys
9. Function keys (function is displayed above the key on the display)
10. Three-stage display of the LED statuses of both total alarms
11. Quit button
12. Battery compartment of the optionally available emergency power supply; fuses

3. Operating Elements

LC display (1)

The LC display is a graphics display with 240x128 pixels.

Charge control light (3)

In case of monitors with UPS, the rechargeable batteries guarantee a power supply in case of mains breakdown. If the batteries are charged, the control light is burning. The batteries should be full after max. 1 day, otherwise the batteries have to be replaced. If the control light is blinking, the batteries are full and the charging electronics are switched to power maintenance.

On/Off switch (4)

The On/Off switch is designed as a push-button. Push the button (approx. 1 second) to turn the device on/off.

Alarm display (6 and 10)

The current alarm status is indicated on this display (standard alarm assignment):

- **green:** no alarm threshold is exceeded.
- **yellow:** alarm threshold 1 is reached
- **red:** alarm threshold 2 is reached

Arrow keys (8)

An alarm threshold is changed with these keys, the keys select the digit to be set.

The keys select a menu item and / or the alarm threshold to be set and increment or decrement the digit to be set.

Enter key (8 center)

With this key you select menu items, store entries and change options.

Function keys (9)

The function of these keys is indicated on the LC display.

Menu-	Open the menu
End-	Exit the menu structure
Back-	Return to last menu item and / or return to normal mode
Strore-	Store changes

Quit button (11)

If an acoustic warning is triggered when an alarm is exceeded, the acoustic signal can be reset (turned off) by pushing this button.

If the measured value drops below the alarm threshold again, the visual alarm can be reset by pushing this button once more (only in the quit mode).

3.1. Internal and External Displays

The device includes the following options to display its current status and to acknowledge errors:

- LC display
- One LED traffic light and blue LED for each probe
- 2 total alarm LED traffic lights and blue LED's (total alarm A and B)
- One internal loudspeaker
- One internal quit button (⇦)
- 2 external traffic lights for each probe
- 2 external total alarm traffic lights (total alarm A and B)
- 2 external total alarm loudspeaker
- 2 external quit buttons

Exceeded alarm thresholds will be indicated by the blue LED of the probe that triggered the alarm which lights up permanently. Moreover, if configured on the menu, they can be indicated on the LC display, by the LED traffic light of the probe that has triggered the alarm, and by the external traffic lights of the probe that has triggered the alarm.
Critical probe errors (no probe, unknown probe, end of the lifetime of a GM probe) are indicated by the flashing blue LED of the probe that has triggered the alarm. Moreover, they can be configured on the menu such that they will be indicated on the LC display and by the respective probe traffic lights.
Critical device errors (hardware error and battery voltage too low) are indicated by all blue LED's flashing.
The device also includes two total alarm traffic lights in addition to probe traffic lights. Besides probe traffic lights, exceeded alarm thresholds and error states can be passed on to these traffic lights. If several errors have occurred, the one with the highest priority will be indicated on the total alarm traffic lights.
For alarm thresholds and also for probe and device errors, the device can be configured such that an acoustic signal is triggered. A 1 second tone with 1 second breaks will be created.

3.1.1. Function of the Quit Button

The device includes an internal quit button (). In addition, two external quit buttons can be connected. These buttons have the following function:

- Push the quit button once to disable the acoustic signal for errors and alarm thresholds which were active at that time.
- Push the quit button once more to disable the traffic light indication of the presently active error with the highest priority. In this case, the next active error or alarm with lower priority will be indicated by the traffic lights. Exempted from this are current alarms (if a measured values exceeds an alarm threshold). In this case, the alarm is still indicated.
- Proceed as follows to turn off the alarm display: set the maximum measured values for all probes equal to the current measured values. If the current measured value is above the alarm threshold, the alarm threshold alarm will be triggered again immediately.

3.2. Menu Overview

3.2.1. Menu Structure

The program structure of the ALMO6 as a flow graph:

3.2.2.

Menu items in red are available in the expert mode (see 4.12) only.

Menu items in green can be turned off.

Menu Operation

The system includes a membrane keypad with 8 keys + On button for operation of the ALMO6. The two buttons below the LC displays are function keys. Their functions are displayed above the respective button in the bottom row of the display, with bright letters on a dark background.

To open the menu, push the right function key (Menu). You can navigate inside the menu using the keys and the ENTER key.

Push the left function key (Back) to return to the higher menu level. The right function key has two different meanings: If one setting has been changed on the menu, the changed setting is stored permanently in the EEPROM after you have pushed the right function key (following a confirmation prompt). If no setting has been changed, you can exit the menu by pushing the right function key and return to the probe display.

To edit values (e.g. alarm thresholds, date/time) select the corresponding entry with the keys and confirm with the ENTER key. The value can be changed with the arrow keys.
Select the digit to be changed with the keys right/left.

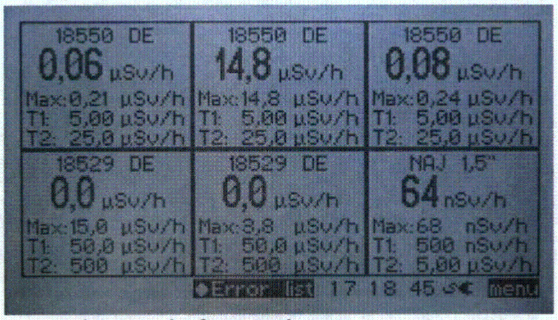
Push the Enter key once more to store the changed value.

4. Measurement Mode

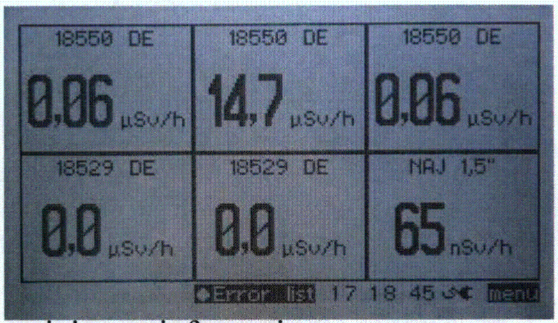
Five different display modes can be selected to present the measured values.

4.1. 6 Probe Display

The information shown on the display can be reduced so much that only the measured value is displayed.
The size of the measured value display will be adapted to the available space.



maximum information

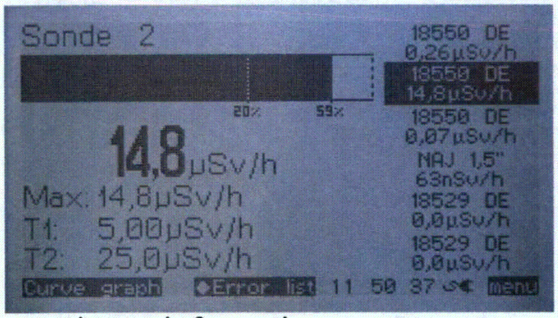


minimum information

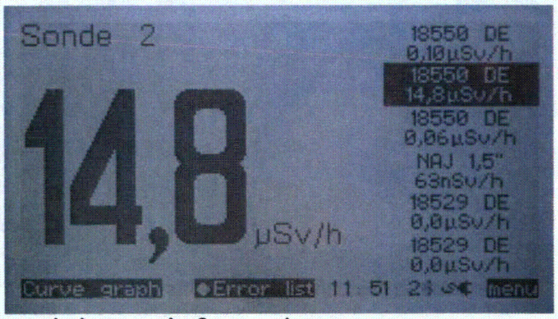
A horizontal bar graph can be displayed instead of the alarm thresholds. The bar graph shows the current and the maximum measured value in % relative to the second alarm threshold in linear or logarithmic scale.
The measuring range is set automatically.

4.2. 1 Probe Display

The information shown on the display can also be reduced to one measured value. The size of the measured value display will also be adapted to the available space. The measured values of the other probes are displayed in the column all the way to the right. The probes can be selected with the ▲ and ▼ buttons.
In case of an alarm for a probe that is presently not displayed, this probe may be switched as active probe.



maximum information



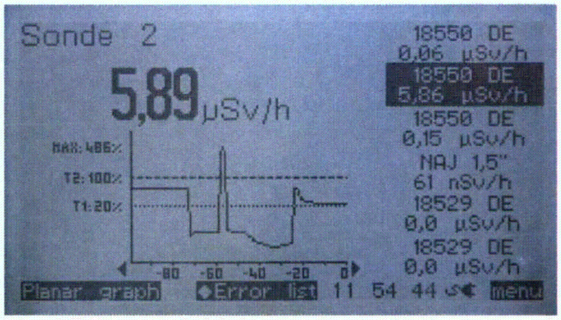
minimum information

4.3. Display as Bar Graph

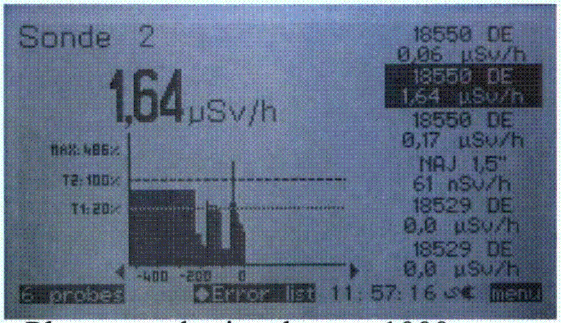
The bar graph is displayed in % relative to the second alarm threshold. You can choose between linear and logarithmic presentation. The current measured value can be displayed as a numerical value above the graph (see screen shot below).
Besides the current measured value, both alarm thresholds and the maximum value are displayed. The first alarm threshold is depicted by a dotted line (........), the second alarm threshold by a dashed line (- - -) and the maximum value by a solid line (___). The presently measured value is the upper end of the black bar.

4.4. Display as Curve Graph or Planar Graph

The time base can be changed between 100s and 1000s using the two arrow keys right ( ) / left ( ). The graph shows the measured values of the last 100s or 1000s in percent relative to the second alarm threshold. The alarm thresholds itself are depicted as a dotted and dashed line. The maximum value is displayed on the Y-axis.



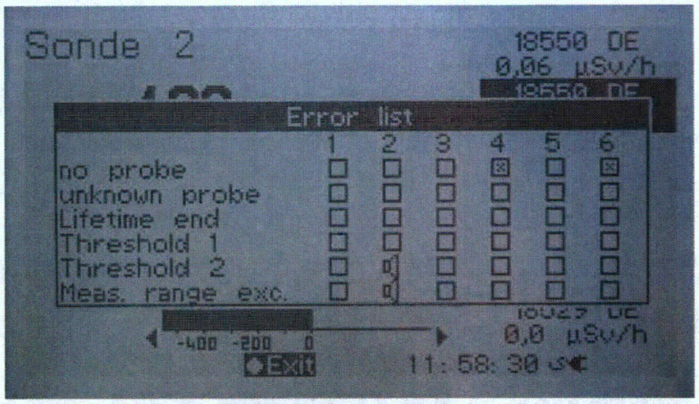
Curve graph, time base = 100s



Planar graph, time base = 1000s

4.5. Error List

If you push the Enter key (●) in the measurement mode, a list of the current errors is displayed for all 6 probes.

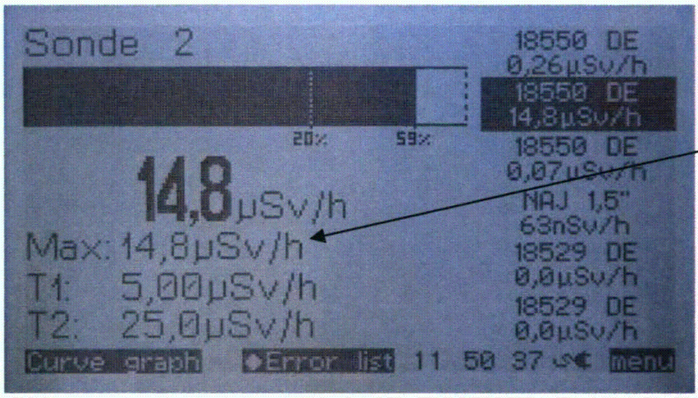


The symbols have the following meaning:

- ☒: active error
- 🕨: active error which triggers an acoustic alarm (internal or external)
- ☐: no active error

4.6. Alarm Triggering

When the defined alarm threshold is exceeded, the alarm indication and, depending on the setting, the acoustic warning are turned on.



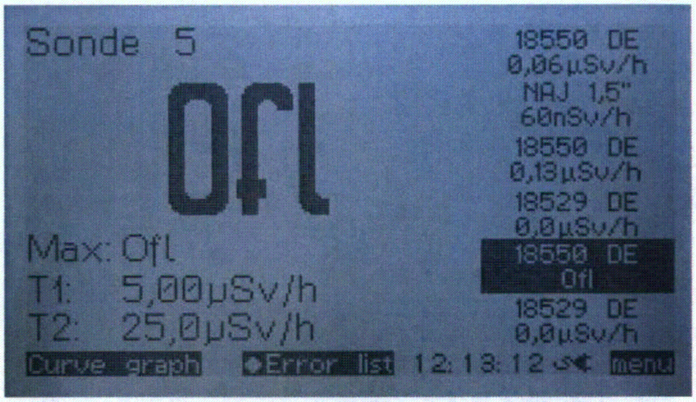
In the quit mode, the maximum value is indicated on the display. It will be indicated until it is reset by pushing the button.

The status of the connected traffic lights is indicated in the LED field. In our example, the second alarm threshold of probe 5 has been exceeded. Therefore, traffic light 5 is switched to **red**. In addition, the traffic light of the total alarm B will also switch to **red**. The blue LED on channel 5 is flashing, which indicates that the quit mode is turned on and an alarm has been triggered. The maximum value of the previous alarm was 154 µSv/h.

How traffic light colors are assigned to alarms is described in chapter 4.10.3.

4.7. Measuring Range Overflow

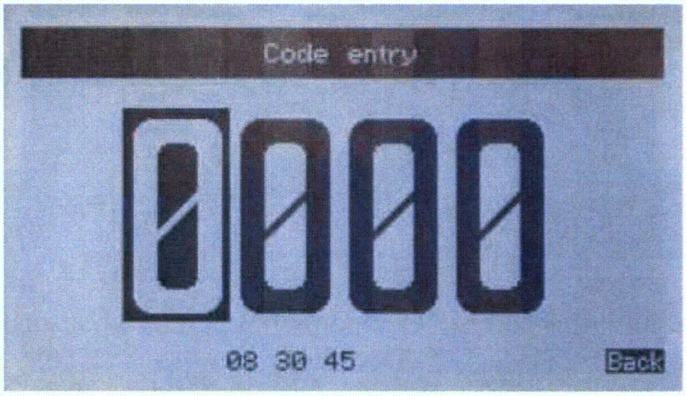
If the measuring range is exceeded, the display looks as follows:



Since the present as well as the maximum measured value are outside the measuring range of the probe, the message „Ofl“ („overflow“) is displayed instead of the value. Moreover, this status is indicated through the traffic lights, blue LED on the device and internal and external acoustic signals, as defined on the menu System parameters → Error display → Measuring range exceeding.

4.8. Code Entry

To avoid that unauthorized persons can change any settings on the device (e.g. change or turn off the alarm thresholds), access to the menu level can be protected by a code entry.



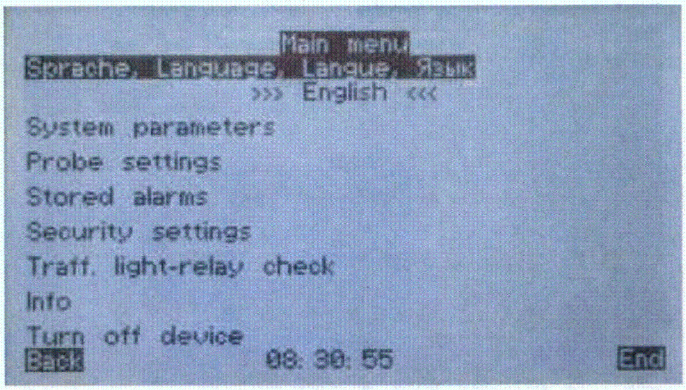
- With the ◀ and ▶ buttons, select the digit to be set. The digit to be set will be displayed inverted.
- With the ▲ and ▼ buttons, increment or decrement the digit to be set.
- Push the Enter ● key or the right function key to go to the menu level. With the right function key ⇧ (back) you get back to the probe display.

The function of the arrow keys is the same throughout the entire menu level.

CODE 0000 has been set by the manufacturer.

We recommend that you change this value after you have taken the device into operation.

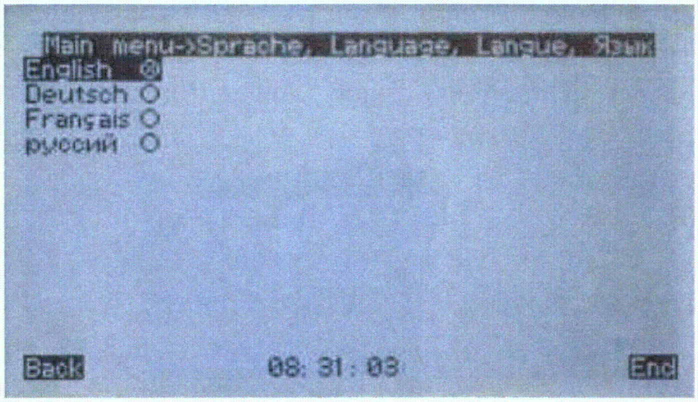
4.9. Main Menu



On this level, the following items can be selected using the ▲▼ buttons:

- **Language, etc:** Setting the menu language
- **System parameters:** Setting the system parameters. Reset of the device and probe parameters
- **Probe settings**: Setting of the alarm thresholds, assignment of the traffic light colors to the exceeded alarm thresholds, setting of the averaging procedure, setting of the probe life-time (only for GM probes)
- **Stored alarms:** View and delete stored alarms
- **Security settings:** Enter new menu code, exit the menu automatically, simplified menus, turning the device off
- **Traff. light relay check:** Checking the internal LED and the external traffic lights and loudspeakers and the external quit button
- **Info:** Information about hard- and software and the manufacturer

4.9.1. Language

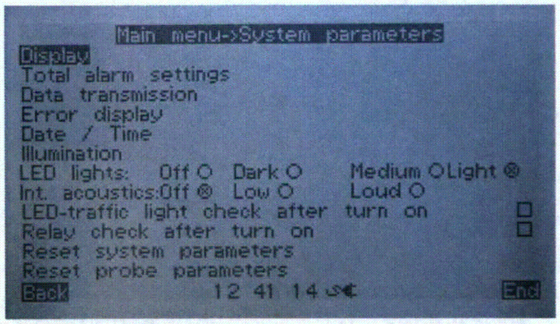


On this menu you can select the menu language and the language of the other messages.
Presently, four languages can be selected: English, German, French and Russian.

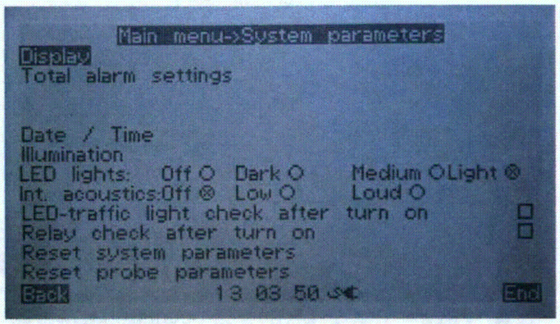
Further languages will follow or can be implemented on request.

4.9.2. System Parameters

This menu has a different look, depending on whether Expert mode has been enabled on the „Security settings“ (see 4.12) menu or not. The Expert mode includes two additional items: „Data transmission“ and „Error display“.



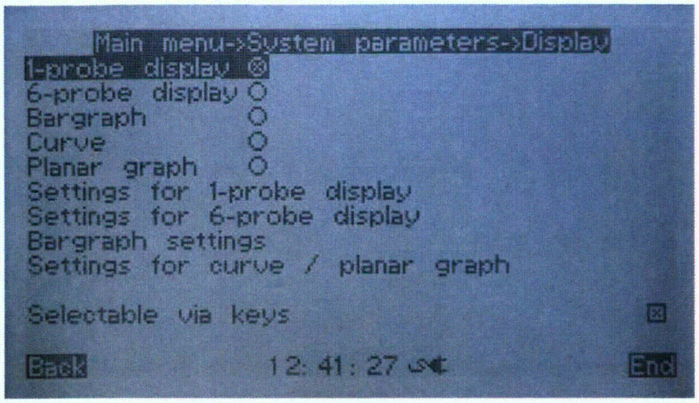
Expert mode



Simple menu

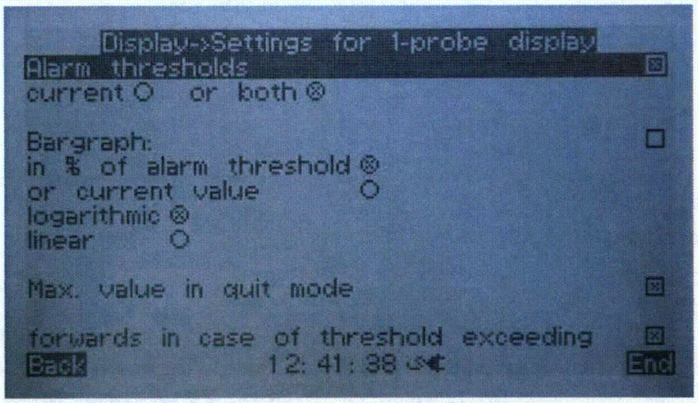
- **Display:** Settings for various display options
- **Total alarm settings:** Hardware parameters for total alarm traffic lights, external loudspeaker and external quit buttons
- **Data transmission:** Settings for printer and data transmission (only in the Expert mode)
- **Error display:** Assignment of acoustic and visual alarms for various error cases. Setting of error priorities (only in the Expert mode)
- **Date / Time:** Setting of date, time and daylight saving time and standard time
- **Illumination:** LCD background illumination
- **LED lights:** Brightness of the LED lights on the device
- **Internal acoustics:** Volume of internal loudspeaker
- **LED traffic light check after turn on:** Enabling and disabling the turn on check of the device-internal LED lights
- **Relay check after turn on:** Enabling and disabling the turn on check of the device-external LED lights
- **Reset system parameters:** Reset the system parameters to factory-set values
- **Reset probe parameters:** Reset the probe parameters to factory-set values

4.9.2.1. Display



On this menu you can set the display mode and whether you can change the display with the left function key. Moreover, from this menu you go to the submenus in which you can set the parameters for different display modes.

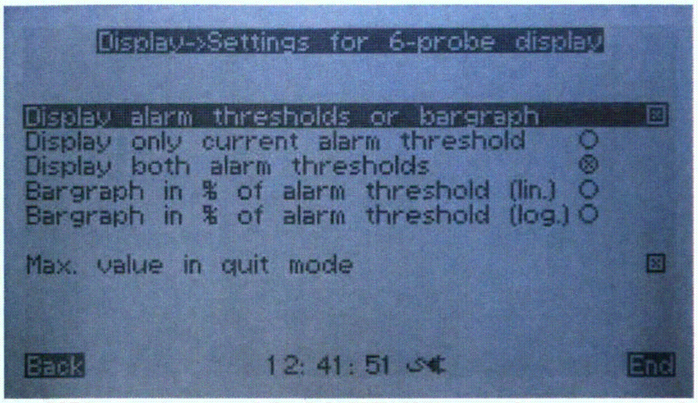
4.9.2.1.1. Settings for 1-Probe Display



On this menu you can set the parameters for the 1-probe display, as shown on the screenshots in chapter 4.2.

- The checkbox „Alarm thresholds“ turns the presentation of the alarm thresholds on the display on and off.
- If the alarm thresholds are turned on, click on the radio button „current“ and „or both“ to select if only the currently exceeded alarm threshold or both alarm thresholds are to be displayed. If the checkbox „Alarm thresholds“ is not ticked, this setting will be ignored.
- Tick the „Bargraph“ checkbox to turn the bar graph on and off.
- With the 4 following radio buttons you can choose if the bar graph shows the current value, the maximum value and the alarm thresholds as absolute values or as %-values relative to the second alarm threshold. Moreover, you can choose between logarithmic and linear scale division.
- The checkbox „Max. value in quit mode“ turns the display of the maximum measured value on and off, provided the quit mode for this probe has been enabled (see chapter 4.10.3).
- If the checkbox „forwards in case of threshold exceeding“ is ticked, the probe whose alarm threshold has been exceeded last will be put forward.

4.9.2.1.2. Settings for 6-Probe Display

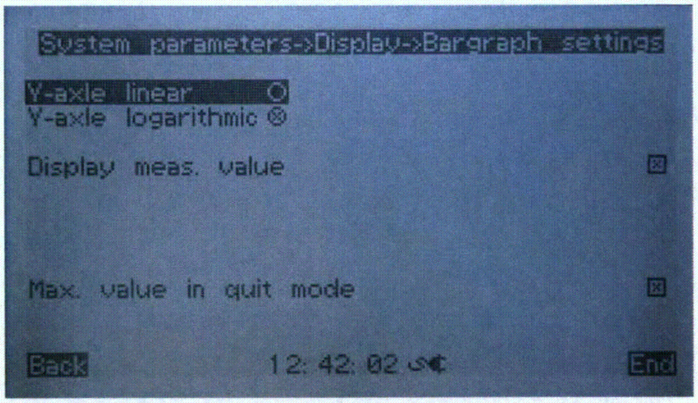


The 6-probe display is shown on the screenshots in chapter 4.1. All 6 probes are displayed at once. This display is configured by the settings on the menu:
System parameters→Display→Settings for 6-probe display:

- The „Display alarm thresholds or bargraph“ checkbox turns the display of the alarm thresholds or the bar graph for each probe on and off.
- If the „Display alarm thresholds or bargraph“ checkbox is ticked, you can select with the radio buttons if
  - only the currently exceeded alarm threshold is to be displayed
  - both alarm thresholds are to be displayed
  - a bar graph with linear scaling is to be displayed
  - a bar graph with logarithmic scaling is to be displayed

  If the „Display alarm thresholds or bargraph“ checkbox is not ticked, this setting will be ignored.
- The checkbox „Max. value in quit mode“ turns the display of the maximum measured value on and off, provided the quit mode for this probe has been enabled (see chapter 4.10.3).

4.9.2.1.3. Bargraph Settings

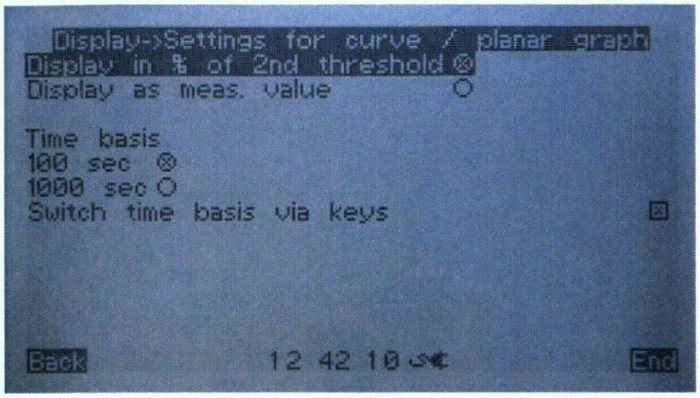


An example for a bar graph display is shown on the screenshot in chapter 4.3. With this type of display, both alarm thresholds and also the current and maximum measured value of all 6 probes are displayed as bar graph. This display is configured by the settings on the menu:

System parameters→Display→Bargraph settings:

- With the first two radio buttons you can either select linear or logarithmic scaling of the Y-axis
- Tick the „Display meas. value" checkbox to turn the display of the current measured value above the graph on and off
- The checkbox „Max. value in quit mode" turns the display of the maximum measured value on and off, provided the quit mode for this probe has been enabled (see chapter 4.10.3).

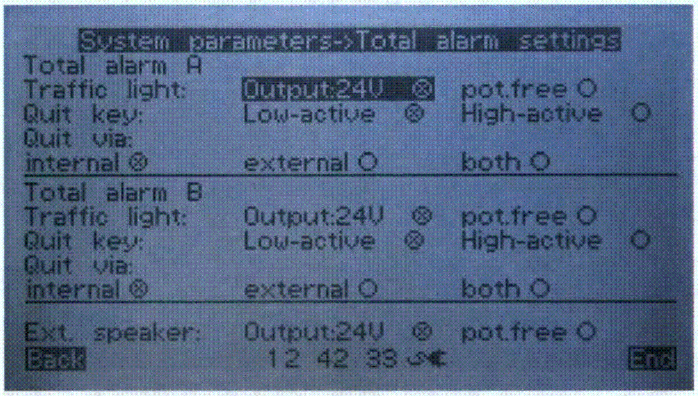
4.9.2.1.4. Display Settings for Curve / Planar Graph



Examples for curve and planar graph display are shown on the screenshot in chapter 4.4. In this display mode, a curve or planar graph diagram is displayed below the current measured value; both alarm thresholds and the max. measured value are also displayed. This display is configured by the settings on the menu System parameters→Display→Settings for curve/planar graph:

- The values in the diagram can either be displayed as absolute values or in % of the second alarm threshold. This is configured by ticking the radio buttons „Display in % of 2nd threshold“ and „Display as meas. value“
- Either the measured values of the last 100s or the measured values of the last 1000s can be displayed in the diagram. Since 100 values are always displayed in the diagram, with the setting „1000s“ each measured value in the diagram corresponds to an average measured value of 10s. This applies only to the diagram. The measured value above the diagram is still updated every second.
- If the „Switch time basis via keys“ checkbox is ticked, you can switch between both time bases 100s and 1000s by pushing the keys ◀ and ▶ in the diagram presentation.

4.9.3. Total Alarm Settings



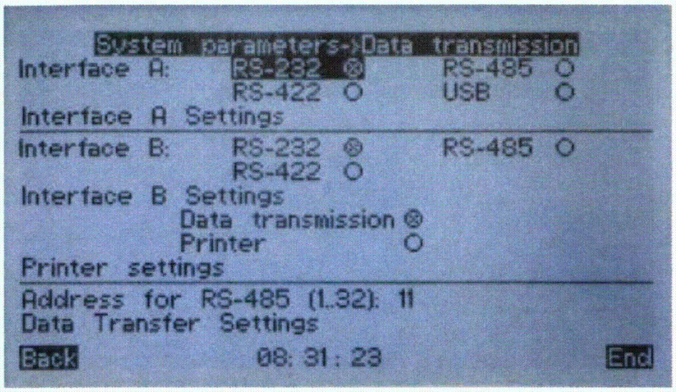
The device includes two total alarms: Total alarm A and B. In addition to the LED traffic light on the housing, each of these total alarms can be indicated by an external traffic light and by an external loudspeaker. Moreover, one external quit button each can be connected.

The total alarm hardware is configured on this menu

- The external traffic light can either be supplied with 24V directly by the device or it may have its own power supply. This can be configured with the radio buttons „Traffic light: Output: 24V“ and „pot.free“
- The polarity of the external quit button is configured with the radio buttons „Low-active“ and „High-active“
- With the radio buttons „Quit via: internal“, „external“ and „both“ you can configure if the external quit button is equivalent to the internal one (setting „both“), or if one of them is disabled
- The external loudspeaker, just like the external traffic light, can be supplied with power by the device or it can have its own power supply.

Caution: Before the 24 Volt are switched to the traffic light or to the additional relay and the acoustics, you have to check if the connected components are designed for these voltages.
If the relays are switched potential-free, max. 24 Volt 1 Ampere may be switched per relay.
In case of a 24 Volt supply of the components by the device, the total power consumption must not exceed 500mA.
If this is disregarded, the device or the connected components may be destroyed.

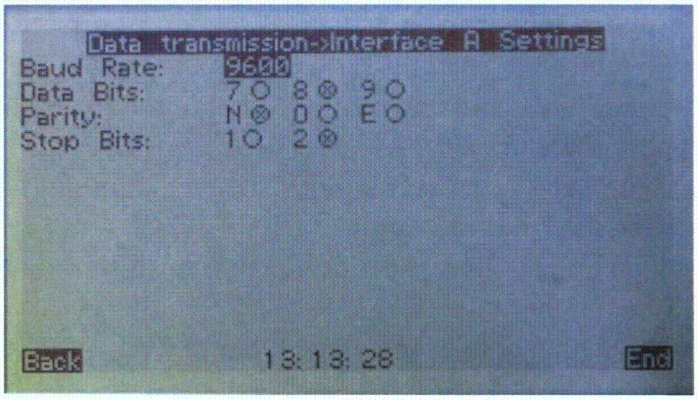
4.9.4. Data Transmission



The device includes 2 interfaces which can be configured as RS-232, RS-422 and RS-485 interface. Moreover, interface A can also be configured as USB interface. Interface A can only be used for data transmission, but a printer (seetings see 4.9.4.2) may be connected to interface B.
For every interface, the settings regarding baut rate, data bits etc. can be configured in a submenu.
With the setting „Address for RS-485“ the device can be assigned to an address, so that several devices can be connected to one PC interface and can be queried by the PC software.
The settings for data transmission regarding send mode and layout are made in a submenu (see 4.9.4.3).

4.9.4.1. Interface Settings

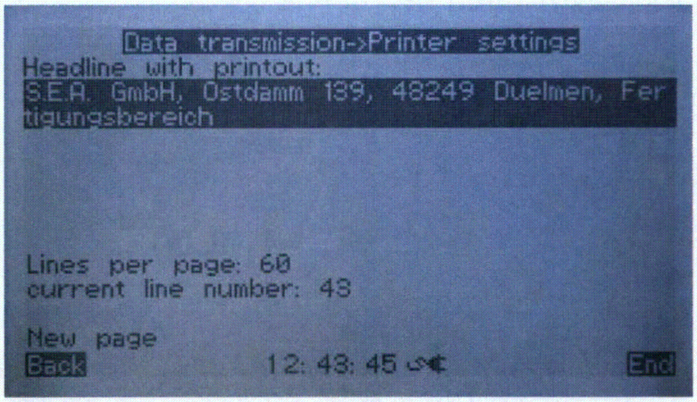
Since the possible configurations for interface A and B are the same, only the submenu for interface A is described here.



You can set the baut rate, the number of data bits, parity and number of stop bits. Make sure that the settings of the communication partner are the same

.

4.9.4.2. Printer Settings



Besides the option to transfer current measured data to the PC, the device can also send information on alarm threshold exceeding through interface B to a printer. Any time an alarm threshold is exceeded, a row containing the following information is printed out:

- Start time of the alarm
- End time of the alarm
- Probe number (1 to 6)
- Probe type
- Max. measured value

An alarm printout of probe 3 may look as follows:

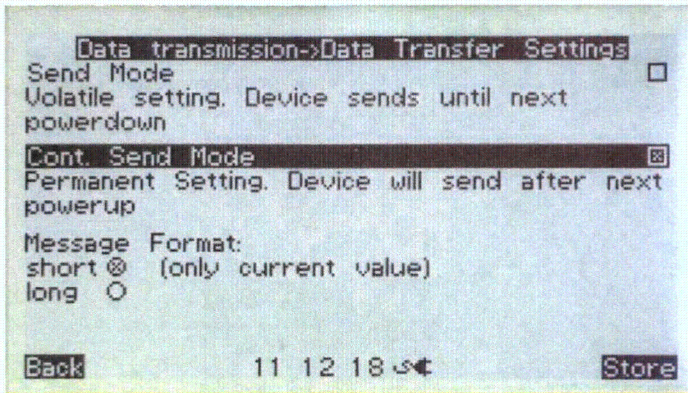
```
13.05.08 09:50--13.05.08 09:54   3   18550 CE              Max:303 µSv/h
```

The following parameters can be configured on the menu:

- Headline with printout: This row is printed at the top of a page. Its contents can be changed. To do this, select it with the key, move the cursor with the and keys to the character you want to edit and push the and keys to select a new character.
- Lines per page: Number of alarm printouts after which a new page will be started, not counting the headline.
- New page: This function sends a signal to the printer to start a new page and sets the current line number to 0.

The current line number cannot be changed; it is displayed only for the user's information.

4.9.4.3. Data Transfer Settings

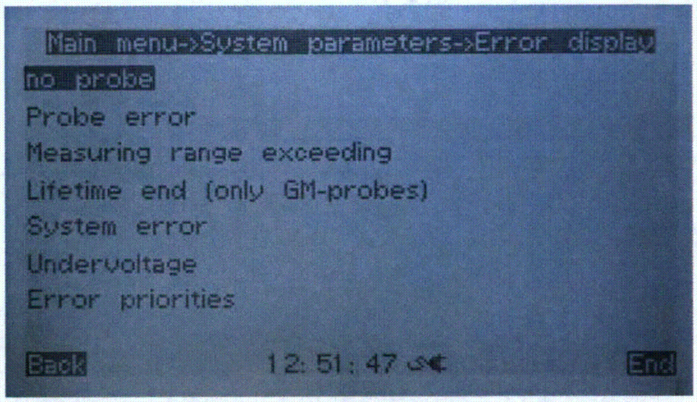


If 'Send Mode' is activated, the data are transmitted till the unit is turned off, provided that data transmission (see 4.9.4.3) is activated. If the unit is turned on again, the send mode is not active anymore. Changes cannot be stored when using the 'Send Mode'.

If 'Continuous Send Mode' is activated (necessary to store), the data are transmitted also after turning the instrument off and on again.

You can define if the transmission format has to be long and all values (see chapter 5) have to be transmitted. If you select the short transmission format, only the measuring value is transmitted.

4.9.5. Error Display



The device recognizes the following error states:

- „No probe“: if no probe has been detected at a probe input
- „Probe error“: if a probe is connected to a probe input, but the probe type is not identified correctly, or if one of the probes did not receive any counts for a long time
- „Measuring range exceeding“: if the measuring range of a probe has been exceeded
- „Lifetime end“: if the total number of counts $5 \cdot 10^{10}$ received by a GM probe has been exceeded
- „System error“: if a hardware error of the device has been detected
- „Undervoltage“: if the battery voltage has dropped below 11V

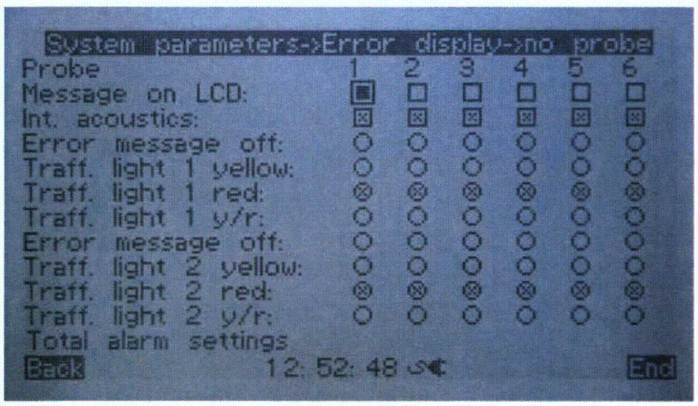
On this menu you can define how individual error states will be indicated. Moreover, you can define the priority of the error displays on the „Error priorities“ menu.
Since the submenus for the error states „No probe“, „Probe error“, „Measuring range exceeding“ and „Lifetime end“ and the submenus „System error“ and „Undervoltage“ look the same, we will only describe the submenus „No probe“ and „System error“ on the following pages.

4.9.5.1. Error Display „No Probe“

The device includes the following options to display an error:

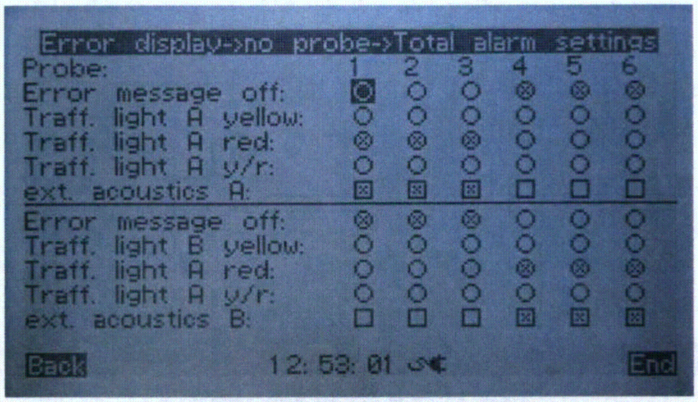
- Message on the LC display
- Acoustic signal through an internal loudspeaker
- Indication through the built-in LED light or the external traffic light 1
- Indication through the external traffic light 2
- Indication through the external total alarm traffic light A and B
- Acoustic signal through an external loudspeaker A and B

The first four display options are configured on the menu „no probe“:



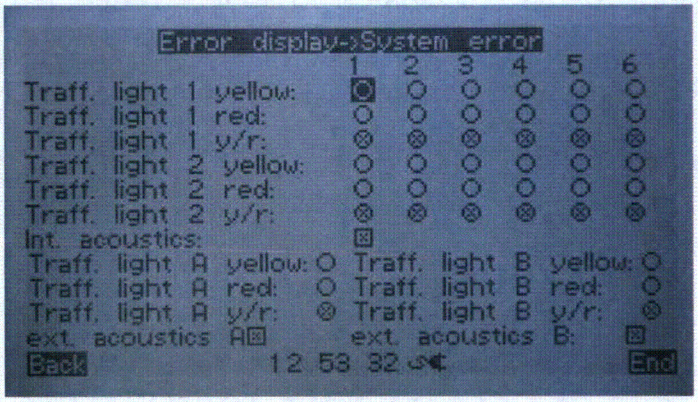
- With the checkbox „Message on LCD“ you can choose if a message is to be displayed on the LC display or not if an error occurs
- With the checkbox „Int. acoustics“ you can enable or disable the signaling of errors through the internal loudspeaker
- With the radio buttons you can select in which color the error is to be displayed by the traffic lights of the probe causing the error

4.9.5.1.1. Error Display „No Probe"→Total Alarm Settings



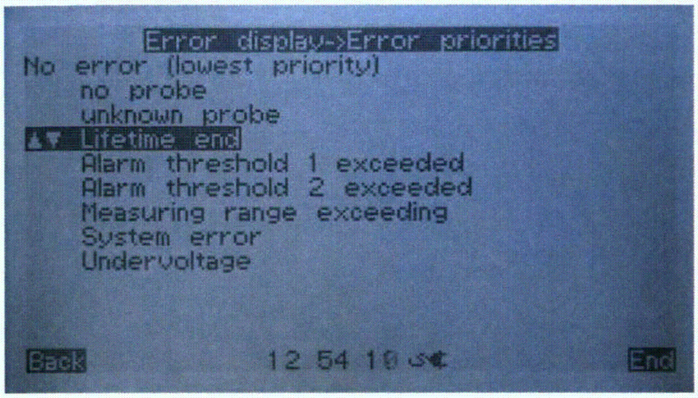
In addition to the probe traffic lights, an error message can also be indicated through the total alarm traffic lights A and B. The color of the lights is defined on this menu. Moreover, with the checkboxes you can define if the error should trigger an acoustic alarm or not.
Since several errors may be indicated by the total alarm traffic lights (e.g. probe 1: no probe, probe 2: alarm threshold exceeding, probe 3: lifetime end), the errors at the total alarm traffic lights are indicated according to the settings on the menu Error display→Error priorities.

4.9.5.2. Error Display System Error



The display of a hardware error can be configured on this menu. You can define the colors of the probe traffic lights 1 and 2 and of both total alarm traffic lights. Moreover, acoustic signaling through the internal and external loudspeakers can be enabled or disabled via the checkboxes.

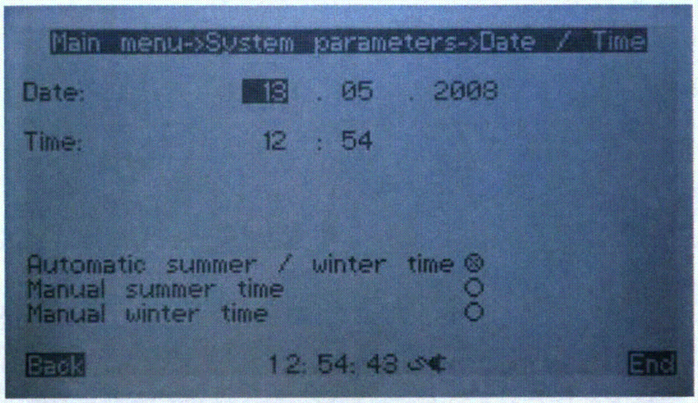
4.9.5.3. Error Display Error Priority



The error priorities are defined on this menu. At the top, you see the error with the lowest priority, at the bottom, the one with the highest priority. To change the priority, select an error with the key and move it up or down in the error list with the and keys.

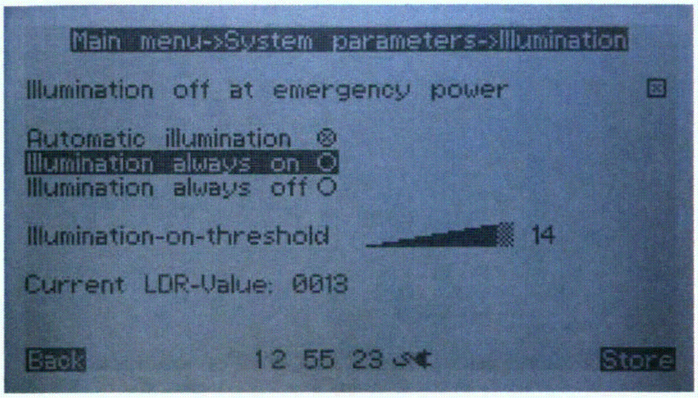
If several errors occur in one probe channel (e.g. lifetime end, alarm threshold 2 exceeded and measuring range exceeded), the probe traffic lights show only the error with the highest priority. Push the key once to turn off the alarm tone and push it once more to display low priority errors. This is true only if the current measured value has dropped below the displayed alarm threshold. If the current measured value is still higher than the alarm threshold, only the acoustic display of the alarm threshold exceeding can be turned off, but not the traffic light indication.

4.9.6. Date and Time Settings



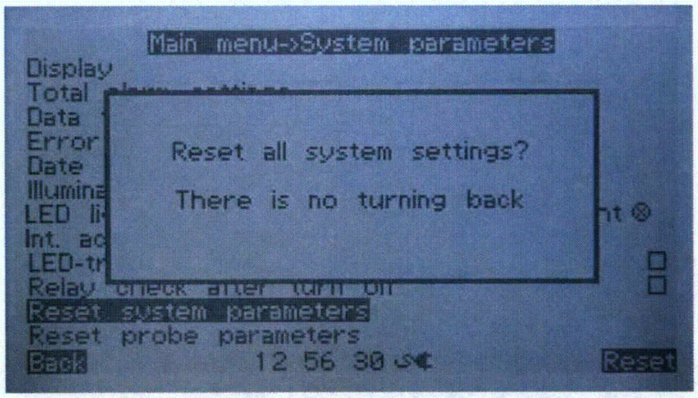
You can set the current date and time on this menu. Moreover, you can turn the automatic change over to daylight saving time on or off. During daylight saving time, one hour is added to the current time. The automatic setting of daylight saving time and standard time takes place on 2 a.m. of the last Sunday in March. The automatic setting back to standard time takes place on 2 a.m. of the last Sunday in October.

4.9.7. Illumination Settings



On this menu you can configure the background illumination of the LC display. If the checkbox „Illumination off at emergency power“ is ticked, the LCD background illumination is turned off if the device power is not supplied by the power supply system, but by the built-in battery.
The illumination can either be turned on or off permanently (radio buttons „Illumination always on“ and „Illumination always off“) or it can be configured such that it will be turned on or off only if a certain brightness level has been exceeded. This threshold can be set in the range from 0 to 15 in the input field „Illumination-on-threshold“. Once you have selected the input field with the key, you can set the new value with the and keys. Push the key once more to accept the new value.
The currently set brightness is displayed as “LDR-Value”.

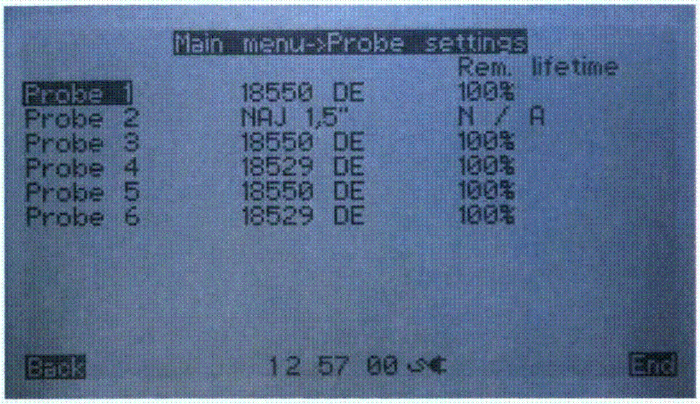
4.9.8. Reset System Parameters to Factory Settings



With the menu items „Reset system parameters“ and „Reset probe parameters“ you can reset all parameters to factory-set values, with the exception of the parameters if external traffic lights and loudspeakers are to be operated with 24V or if they are potential-free. After selection of one of these two menu items with the Enter key, a confirmation prompt will be displayed, as shown on the screenshot. With the left softkey you can close the confirmation prompt dialog again without resetting the parameters. With the right softkey you can reset the respective parameters and store them to the EEPROM.

4.10. Probe Settings

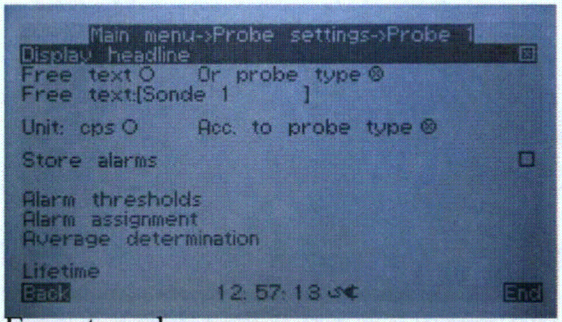
4.10.1. Probe Selection



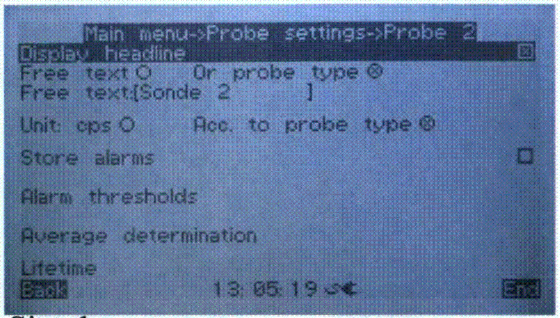
To change the parameters of an individual probe, you have to select this probe on the „Probe settings“ menu. Besides the probe type, the remaining lifetime for the GM-probes is displayed on this menu.

Since the menus for all probes are identical, we will describe them using probe 1 as an example.

4.10.1.1. Settings for Probe 1



Expert mode menu



Simple menu

On this menu you can set the display options for probe 1. The checkbox „Display headline“ determines if a probe headline is displayed in the measured value displays (except bar graph). If display headline is enabled, two options can be selected:

- display the probe type as headline or
- display freely selectable text

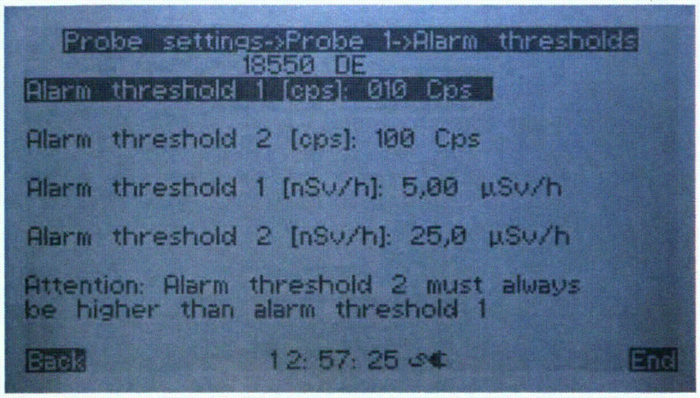
This selection is made with the radio buttons „Free text“ and „Probe type“. If you have selected free text as headline, the contents of the headline is taken from the input field „Free text.

With the radio buttons „Unit: cps“ and „Acc. to probe type“ you choose in which unit the value is to be displayed. You can select the units Sv/h and cps (count per second) for the Graetz probes 18550CE, 18509CE, 18545CE, 18529CE and for the NaI probes 1×1in and 1.5×2in. For all other probes, this parameter is ignored and the measured value is displayed in cps.

With the checkbox „Store alarms“ you can enable the storage of the alarms in the EEPROM for this probe. The alarms can later be viewed under the menu item „Stored alarms“ and deleted, if necessary (see chapter 4.11).

Select the menu items „Alarm thresholds“, „Alarm assignment“, „Average determination“ and „Lifetime“ to open submenus in which further probe parameters can be set. The submenu „Alarm assignment“ is available in the Expert mode only.

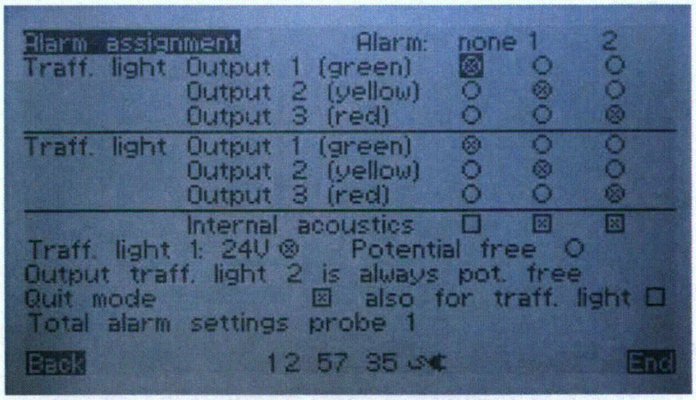
4.10.2. Alarm Thresholds



On this submenu you can set the alarm thresholds in Sv/h and counts/sec. Depending on the unit you have chosen for the probe on the previous menu, the alarm threshold pair will be used with the respective unit. The other pair will be ignored.

The first alarm threshold must always be lower than the second alarm threshold. If this is not the case, both alarm thresholds will be exchanged when you try to store them (you will be alerted by a corresponding message). Moreover, both alarm thresholds must lie within the measuring range of the probe. If you enter an alarm threshold which lies outside the measuring range of the probe, it will **not** be corrected. On the measured value display, this alarm threshold will be displayed as „Ofl“. Nevertheless, exceeding of this alarm threshold will be checked and, if necessary, an alarm is triggered (at the same time with the error „Measuring range exceeding“).

4.10.3. Alarm Assignment

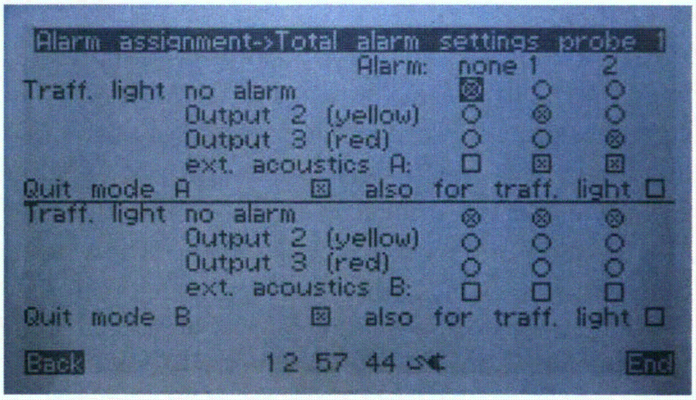


On this menu you can set the following parameters:

- Assign the colors of the external probe traffic light 1 and 2 to the individual alarm states (no alarm, alarm threshold 1 exceeded, alarm threshold 2 exceeded)
- Specify if the external probe traffic light 1 is supplied with 24V by the device (radio button „Traff. light 1: 24V“) or if it has its own power supply (radio button „Potential free“)
- Turn the quit mode on and off (checkbox „Quit mode“). If quit mode is enabled, the decision whether an alarm threshold has been exceeded is not based on the current measured value, but on the maximum measured value. If a quit button (external or internal ( ), depending on the setting on the menu „System parameters→Total alarm settings“) is pushed several times, the maximum measured value is reset to the current measured value
- If the checkbox „also for traffic. light“ is ticked, the determination of the traffic light color is also not based on the current, but on the maximum measured value.

Caution: Before the 24 Volt are switched to the traffic light or to the additional relay and the acoustics, you have to check if the connected components are designed for these voltages.
If the relays are switched potential-free, max. 24 Volt 1 Ampere may be switched per relay.
In case of a 24 Volt supply of the components by the device, the total power consumption must not exceed 1500mA.
If this is disregarded, the device or the connected consumers may be destroyed.

4.10.3.1. Alarm Assignment Total Alarm Settings



Besides the assignment of the colors of the probe traffic light 1 and 2 to the alarm states, the colors of the external total alarm traffic lights A and B can be assigned to the alarm states on the menu „Total alarm settings probe 1“. Instead of the color green, you have the option not to indicate the alarm status (radio buttons „no alarm“). Thus, one can switch the alarms of probes 1-3 to total alarm traffic light A and the alarms of probes 4-6 to total alarm traffic light B.

4.10.4. Averaging

4.10.4.1. Statistical Error

Nuclear decays, i.e. transformation of nuclei are natural, randomly distributed events. If one examines e.g. a radiation source using a detector and measures the number of registered events periodically over a fixed measuring time, then one will see that an accumulation occurs in a certain area. From the size of the area of this average value one can easily infer the intensity of the source. Its true intensity, however, remains unknown, since one cannot choose an infinitely long period of observation. The average value becomes an exact value only if the period of observation is infinite. When interpreting the measured values one only has to indicate the range in which the exact intensity is expected!

The mathematical relationship between random events is described by the probability calculus, where the natural distribution, e.g. in case of nuclear decay, is expressed by a so-called Gaussian distribution.

This can be presented in a simplified manner:
It is more probable to obtain measured values which come close to the exact quantity than measured values that are subject to significant deviations.
It is equally probable that measured values smaller or larger than the exact value will be obtained (symmetrical distribution).

Example:
A radioactive source of known intensity emits on average 100 particles per second which are registered by a detector in 1-second cycles.

The statistical variability for +/- 1 σ (Sigma) is:

$$\sqrt{100} = +/- 10 \text{ counts}$$

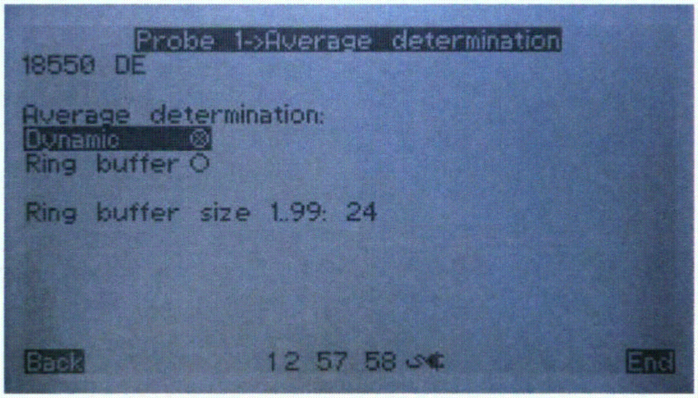
If a large number of measuring cycles are evaluated, the following relationship becomes apparent:

Number of cycles in %	Measured values from	to	Standard deviation (+/- 1 σ) %
27	90	110	1
45	80	120	2
73	70	130	3
997	60	140	4
999943	50	150	5

Table 1

This shows that it may be improbable but by no means impossible to find a measured value smaller than 50 or larger than 150; however, this probability is only approx. 1 to 1 700 000.
The purpose of this short mathematical excursion is to further the understanding of the function of the ring buffer.

The procedure for averaging is selected on the menu „Average determination“. The following options are available: dynamic averaging and averaging by means of the ring buffers. The ring buffer size can be set in the range from 1 to 99 values.
The ring buffer size can be changed only if a probe is connected and correctly recognized.



Dynamic: The ring buffer quantity is automatically calculated and set by means of the count rates. A dynamic smoothing procedure is applied

$$y = \frac{y_{old} * (Smoothing\ factor - 1) + Count\ rate}{Smoothing\ factor}$$

The smoothing factor is calculated using the formula:

$$Smoothing\ factor = 100 - \sqrt{Count\ rate} + 1$$

Limits: For count rates higher than 10000 the smoothing factor is 1; for low count rates (background) approx. 100. The advantage of this is that in case of sufficiently long measuring time the standard deviation is always < 1%.

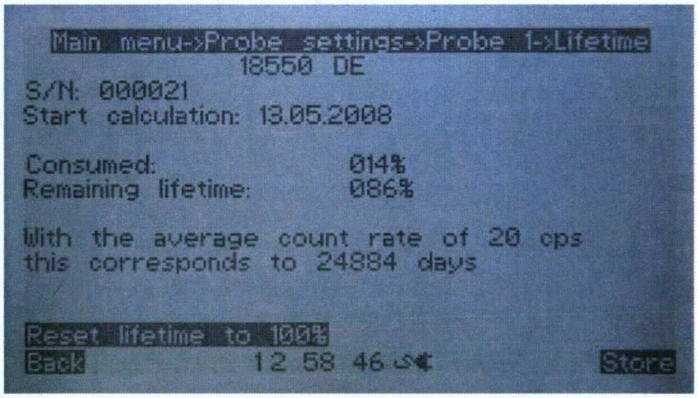
Ring buffer: The counts are collected in a ring buffer. The values are added and divided by the quantity. If the ring buffer is full, the oldest values are overwritten (first in first out). The number of memory slots can be defined from 2 - 99 memory

slots. In case of count rates > 400 cps the system works with a fixed defined ring buffer of 2.

Ring buffer size: For the result display, an average is calculated from the number of values. The number of memory slots is defined in this menu item. A smaller value e.g. < 10 results in a higher variability of the reading but small changes are detected faster. A larger value causes a very stable reading, but small changes require a very long time and may possibly not be detected.
A general recommendation for setting cannot be given, since the setting strongly depends on your field of application.

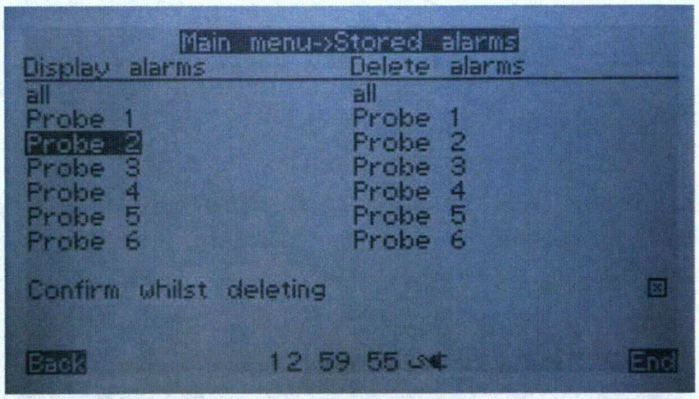
4.10.5. Probe Lifetime

Theoretically, the lifetime of the Graetz probes 18550CE, 18509CE and 18529CE is limited to $5 \cdot 10^{10}$ counts. The device stores the number of counts received, so that the elapsed and the remaining lifetime can be calculated.
If one of the above mentioned probes is connected to the device and if it is of the same type as the probe that was last connected to this probe port, then the prompt appears on the display to enter the lifetime and the serial number for this probe.
If one of the above mentioned probes is connected and it is of another type than the probe connected last, you will be prompted on the display to enter the serial number for this probe. The lifetime is reset to 100%.
The menu „Probe settings→Probe 1→Lifetime“ provides information on the lifetime of the probe that is currently connected to probe port 1.



The six-digit serial number of the probe has to be entered by the user. It identifies the probe and does not have any influence on the calculation. If the probe is separated from the device, the serial number is again reset to 000000.
The elapsed lifetime can be entered in percent of the total lifetime in the „Consumed:“ text field. The remaining lifetime is calculated from this value, and from the average count rate the expected lifetime of the probe in days is calculated and displayed. Both values cannot by changed by the user.
Besides the manual entry of 0% in the „Consumed:“ text field, the remaining lifetime can be reset to 100% using the menu item „Reset lifetime to 100%“. In this case, the number of counts received will be deleted, so that any prediction as to the lifetime is not possible.

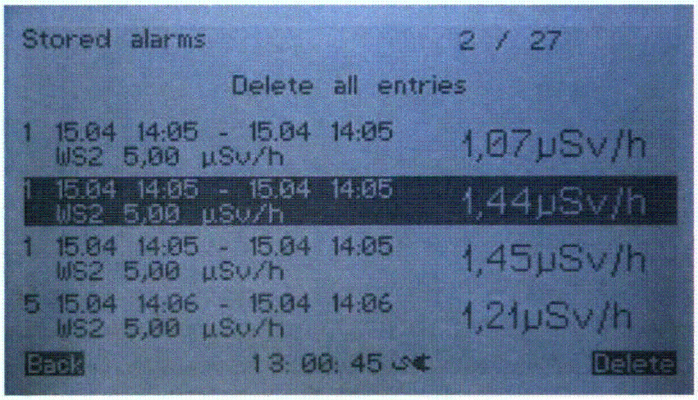
4.11. Stored Alarms



On the „Stored alarms“ menu you can display and delete the stored alarm threshold exceeding of those probes for which storage of the alarms has been enabled (see chapter 4.10.1.1). To view the alarms, select in the left column either the menu item „all“ to view all stored alarms or one of the probes to view only the alarms that have been triggered by this probe. Select an entry in the right column to delete stored alarms.

If the checkbox „Confirm whilst deleting“ is ticked, a confirmation prompt will be displayed before the alarm is actually deleted from the EEPROM.

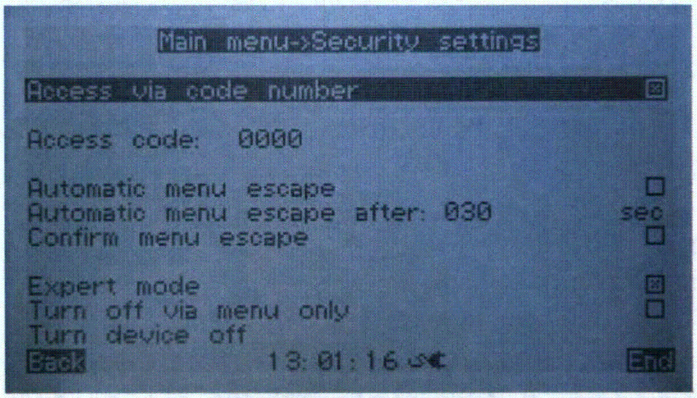
Both menus to delete and view stored alarms differ only in a few aspects: the Delete menu contains as first entry „Delete all entries“. Moreover, on the Delete menu the key and the right key of the function „Delete entry“ are occupied. If you push these keys, the selected entry will be deleted, after confirming a confirmation prompt. To rule out that an entry can be deleted inadvertently by pushing the right key twice, you have to push the left key to confirm the deletion.



The menu includes the following information:

- Total number of displayed alarms (in Figure 27)
- Index of the presently selected alarms (in Figure 2)
- Index of the probe which has triggered the alarm (with the selected entry 1)
- Start and end time of the alarm, exceeded alarm threshold, max. measured value

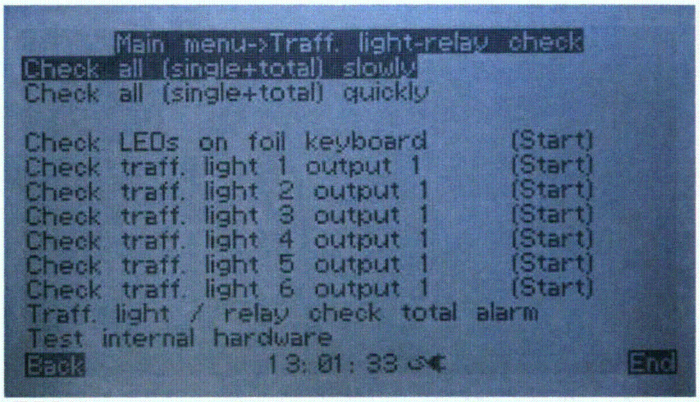
4.12. Security Settings



On this menu you can configure settings to protect the device against unauthorized access. The following options are available:

- Protect menu access by a four-digit access code (checkbox „Access via code number“ and input field „Access code“)
- Exit the menu after a certain time. If the checkbox „Automatic menu escape“ is ticked, the menu is closed after a certain time of user inactivity. The time can be set in the input field „Automatic menu escape after“. This function helps to protect the menu if an authorized user has forgotten to quit this menu manually.
- If changes you have made on the menu have not yet been stored, a confirmation prompt is displayed when you quit the menu manually, provided the checkbox „Confirm menu escape“ is ticked.
- If the checkbox „Expert mode“ is not ticked, some menu items are hidden. The hidden settings are still valid, but they cannot be changed.
- If the checkbox „Turn off via menu only“ is ticked, the „Off“ button on the device is blocked. In this case, you can turn off the device only by means of the next menu item.

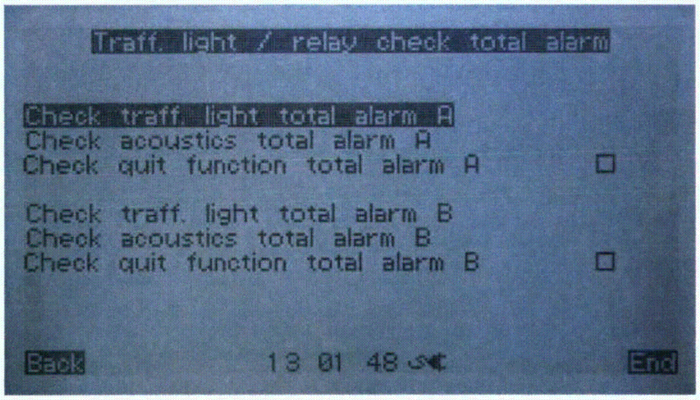
4.13. Traff. Light Relay Check:



This menu includes functions for testing internal and external traffic lights. The two last menu entries include submenus which are used to test the other hardware of the device.

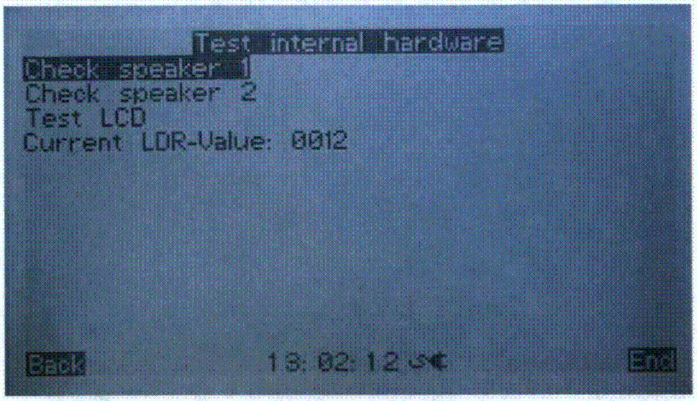
All tests can be quit by pushing the key.

4.13.1.1. Traff. Light / Relay Check Total Alarm



With the functions of this submenu you can test the external total alarm traffic lights A and B, both external loudspeakers and both external quit buttons. The checkboxes cannot be selected by the user. They indicate the status of the external quit button (pushed or not)

4.13.1.2. Test Internal Hardware



On this menu you can test both internal loudspeakers, the LC display and the LDR sensor on the membrane keypad.
If you activate the LCD test, the presentation on the display changes in 1-second intervals from normal to inverted, so that you can check if all pixels on the display function correctly.
„Current LDR-Value“ shows the value currently measured by the LDR sensor. If you cover the LDR sensor by a dark object, this value goes towards 0

4.14. Info

If you select „Info“ on the main menu, the same screen appears as at the start of the device. If shows the following information:

- Hardware version
- Software version
- Date of first use
- Date of last software update (last service)
- Logo and contact information of the manufacturer

5. Transmission Protocol

Interface: RS232

Protocol: ASCII format; 9600 baud, 8 data bit, 1 stop bit, no parity

In the menu 'System parameters|Data transmission|Data transmission setting' (see 4.9.4.3) you can define if the long or short (only measuring value) data record has to be transmitted.

The data record is compatible to the ALMO-6. The data record consists of 6 parts. Each part contains the data for one probe. Each sub record is terminated by a semicolon

Data record (long)

The length of each partial data record is maximal 57 byte (incl. semicolon).
Each sub record consists of the following elements:

- **Probe identification**
  e.g.: `1S1` 1: probe channel, S: fixed letter, 1: probe type (1=Graetz 18550)
  or `1_off`, if no probe is connected. In this case, the sub record is finished
- **Current measuring value**
  e.g.: `1,51_uSv/h` equals 1,51μSv/h
- **Alarm threshold parameter 1**
  e.g.: `WSI_10,0_μSv/h_off`.
  - `WSI`: alarm threshold 1,
  - `10,0_uSv/h` alarm threshold value equals 10.0μSv/h,
  - `off`: alarm threshold is currently not exceeded. (on: alarm threshold exceeded)
- **Alarm threshold parameter 2**
  e.g.: `WSII_1,00_mSv/h_off`. Same meaning as for alarm threshold 1.

Each data record is terminated by the ASCII characters Carriage Return (`0x0D`) and Line Feed (`0x0A`).

Example Data record (long):

```
1S1_1,51_uSv/h_WSI_10,00_uSv/h_off_WSII_1,00_mSv/h_off;
2_off;3_off;4_off;5_off;6_off;F40D<CR><LF>
```

Data record (short)

The length of each partial data record is maximal 16byte (incl. semicolon).
Each sub record consists of the following elements:

- **Probe identification**
  e.g.: `1S1` 1: probe channel, S: fixed letter, 1: probe type (1=Graetz 18 550)
- **Current measuring value**
  e.g.: `1,29_uSv/h` equals 1,29μSv/h

Each data record is terminated by the ASCII characters CR and LF.

Example Data record (short):

```
1S1_1,29_uSv/h;2_off;3_off;4_off;5_off;6_off;76A0<CR><LF>
```

If the measuring range is exceeded, the message `'Ofl'` appears instead of a measuring value.

```
1S1_Ofl;2_off;3_off;4_off;5_off;6_off;9D7E<CR><LF>
```

In case of an extraordinary error, the message `'Err'` appears:

```
1S1_Err;2_off;3_off;4_off;5_off;6_off;7EDC<CR><LF>
```

In these examples, only one probe is connected to channel 1. Channel 2 to 6 are not connected to a probe.

6. Technical Data

6.1. Technical Data ALMO 6

Device type:	Stationary alarm device for connection of up to 6 detectors
Type :	ALMO 6
Company:	MED Nuklear-Medizintechnik Dresden GmbH Dornblüthstrasse 14 a 01277 Dresden, Germany
Dimensions:	Depth: 280 mm Width: 300 mm Height: 120 mm
Weight:	approx. 2.2 kg (with emergency power supply 2.7 kg)
Operating voltage:	Mains adapter / charger 24V=; Mains voltage 100-230Volt~
Power consumption:	max. 60 VA, depending on alarm triggering
Display:	LC display
Display illumination:	CCFL background illumination
Keyboard:	Membrane keypad
Alarm thresholds:	2 for each probe, freely definable
Setting range:	Dependent on probe. Example probe 18550 CE: 0.1 - 999.9 μSv/h 0.1 μSv/h steps 0.01 – 19.99 mSv/h in 10 μSv/h steps
Alarm:	Visual and acoustic, automatic reset Reset of alarm (quit mode)
Relays:	Switching capacity: max. 24 V, 1 Ampere per channel Current for traffic light, acoustic and additional elements If not switched potential-free: 24 V, total current of all 6 channels max. 1500 mA
Serial interfaces:	A: switchable: USB, RS-232, RS-422 or RS-485 B: switchable: RS-232, RS-422 or RS-485

6.2. Technical Data Probes

6.2.1. γ - Low Dose Probe with NaI-Detector

Type of radiation: for Gamma measurement (DC installations)

Calibration: with Gamma radiation, Cs 137

Unit of measurement: photon equivalent dose rate

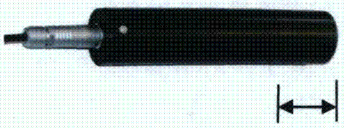
Nominal working range of the Photon energy: 25 keV-1.3 MeV

Preferred direction: Axial radiation onto the probe body

Detector: NaI(Tl) crystal

Position of detector: The detector is positioned axially in the center of the probe.

NaI 25B38

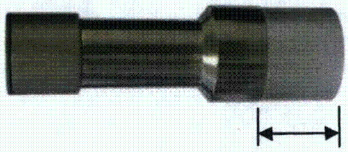


Active range

NaI 38B38

Active range

NaI 76B76



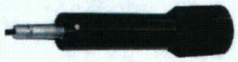
Active range

Nominal working range of the relative humidity: 0 - 95 %, no influence.

Nominal working range for outside air pressure: 100-1300 hPa, influence negligible.

Nominal working range of the temperature:
Operation: - 20 °C to + 50 °C
Storage: - 25 °C to + 60 °C
Δt < 10° C/h

Housing: Aluminum sleeve, black anodized, protection class IP 55

Type	**NaI 25B38** 	**NaI 38B38** 	**NaI 76B76** 
Dimensions of Detector	38 x 25 mm Ø	38 x 38 mm Ø	76 x 76 mm Ø
Dimensions / Weight	length 145 mm, Ø 32 mm, 210 g	length 190 mm, Ø 45 mm, 370 g	length 285 mm, Ø 85/59/68 mm, 1940 g

6.2.2. γ-Low Dose Rate Probes

Type of radiation: for Gamma and X-ray measurement of (DC installations)

Calibration: with Gamma radiation, Cs 137

Unit of measurement: photon equivalent dose rate

Preferred direction: radial radiation onto the probe body; +/- 45°

Position of detector in device: The detector is positioned axially in the center of the probe.

Position of detector in device: The detector is positioned axially in the center of the probe.

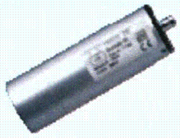
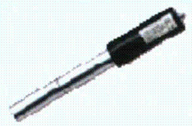
***Nominal working range of the relative humidity:** 0 -95 %, no influence, the device is dustproof and watertight according to DIN 40050 (IP 67)

***Nominal working range for outside air pressure:** 100-1300 hPa, influence negligible.

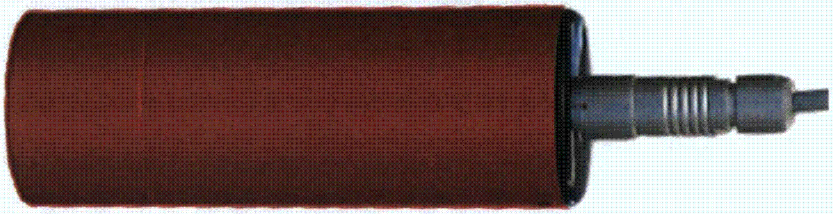
***Nominal working range of the temperature:** Operation: - 30°C to + 60°C
Storage: - 40°C to + 70°C

Average life expectancy of the counter tube: 5 x10^{10} h

Housing: Aluminum sleeve, bronze anodized, protection class IP 67

Type	**Probe 18509 CE**	**Probe 18529 CE**	**Probe 18545 CE**	**Probe 18550 CE**
				
working range of the photon energy	55 keV–1.3 MeV	70 keV–3 MeV	40 keV–1.3 MeV	40 keV–1.3 MeV
Measuring range	50 µSv/h – 999 mSv/h	0,5 mSv/h – 9,99 Sv/h	150 nSv/h – 199,9 µSv/h	10 µSv/h – 19,9 mSv/h
dimensions / weight	length 110 mm, Ø 40 mm, 150 g	length 110 mm, Ø 40 mm, 150 g	length 345 mm, Ø 25/40 mm,380g	length 110 mm, Ø 40 mm, 150 g
detector dimensions effective length: wall thickness : dimensions:	 17 mm 80-100 mg/cm² 16 x 6,2 mm Ø	 7 mm 80-100 mg/cm² 16 x 6,2 mm Ø	 244 mm 525 mg/cm² 266 x 24 mm Ø	 40 mm 250 mg/cm² 41 x 15 mm Ø
overload capacity (continuous radiation)	> 50 Sv/h	> 50 Sv/h	> 20 mSv/h	> 1 Sv/h
life expectancy	at10 mSv/h approx. 17500h	at10 mSv/h approx. 55000h	at100 µSv/h approx. 92 000h	at1 mSv/h approx. 17500h

6.2.3. Low Dose Probe 18526 D



Detector:	ZP 1430, window counter tube	
	Window :	mica
	Thickness :	1.5 - 2 mg/cm²
	Effective diameter:	27.8 mm
	Effective area:	6.1 cm²
	Covered by protection grid:	20 %

Background: approx. 25 counts / minute

Counts in case of radial irradiation (Cs 137): approx. 4 counts/s/μSv/h

Radiation axial:	with cap:	only γ-radiation
	without cap:	α-, β- and γ-radiation
Temperature range:	Operation:	- 30°C to + 60°C
	Storage:	- 40°C to + 70°C

Outside air: 500-1300 hPa, influence cannot be determined in practical use. Transport in planes up to a height of 3000 m: Changes in air pressure have to be performed slowly.

Housing: Aluminum sleeve, red anodized

Dimensions: 40 mm ∅ x 110 mm

Weight: approx. 150 g

If Geiger-Mueller probes are connected, the unit can no longer be changed to Bq/m³.