The EDR Gamma Scanner

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Abstract.

A gamma scanner developed for remotely surveying radioactive areas is presented in this paper. Its hardware is described in detail. Its software has been designed to be compatible with the 3D dose assessment tool VISIPLAN. The characterization and tests under laboratory conditions of the equipment are presented. As example of its functionality in an industrial scenario, some qualitative results of the scanner response in areas of a nuclear power plant are discussed.

1. Introduction.

The EDR is a gamma scanning system based on the integration of three sensors in a mobile head, namely, a collimated gamma detector, a video camera and a laser distance meter. Initially, the video camera is used for selecting the desired scenario to be scanned. The center and size of the area of interest are chosen by operating the pan & tilt unit and the camera focal distance. Once the scenario is selected, its image is frozen on the computer screen and a rectangular grid of points to be swept is marked on it, according with the spatial resolution required. In operation, the head of the scanner is pointed consecutively towards these positions, acquiring a spectrum and a measurement of the distance on each position. Once the survey is completed, the array of distances and spectra is stored. The radiometric information is processed. With the aid of the distance measurements, it can be translated to radiometric (or dosimetric) information in contact to the source. Measurements can be merged with the video image in order to correlate radiometric and geometrical information in the scenario.

The software has been designed to be compatible with the dose assessment tool VISIPLAN [1,2]. This expands the capabilities of the scanner and can even improve its sensitivity.

The directional sensitivity of the detector-collimator couple has been characterized in laboratory by making use of point sources (^{137}Cs, ^{60}Co). After its calibration in an experimental laboratory, the EDR gamma scanner has been tested in a Nuclear Power Plant.

2. Description of the equipment

2.1 General Description

The EDR scanner head integrates a collimated gamma detector, a video camera and a laser meter (see Fig. 1). Video camera and laser meter supports have been engineered to be independently orientated relative to the gamma detector axis. The three sensors are conveniently disposed in the equipment head with the aim of minimizing parallax distances between their corresponding main axis The correct orientation of the three system is performed during a calibration process, permitting deviations lower than 1 cm in 10 meters.

The system dimensions and weight are basically imposed by the gamma collimator, motors and control systems. The gamma collimator (35 kg) has been designed in order to reach a trade-off between shielding effectiveness and weight constraints. The equipment body has been constructed to be operated in industrial facilities, fulfilling requirements of robustness, reliability and ease of decontamination. Its total weight is 80 kg, transportation platform not included.

Control and data acquisition are performed remotely from a computer. Due to intrinsic problems associated with the hostility of the environments where the system has to operate in, an extensive work has been done in order to

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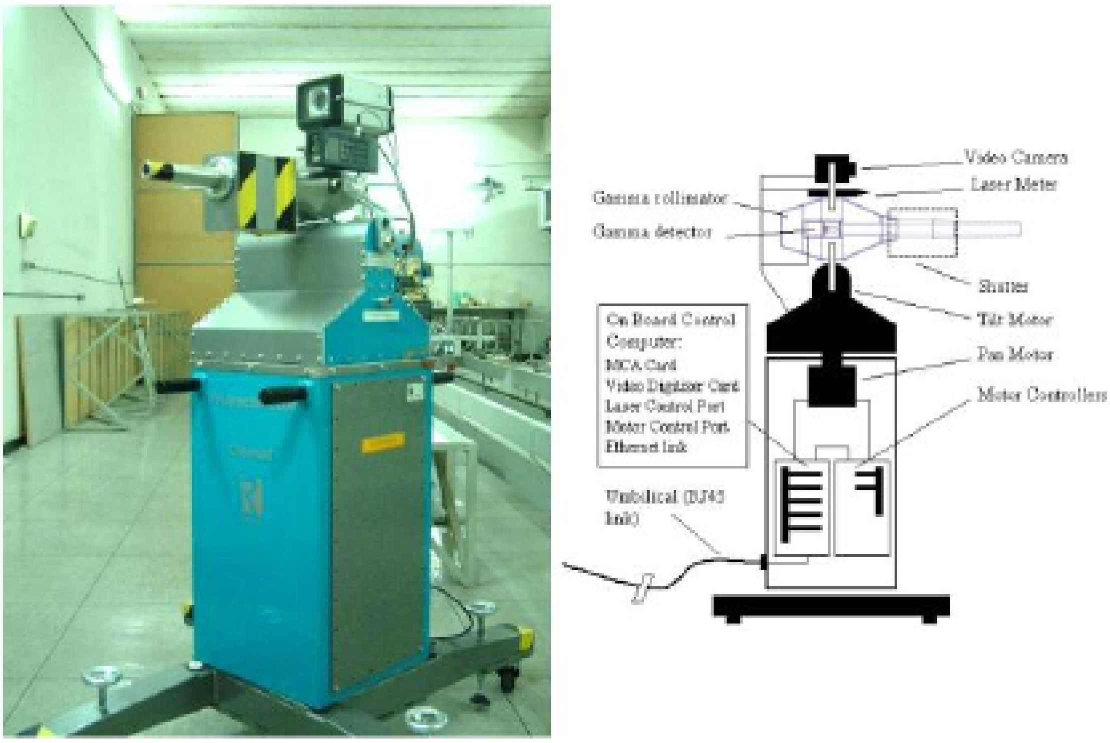
minimize the limitations associated with connections. In operation, the unit have to be connected just by two single cables: power and control.

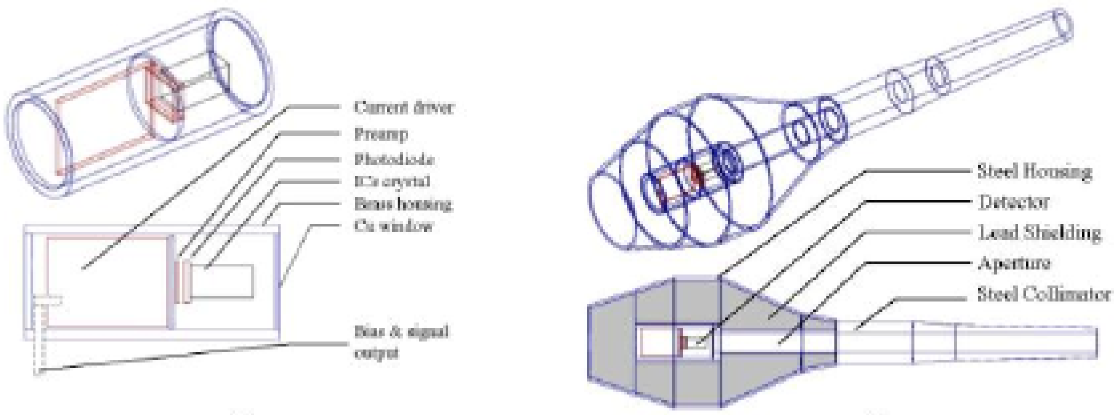


(a) (b)

Fig. 1. (a) General view of the EDR gamma scanner. (b) Schematic representation of its different parts.

2.2. Sensors

The gamma sensor in the scanner is a detector probe housed in a collimator. Both of them have been designed for this application. The sensor in based on a 1.0 cm x 1.0 cm area, 2.0 cm long ICs(Tl) crystal (Scionix Holland Type V10C20-CS) optically coupled to a 1.0 cm x 1.0 cm sensitive area silicon photodiode (Hamamatsu S3590-01). The photodetector is matched to a charge sensitive preamplifier followed by a current driver. A general scheme of the probe can be seen in Fig. 2.a.



(a) (b)

Fig. 2. Schematic representation of the detector probe (a) and the gamma collimator (b).

The energy resolution of the detector is in the order of 12% for the 662 keV ^{137}Cs photopeak at 20ºC temperature, the exact value depending on the selected unit. The minimum acceptable energy threshold is 100 keV. More conservative levels (150-200 keV) have been used in the measurements presented in this paper.

The collimator is a stainless steel and lead shielding. It has been designed to present an effective shielding comparable to 5 cm of lead for photons incoming to the detector crystal from any direction but from the front, near the aperture. The shielding is much more effective in the region closer to the aperture hole. In Fig. 2.b it can bee seen schematic viewgraph of the collimator. Lead fillings and detector position are shown.

The collimator aperture presented in Fig. 2.b corresponds to ±2.0º. This is defined by the detector area, the aperture diameter and the distance from the detector to the collimator edge. Other angular apertures (±1.0º and ±4.0º) are available if needed by coupling or decoupling mechanical parts to the collimator.

As mentioned above, the gamma detector is supported by two other sensors: a video camera (Hitachi VK-C77E) and a laser distance meter (Leica DISTO-pro). Both units are controlled from the computer.

2.3 Mechanical Units

Rotation of the head in horizontal and vertical planes are performed by two motors (Faulhaber 3863-024C) with a torque up to 0.11 N·m. They are coupled to optical encoders (Faulhaber HEDS 5500 A12) and controlled via two motion controllers (4-Quadrant PWM Faulhaber controllers), each of them connected to a computer through a RS232 serial link.

2.4. Hardware Integration

Cabling from the control site to remote systems in hostile environments such radioactive installations are generally a cumbersome task. In many occasions, time and efforts needed for cabling should be minimized because of the application of ALARA criteria. In order to avoid complicated installation procedures and reduce the probability of contamination, the complexity of the umbilical cables has been tried to reduce as much as possible. In this way, control hardware has been included in the system body by implementing a fully operative computer (see Fig. 1). The following boards are inserted on its mother board:

- One MCA Aptec Model 5002, connected to the detector output. It collects all the radiometric information.
- One National Instrument video imaging digitizing card. It digitizes the acquired images of the scenario.
- Three RS232 serial ports for controlling the laser meter and motors
- One Ethernet link card

The on board computer works in slave mode commanded by a master PC connected via one RJ45 cable in a two-computers network. In this way only one twisted pair cable is needed for establishing the link. The control site to scanner distance can reach fairly longer than needed in most occasions. On the other hand, according with its cost and availability, this umbilical can be treated as disposable material for decontamination purposes.

Together with the network link, a second cable is needed to power the scanner body (220 VAC).

2.6 Control Software

The software commanding the system has been developed in Labwindows (National Instruments). Three basic operations have been implemented: (i) selection of the scenario to scan, (ii) scanning process and (iii) data process and visualization. The scenario is selected by adjusting the pan & tilt unit and the camera zoom until the acquired image suits the desired field of view. Once the image is digitized, the grid of dots (locations in the scenario) to scan and the acquisition time are selected. Each dot represents a position the collimator will point at. It should be remarked here that the angular distance between two adjacent scanning positions can be narrower than the collimator aperture. In this way, more detailed information can be obtained. After the selection of the scan parameters, the scanning process is carried out automatically. One 1k channel spectrum is stored per each position. This spectrum stores the full radiometric information gathered from the corresponding portion of the image. Together with this information, the distance measurement is acquired.

A standard format for the files sharing spectrometric information with VISIPLAN has been implemented. This format includes a header with scanning parameters and detector position in the considered coordinate system. Below the header, data relating relative coordinates of each scanned position and spectrometric information acquired in this position are given in columns.

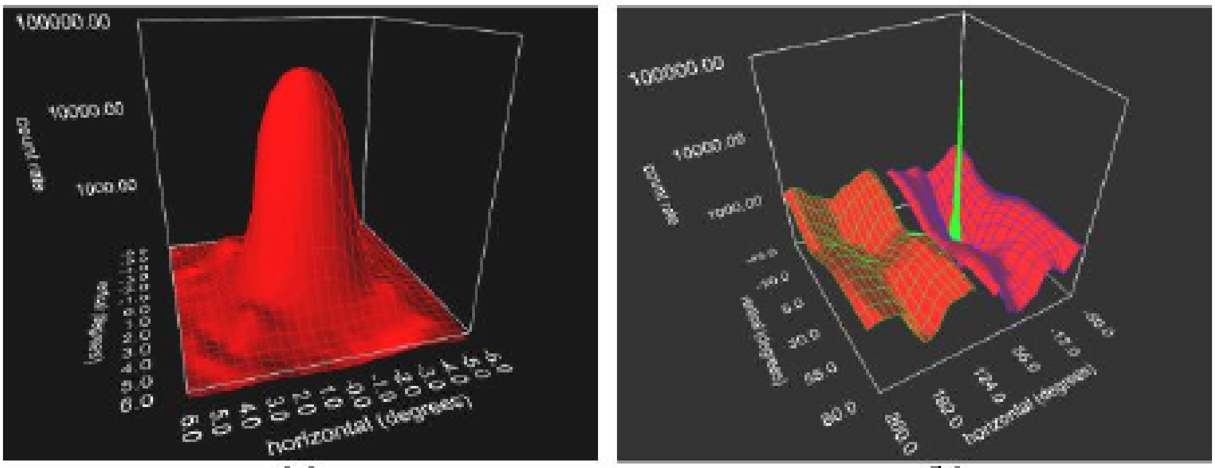
Several graphical modes have been implemented for visualizing the results. Scanned areas in the image can be colored according with radiometric information such as total count rate, presence of determined isotopes or count rate in a previously defined energy band. Examples of result presentations are given in sections 3 and 4. The images of scanned areas become active. All the gathered radiometric information is available by clicking on the desired scanned area.

3. Characterization

3.1. Directional response

The directional sensitivity of the detector-collimator couple has been characterized by making use of a point source located at a distance large enough to be considered at the infinity. The source was positioned in front of the scanner, in the detector axis, at 10 m. distance. This direction was considered as reference (φ=0, θ=0). Scans from this position were performed in order to acquire the detector response at several predetermined (φ, θ) position.

According with the collimator profile, there must be much higher shielding effectiveness for photon incoming from directions near the detector aperture, as long as all the material in the tube surrounding the aperture acts as effective shielding. This region is very important, so a finer characterization was decided in a solid angle near the collimator axis. In this way two scans were performed, the first one using a very narrow step, 0.5 degrees, in horizontal and vertical angular rotations. The angular range swept in this measurement was ±6 degrees. The second one covered the full solid angle 4π ($0 \le \varphi < 2\pi$, $0 \le \theta < \pi$) but using a coarser step in order to have reasonable acquisition times. Identical measurements were performed for ^{137}Cs (activity 1.55E12 Bq) and ^{60}Co (8.26E10 Bq) sources. Some of the results are presented in Fig. 3.



(a) (b)

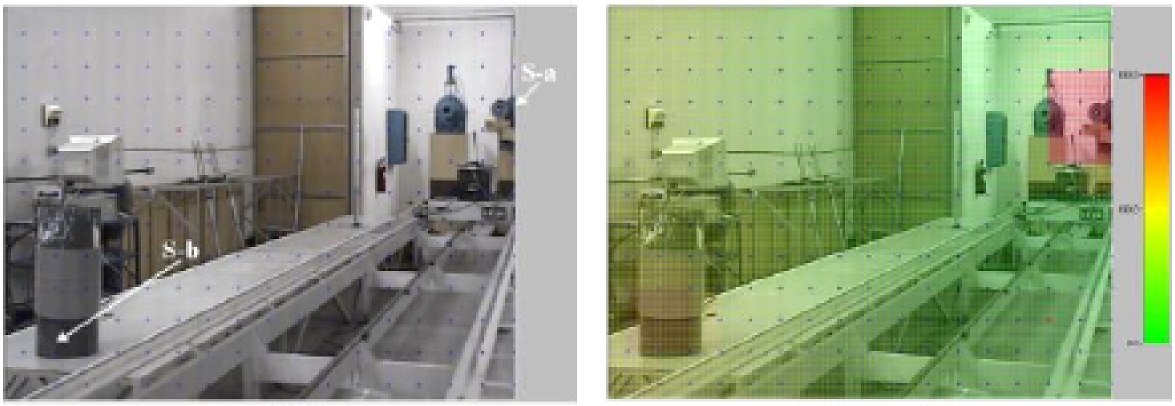
Fig. 3. (a) Fine directional response characterization in a solid angle close to collimator axis. Count rate obtained for a ^{137}Cs source positioned sequentially in the range θ=[–6º,+6º], φ= [–6º,+6º] using a step of 0.5º. (b) Coarse directional response characterization in 4π for ^{137}Cs. Step: 10º. Data in (a) has been merged in green at corresponding scale.

The lobes in Fig 3.b correspond to differences in shielding effectiveness found at different radiation incoming directions. This is related with anisotropies of the effective collimator shielding thickness. The EDR scanner is less sensitive than expected to this effect, since the tool used for generating the radiometric information can (partially) correct for it. The results obtained in the directional response characterization presented in this section was included in VISIPLAN as correction factors database. VISIPLAN takes into account this information, intrinsic to the detector system, and perform corrections based on it before generating a dose estimate.

3.2 Tests in Laboratory

The EDR gamma scanner has been tested in a controlled radioactive laboratory at CIEMAT, shown in Fig. 4a. Two point (~1 cm diameter) sources were used. One of them was a ^{137}Cs source with 1.55E12 Bq of activity (labeled as S-a in Fig. 4) located in a collimated irradiator. A collimation angular aperture of 13º was selected, becoming panoramic for our purposes. A second ^{137}Cs source, a portable source with weaker activity (5.22E8 Bq), was hidden in a portion of pipe and positioned in the opposite corner of the field of view (source S-b in Fig. 4a).

Several scans were completed. A representation of results obtained in one corresponding to a step of 2 degrees is shown in Fig. 4.b. In this figure, the total count rate has been selected for generating a color map superposed to the real image. The identification of the sources in the scenario is evident. The obtained maximum value at S-a source position was ~2.8E4 cps (counts per second), whereas ~600 cps were measured at S-b position. Background was measured between 100 and 400 cps. It is evident that in an automatic selected color scale, Fig. 4.b would only identify the S-a source. From this result, we confirm that attention must be paid to the presentation of the results in order to have a correct interpretation of results.



(a) (b)

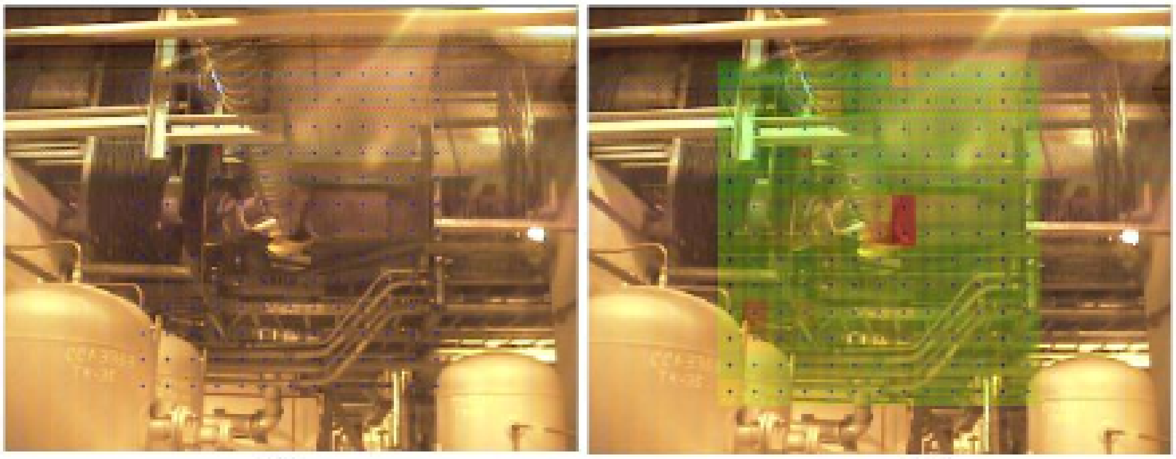
Fig. 4. (a) View of the laboratory used for testing the EDR scanner. (b) Same view colored according with total count rate detected. Color scale adjusted linearly between 0 cps (green) and 800 cps (red).

4. Tests in an industrial scenario

After its calibration and characterization in an experimental laboratory, the EDR gamma scanner was tested in an industrial facility. The EDR was transported and installed in a facility of the Almaraz Nuclear Power Plant, Spain. A radioactive area in the fifth level under ground floor at the Auxiliary Building of the plant was selected for these tests. The equipment was transported by using a mobile platform and a crane.

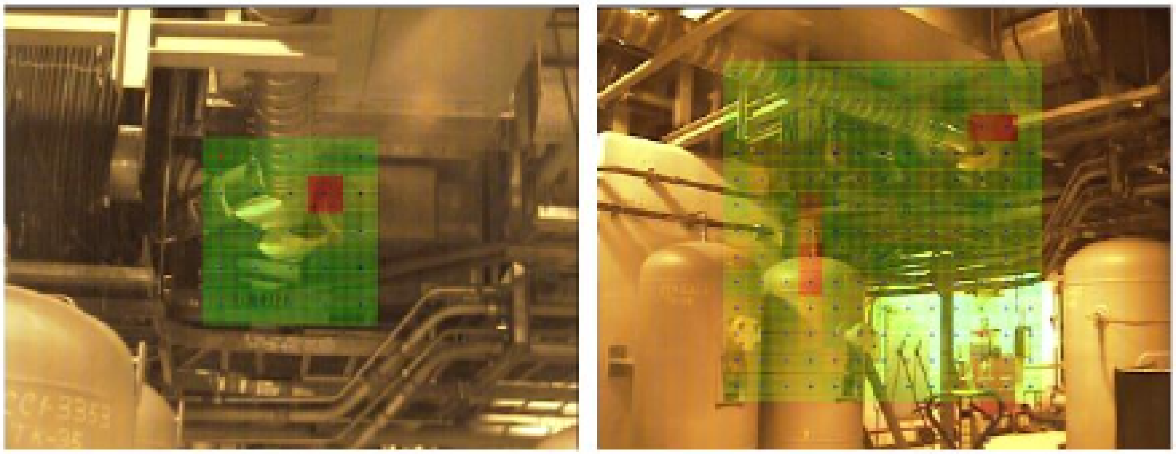
Several scenarios were studied. In some of them, hand measurements performed with GM ratemeters showed high background (50 μSv/h) and large continuous sources with dose rate in contact one order of magnitude (at most) higher than the background. Results with the gamma scanner confirmed a high background field and no identifiable sources were located. The radiological situation of that areas was clearly not optimum for a remote survey. Differences in the counting rate lower than 10%, below one standard deviation, were found in all the scanned positions. Spectrometric measurements showed a mixture of isotopes with energies below the 1333 keV ^{60}Co photopeak.

Other areas of the facility revealed measurable radioactive sources. In the scenario shown in Fig. 5.a three of the pipes located throughout the corridor ceiling are the most relevant radioactive source. The wider one is shielded with lead cylinders all along but in the elbow, this just protected with a lead blanket. Contact dose rate at this point was 0.6-0.8 mSv/h. Background dose rate in detector position was ~5 μSv/h and 10-20 μSv/h were measured in contact to the pipe shielding far away the elbow. A scan of this area revealed a higher activity in the elbow (see Fig. 5.b). Surveys from other positions and different conditions confirmed the presence of the source (Fig. 6).



(a) (b)

Fig. 5. (a) View of the studied radioactive facility at Almaraz Nuclear Power Plant. (b) Same scenario colored according with detected total count rate.



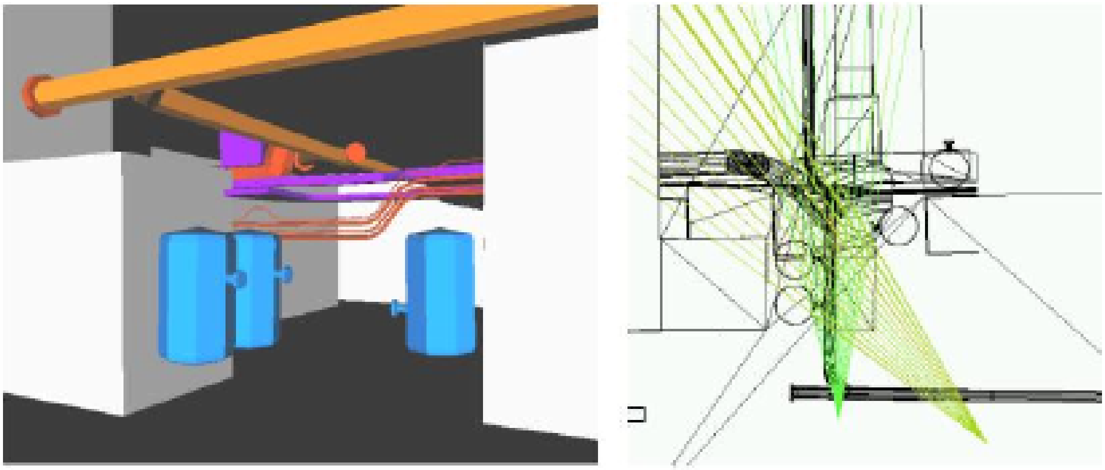
(a) (b)

Fig. 6. Results of different scans in the scenario shown in Fig. 5.

4. Integration with VISIPLAN

As example of the capabalities of a gamma scanner when used together with a dose assesment CAD tool, we present in this section the results processed by VISIPLAN for the data collected in the facility presented in last section. In Fig. 7 a 3D geometrical model of the site (Fig 7.a) and a VISIPLAN model of the same area (Fig. 7.b) are shown. Model in Fig. 7.a. was performed by Z+F ltd (UK) within the VRIMOR project [3] using a laser scanner (IMAGER 5003). In the VISIPLAN model in Fig. 7.b, the overlay image of two gamma scans performed by the EDR are given, the green lines corresponding to the scanned directions.

Three cylindrical volumes representing pipes containing active fluids and resins were used by VISIPLAN to define the radioactive sources present in the site (Fig. 8). VISIPLAN determined the source strength of the sources in the cylinders according with the EDR measurements. An agreement within 20 to 30 % was found between estimated data and measurements at different locations in the site.



(a) (b)

Fig. 7. 3D geometrical model (a) and VISIPLAN model (b) of the site geometry.

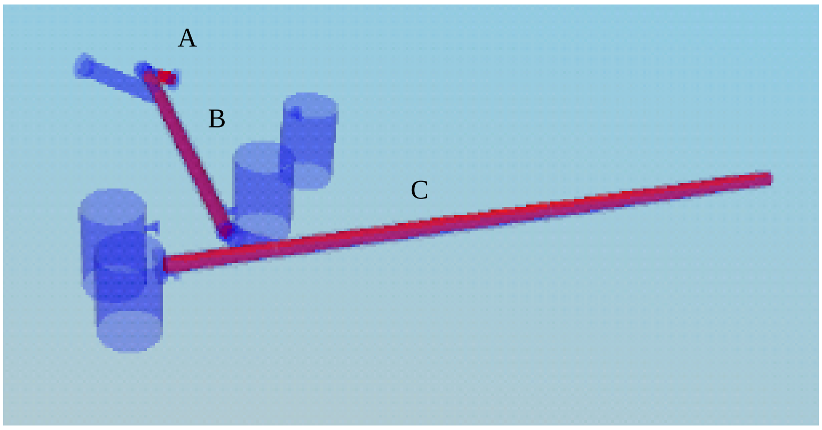


Fig. 8. Simplified geometry used by VISIPLAN. Cylinders in red represent radioactive pipes. Cylinders in blue represent conventional volumes

5. Conclusions

The EDR gamma scanner prototype is fully operative. The hardware has been designed to be operated in hostile scenarios at large distances from the control computer via an Ethernet link. The detection capability has been characterized by studying in detail its directional response for two representative energies (660 keV and 1100-1300 keV). The scanner has been tested in an experimental laboratory with two point sources. In a second test program, its operability in a nuclear facility has been demonstrated. The scanner could be transported and mounted in a site relatively difficult to access without major limitations. The equipment worked successfully at temperature ~ 40ºC and a very high relative humidity.

Up to date, tests have only included point and small continuous sources. In a near future, further tests should be considered in order to improve the knowledge about the detector sensitivity and discrimination capability in scenarios with large continuous radioactive sources.

The scanner is compatible with VISIPLAN. The integration of these two technologies has been successfully tested in a nuclear facility. The advantages of the merge of these two technologies has been shown.

6. Acknowledgements

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7. References

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