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Nuclear electronics instrumentation

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Nuclear electronics instrumentation

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Abstract

The activities of the National Institute of Nuclear Research (ININ) in Mexico on the field of nuclear electronics instrumentation are described. Several generations of specialists, mainly electronic engineers have participated in this task. In the early years, the design and fabrication of nuclear instruments was the main activity and across the years the support to institutional projects with design, repair and maintenance of nuclear instrumentation were the dominant activities. The Institute has collaborated continuously in this field with the International Atomic Energy Agency under different programs and projects. The establishment of the Radiation Detectors Laboratory has been an important event due to its special characteristics and capabilities on the repair and maintenance of cooled semiconductor radiation detectors, the laboratory is unique in this specialty. The research and development in the field of new radiation detectors and their applications are important activities which have contributed to solve problems in national institutions like PEMEX (Mexican Oil Company), CNSNS (Nuclear Safeguards) and CFE (Electricity Company). Finally, an overview on the future of these activities is presented, considering the very fast advance of the nuclear and electronics technology.

1.- Introduction

Electronic instrumentation is essential for the measurement and characterization of radiation. Thanks to this instrumentation, the essential characteristics of the radiation are determined, i. e. its amount and energetic components. Nuclear instrumentation is based on the technical characteristics of radiation detectors and associated electronic devices. Radiation detectors are very important devices in the fields of nuclear physics, medicine, radiological protection, industry, because they are the only mean to evaluate and quantify the radiation in a precise way.

When the radioactivity was discovered, the researchers noticed its capability to sensitize a photographic plate, this was the first method to detect the radiation, after that and until now the radiation detection methods have been improved and getting a sophisticated status in which the measurement and detection systems apply time and spatial coincidence techniques, for example, and use computerized systems widely.

Radiation detectors can be considered, from the electric point of view like: passive detectors and active detectors. The photographic plate and thermo-luminescent detectors (TLD) are examples of passive detectors whereas Geiger-Müeller, semiconductor and scintillation are active detectors. Nowadays there are active detectors that provide information not only of the amount of radiation that interacts with it, but also information of the type of radiation and its energy.
The kind of radiation considered in this work is that related with the emission of energy coming from a nuclear or atomic process, generally it is a consequence of an excess of energy in the excited atom or nucleus, this energy also could be created in other physical processes like high energy collisions. The detected energy could have characteristics of electromagnetic waves, like the gamma and X-rays, or it could be associated with atomic or subatomic particles like electrons, protons, alpha or beta particles or neutrons.

There are big differences between the characteristics of the different kinds of radiation, therefore there is an optimal detector for every application, the proper selection of the best detector is fundamental if we require the best result in our characterization of the radiation.
The nuclear electronics instrumentation employed in research, industrial and medical applications is very expensive due to its high level of specialization. The reduction of the capability for buying scientific equipment and instruments in the research institutions of developing countries and the increase in the cost of specialized equipment has led to the search of new alternatives, looking for more accessible and lower cost instrumentation for the activities of research and experimentation. Considering the main objectives established in the corresponding laws for the creation of ININ and similar former institutions, the tasks in this field have been the research, development, design, construction, maintenance and repair of nuclear instrumentation, these activities have satisfied the institutional and external needs. The objective of this chapter is to describe the activities and results obtained along the time.

1.1 Different types of radiation

Ernest Rutherford was the first one to classify the different kind of radiation; in 1899 he discovered that a strange ionizing radiation could pass through metal sheets of different thickness. Some of these radiations could pass only through very thin sheets whereas others had more capability to penetrate and could pass through thicker sheets. Rutherford called these radiations alpha and beta rays, respectively, he demonstrated that alpha rays are He (Helium) nuclei electrically charged and that are a product of the spontaneous fission of heavy atoms. Nowadays we know that beta rays are electrons that have been emitted by a nucleus in a natural or induced radioactivity.
Another kind of radiations are the gamma and X-rays that have an electromagnetic character, gamma rays are produced in a nuclear process, whereas that X-rays are the result of a transition between electrons from one orbit to another or are produced by the deceleration of an electron beam, mainly when the beam collides against an element with a high atomic number. Neutrons, discovered by Chadwick in 1932, are particles with no electric charge and a mass slightly greater than that of the proton.

1.2 Characteristics of the radiation

The radiation is characterized mainly by its type, its energetic content and its amount; considering its type, the classic examples are:

- Alpha radiation, are particles electrically charged, with a charge of 3.2×10^{-19} C and with a considerable mass that equals the mass of a helium nucleus, 6.696×10^{-27} kg.
- Beta radiation, are electrons with a mass of 9.109×10^{-31} kg and a negative charge of 1.6×10^{-19} C.
- Electromagnetic radiation like gamma and X-rays, called also photons, which have neither charge nor mass.
- Neutrons, are particles without charge but with a mass of 1.674×10^{-27} kg.

The traditional unit used for the determination of the energy of the radiation is the electron-volt, eV, being the kinetic energy obtained by an electron after it was accelerated through a difference of potential of 1 volt [1]. The more common energies in conventional nuclear experiments are in the range between some kilo electron volts (keV) and some mega electron volts (MeV).

1.3 Radiation detectors

Radiation detectors are widely used in the different branches of science and its operation is based on the interaction of the radiation with matter, consequently, there are different kinds of detectors that satisfy the more distinct needs. We have studied and analyzed these detectors, its possible new applications together with the electronic components of a detection chain: preamplifiers, nuclear amplifiers, analog to digital converters, multichannel analyzers, counters, timers, etc.

The radiation is detected mainly by:

a) Chemical changes like in the photographic plates; this property is still used in the X-ray plates, conventional radiography, mammography, etc.

b) Ionization of matter, like in the ionization chambers, Geiger-Müller detectors, proportional detectors [1] and in semiconductor detectors [Be-1968].

c) Physical changes, like in the thermoluminiscent materials that are used in personal dosimeters.

Gas detectors

Gas detectors, like the classical Geiger–Müller detectors, ionization chambers and proportional chambers (Figure 1a) are fundamental components of portable radiation monitors (Figure 1b) that are utilized in radiological protection and safety in all the nuclear facilities. The detection is possible thanks to the fact that the radiation ionizes the gas contained inside the detector. After that, the produced charge is carried out by means of a high voltage applied between its electrodes, then producing an electrical signal in the external circuit.

The ionization chambers have an important application in the determination of the amount of radiation; they can measure with a high degree of accuracy the amount of radiation and are considered as calibration standards, they are widely used in the Metrology Center for Ionizing Radiations of ININ, for example.

The Geiger-Müller detectors measure the radiation in an approximate way in portable monitors. The proportional detectors are commonly utilized in the feet and hands radiation monitors, a special gas called P-10 is the sensible mean and is passing continuously through it. There are also special multiwire proportional detectors that are used to get images in nuclear medicine and industrial applications.

(a) (b)

Figure 1. Radiation detectors used in portable radiation monitors: a) Gas detectors, b) Portable radiation Monitor.

Scintillation detectors

The property of the radiation to make that certain materials called scintillators, like the Sodium Iodine with some impurities of Thallium, NaI(Tl), allows the detection of radiation by measuring the generated light in these materials. The amount of light generated is very small, only some photons, therefore the human eye cannot see it, the light needs to be converted in an electrical signal and this signal needs to be amplified because it is also very small. Therefore the scintillation detectors require of an additional electronic device to perform this function; this element is called photomultiplier tube (Figure 2). For example, NaI (Tl) detectors are used in the gamma cameras for nuclear medicine studies. The bismuth germanate, BGO, is a scintillator material utilized in new detectors having very high detection efficiency due to its high density.

The photomultiplier tube needs a high voltage for its operation. Scintillation detectors are better suited for applications where high detection sensitivity is required. For example they are widely used in portable monitors and in the dose calibration of radioactive materials applied in nuclear medicine patients.

Figure 2. Scintillation detector with photomultiplier tube.

Semiconductor detectors

The more delicate and sensitive radiation detectors are semiconductor detectors that are made mainly of germanium or silicon. Semiconductor detectors started to be used around 1950 for the measurement of alpha radiation, after that, a great variety of differente types have been developed, examples of that are: silicon surface barrier, germanium–litium, silicon-litium drifted or high purity germanium detectors. Until 1979 the high purity silicon PIN diodes detectors started to be fabricated. The density of the semiconductor materials is greater than the density of gases; therefore the detection efficiency of semiconductor detectors is also greater than the efficiency of gas detectors. Other advantage of semiconductor detectors is that they require a very low energy (3.6 eV for silicon) to create an ion pair [7], whereas in the gases the energy required is greater than 30 eV. One great advantage of semiconductor detectors with respect to scintillation detectors is its simplicity, small size, low power requeriment and the elimination in the use of high voltages. The opperation of these detectors at very low temperatures, liquid nitrogen temeperatures, can reduce the electric noise to very low levels; therefore very high sensitivity and energy resolutions can be obtained. In recent years the cooling of detectors with Peltier effect has been realized, with this technique the size of the detection system has been reduced drastically because no liquid nitrogen is required for the cooling. Semiconductor detectors have now new applications in Medical Physics [2] for generation of medical images thanks to the great development of semiconductor and microelectronics technology [3]. Research in semiconductor technology in México has been carried out for the development of semiconductor detectors specially, in CINVESTAV and in INAOE, with the collaboration of ININ [4-6]. At ININ the response of these detectors to different radiations and its associated electronics is a field of research and study. It is well known that the quality of the preamplifiers, determines the optimization for the energy resolution in a measuring system. In the next paragraphs there is a description of the detectors that have more applications.

Surface barrier detectors

Surface barrier detectors are employed for detection of charged particles like alpha radiation, electrons or other ions. For its operation they are generally put in a vacuum chamber at room temperature (see Figure 3), having a very thin gold window to allow the pass of charged particles without any attenuation in neither energy nor intensity.

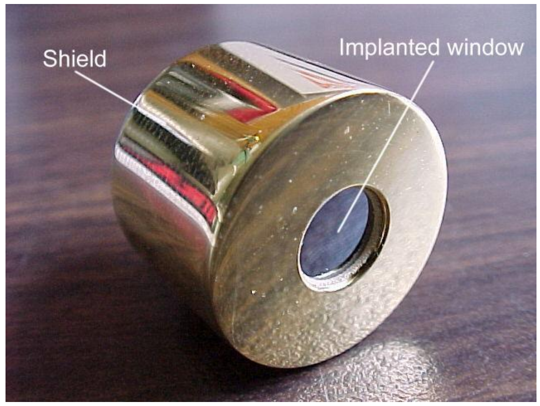


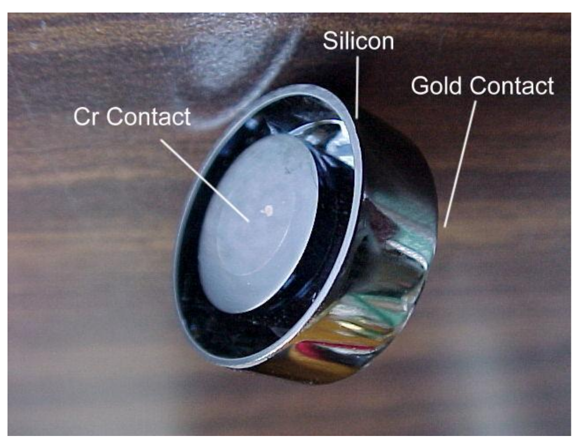
Figure 3. Surface barrier detector.

Silicon-lithium drifted detectors

Silicon-lithium drifted and high purity germanium detectors need to be operated at cryogenic temperatures to reach its high sensitivity and low noise behavior. The semiconductor crystal is normally at very low temperatures, -90 ºC approximately; therefore these kinds of detectors are very delicate and fragile detection instruments. Cooled detectors have two main components: a thermal container commonly called "Dewar" and a vacuum chamber (Figure 4a). The Dewar is a fragile container of liquid nitrogen with vacuum isolated double walls; the inner temperature with liquid nitrogen is -190 ºC approximately. The semiconductor crystal that acts as detecting element is inside the vacuum chamber and is in thermal contact with a copper rod called "cold finger" that transfers the liquid nitrogen temperature to the detector.

Silicon-lithium detectors (Figure 4b), have the capability to detect the electric charges generated inside its active volume being as small as equivalent to the movement of only some electrons. These detectors are used in X-ray spectroscopy, mainly in X-ray fluorescence and PIXE (charged particles induced X-rays emission) applications to determine the elemental content from different samples.

a)



b)

Figure 4. a) Cooled semiconductor detector, b) Crystal of a Si-Li detector.

High purity germanium detectors

High purity germaniums Detectors, (Figure 5) are the more expensive detectors; their cost depends on the volume of the germanium crystal, there are some with a relative efficiency of 50%, with a cost of around $50,000 US dollars. They are more appropiate to detect gamma radiation, mainly in applications for neutron activación analysis, determination of radiation present in food, soil or water and in nuclear physics experiments.

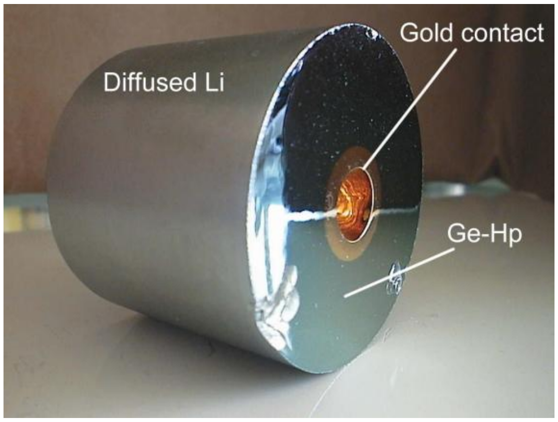


Figure 5. High purity Germanium crystal used as radiation detector.

New radiation detectors

New radiation detectors generally have been a result of frontier experiments in challenging fields as high energy physics [6, 8]. Special and restringing requirements such as good detection efficiency, better sensitivity, less noise [5], smaller size and a better linearity are always a must. These good characteristics can be obtained, for example, with solid state sensors, especially with semiconductor devices like PIN type diode structures in different configurations: strips or pixels, built with new materials Cadmium telluride (Cd-Te), high purity silicon, amorphous silicon, etc. [9].

There are several research activities and applications in which it is interesting measuring at a microscopic level, the spatial distribution of radiation or chemical elements in a sample. In these applications the detector has to be as small as possible. New gas detectors with multi-wire electrodes or plastic scintillation fibers can offer a very small spatial resolution, only some microns. Especially in the last years, semiconductor detectors are having new applications taking advantage of the fast development of the semiconductor technology and microelectronics (Figure 6), now it is possible to realize detectors with very small dimensions, therefore, every time we can get more information of smaller regions.

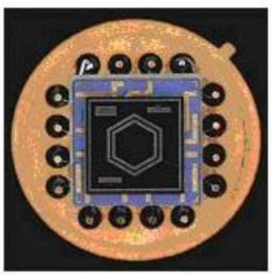


Figure 6. Radiation detector with microelectronics included.

Experimentation is on the way with new semiconductor materials like amorphous silicon and amorphous selenium, which have found applications in the generation of digital medical images in nuclear medicine. Also, the CCD detectors (coupled charge devices), similar to the ones used in the modern video cameras, show good perspectives in the detection of radiation [10].

One of the desired advantages with these detectors is the acquisition of radiological images with better image quality, such digital images can be processed in a personal computer, and this technique can contribute to the dose reduction in the patients. Semiconductor detectors are also used to measure the absorbed dose in medical treatments with radioactive sources.

2. - Development in the first years, history

The first activities in nuclear instrumentation started in the National Commission on Nuclear Energy, in the Special Devices and Instrumentation Laboratory, with a small group of physicist and electronic engineers. This body was established in Mexico City. After 1972 this institution was transformed in the National Institute on Nuclear Energy (INEN) with a big budget and support for the development of the Laboratory, in a very ambitious plan, it was considered that the research and development activities should cover:

- **Development and production of electronic modules under the NIM Standard** (Nuclear Instrumentation Modules) for nuclear applications in the scientific field, including: timers, counters, nuclear pulse amplifiers, single cannel analyzers, high voltage power supplies for detectors, etc., additionally portable radiation monitors. A small scale production of all these equipments was realized (Figures 7 y 8).

Figure 7. NIM modules built at INEN and ININ.

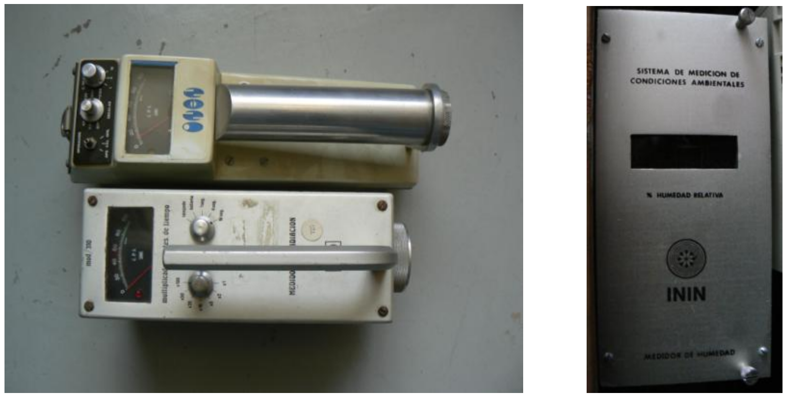


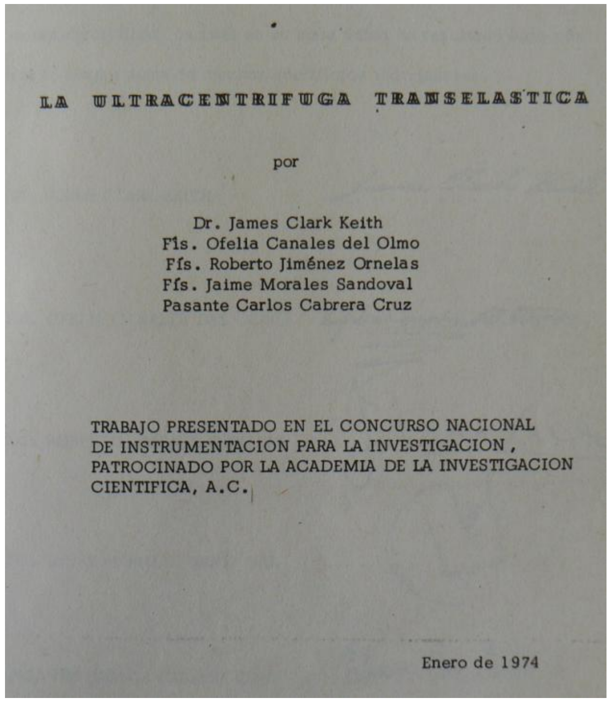
Figure 8. Some portable radiation monitors built at ININ.

- **Development of radiation detectors**, gas detectors like Geiger- Müller were developed, also vacuum techniques were applied for the fabrication of gas detectors, application of photomultiplier tubes for scintillation detectors was done, growing of sodium iodine crystals to be used as scintillation detectors was performed, finally the fabrication of surface barrier detectors was carried out (Figure 9).

Figure 9. Surface barrier detector prototype built at INEN.

- **Development of integrated circuits**, these activities included the growing of semiconductor crystals, diffusion of impurities in semiconductors and built of non rectifying ohmic contacts for radiation detectors. After some time, these activities were assigned to the Electrical Engineering Department at the Research Center and Advanced Studies, CINVESTAV.

In this epoch, INEN collaborated in a frontier research project for enrichment of uranium by using the isotopic separation technique, in this project the forced diffusion in solids theory was verified by using centrifugation. In 1974, the Scientific Research Academy of Mexico gave the National Prize in Instrumentation for Applied Research to James Clark Keith, Carlos R. Cabrera Cruz, Jaime Morales, Roberto Jiménez and Ofelia Canales, from INEN, due to their results obtained in the project along 3 years (Figure 10).


LA ULTRACENTRIFUGA TRANSELASTICA

por

Dr. James Clark Keith
Fís. Ofelia Canales del Olmo
Fís. Roberto Jiménez Ornelas
Fís. Jaime Morales Sandoval
Pasante Carlos Cabrera Cruz

TRABAJO PRESENTADO EN EL CONCURSO NACIONAL DE INSTRUMENTACION PARA LA INVESTIGACION , PATROCINADO POR LA ACADEMIA DE LA INVESTIGACION CIENTIFICA, A.C.

Enero de 1974

Figure 10. Fist page of the technical report presented to support the nomination for the National Prize on Applied Instrumentation, year1974.

In this Project, a controller-coupler for data acquisition was used; the data was feed to a HP 9100 computer for analysis. An automatic control system put to float and rotate a steel sphere around its axe at very high speed, around eight thousand turns per second, this high speed was required to generate a plastic flux inside the sphere by means of centrifugation. This development was a world class research in this time.
During the years 1977-1979 the main activities were oriented to the study of prospection techniques for uranium by using the electric contrast properties of the materials in the Sierra Peña Blanca, Chihuahua mines.

3.- The recent past, design, maintenance and repair of nuclear instrumentation

After the year 1979 the activities of the Instrumentation Section of the new National Institute of Nuclear Research (ININ) were classified in: design, maintenance and repair of nuclear instrumentation, reducing the activities on the radiation detectors field.
The main designs and developments realized during this period of time were:
- **Basic Analyzer System,** Mini Scaler. This system has been used in several projects at ININ: the heavy water project for the measurement of the liquid level in distillation columns, in experiments with neutrons at the Tandem accelerator, in training courses on nuclear instrumentation, etc. A portable version of this instrument, to be used with batteries, was built; it was called Portable Basic Analyzer System. A small production of these instruments was done in 1982 (Figure 10). These equipments integrated in a single instrument the high voltage power supply for biasing the radiation detector, pulse preamplifier, amplifier, single

channel analyzer, clock, pulse counter and a rate meter which calculated the average of counts per second, corresponding to the nuclear disintegrations produced by a radioactive source [11].

Figure 10. Basic Analyzer System "Mini Scaler" prototype to be coupled with radiation detectors.

- **Geiger-Müller radiation monitor.** This is portable instrument designed for gamma and beta radiation measurement in the field or in nuclear facilities. The instrument includes a circuit to indicate the saturation condition that could happen in a very high radiation field. A prototype was built in1984 for commercialization.

- **Ionization chamber radiation monitor.** Portable instrument designed for alpha, beta and gamma radiation measurements on the field or in nuclear facilities (Figure 11). A prototype was built for commercialization in 1984: This was one of the first instruments of its kind to use a solid state operational amplifier as electrometer; the former equipments used electronic valves [12].

Figure 11. Ionization Chamber Radiation Monitor prototype.

- **Process instrumentation.** We collaborated widely in the project dedicated to the setting up of the ININ pilot plant for the fabrication of nuclear fuels, mainly in the instrumentation and process control.

- **Multichannel analyzer system** compatible with a personal computer. This system can be used to make nuclear spectroscopy of radiation in the pulse height analysis modality. The development of this system was made under a research project with the International Atomic Energy Agency, IAEA, a production of 25 systems was done and many of them were distributed in 1994 to 16 Latin American countries for nuclear applications (Figure 12). The system includes an Analog to Digital Converter, ADC, in a NIM module that realizes the analog to digital conversion and a printed circuit card that is plugged into the ISA slot of the personal computer. This system was one of the first ones to use the successive approximations technique in the analog to digital conversion, former commercial equipment used the conversion technique by Wilkinson type integration. The system operates with 4096 channels and with a fixed conversion time of 5 μs [13].

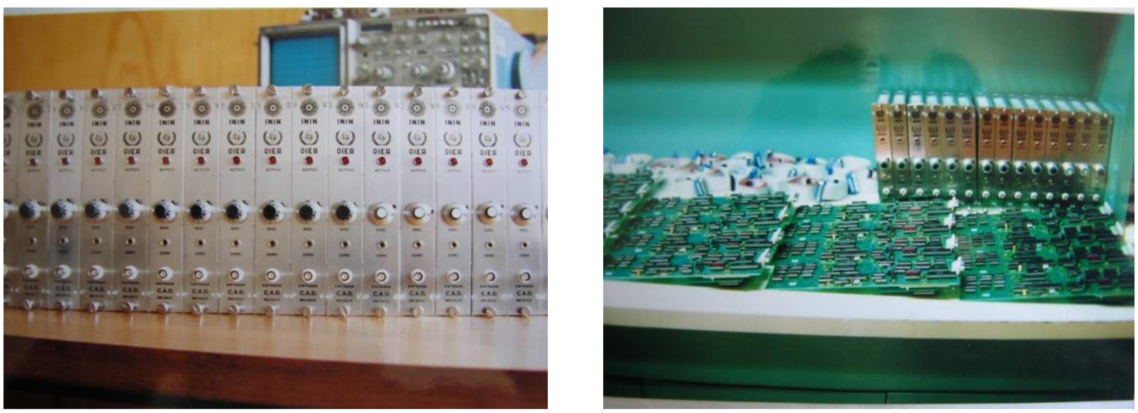


Figure 12. Multichannel Analyzer System to be used with a personal computer.

- **Fabrication of conventional instrumentation for laboratories**. Several equipments were built to support the inner research projects from ININ: voltage power supplies, temperature controllers, temperature meters, etc. (Figure 13).

Figure 13. Voltage power supplies, instruments and equipment for laboratories.

In this period we built the first electronic circuits with superficial mount technique. The Figure 14 shows the printed circuit of a preamplifier for nuclear adapted to a germanium detector.

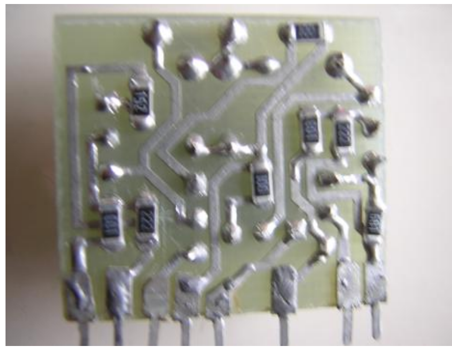


Figure 14. Surface mount devices in a printed circuit board of a nuclear preamplifier.

4.- Participation in IAEA activities.

The relationship with the IAEA in the nuclear instrumentation field started around the year 1970, several nuclear instrumentation specialists from ININ participated as students in the *International Training Course on Nuclear Electronics,* this annual course covered all the more important topics in a very intense theoretical and practical training along three months. This course has contributed to the establishment of well trained groups in developing countries in this field. Up to the year 2003, more than 10 specialists from ININ were trained in these courses. ININ was the venue of this international course in 1991 and 1992, a great experience was gained in the organization of this kind of courses and the participation included some ININ specialists as lecturer assistants for the first time.

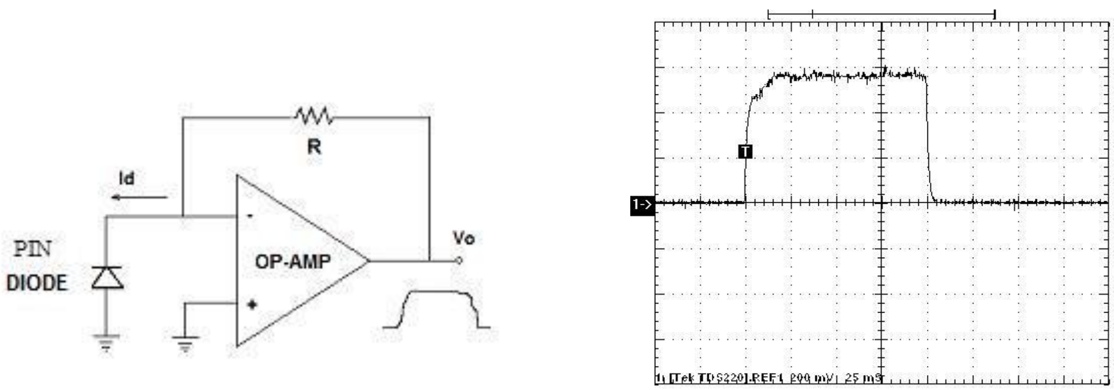
The Italian expert P. Francesco Manfredi visited ININ in 1985 helping in the establishment of a good group in analog electronics for nuclear applications, mainly the design of nuclear pulse preamplifiers to be coupled to radiation detectors.

Since then and until now we participate continuously in different research projects in ARCAL (Acuerdo Regional de Cooperación para la Promoción de la Ciencia y la Tecnología Nuclear en América Latina y el Caribe) and in the practical training of specialists from developing countries. Under these activities different nuclear equipments have been designed, also operation manuals for calibration and maintenance of nuclear instruments have been devised, also test procedures for nuclear electronics modules have been realized [14]. This participation has given to México a good acknowledge due to its capability in this field in Latin America, giving technical support and training to specialists from the region.

In one of these projects, the detection of X-rays coming from an X-ray machine for medical applications by using PIN diodes was proposed. Therefore, new measuring tools were developed for the determination of the electric characteristics of X-ray machines used in medical diagnostics: (i) waveform meters; (ii) high voltage meters by using an indirect technique, based in the physics principle of the attenuation with different materials; (iii) exposure time meters; (iv) dose meters. By applying these instruments, the quality control of the services delivered with X-ray machines in hospitals from the country can be improved. A better quality control helps to guaranty the safety of the patients and operative technical personnel, reducing the radiation exposure at a minimum level.

The waveform meter for X-rays was designed and produced to be distributed for its use in 16 Latin American countries and Ethiopia in the year 2003 (Figure 15), this is a concrete result of these projects. In the Figure 16, the operation principle of the meter is shown [15-18].

Figure 15. Waveform Meter for X-rays.



a) b)

Figure 16. a) PIN diode in photovoltaic mode connected to a current amplifier. b) Voltage signal obtained at the output of the amplifier for an X-rays beam of a high frequency machine.

When the radiation field from the X-ray machine is very intense, the PIN diode can be used in photovoltaic mode, as shown in the Figure 16a). In this condition the PIN diode response to the X-rays is directly proportional to its intensity.

5.- Establishment of the Radiation Detectors Laboratory

This event was important due to its implications on future activities. The laboratory was established in 1994 under a research project with the IAEA. Ruth García Ruiz from ININ made a very good management of the project for its approval in the IAEA, a big support was received for acquisition of equipment and for training of the specialists in the repair and maintenance of cooled radiation semiconductor detectors. Now, the laboratory is well specialized on radiation detectors for nuclear spectroscopy, with a good infrastructure that cannot be encountered in any other nuclear instrumentation laboratory of Latina America or in other developing countries. The laboratory is recognized by the IAEA as "Regional Training Center for Nuclear Detectors and Analog Electronics" for Latin America and the Caribbean (ARCAL region). Many radiation detectors have been repaired from: ININ, Laguna Verde nuclear power plant, private and public companies, institutes and from the countries in Latin America and the Caribbean, we have also provided education and training in this field to more than 60 specialists from the region. Now, in a second step, we are providing support to countries in Mid Asia: Jordan, Siria, some detectors from Algeria, Niger and Tunisia have been repaired.

The laboratory has an adequate infrastructure for the activities that are realized normally, the main equipments are:

- High purity germanium detectors, for gamma and X-ray measurements
- Silicon-lithium drifted detectors for gamma and X-rays
- Scintillation detectors, Na I(Tl)
- Neutron detectors
- Surface barrier detectors for charged particles (alphas, electrons, etc.)
- NIM bins, charge sensitive preamplifiers, spectroscopy nuclear amplifiers, high voltage power supplies for radiation detectors, pulse generators, single channel analyzer systems, multichannel analyzer systems, portable radiation monitors.
- Electrometers, pico-ampere meters, high resistance meters, curve tracers for semiconductor devices.
- Pico-ampere sources
- Capacitance analyzers
- kVp meters for X-rays
- Mechanical and turbo molecular pumps for vacuum.
- Vacuum Leakage detector, anaerobic chamber, vacuum oven.
- Calibration radioactive sources
- Ultrasonic iron solder
- Ultrasonic cleaner.

6. - Current activities

Now, the nuclear activities of the de Electronic Systems Department at ININ are classified as: Design of Nuclear Electronics, repair and maintenance of radiation detectors, maintenance of electronic and Nuclear Instrumentation, calibration of radiation measuring systems, development of new applications on Nuclear Instrumentation and characterization of radiation detectors. The main research and development projects are described as follows.

6.1 Low energy gamma and X-ray spectroscopy.

A measuring system is developed in which we propose several detectors and the associated electronic instrumentation, it is used to detect and characterize low energy gamma and X-rays in different processes: measurement and calibration of radioactive sources used as standards and radioisotopes used in nuclear medicine for example.

X-ray spectroscopy can be realized with PIN type photodiodes that originally were designed to detect light; in this application the diode is polarized in reverse mode to get the maximum detection volume (Figure 18a). The charge sensitive preamplifiers [19] were developed at

ININ (Figure 17). The size of the charge pulses generated inside the detector is directly proportional to the energy of the X-rays. If we use Si-Li detectors, we can get better results in the X-ray analysis due to its good energy resolution (typically 180 eV) and better detection efficiency in the energy range from de 1 keV to 100 keV. Moreover, there are special PIN diodes, that are commercially available and best suited for X-ray detection, they are more expensive than conventional photodiodes, but with some advantages against Si-Li detectors, mainly related with the small size and the possibility of working without liquid nitrogen.

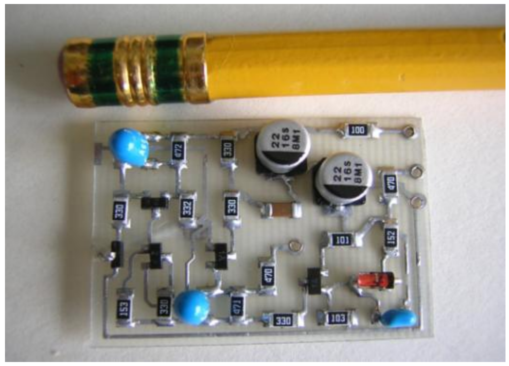
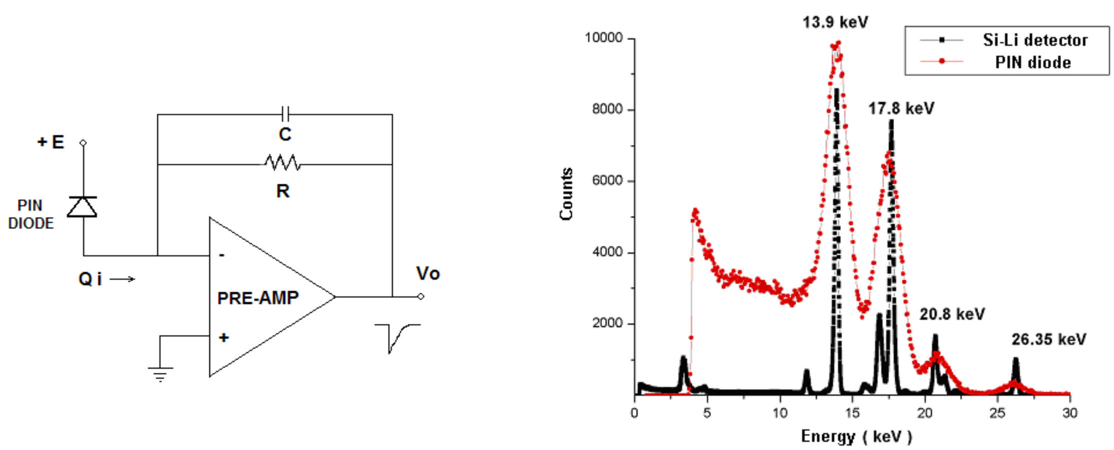


Figure 17. Charge sensitive preamplifier designed for PIN type diodes.

Figure 18b shows the comparison of the energy spectra obtained with a PIN photodiode and a Si-Li detector in a multichannel analyzer system, the spectra are for an Am-241 X-rays radioactive source. Of course, the energy resolution of the Si-Li detector is better, but also the great accuracy in the peak position is noticed for the spectrum measured with the PIN diode.



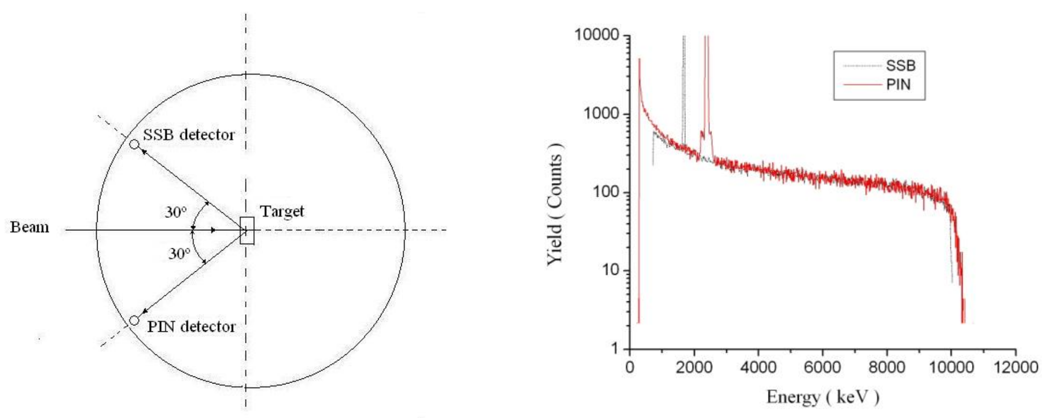
a) b)

Figure 18. a) PIN diode connected to a charge sensitive preamplifier. b) Comparison of two spectra obtained with a PIN diode and a Si-Li detector for an Am-241 radioactive source.

The proposal of this research uses a very low cost radiation detector that is adequate for many different applications. Also, we looked for easy to acquire and low cost associated electronics but keeping the best electrical characteristics. These attributes could have a big impact, especially in experiments in which a great number of detectors are required.

6.2 Application of radiation detectors in physics experiments with charged particles

There are some researches on applications in charged particles spectroscopy with alpha and beta particles in nuclear physics experiments around particle accelerators. For example, an interesting problem in nuclear physics is the determination of the resultant products in the fusion of two heavy ions at low energies. When two nuclei are fusioned, a new compound nucleus is formed, that in general is highly excited therefore it decays mainly by proton, alpha or neutron emission. In this study a detection system is proposed and put to run, it uses PIN detectors that allow the precise measurement of charged particles coming from this kind of reactions. PIN photodiodes have been used in various experiments at ININ in Rutherford backscattering (RBS) processes. Furthermore, its behavior as charged particle detectors was compared with the results obtained at the same time with a classical detector for this application, i.e. the silicon surface barrier detector (SSB). A charge sensitive preamplifier similar to the one shown in Figure 17 was utilized. The set up of the experiment is shown in Figure 19a). The ion beam was ^{12}C (12 MeV) obtained from the tandem accelerator, the beam was directed toward a Ta sample and the backscattered particles were detected both by the SSB detector and the PIN photodiode; the two detectors were put at the same angle, symmetrically [20, 21]. The Figure 19 b) shows the obtained RBS spectra; after corrections considering the solid angle, both spectra agree with the simulated values.



a) b)

Figure 19. a) Experimental set-up utilized in the RBS process. b) RBS spectra obtained with a PIN diode and SSB detector.

The peaks shown in the low energy region correspond to test signals coming from a pulse generator thought the respective preamplifier; these peaks are used as reference points. With these results we verify the capability of both detectors to detect charged particles in all the energy range covered in the experiment as shown in the Figure.19b).

6.3 Detection of “Bremsstrahlung” radiation in an electron accelerator

The wide applicability of PIN diodes as radiation detectors has led us to apply it in various experiments at the electron accelerator, like the measurement of the “Bremsstrahlung” radiation in the range from 70 keV to 470 keV [22] and the direct determination of the intensity from the electron beam. An OPTEK OPF420 PIN diode was used for the detection of the X-rays generated. The active area of the diode is 1 mm^2 and the active thickness is 150 µm, it is connected in photovoltaic mode to an associated preamplifier (Figure 16a).

The detector is put in front of the accelerator beam, as shown in the Figure 20. The distance between the output of the electron beam and the detector is 5.5 cm; an aluminum plate is used as shutter and can be removed at will, it is at 3.8 cm from the output of the beam, the purpose of the plate is to stop the electrons before the detector. The preamplifier output is connected to a 4 digit digital voltmeter; the obtained voltage is proportional to the X-ray intensity.
The Figure 21 shows the parametric curves that relate the X-ray intensity with the beam current and with the accelerating voltage employed in the accelerator.

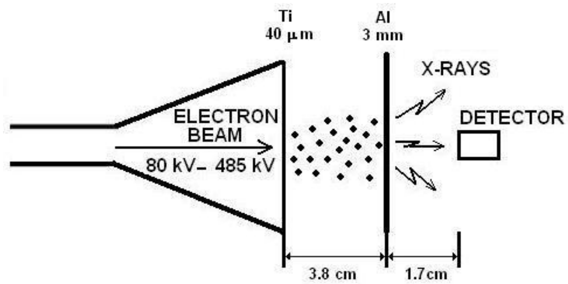
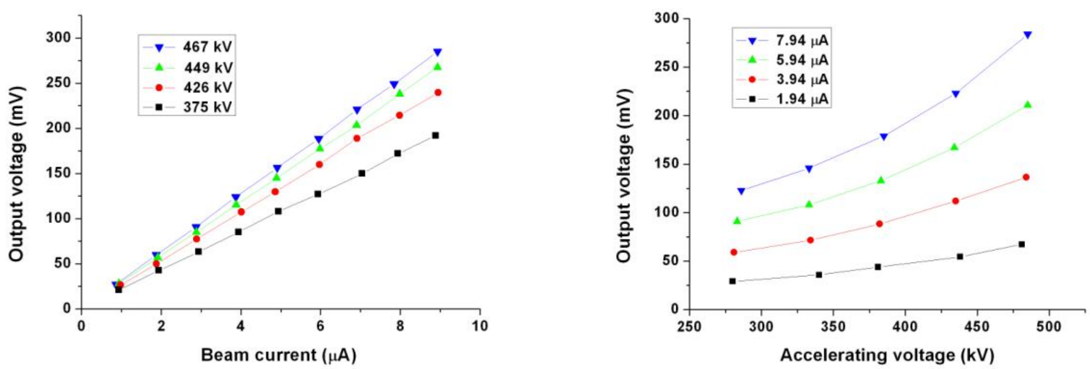


Figure 20. Experimental set up employed for the measurement of electrons and X-rays with a PIN diode in an electron accelerator.



a) b)

Figure 21. a) Experimental results from the measurement of X-rays for constant accelerating voltage and variation in the beam current. b) For constant current and variation of the accelerating voltage.

6.4 Monitoring the intensity of an electron beam

With the same set up shown in the Figure 20, the intensity of the electron beam can be measured directly. When the aluminum plate is removed, the electrons can pass to the detector. A careful adjustment of the current is required because if the beam current is very high, the detector could suffer radiation damage. The results obtained in the measurement during the irradiation process are shown in the Figure 22; the beam was blocked in several periods of time.

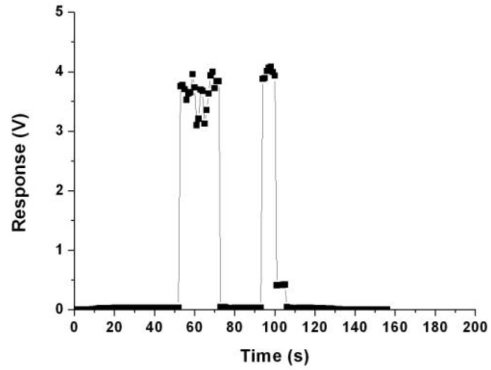
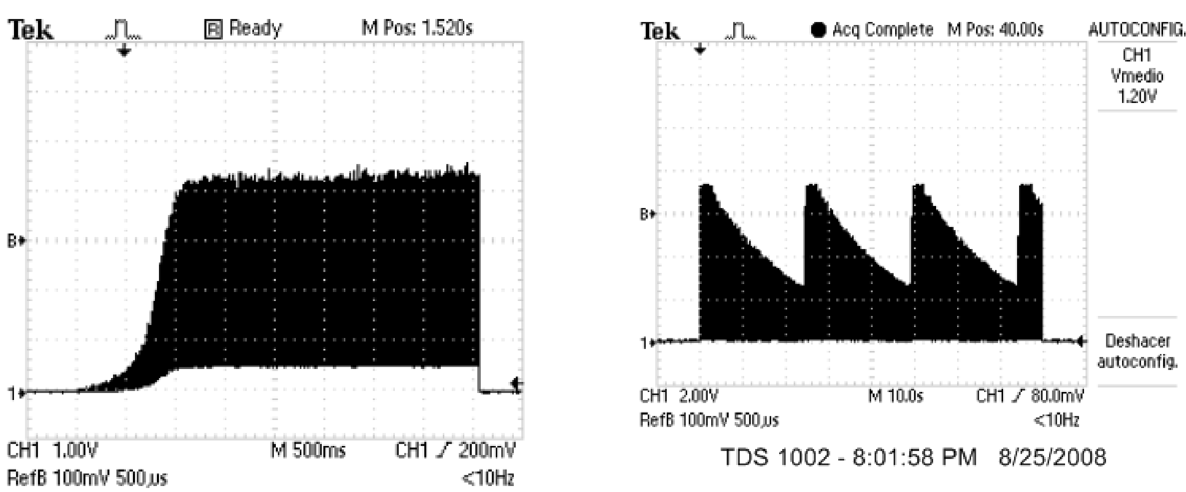


Figure 22. Output signal obtained from the electron intensity monitor. The different levels indicate the changes performed during the experiment.

6. 5 Measurement of the photon intensity in linear accelerators, LINACs

We study the electrical response obtained in PIN diodes when they are in a radiation field generated in a linear accelerator, LINAC, at radiotherapy facilities, the objective of this study is the measurement of the dose delivered to the patients, and therefore this measurement could help to assure the value of the applied dose as a redundant mean. The X-ray intensity has been measured for energies up to 18 MeV (Figure 23) [23, 24]. The electronic circuit utilized to perform the measurement is similar to the one shown in the Figure 16a.



a) b)

Figure 23.- Signals obtained in the measurement of the intensity of photons coming from LINACs a) For an energy of 6 MeV. b) For an energy of 18 MeV.

In the Figure 23a) we can observe the pulsed character of the photons delivered by the LINAC model Elekta and in the Figure 23.b) we notice the modulation applied to the beam of photons in a LINAC from Varian.

6.6 Development of instrumentation for the industry

Now we are involved in several projects with the official Mexican oil company, PEMEX, the aim of them is the development of monitoring networks for the evaluation of hydrosulphuric acid in refinery plants, new technologies for data transfer are used: radiofrequency and internet communication. We also collaborate in the improvement of the technical capabilities of the laboratories in the process of Enhancement of Recovery in Oil Fields. Our technological services include the advising in the handling of nuclear spectroscopy systems, training, refurbishment of nuclear instruments and radiation detectors. Additionally we deal with the development of new applications of nuclear instrumentation in medicine and industry and in the application of new radiation detectors. An important contribution to the nuclear power plant of Laguna Verde is the design and fabrication of different electronic modules to substitute the original ones in a modernization process of the plant, Figures 24, 25 and 26 show some fabricated modules.

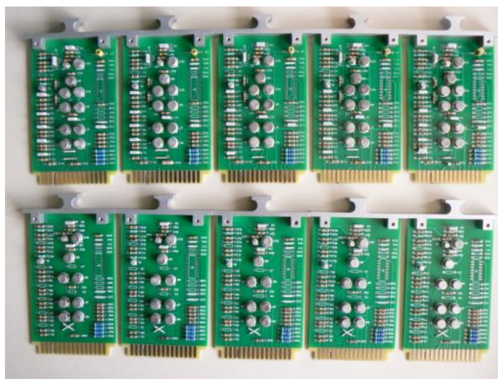


Figure 24. Instrumentation modules for the nuclear power plant of Laguna Verde that were designed and built at ININ. They belong to the Alarm Annunciator System of the plant.

Figure 25. Instrumentation modules for the nuclear power plant of Laguna Verde that were designed and built at ININ. They are in the electro-hydraulic control system for the turbo pumps.

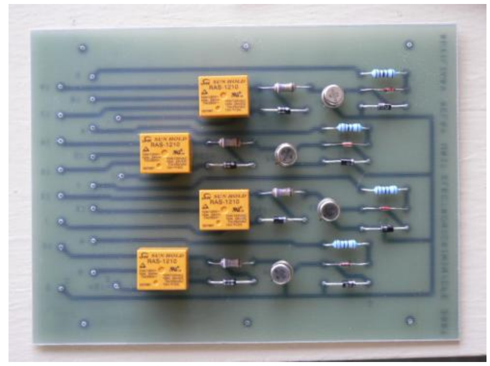



Figure 26. Instrumentation modules for the nuclear power plant of Laguna Verde that were designed and built at ININ. They are in the electro-hydraulic control system for the turbo pumps.

We collaborate with the National Commission for Nuclear Safety and Safeguards of Mexico (CNSNS), and we developed an automatic positioning system used in the calibration process for radiation detectors. CNSNS also utilize a monitoring network for environmental radiation that was developed at ININ. This system is based on Geiger- Müller detectors (Figure 27); in this network all the information is collected in a personal computer thought communication with radiofrequency and intranet. The network is installed at the nuclear power plant in Laguna Verde.

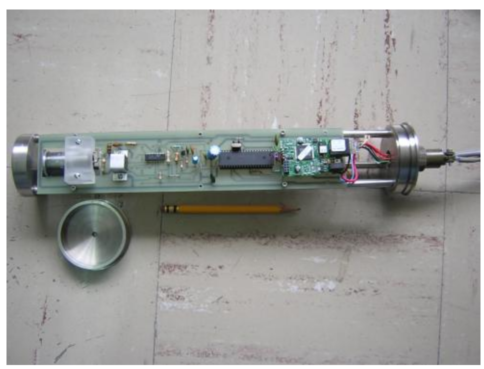


Figure 27. Geiger-Mueller module of the monitoring network for detection of environmental radiation.

7.- The future, research and development of new detectors and applications

The newest radiation detectors have been a product of frontier research mainly in the field of high energy physics with the bigger and more powerful particle accelerators that exist in the world, they can operate with energies in the order of 10^{12} eV (TeV), the goal of the detectors is the detection and identification of the resultant products of the different interactions that happen during the experiments.

Now, many international research teams are working in the development of new semiconductor detectors and associated electronics for the detection of the radiation produced in the collision experiments in high energy particle accelerators. The interest of the experiments is the information of the energy of the generated radiation, the amount of delivered radiation and the position of all the interactions with all the detectors put around the collision. Detector with good energy and spatial resolution and the capability to handle high count rates are required. In several multinational projects from the European Center for Nuclear Research (CERN), like : ALICE, ATLAS, BaBar, LHC [25-28], millions of very small semiconductor detectors, are put around the collision center with the idea of reconstruct in images all the possible interactions. Pixel and strip semiconductor detectors are very common in these experiments; they must have good detection characteristics and additionally, must be hard radiation resistant for high dose rates.

In astrophysics and physics of astro-particles projects [29] special nuclear instrumentation is required for space applications in which the design considerations are restringing: hard resistant to high levels of cosmic radiation, small power consumption, and exhaustive utilization of microelectronics to reduce the size of the electronic circuits.

Other teams, like the Electronics Department of the Polytechnic of Milano, are also working in the development of new radiation detectors for extreme conditions of temperature like the commonly encountered in space missions [30], in which the noise levels must be keep as low as possible. A new semiconductor detector made with SiC was discovered recently, the big advantage of this detector is the very low noise even at high temperatures, an equivalent input noise charge, ENC, as low as one rms electron has been obtained at low temperatures without a big increase at 100ºC [31].

The participation of ININ in these international projects in the nuclear instrumentation field has been occasional because it is a very wide field and is beyond of the general objectives of the institution, moreover, our great challenge is to know, assimilate and apply these very new technologies and furthermore reach the point in which we could propose new applications and new technologies in nuclear instrumentation.

8. - Conclusions

ININ has a good prestige and acknowledge in their activities on nuclear electronics instrumentation as never before, thanks to the continuous advance reached in this field, several of our experts are required by the IAEA in the topics of radiation detectors, analog electronics, virtual instrumentation and microcontrollers. Now the collaboration with the Nuclear Power Plant of Laguna Verde in this field is permanent and has grown with consultant services, training and works of re-engineering on electronics systems. Now we have collaborations on nuclear instrumentation with institutions like the: Instituto Tecnológico de Toluca, Instituto Politécnico Nacional, Universidad Nacional Autónoma de México, Universidad Autónoma de Puebla, Universidad Michoacana de San Nicolás de Hidalgo de Morelia, CINVESTAV and Universidad Autónoma del Estado de México.

In the international ambit we have experts working as consultants for the IAEA and in various diffusion forums like the IEEE Nuclear Science Symposium and IEEE Medical Image Conference, ´participating as reviewers for the submitted work. Also we collaborate as arbiters in the IEEE Transactions on Nuclear Sciences magazine, which is one of the more recognized magazines in this field.

It should be noticed that one of the main factors that has contributed to the good actual status of the electronics instrumentation area at ININ is the continuity of the activities and working programs that we have followed. This chapter has allowed us and gave the opportunity to realize the overview of our activities.

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