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Upgrading of gamma cameras for developing countries

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Abstract

The project of upgrading the analog gamma cameras with PC based systems from International Atomic Energy Agency (IAEA) and the Ministry of Science and Technology of RS is presented from basic startup demands to the final developments. Several national research groups (from China, India, Cuba and Slovenia) were involved in the IAEA development project for the acquisition card with software and the standard set of clinical protocols. The most functionally stable acquisition system tested on several international workshops and in university clinics was the Slovenian one with a complete set of nuclear medicine clinical protocols, documenting, networking and archiving solutions for simple MS Network or server oriented network systems (NT server, etc). More than 300 gamma cameras in 52 countries all over the world were digitized and put in routine clinical work.
Key words: Upgrading of analogue gamma cameras, acquisition card, PIP-GAMMA-PF system.

Introduction

In last ten years the IAEA put a big effort to help developing countries in renewal of old gamma cameras and nuclear medicine computer systems. It was high time for this action because many gamma cameras were already out of the function for different reasons. Most of them had broken or technologically too old computers for new nuclear medicine methods, radio pharmaceuticals and information technology. In many countries the old analogue gamma cameras (20 years or more) were put out of the function and as a consequence the nuclear medicine departments were closed. The nuclear medicine as a relatively young health branch started to “die”. At the same time the nuclear medicine stuff also started to leave the field and went to other mostly imaging fields.

For these reasons the IAEA upgrading action of analogue gamma cameras started to help developing countries to revive or to extend the life of nuclear medicine. Because of the high cost for new equipment the idea of the IAEA was upgrading the old analogue and semi digital gamma cameras and computer systems with low cost interfacing cards, developed under the agency support, and the PC based computer systems with acquisition and processing software, ink-jet or laser-jet printers, CD archive and network. The whole cost per system was limited to 5.000 US $, what is only a small fraction of the price of new commercial systems. At the same action with upgrading the equipment the training courses for this technology and validation seminars took place in all the world regions.

Methods

IAEA established a group of experts for defining the upgrading objectives, criteria for selecting the research institutions for the development of acquisition hardware and software, defining the procedures for following the results of development and creating the final report of the project. The expert group defined the following demands for the upgrading system of analogue gamma cameras.

Basic demands for development of acquisition cards

- Single ISA format acquisition card,
- solution for adjusting amplitude and timings for input signals from a variety of gamma cameras,
- simple installation and setup of X, Y (positional), Z (strobe), E (energy) and G (gated) signals such that most of the end users can install the system by themselves,
- matrix size up to 256x256,
- acquisition driver incorporated in PIP (Portable Image Processing),
- on-line energy and count correction of image data,
- negligible count loss,
- stable function of the system for all kind of possible clinical studies (fast and slow dynamic, static, gated and combined studies),
- continuous upgrading,
- low price (less than 3.000 US $),
- 4 years for development and validation.

Basic demands for software development

- MSDOS operating system in WINDOWS (3.1, 95, 98),
- PIP system for patient database and general data processing,
- tools for end-user development of clinical protocols (C++ library, macro functions) ,
- algorithms for automatic analysis of clinical data with possible manual intervention,
- tools for image, dynamic curves and ROI processing,
- images from study analysis in standard picture formats (i.e. PCX, BMP),
- set of gamma camera quality control functions (NEMA tests),
- converter to and from "Interfile" format,
- SVGA colour scale for display,
- results of analysis on one page,
- printing of documents in high spatial resolution (1200x1200 dots/inch) and on low cost high quality media (paper, transparencies),
- archiving the original image data and reporting documents on low cost CD as "soft" copy,
- network support,
- user friendly system,
- clinically validated software.

Three experienced research institutions from developing countries were selected for building the upgrading system: Ljubljana University Medical Center (1, 2), Bombay Nuclear Research Institute (3) and Havana University Institute (4),

Acquisition system

Basically two different approaches were used in the development:

1. Acquisition card from Bombay Nuclear Research Institute (3) with signal's gain and offset control, AD conversion, energy correction, creating images and gate control. Communication with computer is triggered by interrupt service. Computer's time control is used. Setup of gamma camera signal`s gain and offset is performed manually (Diagram 1)

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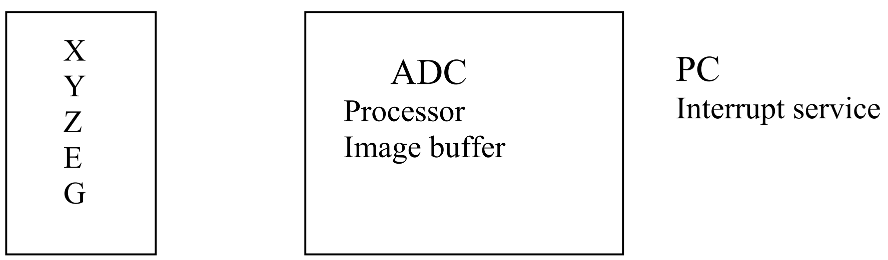


Diagram 1. Principle of the Indian acquisition system. Positional (X and Y), strobe (Z), energy (E) and gate (G) signals are converted into digital form in the acquisition card, which also creates image and send it to the computer by applying the interrupt service

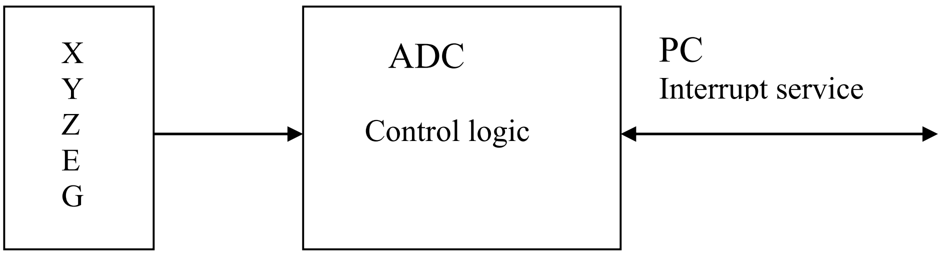


Diagram 2. Principle of the Cuban acquisition system. Positional , strobe, energy and gate signals are converted into digital form in the acquisition card, which sends them to the computer by applying the interrupt service

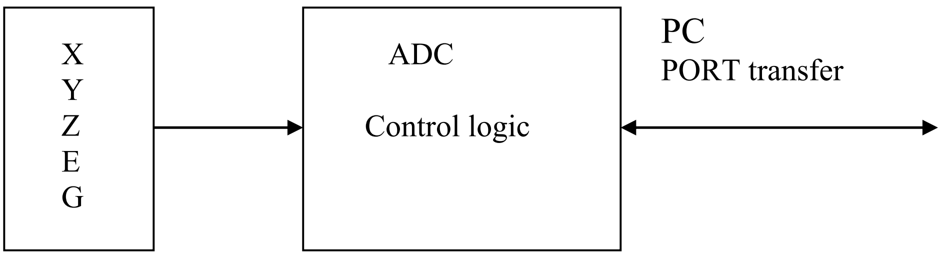


Diagram 3. Principle of the Slovenian acquisition system. Positional, strobe, energy and gate signals are converted into digital form in the acquisition card, which sends them to the computer through PORTs without interrupt service

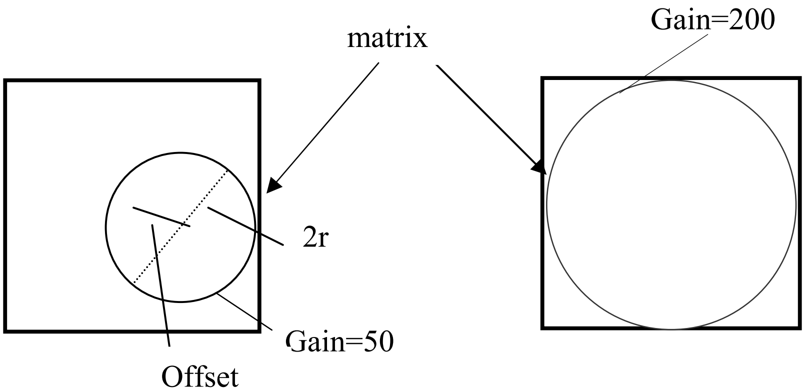
2. Acquisition card from Havana University Institute (4) with signal`s gain and offset control, AD conversion with saving the position, energy and other control data (i.e. gate signal, signal for gantry control) are transferred to the computer`s memory using PORT transfer. The interrupt service is used for triggering the data transfer (Diagram 2). Gain and offset adjustment is performed manually.

3. Acquisition card from Ljubljana University Medical Centre (2) with signal`s gain and offset control, time control, AD conversion, saving of position, energy and all other control data for each detected gamma event by computer`s PORT transfer to the computer memory, software control of analogue signals for zooming, gain, offset and orientation settings. Computer has complete control on the acquisition at every moment. Interrupt pulse is not used

for triggering the communication between acquisition card and computer (Diagram 3). The setup of signal`s gain and offset (for X, Y and E) is performed automatically through “computer – acquisition card” feedback control (Diagram 5) by appropriate software (1) algorithm (Diagram 4).

4.1. Initial gain and offset settings:
X, Y range: ±0.5V to ±3V
GAIN = 50 , OFFSET=128

4.2. Gain and offset settings at the end of automatic adjustment:
GAIN=200, OFFSET=90



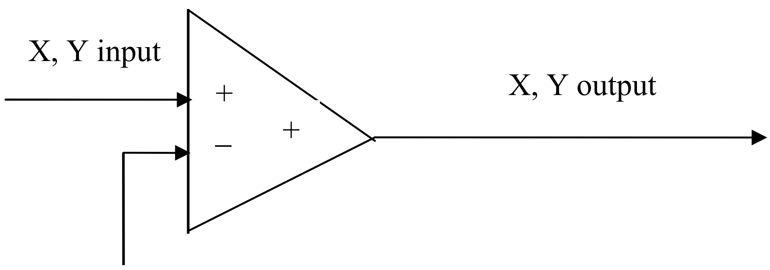
4.3. Iterative loop for gain adjustment. By increasing the gain of positional signals the image diameter is proportionally increased.

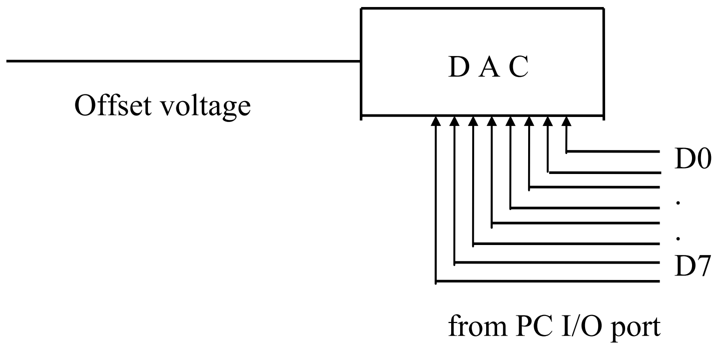
gain $\uparrow$ $\Rightarrow$ 2r $\uparrow$

Diagram 4. Algorithm for automatic adjustment of interfacing card’s gain and offset settings for positional signals X and Y

All manipulations with data: image creation, time, count and gate control are performed by PC.

a) Offset adjustment





b) Gain adjustment

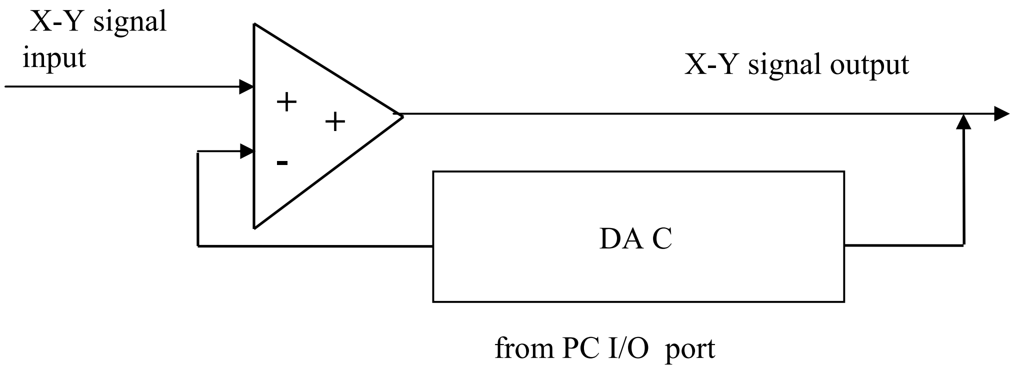


Diagram 5. Digital control of offset (a) and gain (b) for analogue positional (X and Y) signals. By reverse control from computer to the acquisition card the analogue signals are appropriately adjusted: a definite constant voltage is added for offset adjustment (a) and part of the signal is taken for gain adjustment (b).

Results

Acquisition cards

All three research institutions have developed few prototypes in the project time. The last and the final version was evaluated in details by several institutions: Institute of Biomedical Techniques and Physics, AKH, Vienna, Turkey Atomic Energy Commission, Argentina National Atomic Energy Commission and at three expert meetings (in Ljubljana, Ankara and Santiago de Chile). The conclusion from all involved testing institutions and experts was that all acquisition cards fulfil most of the required features. The final conclusion of the testing was (5): “The Slovenian system GAMMA-PF is the most adequate, due to better technical performance, stability of functioning, facility of installation, technical support, lower price, accomplishing in delivery rime schedules and professionalism of the involved team”. The most probable cause of instability of Indian and Cuban cards is interrupt service for communication between acquisition card and PC.

Slovenian acquisition and processing system GAMMA-PF

In the following, the features of Slovenian acquisition card are presented:

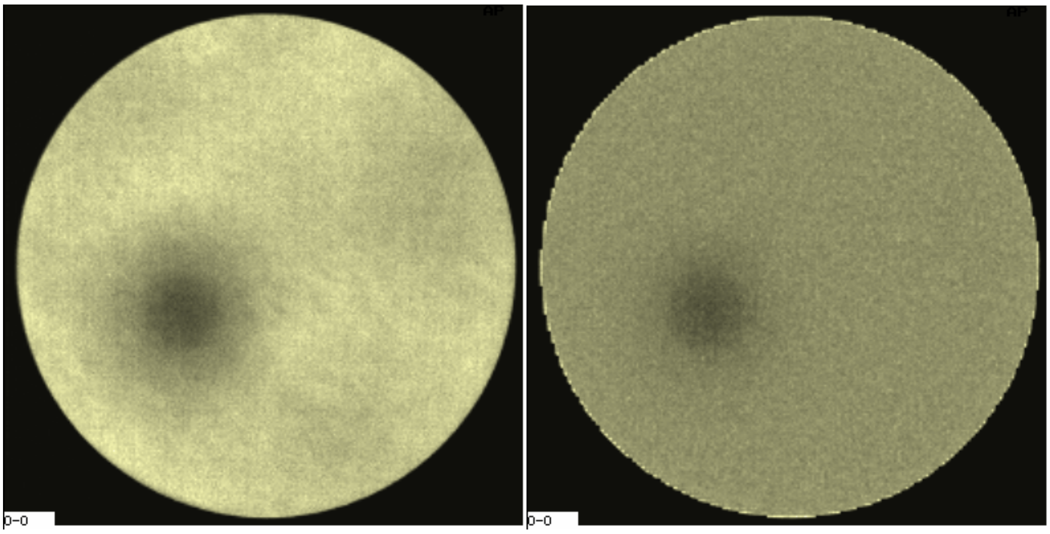
- Standard PC hardware,
- acquisition can not run simultaneously with processing,
- one 16-bit PC AT professionally designed card in four layers,
- range of X and Y analogue bipolar signals from ± 0.5 V to ± 10 V,
- alternative software or manual adjustment of GAIN and OFFSET settings for X, Y and E signals,
- software adjustment of ZOOM (1.0, 1.5, 2.0 and 2.5) to analogue positional signals and image ORIENTATION,
- matrix sizes from 32 x 32 to 256 x 256 in words,
- all standard acquisitions (static, dynamic, gated and combined static-dynamic) with on-line energy and count correction,
- stopping condition: by time, counts or time/counts (which is reached the first),
- persistence scope function for gamma camera tuning with continuous computation of regional count density,
- count loss: < 1 % without energy correction, < 10 % with energy correction measured at count-rate of 50 K c/s,
- energy correction is performed by the acceptance of current pixel's energy from the look-up matrixes of low and high photo-peak limits,
- energy correction: integral uniformity index is lowered by factor 2,
  count correction: integral uniformity index is lowered by factor 3 – 5.

One of the most important results when testing the effect of uniformity and energy correction was that the count correction decreases the integral uniformity index much more (by factor 3 - 5) than the energy correction (by factor 2). This study was performed on GE 300A gamma camera with artificially suppressed one of the PMTs for approximately 60 % (Table 1 and Picture 1).

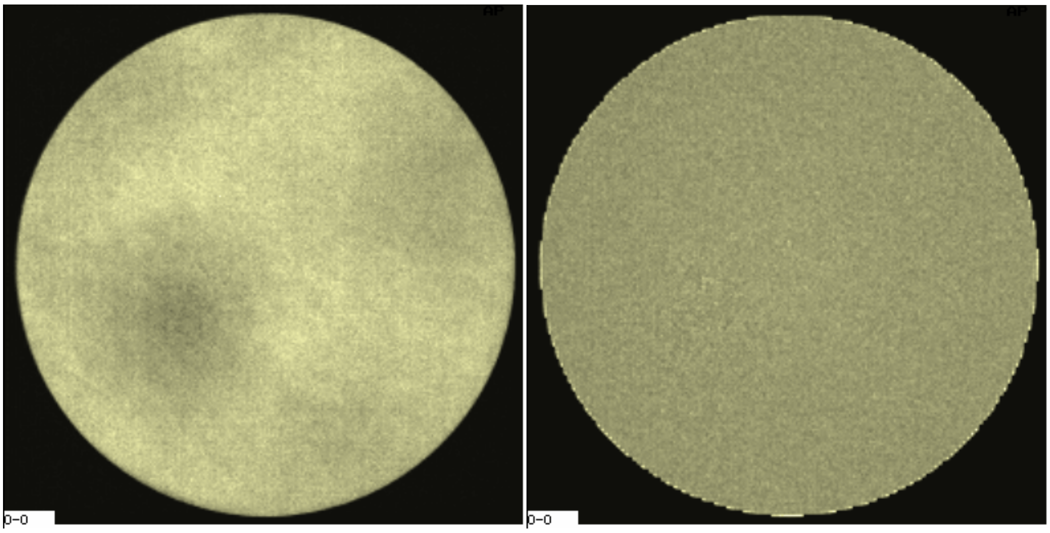
SCAN	Integral uniformity (%)		Differential uniformity (%)	
	UFOV	CFOV	UFOV	CFOV
Original	49.8	49.2	23.2	23.2
Energy corrected	23.6	23.6	9.6	9.6
Count corrected	6.7	6.6	3.4	3.4
Energy and count corrected	4.7	4.6	2.4	2.4

Table 1. Analysis of scan uniformity by NEMA standards

1. 1. **1.2.**



1.3. **1.4.**



Picture 1. Effect of on-line energy and count correction on gamma camera (GE 300A) image with 60% suppressed one PMT. 1.1. Original image, 1.2. Only count corrected, 1.3. Only energy corrected, and 1.4. Energy and count corrected

Another important result is the recommendation that the count correction should be applied only for images from gamma cameras which have integral uniformity index less than 30 %. At higher values the noise amplification overcomes the signal and the false positive spots become visible in the corrected scans at low count images (2).

Clinical software

Besides the basic tools for image, region of interest and dynamic curves processing functions the set of most important clinical protocols was developed (1)

- Heart:

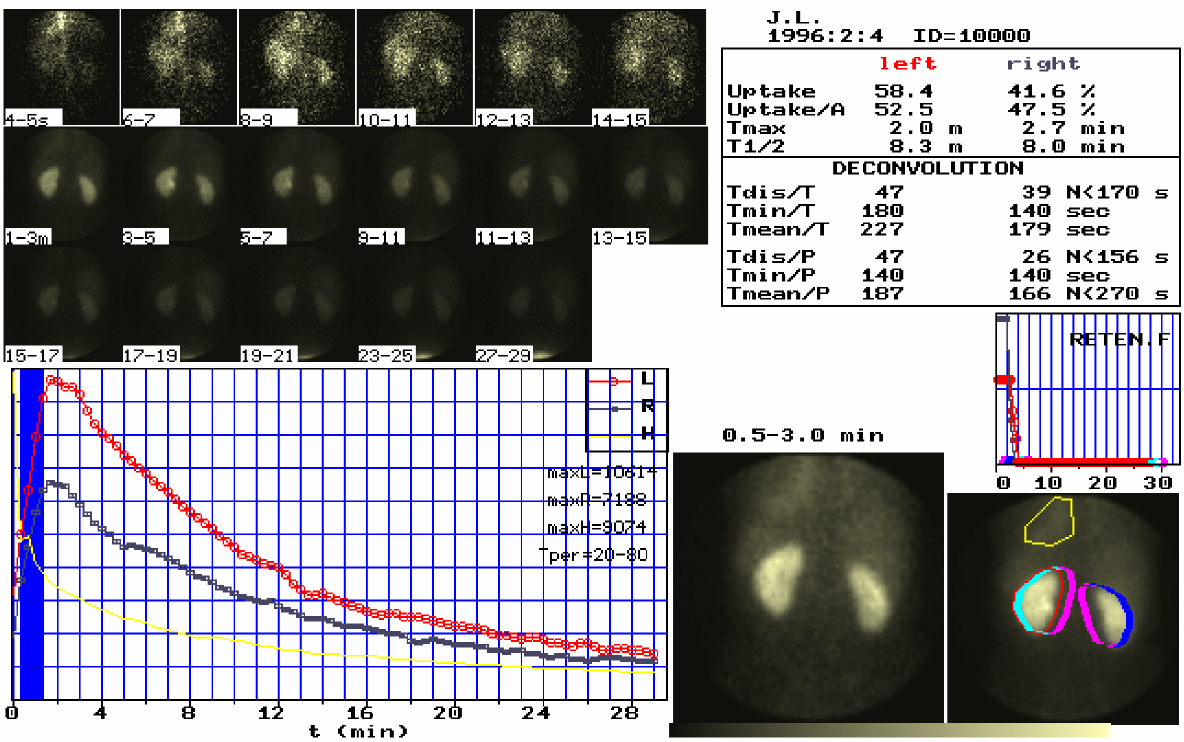
Gated ventriculography: ejection fraction, amplitude and phase images, phase histogram, contraction images, movie display,

Shunt: gamma-variate fit, left-right shunt ratio.

- Kidneys

  Renography (MAG3, DTPA): relative function, Tmax, T1/2, deconvolution analysis.

  DMSA: relative function with attenuation correction.
- Lung perfusion: relative function with attenuation correction.
- Salivaries: pertechnetate uptake, excretion after ascorbic acid stimulation.
- Thyroid: pertechnetate uptake in 15 minutes.
- For all other studies the basic tools for image processing is available (contrasting, movie display, different colour scales, ROI selection, dynamic curves, etc).



Picture 2. Example of the final results from MAG3 study analysis

Analysis is nearly completely automated with possible quality assurance interventions: correction of automatically determined ROI, manual correction of time intervals for relative function computation in dynamic curves, movie display of sequential images with plotted ROIs, manual correction in automatic selection of end-systolic image, manual correction of time intervals for “shunt” analysis, etc. Most of the patient studies can be processed in less than 2 minutes. An example of MAG3 analysis is shown on picture 2.

Networking

Setup of network with GAMMA-PF system (Diagram 6) can be done either by NOVELL, Microsoft Network or WINDOWS NT network software. The acquired studies, images from analysis and documents are stored on common server's disk, archived on CD or other large scale storage media, printed on high quality ink-jet or laser-jet printers and communication performed through hospital to external lines.

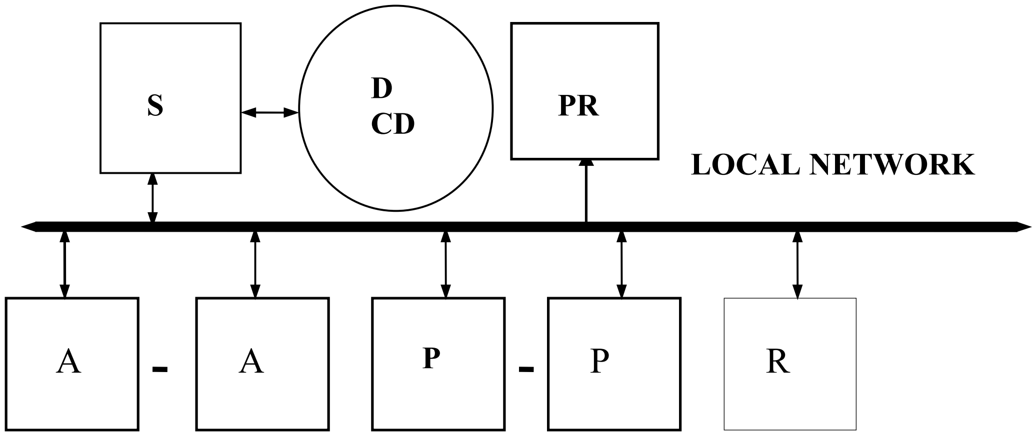


Diagram 6. Functional schema of GAMMA-PF network. A–acquisition, P–processing, R–reporting PC, S – server, D–common hard disk, CD–compact disk (read/write), PR–printer

Distribution of acquisition cards with software

In the developing world there were 2689 gamma cameras in the year 1998. This is nearly the same as in Japan. In the past 15 years 48 planar and SPECT gamma cameras were donated to 39 member states. Along with the donated cameras IAEA distributed 234 PC gamma interface cards to 52 member states. Main achievements of the IAEA projects on upgrading are the following (6):

- Low cost,
- significant improvement of old gamma camera images (uniformity from 20 % to 5 % after both on line energy and count corrections),
- life prolongation of old gamma camera for about 5 - 10 years,
- increment of diagnosis throughput by estimated 30 - 40 %,
- high quality black and white or colour images with new low cost generation of printers instead of film,
- knowledge improvement in nuclear medicine technology for engineers, physicians and technologists from training courses in all regions of the developing world.

Discussion

The IAEA project of upgrading analogue gamma cameras in the developing world has gained some important results: prolongation of old analogue planar gamma cameras, improvement of quality assurance for images by on-line count and energy correction, replacing old computer technology with new PC, introducing computer network, archiving of studies, communication inside nuclear medicine departments and improvement of the technological knowledge of nuclear medicine stuff. These results have a definite limited value. Upgrading project should be implemented also to other nuclear medicine equipment i.e. thyroid uptake system, gamma counters for RIA, multi-probe systems and monitors. There are also some other detector systems that should be included in the future development, i.e.: radio-chromatograph, whole-body scanning bed (bones, white cells, metastases), monitor for patient whole body radioactivity (for checking patient activity before dismissing form hospital), etc. Also the energy and count correction should be improved in the future by physically more feasible method – equalizing the PMT output (either changing the high voltage setting or changing the PMT gain). This should improve the gamma camera spatial uniformity as well as linearity. But to achieve this the electronics of the gamma camera head and the electronic console should be replaced completely by the digital system.

Conclusions

The IAEA project of upgrading the old analogue gamma cameras by PC based acquisition and processing systems gained a high promotion of nuclear medicine in the developing world. Besides the immediate help to 52 member states in the life prolongation of old gamma cameras, somewhere also reviving the nuclear medicine, it also improved the technological knowledge of nuclear medicine stuff on several training courses on upgrading and quality assurance of planar and SPECT gamma cameras and programming of clinical protocols. Among three financially supported projects for development of acquisition system the Slovenian one was determined by expert testing and end-user evaluation as technically most advanced, functionally stable, user friendly concerning the installation with setup of image size, offset and energy settings, simplicity of clinical protocols with quality assurance functions, delivery in time, with smallest price and was mostly distributed.

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