A Backward Glance at Nuclear Medicine Computers: 1970–1995

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Key Words: nuclear medicine computers; history

J Nucl Med Technol 1995; 23:21S–26S

This edition of the journal marks the 25th anniversary of the Technologist Section of the Society of Nuclear Medicine. Coincidentally, the first computers specifically designed and programmed by major vendors for nuclear medicine applications also came to the market approximately 25 years ago.

Nuclear medicine, of all the medical imaging modalities, has always been a leader in the application of computers for image processing and analysis. Even before the first commercial nuclear medicine computers became available, a number of leading investigators had either designed and built digital analysis systems (*1*), or were finding ways to transport imaging data to large university campus mainframe computers for uniformity correction and image enhancement (*2*).

A book published by the Society of Nuclear Medicine in 1974, entitled *Computer Processing of Dynamic Images from an Anger Scintillation Camera* (*3*), gives the proceedings of a four-day workshop held in January 1971. A lung physiologist of considerable repute questioned whether "people practicing nuclear medicine should go out and buy computers for their cameras." He thought they should not. This whole meeting seemed to be struggling with the fact that nuclear medicine imaging up to that time had been a static modality and the potential of the scintillation camera to view dynamic images was only just being recognized. Later sessions at this workshop took the form of debates with statements such as "the Anger scintillation camera interfaced to a computer may have clinical utility for studies of the lung," with well-respected nuclear medicine physicians speaking for both sides of the argument. What is fascinating is that although the brain, kidneys and lungs are all discussed there was no mention of cardiac studies. It must be borne in mind that rectilinear scanners were very much in vogue throughout the 1960s, and it was the introduction of ^{99m}Tc-labeled compounds in the mid-1960s that stimulated the replacement of rectilinear scanners by scintillation cameras during the 1970s. The notion, at the workshop referred to above, that a nuclear medicine study was constrained to be a static one, was born out of the rectilinear scanner era.

Despite the references made above, it was soon recognized that the scintillation camera, because it viewed a large area of interest at a time (maybe only 10 in diameter in 1970), and because it lent itself to digitization of the image, facilitated the collection of dynamic studies and some means of storing and analyzing these studies was required. Indeed, some nuclear cardiology investigations were reported by Van Dyke, et al. as early as 1972 (*4*) and by Schelbert, et al. in 1975 (*5*), although these were primarily systems based on analog techniques and did not use digital computers. Computers in one form or another had already been applied to rectilinear scanners (*6*), and the way had been paved for the development of computer systems to be applied to scintillation cameras. It is perhaps worthy of note, that the brain scanner described by Kuhl and Edwards (*6*) preceded Hounsfield's x-ray CT scanner by several years. The tomographic reconstruction of Kuhl and Edwards was more sophisticated than most of the applications involving rectilinear scanners. In most instances the computer was being used simply to capture the data for purposes of image enhancement after the event (*7*).

The changes in the systems used over the past three decades have been profound and are summarized in Table 1. It is natural that the history of nuclear medicine computers should parallel that of the entire computer and micro-electronics industry. Thus, while physical size and power requirements have diminished dramatically and computing power has improved by orders of magnitude, the cost has remained relatively stable, at least in terms of today's dollar value. Operating systems and software have similarly progressed, though whether they have kept pace with the hardware is debatable, and ease of use has improved.

Some estimates suggest that the computer is evolving at a rate that doubles its power each year or so. This implies that computers become 10^3 times more powerful in about 10 yr, 10^6 times in about 20 yr, and possibly 10^9 times in 30 yr. The numbers portrayed in Table 1 do not fully support this estimate, which is probably related to the advances being made today rather than 25 yr ago, but there is little doubt that the

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TABLE 1
Summary of Computer System Changes

	1970s	1980s	1990s
Physical size	72-in cabinets	48-in cabinets	Desktop workstations
Memory size	256 kb	16 Mb	64 Mb
CPU speed	0.1–1 MIPS	5–20 MIPS	100–200 MIPS
Disc capacity	5 Mb	500 Mb	2 Gb
Display technology	Storage screen	Standard video	High-resolution video
User interface	Menu/commands/ macros	Programmed buttons	GUI/Windows
Operating system	General purpose real time	Proprietary	Open systems
Environment	Stand alone	Integrated	Networked
Applications	Image enhancement, ROIs, curves	SPECT reconstruction, functional imaging	3-D visualisation, multi- modality, artificial intelligence
Users	University hospitals	Large and medium departments	All departments

power of the computer has advanced phenomenally over the past two and a half decades. At the same time, the cost of hardware has decreased dramatically while the cost of software has risen. Overall, the cost of today's nuclear medicine computer in 1995 dollars is almost identical to the price of yesterday's computer in 1972 dollars. That zero rate of inflation needs to be compared to the corresponding increase in salaries over the same time interval. The ratio of associated cost has also shifted from predominantly hardware costs to software.

The first computers used either of two technologies for the image display that was separate from the display used for the command interface. Some systems used large storage screen oscilloscopes with essentially infinitely long decay times. In these systems the count intensity in a pixel was portrayed by the number of dots clustered within the area of the pixel so that the display was quite similar to the scintigraph obtained directly from a scintillation camera. Other display systems used a live oscilloscope and the count density of a pixel was depicted by the intensity of the beam at each pixel location. The storage screen technology was favored because it used CPU power only to write the screen once, whereas the live oscilloscope required continuous rewriting of the display screen thereby using up valuable CPU power. The live oscilloscope display was, however, much more amenable to direct contrast adjustment and subsequent hard copy recording.

By the 1980s the displays were becoming more advanced and direct color video display was becoming available. These displays required a separate video memory but, by this time, memory was converting from the old magnetic core memory to the newer semiconductor memory which was less costly, consumed less power and produced less heat, so that video displays could be accommodated without much cost increase.

Another aspect of the technology that has advanced at a phenomenal pace is that of memory and data storage. The first removable discs were huge and expensive compared to today's floppy discs and diskettes, yet the capacity was similar or even less. The RK05 removable discs supplied with the GAMMA-11 (Digital Equipment Corp., Maynard, MA) (Fig. 1) in the early '70s were about 16 in. in diameter yet the capacity was only 2.4 Mbytes and they cost about $200 each. That is the same capacity as a present day 3.5-in. diskette costing less than $1! It is interesting to speculate what kinds of cars we might be driving had the field of automobile technology advanced at that same rate. Even as late as the mid-1980s discussion of the

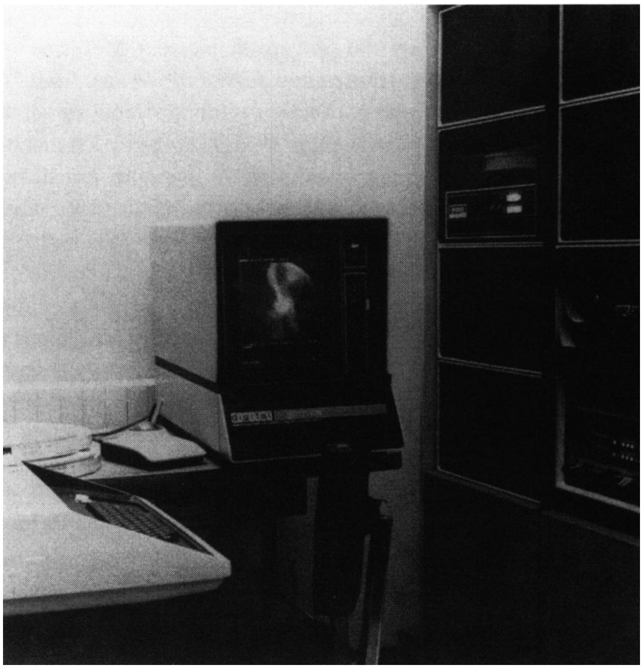

FIGURE 1. DEC GAMMA-11 circa 1970. Notice that software was loaded from paper tape (mid-right) and the user interface was via the keyboard (left) and the joystick (center). The display was a large storage screen.

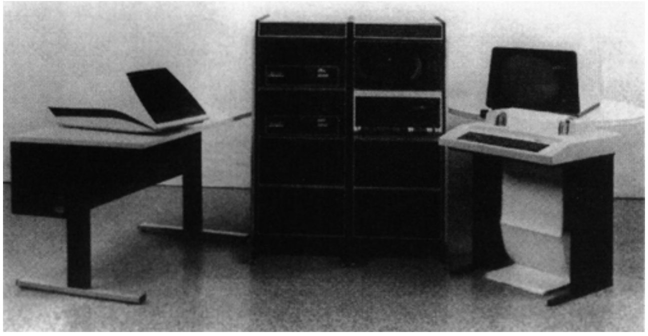

FIGURE 2. DEC GAMMA-11 circa 1977. Note that the cabinet size has reduced from 72 in. to 48 in. but that software is still loaded via paper tape (just visible in the top section of the right cabinet). The display in this system is a video monitor which, by this time, had replaced the storage screen technology and was driven from its own video memory. The user interface was still from the printer/keyboard. The terminal on the left represents the acquisition terminal that could be placed at the camera.

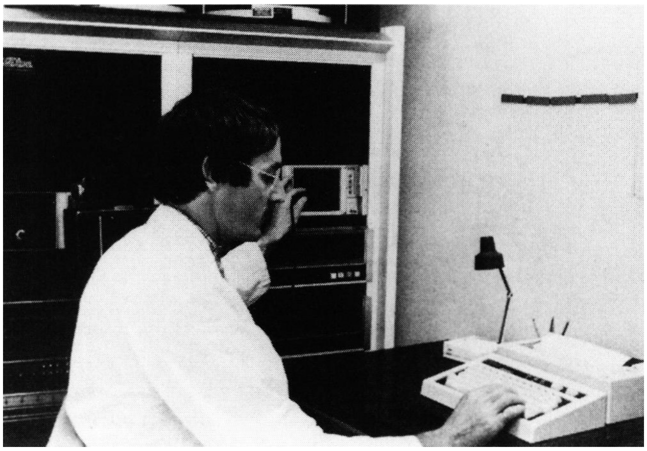

FIGURE 3. MDS A2 system circa 1970. This system used a live oscilloscope that was refreshed by the computer memory and regions of interest were drawn using a light pen. The user interface was from a keyboard (right).

merits of using large reel-to-reel, 9- and 7-track, magnetic tape versus 8-in. floppy discs for archiving medical data was a serious consideration in the purchase of a new system. The high cost of magnetic tape systems meant that most departments chose to archive on floppy discs unless the workload was sufficient to justify magnetic tape. The cost of magnetic tape systems dropped considerably when small streamer tape units were developed and it became possible to store very large amounts of data on small cassette tapes. Today, in a department where about 15,000 studies are performed annually, all those studies can be archived with loss-less compression on two optical discs for about $400 and the cumulative index of all the studies is retained on-line. Recent developments in the technology of surface storage suggest that these capacities will increase 10-fold in the very near future. No doubt this form of archiving will be superseded in time by writable CD-ROMs with the inevitable result that the capacity will increase while the cost decreases even more.

The user interface of the early nuclear medicine computers was, to some extent, governed by the prevailing technology as much as by the software available. The user interface was predominantly a keyboard, with a joystick or light pen to define regions of interest. Mice and trackball devices were not developed until much later on. The major arguments about the user interface in the 1970s was whether it should be via a command structure, such as the DEC GAMMA-11 (Fig. 2), or the menu structures favored by MDS (Ann Arbor, MI) (Fig. 3) and ADAC (Milpitas, CA). In the case of the command structure, the user entered a mnemonic such as UT for upper threshold or IR for irregular regions of interest, from a documented set of commands specific to the software level at which he or she was working at the time. The menu structure, on the other hand, presented the user with a table of commands, or prompts, from which the user could select an action either by typing the letter or number corresponding to the desired item or moving to it, using the arrow keys, and selecting it with the enter key. The argument in favor of the command structure was that, once learned, a whole line of commands could be entered and the desired action would take place in one move, whereas the menu structure required the operator to step through the menus one page at a time to achieve the desired overall operation. On the other hand, the menu structure was easier to learn than a set of 100 or so commands. Both systems developed the concept of macros so that commands or menu selections could be edited into handy user-written protocols that could handle repetitive tasks quickly and with minimal interaction. For example, the analysis of a particular study is almost always performed in a routine fashion. It was obviously tiresome to type in all the commands or menu selections for that analysis everytime so that a macro programming structure was developed. A macro was a mechanism whereby the computer could be put into learn mode and all the subsequent commands would be recorded into a set that could then be invoked with a simple macro call. Some of these systems had the added advantage that the macros could be created and edited outside of the learn mode.

The windows environment of 1990s computers, with a graphical user interface (GUI), has superseded command and menu interfaces (Fig. 4). It has also led to the elimination of a terminal screen since the early systems needed a text screen where the user made menu selections in addition to the image display screen. Additionally, the screen is of much higher resolution and can be used to display a number of images simultaneously.

Early systems used single-user operating systems which, in the 1980s, developed into multi-tasking systems. These so-called multi-tasking systems had some disadvantages in that the types of studies that could be collected simultaneously were restricted. One could not, for example, expect a multi-tasking system to be capable of collecting two dynamic studies simultaneously, since one data acquisition port had to be given priority over another and data would be lost if two dynamic studies were attempted at the same time. The trend in the 1990s is to use a data acquisition system that is separate from the image processing and analysis system. Only when the data have been acquired are they transferred to the processing and

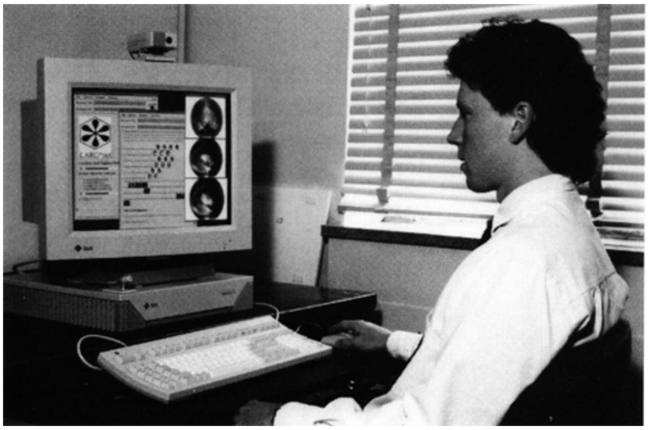

FIGURE 4. Full Windows environment system. The "pizza box" under the monitor is far more powerful and contains far more memory, both RAM and disc, than any of the previous systems shown.

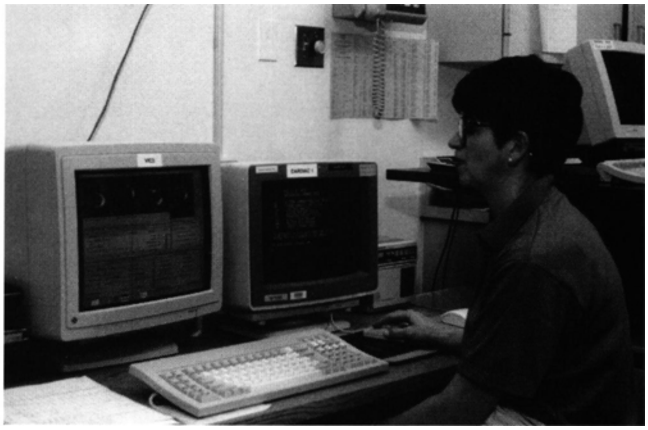

FIGURE 5. Two computer systems are depicted here. On the left is a modern system using the windows interface and the operator is using a mouse to select operations. On the right is the screen for an older, but much modified, GAMMA-11 in which the command structure still prevails as the user interface, but is integrated into the video display screen. The keyboard in this instance is used for both systems.

analysis stage. UNIX, as one example of an open operating system, is a multi-tasking system but it is certainly not renowned for its real-time acquisition capabilities. As such it cannot be used for several high-priority tasks and certainly cannot be used to collect data from several devices simultaneously.

Software languages have evolved over the years. Early systems used BASIC as a programming language; the first GAMMA-11 used a similar language called FOCAL. Later FORTRAN was adopted and a large number of users were able to augment the capabilities of their systems using software interfaces provided by the manufacturers for FORTRAN or FORTRAN-like languages. One or two companies developed their own brands of what were basically standard languages and other languages such as FORTH and PASCAL were used. The common language of the 1990s is object-oriented language C, C+ or C++. This does not imply that programs in these languages are any more transportable between machines because the formats used by the different manufacturers for data storage and display still differ with the result that programs still require vendor-specific software interfaces to access the data.

Another interesting aspect is the marketing position taken by vendors. Early stand alone systems were developed either by computer companies (e.g., Digital Equipment Corporation, Hewlett Packard) or by software houses (e.g., Medical Data Systems, ADAC) who built their systems around general purpose machines with real-time operating systems. To their credit, some of these systems, albeit considerably upgraded and in vastly different reincarnations since their first introduction, are still in operation today (Fig. 5).

By the late 1970s and early 1980s the camera manufacturers had recognized that this was a market niche in which they could also compete so they began to build proprietary hardware and integrate it into their camera systems. This change of marketing strategy took place at the same time as microelectronics enabled the on-line correction of uniformity and, later, energy and linearity correction. Although some cardiac tomography had been achieved using multiple pinhole collimators (*8*), the early SPECT systems based on rotating camera technology came to the market at this time (*9*). The computer was needed not only to reconstruct the image but to control the movement of the camera, causing the natural integration of the camera and computer electronics.

One serious consequence of this marketing strategy was that users found it difficult to purchase both a good camera and a good computer. A manufacturer was recognized as either marketing a good camera with a poor computer or vice versa. Also, because the systems were proprietary, the purchaser was at the mercy of the vendor when it came time to consider options or upgrades. Because special, low-production volume interfaces were needed for such peripherals as disc and magnetic tape drives, they were far more expensive than the equivalent devices for general purpose computers.

In the 1990s this trend has changed. Most vendors recognize that they cannot be good at both camera and computer development. In addition, users are demanding that systems from different vendors interface with each other. There has been a major shift towards open systems that can take advantage of networks and lower cost hardware. An open system is one where, theoretically, software can be transported between different hardware platforms and is no longer vendor specific. At least one vendor is making a move towards adopting what one might almost call an open system image processing software package to which they are adding their own enhancements for nuclear medicine applications. In this case, the user will probably be free to choose competitively priced hardware to run the software.

Nuclear medicine software developers and users capable of programming their own systems have always been quick to exploit the potential of new computer developments and increased CPU power. In the 1980s CPU power was augmented by array processors (*10*) which accelerated SPECT reconstruction and filtering. Three-dimensional surface and volume-rendered images of organs, such the heart and brain, are good current examples of the exploitation of CPU memory and speed. The high power of present day workstations is enabling visualization of these three-dimensional images in a number of useful ways together with tomographic images from other modalities such as CT and MRI to facilitate correlative imaging (*11*). However, the same exploitation took place in the mid-1970s when Alpert, et al. (*12*) first described a method for acquiring camera data using the R-wave of the patient's ECG to trigger or synchronize the data collection so that a large number of heart beats could be visualized as one, and the actual motion of the heart wall could be observed. This was quickly followed by improved techniques described by Strauss, et al. (*13*) and Bacharach, et al. (*14*). Until this time nuclear cardiology had been restricted to either first pass studies or to visualization of the myocardium over many heart beats with the data being smoothed by the motion of the heart. Gated synchronous acquisition of multi-gated acquisition acted as a stimulus to the computer industry and marked the beginnings of nuclear cardiology as we know it today. Wall motion studies are less popular now than in the 1970s and 1980s, but this is probably due to the fact that SPECT and gated SPECT can give so much more diagnostic information.

Following the successful use of computers and computer technology to correct the nonuniformities inherent in the Anger camera design, several attempts have been made to carry this a stage further and to use the power of the computer to correct images for scatter and attenuation (*15,16*) by collecting data from several energy windows rather than one. The earlier attempts based purely on the energy spectrum of the acquired data do not seem to have been entirely successful. In the 1990s attention seems to have been focused more on the use of line sources to provide transmission data from which some deductions can be made about the attenuation within the patient (*17,18*). Many of the camera/computer systems exhibited at the annual meeting of the Society of Nuclear Medicine in Minneapolis in June 1995 included these additional features and a number of vendors were demonstrating works-in-progress associated with attenuation correction (*19*).

The lower resolution and slower data collection rates of nuclear medicine make it an attractive modality for small and medium enterprises to develop specialized systems which fill a particular market niche at reduced cost. The performance of Mac- and DOS-based computers has improved to such an extent in recent years that a number of small companies are able to offer attractive systems. Although they do not strictly comply with the open systems concept, nuclear medicine systems based on the MS-DOS and Macintosh platforms are becoming more and more popular. They are particularly useful for teleradiology applications, where nuclear medicine physicians can review cases remotely. Some systems are becoming sufficiently powerful that they can not only augment but replace fully functional systems. Todd-Pokropek (personal communication, June 1994) has developed such a low-cost system for use in developing countries and other similar systems are being offered by commercial vendors.

This review would not be complete without some mention of the FDA's influence on the development of nuclear medicine software. In the 1980s the FDA, in response to several reports of software failure on radiation treatment units, introduced regulations that defined software as part of a medical device and therefore subject to approval both for initial release and for all upgrades. Where a computer controls camera movement there is some risk involved should that software fail. The mechanics can be designed to act in a fail safe fashion to minimize the risks. Software used for image processing and analysis is subject to assessment by the nuclear medicine physician before issuance of a diagnostic report. The risks to the patient are extremely small and are assumed by the physician as soon as he or she signs the report. One consequence of the FDA's software approval process has been that software development has become very costly and time-consuming. In much the same way that the control of radiopharmaceutical development has stifled the development of nuclear medicine, so has the control of nuclear medicine software.

A different initiative was taken in Europe. Rather than give responsibility for the quality of software to government agencies, a project was initiated under the Cooperation On Science and Technology (COST) program. The COST-B2 project is user-driven and has developed a number of procedures to allow the quality assessment of nuclear medicine software using software phantoms in several clinical areas (renal, cardiac, bone, brain). One of the outcomes of the COST-B2 project has been the development of the Interfile format for nuclear medicine file exchange and, although not intended for this purpose, this has been used extensively by vendors networking to foreign systems. One consequence of this approach is that the regulation of quality control of computer software has remained in the hands of users rather than government.

The future holds much promise though some avenues of development appear to be stifled by marketing policies. Now that many departments have installed local area networks, the next logical step is for nuclear medicine computers to be interfaced in some way to the hospital admissions and discharge system, so that patient demographics do not need to be re-entered in nuclear medicine. An extension of the same philosophy is to interface order entry and results reporting systems as they are developed so that nuclear medicine studies can be scheduled promptly and the physician reports can be provided to the referring physicians in a timely and attractive manner. Unfortunately development of these interfaces is slow. One possible explanation is that the nuclear medicine computer vendors have few commercial relationships with the vendors of radiology and hospital information systems. There is little motivation for them to partner in such ventures. Those companies that do participate in such developments will probably gain a significant advantage over their competitors in the area of health information networks.

More and more nuclear medicine departments are gaining access to the Internet. In doing so they are finding that their more generic open systems computers can be used to access the resources that exist on that medium and are able to take advantage of the huge amount of educational material that is available from all corners of the globe (*20–23*). There will be more sharing of resources and already a number of nuclear medicine physicians are using the Internet to exchange studies for consultative purposes.

What does the future hold and where will we be in another 25 years? It is dangerous to consult any crystal ball regarding computer technology for even a one-year projection, let alone 25. However, some developments that might be predicted with reasonable confidence are that we will see greater deployment of open systems and networking and integration of nuclear medicine systems with hospital information systems. We are already seeing the application of artificial intelligence and neural networks to nuclear medicine problems (*24–26*). Can we expect that virtual reality will allow us to explore the internal structures of the organs which we presently view externally? There is one thing of which we can be certain—nuclear medicine will continue to provide the vision of what can be achieved.

ACKNOWLEDGMENTS

Early draft versions of this manuscript were reviewed by a number of colleagues and I would like to acknowledge their considerable assistance in helping to jog my memory and improve the content. As past editor of the *Journal of Nuclear Medicine Technology*, Sue Weiss has been very generous in providing valuable input. Others who have contributed useful discussions include Cor Posch, Stephen Graham, Ellinor Busemann Sokole, Jon Erickson, Piotr Slomka.

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