Computers

Nuclear Medicine Computer Systems: A Buyer's Guide to Current Performance and Future Promise

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Computers, formerly regarded as research tools, are attaining increasingly wide clinical use in nuclear medicine. Physicians and technologists who wish to purchase computer systems are usually inundated with confusing and sometimes contradictory specifications by salesmen and manufacturers. Relatively few of these data, however, are important in determining whether a given computer can perform the functions for which it is required at a reasonable speed. These critical specifications are defined and their pertinence to the cost-effectiveness of various computer systems is discussed. Likely developments in computer design and construction during the next few years are also described.

Over the past 15 years, during which digital computers have been applied to various problems in nuclear medicine, enormous changes have been wrought by advancing technology on both the computer and the nature of its applications. Improvements in electronic construction and production have greatly increased both the speed and the power of computers, while enormously decreasing production costs. Nuclear medicine physicians and technologists have lost little time in applying these advantages to their own ends to solve even more complicated problems. In the face of competition from x-ray computed tomography (CT) and ultrasound, many departments have pressed onward into studies, often involving computers, designed to make use of the matchless ability of tracer materials to provide clinically useful physiologic data not derivable from anatomic displays.

Why Buy a Computer?

At the same time that new procedures such as multiple-gated cardiac imaging (*1,2*) and renal perfusion/excretion determinations (*3*) have been devised, some of the older computer applications such as regional pulmonary function quantitation (*4*), renography (*5*), and first-pass radionuclide angiocardiography (*6*) have attained wide use throughout the academic medical community. The computer's increased utility has led many medium-sized nonacademic hospitals to investigate purchase.

Numerous equipment manufacturers have responded to this interest by developing and marketing digital data-processing devices with a bewildering variety of prices and capabilities. Nuclear medicine physicians, hospital administrators, and technologists are beset by competing claims and counterclaims from salesmen and manufacturers, as well as by their inexperience with electronic data processing. They must choose wisely from the array of equipment and services offered lest they buy equipment which is obsolete before it is delivered or insufficient for future applications. At the same time, they should not acquire much more computer power than needed, since, despite decreased cost-per-unit capability, computers are still quite expensive and become obsolete—as computers, though not necessarily as data processing tools—quite quickly. Deciding which computer system to buy is often difficult, especially since data-processing devices are available in such variety and at so many price levels.

Hard-Wired Versus Programmable Processors

At the outset, there are two major types of digital data processors available for connection to radiation detectors (most often, to scintillation cameras, but occasionally with provisions for data collection from probes, scanners, and physiological signals). "Hard-wired" data processors are usually built and sold by scintillation camera manufacturers. These units are designed for their own equipment and cannot be connected to other cameras. Hard-wired processors can be quite capable (and as expensive as medium-priced digital computers), but are ultimately inflexible. They do what they are wired to do but little else. In order to upgrade their capabilities, these units must be redesigned at great expense. However, they do perform their dedicated tasks very efficiently and thus may be

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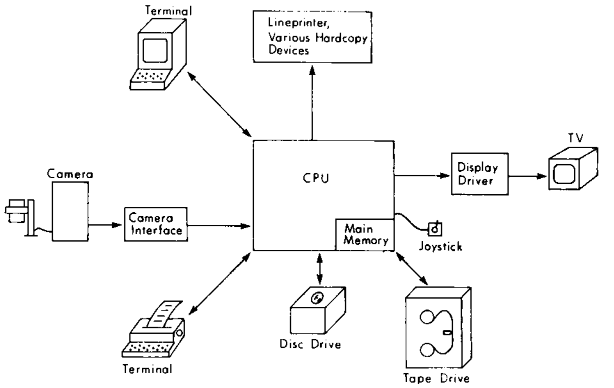

FIG. 1. Hardware components for the nuclear medicine computer system.

valuable in larger nuclear medicine departments, which can use them to process large numbers of routine studies, reserving the programmable computer for more complex applications. Small departments, on the other hand, usually benefit more from minicomputer systems, which can be expanded to fit later needs.

"General purpose" digital computer systems are far more flexible than hard-wired processors but are also more prone to breakdown and frequently more expensive. Unlike hard-wired machines, these computers can usually be attached to any variety of cameras with minimal modification. Also, any computer with the right attachments can accept data from probes, ECG machines, or almost any other electronic equipment.

Hardware + Software = Computer System

Digital computer systems consist of a central processing unit (CPU) attached to a "main memory" (also loosely called "core" after the most common form of electronic memory device). The CPU is also attached to many other electronic modules called "peripherals," which perform various functions necessary to acquire, store, process, and then display and print data so that results may be interpreted.

In addition to the machinery that does the actual work, i.e., the "hardware" (Fig. 1), every computer is supplied with numerous programs (sets of instructions which tell the hardware what to do)—generically called "software"—which control data manipulation. Together, hardware and software comprise the computer system; one is useless without the other. Furthermore, it is possible to buy marvelous hardware with inadequate software—or vice versa. Either of these is a bad deal; however, any department with access to high-quality computer programmers can develop its own software, given good hardware and assuming it is willing to pay the price in delays, costs, and aggravation. It is absolutely essential to consider the capabilities of any nuclear medicine computer system as a whole (hardware + software) when determining if it will be adequate for department needs.

Evaluating: Critical Specifications

Unfortunately, the amount and types of hardware and software supplied with nuclear medicine computer systems vary enormously not only from manufacturer to manufacturer, but even within a single product line. Furthermore, most suppliers stock several varieties of each type of peripheral device (e.g., two kinds of display and three types of lineprinter) at different levels of cost and capability. Each peripheral must, of course, have programs designed to run it for the benefit of the computer system and its users; these programs usually vary according to the type of peripheral supplied. Hence, the ability of the computer system to perform a particular operation often depends entirely on the presence of the correct set of individual peripherals. For example, gated cardiac images cannot be displayed in movie form unless the TV display attached to the computer has sufficiently fast data transfer rates to permit flicker-free presentation of the images—a specification usually buried in the depths of the manufacturer's system support literature.

Obviously, numerous pitfalls await the buyer of nuclear medicine computers. Fortunately, computer systems do fall into several general categories of price and power, within each of which most system hardware and software configurations are quite similar. Also, relatively few of the megamultitude of specifications are truly helpful in distinguishing one computer from another. The rest are distracting, and often misleading to the physician, administrator, or technologist unversed in "computerese."

Nevertheless, by following a sound strategy, the computer buyer can almost always assure himself of buying an adequate computer at a fairly reasonable price. The discussion of the following principles is based on six months of hard labor. I was charged with the unenviable task of gathering sufficient data to assure a quasi-intelligent decision about purchasing a large-scale scintillation camera computer system. These principles should be useful for buyers of less ambitious equipment as well.

Hardware Specifications

Central Processing Unit. The first group of key specifications relates to hardware capacity. By far the most important of these is the type of CPU provided. Most nuclear medicine computers are based on "minicomputer" CPUs; though some "minis" work faster than others, all of them are much swifter than "microprocessors," which are almost always found in low-cost computer systems. In my opinion, the latter are presently not sufficiently less expensive than minibased computers to justify the inconvenience imposed by their lack of speed, but they are a boon to the budget-strapped.

TABLE 1. Typical Specifications of Mass-Storage Devices

Type	Capacity (16-bit words)	Transfer Rate (words/sec)	Time to Access Data (Avg)	Cost
Floppy disk	256,000	25,000	0.2–0.5 sec	$1,000–2,000
Single-density hard disk (single platter)	1.17 million	92,000	0.06 sec (60 msec)	~$5,000
Double-density hard disk (single platter)	2.34 million	156,000	0.035 sec (35 msec)	~$8,000
(Double platter)	4.68 million	156,000	0.035 sec	~$9,000
Multiplatter floor-mounted				
Multiplatter floor-mounted disk	10–186 million	312,000	0.020 sec (20 msec)	$15,000–50,000
Tape drives 25 IPS 800 BPI	Depends on tape length 12 million/2400 ft	10,000	minutes	~$7,500
45 IPS 1600 BPI	Up to 24 million/2400 ft	36,000	minutes	~$15,000

The prospective buyer should be aware that the longer a particular type of CPU has been produced, the more likely it is to be superseded by an improved version, and when that occurs, it may become difficult to get service and parts for the old model. The newest CPUs, however, may not be completely debugged!

Main Memory. Main memory size is important and computer main memory is sufficiently inexpensive so that most manufacturers supply at least 32k words (not "bytes," each of which is half a minicomputer word or 8 bits) of main memory with every CPU. Less than 32k—but never less than 16k—may be acceptable on small-scale systems.

Mass Storage: Disk and Tape. Mass storage capacity and speed are extremely important, since these determine both the maximum count rates in list mode acquisition (used for radionuclide angiocardiography) and the total amount of data, in list or frame mode, which may be stored. Access speed also determines how easy and pleasant the system is to use, since long waits for simple procedures can be most frustrating to the operator. Virtually all computer systems use magnetic disk for most mass storage. A few use "floppy disk" or "diskette" storage, which is far less capacious and much slower than "hard disk," but also less expensive. Both are faster than magnetic tape, which is almost never used as the main mass storage device on modern computer systems. Since a single tape can hold several hard disks of data, it is therefore most useful for archival storage of image data and programs.

Hard disks vary in size, capacity, and price, depending on amount of storage and speed of data access. Most manufacturers now offer both "regular" and "double density" disk drives (note that the drive determines capability—the magnetic disk cartridge itself is the same). Of the two, double density is preferable, having twice the capacity (typically 2.34 million words per platter compared with 1.17 million words) at slightly greater cost. Double-density drives are also usually faster. Drives are available with a fixed platter in addition to the removable cartridge; these are usually a bargain compared to single-platter disks. Larger disk drives (i.e., the floor-mounted monsters found in large-scale computer systems) are not worth the noise, space, and expense, except for unusual purposes. In general, nuclear medicine computer applications require a minimum of two disk drives (for insurance, if no other reason) with a total capacity of at least 2.34 million words. More storage will be necessary for long list-mode recordings, although at low count rates, tape can sometimes be used for this purpose. Rarely will more than 10 million words of disk storage be necessary under any circumstance.

Tape drives are specified according to reel-size accepted, data density written and read, and speed of linear motion of tape past the read–write head(s). Except on extremely small-scale systems, tape drives which will not accept full-sized (12 in.) reels should be avoided if possible. Also, the faster the tape moves past the heads, the less time is spent in searching for and retrieving data. Virtually all drives offered with nuclear medicine systems have normal density of 800 bytes per in. (BPI). A few more expensive drives will pack 1,600 BPI, taking half the length of tape-per-unit data. However, such units are quite expensive and usually unnecessary, except for long list-mode recordings. Table 1 lists representative specifications for various mass storage devices.

Camera Interfaces and Video Displays. Two peripherals essential for nuclear medicine computers are the camera interface, which converts x- and y- pulses into digital data, and the video display. The most important specification of the interface is that the maximum count rate is accepted in both list mode and frame mode. Virtually all interfaces will handle more than 100k counts/sec in frame mode; the list mode data rate is usually limited by disk access speed (about 30k counts/sec with single-density drives; more than 50k counts/sec with double density). The time resolution in list mode should be at least 10 msec per time marker. Some manufacturers' interfaces have time resolutions which decrease with count rate—an undesirable situation for equilibrium gated cardiac imaging but one an astute programmer can easily overcome. The spatial resolution of the interface should ideally be 1/256 of camera-face diameter, but 1/128 is acceptable.

Virtually all of the video displays currently offered contain internal memory enabling them to display images without flicker. Standard oscilloscope and storage-scope displays are obsolete and should be avoided. The resolution and speed of the display may be important if cine presentation is needed; in general, the best way to evaluate this is to observe a cine display in action on the unit in question, as the specifications themselves are meaningful only to computerholics. The resolution of the display, if 128 × 128 pixels (individually addressable dots) or greater, is not critical.

Most of the display units will drive color monitors, which are more expensive than black and white, and also more effective visually. With these, however, it is essential that the user be able to set the color table (determining which color represents each level of activity in the image) quickly and easily with an acceptable (i.e., 16 or more) number of shades of each primary color. Virtually all currently available color- or gray-scale displays will show only 16 different color or gray levels in an image. This is adequate for most applications, although 32 or 64 levels do improve the visual resolution of the count data in the image (at the price of accentuating statistical variation). In addition to the display, most systems include a joystick or a lightpen for selecting regions of interest. Which of these is more desirable is a matter of personal preference, but most of the users I have polled find the joystick easier to use.

Terminals and Other Printers

The terminals supplied with the system can make a large difference in its utility. The console (or foreground) terminal—which is used to start up the system and run data collection—ideally should be a video display unit. It is silent, features a very high data display rate (messages appear instantaneously), and is usually more compact than printing terminals.

A good second choice is the electrostatic printer terminal, although the paper it requires is expensive. Impact printing terminals are noisier and larger than the preceding but will print on any kind of paper. Most other printing terminals and most lineprinters (excepting electrostatic printer-plotters) are too bulky and noisy for the usually cramped subterranean nuclear medicine department. The data transmission speed of any terminal should not be critical as long as it is greater than 30 characters/sec ("300 baud"). At least one printing terminal or printer-plotter should be ordered with any system to provide hard copy of calculation results and programs.

Software Specifications

So much variation exists in the software and its applications in nuclear medicine computer systems, that it is virtually impossible to formulate meaningful specifications regarding purchase. The computer buyer must assure himself that the programs supplied with the hardware will perform all of the procedures needed for his department and that his staff can add to or modify software without unreasonable effort. Since software is often modified to fit a department, there are a number of programming facilities which, if present, will make life much easier for applications programmers. The operating system (those programs that control the operation of the computer hardware and monitor the execution of applications programs) under these circumstances should support more than one computer language—preferably FORTRAN and one other (I prefer BASIC, though others might disagree)—with access to image and time-activity curve data via subroutines callable in either language. A powerful editor, to enable easy entry and correction of programs, is another necessity. Interactive debugging software, which enables slow execution of programs to make error identification easier, is also a very desirable feature. Certainly if the operating system allows more than one user access to the system (foreground-background operation), the programmer will not be interrupted by routine studies, and will, therefore, be happier and more productive.

Several other software considerations can materially influence the system's utility. If it is possible to chain the programs normally used for data collection and processing during a routine study into a predefined protocol, then most routine procedures can be set to require a minimum of operator interaction, minimizing errors and maximizing throughput. Also, if the questions asked of the operator by the applications programs are easily understood by persons uneducated in computer terminology, it will be easier for the department to train

TABLE 2. Examples of Typical Data Processing Systems

Type	CPU	Main memory	Mass storage	Display	Cost
Hard-wired	Microprocessor	Variable	Tape or diskette	B & W or color	$30,000 50,000
Microprocessor-programmable	Microprocessor	16–32k	Diskette, tape optional	Color	$30,000–50,000
Minicomputer (small system)	Minicomputer (Nova, PDP-11 PDP-8, et al.)	16k	Single-density hard disk (1 or 2 drives), tape optional	Color	$45,000 60,000
Minicomputer (medium system)	Minicomputer	32k	Single- or double-density hard disk, tape optional	Color	$53,000 80,000
Minicomputer (large system)	Minicomputer	32k	Double-density hard disk (2 drives) with tape	Color	$80,000 100,000

and retain computer operators. Protection of data and programs from accidental erasure can never be made entirely foolproof, but the stronger the safeguards provided, the better.

An important part of the software, but one which is sometimes neglected, are the manuals for the operating system and applications programs. If they are well written and accurate, the computer will be far easier to operate. All too often, instructions are either incomplete or too infrequently updated to cover changes in the software. Though this point may appear minor, errors in manuals can easily cause dangerous mistakes in interpretation of results, as well as unnecessary loss of data and programs.

The Bottom Line

Clearly, determining which computer system to buy involves a complicated series of decisions concerning which features are most desirable and cost effective for the nuclear medicine department. Often, desires are constrained by a tight budget; in every case, cost-effectiveness is paramount. Manufacturers have simplified the decision somewhat by providing system packages at several cost levels (Table 2). At the lowest price is the microprocessor-based computer, which usually uses floppy disk for mass storage. This type of system runs slowly and may not perform gated cardiac imaging or other complex tasks, but is adequate for many other studies performed in a small, low-volume department.

The next step up is the basic minicomputer system, starting with a single cartridge disk and 16k of main memory, and working up to two disk drives and magnetic tape. Such a system will not support foreground-background operation, and unless main memory is expanded to 32k, will not perform gated cardiac imaging. However, the basic minicomputer system will efficiently perform other less complicated tasks adequately for a moderate-sized department, without the delays and inconveniences of the microprocessor system.

At the high end of the cost scale is the large minicomputer system, with two or more single- or double-density disk drives, often with magnetic tape drive, 32k of main memory, two terminals, and printer-plotter, etc. Such systems are best suited to large nuclear medicine departments, in which the increased throughput of studies via foreground-background operation can more than justify the greater start-up expense of the system. Such computers are also best for development of new applications software, and can also provide general-purpose computing facilities (i.e., billing, radiopharmacy management) for the department, as can smaller computers if they are not heavily used for clinical applications.

Computer Buying Strategy

Once the computer buyer has decided which size computer he is looking for—and which applications most appeal to him given his clinical interest and the population of physicians and patients he serves—he must then decide which manufacturer offers him the best system for his purposes. The strategy I used was first to gather brochures and price lists from all manufacturers, and then to eliminate all computer systems which were too expensive or insufficiently powerful. The eight remaining units from three manufacturers were graded according to the criteria already described. Then, representatives from each manufacturer were invited to make presentations to me, the chief of nuclear medicine, and two dispassionate and skeptical observers from the local data-processing community. Price quotes were solicited from the manufacturers for each acceptable system.

Next, after obtaining and studying software manuals, I traveled to a site where a representative system of each manufacturer was in use. In addition to invaluable

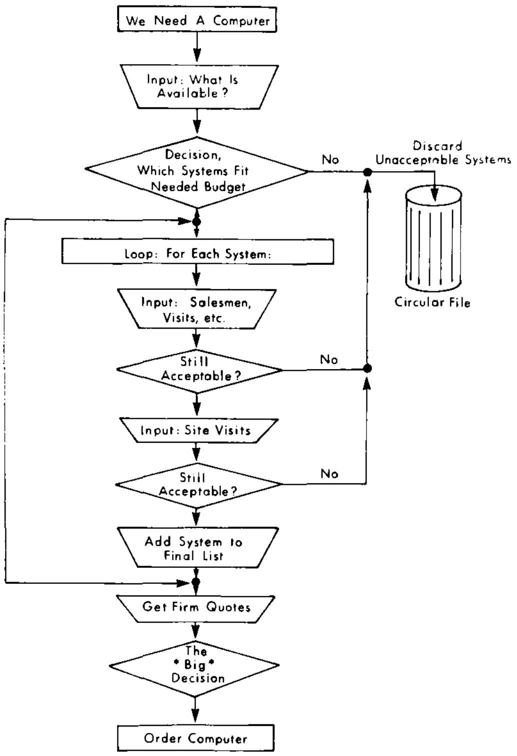

FIG. 2. A decision-making strategy for considering the purchase of a nuclear medicine computer system.

hands-on experience, priceless information about reliability, quality of service, and ease of use was gathered from these sites, and from other users known to the members of our department.

Using this information, as well as the expected delivery dates quoted by the manufacturers and the availability and quality of local service, the systems were regraded. After considerable (and occasionally heated) discussion, the decision was made. The sequence of events thus described is similar to that involved in the purchase of any large and expensive piece of equipment, with a major difference—the involvement of several individuals outside the department with general data-processing experience, whose aid and insight proved invaluable. The site visits also had considerable impact on the decision, inasmuch as a number of shortcomings of each system not evident from the manuals were discovered. The procedures involved in buying a computer system are summarized in Fig. 2.

Summary and Future Prospects

Deciding which nuclear medicine computer system to buy requires a knowledge of the important hardware and software specification of each potentially acceptable unit, the ease of use, availability of service, reliability, price of units from each manufacturer, and most important, the data-processing requirements of the nuclear medicine department. Many of these factors are quite mutable, especially where they depend on rapidly changing technology. Computer power per unit price has increased astoundingly over the past 5 years, and may advance even more if but three of the newest developments in the computer industry take hold. Microprocessor design, in fact, has had revolutionary impact on the low-cost end of the industry; if these "computers on a chip" become adequately fast, they will significantly decrease the cost and increase the power of nuclear medicine systems. Recent advances in production of cheap, high-speed semiconductor main memory will undoubtedly cut computer prices, but, more important, will bring large-computer power within the financial reach of many nuclear medicine departments. The most exciting prospects, however, lie in mass storage technology where "magnetic bubble memory," a semiconductor storage device, promises high data capacity at remarkably low cost and at access speeds equivalent to the fastest disk currently available. This development is most likely 3–5 years away from production, assuming that all of its present shortcomings can be corrected. Other feats of technical wizardry will undoubtedly influence computer buyers' decisions over the next decade. The computer systems described above will remain quite sufficient to perform studies and derive physiologic data for the nuclear medicine departments and the clinicians they serve.

References

1. Bacharach SL, Green MV, Borer JS, et al: A real-time system for multi-gated cardiac studies. *J Nucl Med* 18: 79–84, 1977

2. Parker JA, Secker-Walker R, Hill R, et al: A new technique for the calculation of left ventricular ejection fraction. *J Nucl Med* 13: 649–651, 1972

3. Degrazia JA, Scheibe PO, Jackson PE, et al: Clinical applications of a kinetic model of hippurate distribution and renal clearance. *J Nucl Med* 15: 102–114, 1974

4. Secker-Walker R, Hill R, Markham J, et al: The measurement of regional ventilation in man: A new method of quantitation. *J Nucl Med* 14: 725–732, 1974

5. Ortiz-Berrocal J, Moreno Gonzalez J, et al: The computer in the functional study of the kidney with radionuclides. In *Proceedings of the Sixth Symposium on Sharing of Computer Programs and Technology in Nuclear Medicine*, Howard BY (ed), New York, Society of Nuclear Medicine, 1976, pp 260–287

6. Maltz DL, Treves S: Quantitative radionuclide angiocardiography: Determination of QP:QS in children. *Circulation* 47: 1049–1056, 1973