tals in the continental states. Nuclear pharmacies emerged as intermediate suppliers as they demonstrated proficiency in dispensing ready-to-use unit or multiple dose radiopharmaceuticals. By centralizing Tc-99m generators and long-lived inventories, pharmacies were able to provide complete services competitively.

Not all developments have favored nuclear medicine. Organs such as the brain and pancreas are better studied by other imaging modalities. Such erosion in nuclear medicine may continue unless new radiotracers are designed that provide unique quantitative and functional information about physiologic phenomena. Although therapeutic applications did not keep pace with diagnostic studies, the future is now bright with the development of radiolabeled monoclonal antibodies for certain neoplasms.

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A Review of Instrumentation 1970–1985

"Change, that is the only thing in the Universe which is Unchanging." —**Helmuth Wilhelm (1905–)**

The past decade and a half has witnessed some profound changes in the technology of nuclear medicine—particularly the instrumentation. Admittedly, this time span does not include the announcement of the Anger scintillation camera (*1*), the introduction of Tc-99m (*2*), or the earliest applications of computers to nuclear medicine (*3*). Nevertheless, those three items—scintillation cameras, Tc-99m tagged radiopharmaceuticals, and computers—have all undergone considerable development and their impact on the practice of nuclear medicine since 1970 accounts for the important role presently played by nuclear medicine in medical diagnosis.

In 1970, a very large proportion of nuclear medicine imaging was performed using rectilinear scanners, and there was considerable debate concerning the merits of scanners versus cameras if one was budgeting for new equipment. This debate was justified by the fact that scintillation cameras did not exhibit spatial resolution much better than good scanners and the uniformity of the field of view was only marginally acceptable.

Unquestionably, the most significant development outside of nuclear medicine that has affected the instrumentation has been the development of large scale integrated circuits or "chips" and "micro-chips." Electronic circuits have become much more powerful, cheaper, and considerably more stable. It is this factor that has enabled manufacturers to progress: from 19 photomultipliers to scintillation cameras with as many as 90 tubes; from scintillation cameras that exhibited poor differential linearity and uniformity to those which have energy and linearity correction built into the detector heads; from scintillation cameras that could accept only 50,000–70,000 cps to those which can respond to 400,000 cps; and from scintillation cameras that gave an analog output on Polaroid film to those which have computers as an integral component of the camera.

The technology of scintillation crystal manufacturing has advanced so that a scintillation camera can have a 16-in diameter, ¼-in-thick crystal compared to 12-in diameter by ½-in-thick. At the same time, more sensitive and stable photomultipliers have been introduced in a variety of shapes and sizes that have provided far better light gathering properties. On the other side of the crystal, the technology of collimator manufacturing has changed considerably and the spatial resolution of collimators can now be made to match the much improved intrinsic resolution of scintillation cameras.

The performance specifications of scintillation cameras improved steadily during the 1960s and 1970s (Fig. 1), but are probably close to theoretical limits now. With sodium iodide

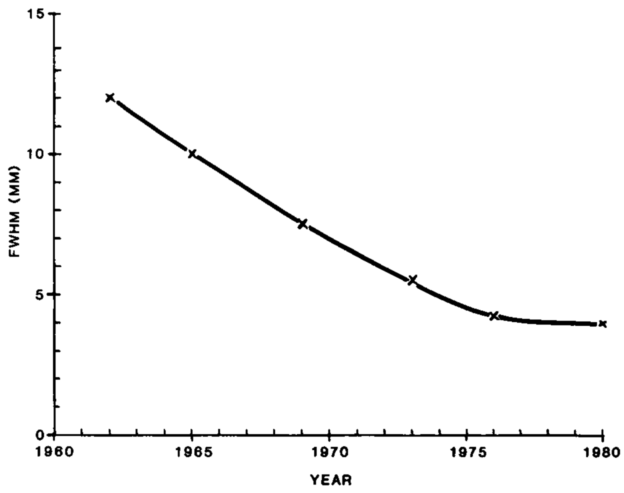

FIG. 1. Intrinsic spatial resolution of scintillation cameras improved dramatically during the 1960s and early 1970s—values are approximate for commercial cameras. It has not improved remarkably since 1980 though intrinsic uniformity has continued to improve with the development of sophisticated linearity correction circuits.

crystals as detectors, it is doubtful if the resolution and count rate capabilities can be extended much further. Uniformity, or, more correctly, linearity, is remarkably good now, but further refinement of energy and position correction circuits will probably see some improvements. Undoubtedly, reliability of scintillation cameras will continue to improve and we can expect to see introduction of more self-test and self-tuning features.

The early use of computers in nuclear medicine was directed at image enhancement (*4*). The pay-off was not very significant and it was difficult to justify an expensive computer to perform contrast enhancement of static images. As Tc-99m compounds were developed and greater use was made of dynamic studies, computers could be justified. It was no longer sufficient to collect the data on a set of "rapidly-pulled Polaroid," or on a pen chart recorder via a ratemeter. The introduction of multigated cardiac imaging (*5*) in 1976 was the final persuasive argument that has justified the introduction of computers to even the smallest departments. Nuclear cardiology, and specifically multigated acquisition of blood-pool studies, cannot be performed without a computer programmed to capture the data.

Just as the design of scintillation cameras has changed because of micro-electronics, so has the design and performance of computers. In the early 1970s, a typical computer used in nuclear medicine would have 64K bytes of core memory, 5M bytes of hard disk storage, no separate display processor (it would be either a storage scope or a live scope refreshed from main memory) and it would be housed in a 6-ft cabinet. Today a typical computer has 256 kilobytes of semiconductor RAM memory, 80M bytes of disk storage augmented by a 1-M byte floppy disk, a separate display processor driving a video color monitor, and it can all be housed in one 5½-in high box mounted in a 30-in cabinet. Surprisingly, the cost of this present-day computer is about the same as its predecessor in 1970!

The software has also progressed enormously. Sophisticated real-time operating systems are now the norm and a vast number of applications programs have become available.

Whereas nuclear cardiology could not have developed without the availability of the computer for data acquisition and analysis, perhaps the most significant confluence of these two technologies, scintillation cameras and computers, has been the development of emission computed tomography (*6*). In this case, the computer is used to control the motion of the scintillation camera as well as collect the data arising therefrom. Although emission tomography (*7,8*) preceded transmission tomography (*9*) by several years, it was only after the recognition of x-ray CT as a valuable diagnostic tool that SPECT received the commercial backing that gave it wider acceptability.

To a very large extent, the development of instrumentation for nuclear medicine is dependent on the marketing whims of the various commercial interests involved. The large investment required to develop new and innovative imaging equipment is beyond the scope of most research granting agencies and requires the existence of a potential market to encourage that investment. The advent of x-ray CT and, more recently, magnetic resonance imaging has discouraged some companies from investing large amounts of research and development funds for fear that nuclear medicine was no longer a viable modality. This fear has repeatedly proven not to be the case and we can all take pride in the fact that nuclear medicine procedures form such an important part of the physician's diagnostic protocols.

Nuclear medicine technologists, in particular, can be proud of their ability to progress with their technology. They have demonstrated an inate capability to "keep up with the times," to learn how to use computers to advantage, to develop appropriate quality control procedures as new technologies have emerged, and to cope with the greater complexities that new equipment, new pharmaceuticals, and new procedures have thrust upon them. There is little doubt that the next 15 years will also witness some significant developments in our field and I have every confidence that the professionally motivated nuclear medicine technologists who belong to our society will continue to adapt to meet those challenges.

'Tempora mutantor, et nos mutamor in illis.'
—Times change, and we change with them.
—Emperor Lothar I (795–855)

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