

Report of the Inter-Society Commission for Heart Disease Resources: Optimal Resource Guidelines for Radioactive Tracer Studies of the Heart and Circulation

S. James Adelstein, Chairman, Carl Jansen, and Henry N. Wagner, Jr.

The status of radioactive tracer studies in cardiovascular diagnosis is summarized. Planning guidelines are suggested for a hospital nuclear medicine service including a central nuclear medicine facility and satellite units, and resource criteria are given for professional personnel including training and duties, equipment, space, and support systems. The administrative organization of a nuclear medicine service and case loads are discussed. Guidelines for equipment maintenance and quality controls are described.

Radionuclide techniques are of growing importance in the field of diagnostic cardiology. Among the earliest noninvasive procedures for obtaining quantitative physiologic information about the cardiovascular system, they currently provide diagnostic data unavailable by other means—such as measurements of regional blood flow—as well as important information supplementary to hemodynamic and angiographic examinations during cardiac catheterization.

An increasing number of community hospitals have established nuclear medicine facilities or are in the process of doing so. The *convenient availability* of such facilities is, in fact, a requirement of the Joint Commission on Accreditation of Hospitals. There are 1,700 physicians in the United States certified as specialists in nuclear medicine and many others are using radioactive tracers as part of the diagnostic process. Radioactive tracers play a role in the care of approximately one out of every three hospitalized patients and in the next few years at least an equal number of outpatients will also be candidates for such examinations. This report is an overview of the status of cardiovascular radionuclide diagnostic studies and a guideline to the hospital resources, both physical and human, required for a nuclear medicine service of high quality.

In a previous statement (1) we outlined resource specifications for two nuclear medicine examinations, regional pulmonary perfusion and blood pool imaging, and we anticipated the development of two others, regional myocardial perfusion and regional pulmonary ventilation. In this guideline we report on 11 categories

of nuclear cardiovascular examinations. Some, such as central nervous system (CNS) and renal studies, relate to standard techniques for determining the state of the peripheral circulation, but other procedures have only recently become clinically possible. Many applications, while extremely promising, are still investigational and at present occupy an intermediate stage between early clinical testing and broad clinical or routine use. A few, such as acute myocardial infarct scanning, are embryonic but, considering the pace of trial and acceptance in this field, they too may soon be in widespread use. The particular examinations included in these guidelines are, in our judgment, those most likely to have an impact on patient care.

We have also reviewed, updated, and expanded our resource guidelines for organizing a hospital nuclear medicine program. The space, equipment, and manpower requirements will provide services for *all* kinds of diagnostic problems, not only those associated with cardiovascular diseases. In large institutions with heavy cardiac case loads, special cardiovascular nuclear units may be both medically and economically practical. We also propose training qualifications for the professional and technical staff, appropriate case loads and utilization levels, methods of quality control, and procedures for protecting the safety of both patients and staff from excessive exposure to ionizing radiation.

These resource guidelines are directed to technologists, physicians, and hospital administrators responsible for planning and organizing nuclear medicine programs who anticipate either current or future needs for such services in their community. It is assumed that the selection and use of these procedures will be the joint responsibility of a nuclear medicine specialist and one or more cardiologists who accept the obligation to keep abreast of advances in this rapidly

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For reprints contact: Irving S. Wright or Donald T. Fredrickson, Inter-Society Commission for Heart Disease Resources, Suite 316, 44 E. 23rd St., New York, N.Y. 10010.

changing field, particularly with regard to instrumentation and methodology.

Syllabus of Cardiovascular Radionuclide Procedures

Radiocardiography. Single crystal, simply collimated, and portable radiation detectors or *probes* can be used for the determination of cardiac output, transpulmonary transit time, and ejection fraction. Determination of cardiac output by the radioactive indicator dilution technique requires measurement of the blood volume, and measurement of the change in arterial or cardiac blood concentration of a radioactive tracer as a function of time after its injection into the circulatory system. Measurements are made by direct arterial sampling or by external monitoring of a vascular pool, usually the heart itself. Tracers include radiolabeled albumin, transferrin, or red blood cells. Indium-113m and ^{131}I require greater shielding than $^{99\text{m}}\text{Tc}$.

Radioisotope tracers have not been used commonly for measuring cardiac output during catheterization procedures because they offer no significant advantage over nonradioactive tracer dyes, which can be accurately measured spectrophotometrically. They are, however, most appropriate for this purpose in conjunction with other radiotracer studies such as radionuclide angiocardiology, and their short physical half-life facilitates serial determinations.

Transpulmonary transit time measurements, the oldest of radiotracer measurements of the circulation, can be made by positioning the detector so that the activity from both ventricles is recorded. The cardiopulmonary activity can be instantaneously displayed in analog form on a strip chart recorder or continuously recorded on magnetic tape or directly into a computer. When both cardiac output and transpulmonary transit time are measured, the pulmonary vascular volume can be estimated.

When the ventricular activity is recorded on magnetic tape or directly into a computer, the left ventricular ejection fraction can be estimated from analysis of the first-transit time-activity curve.

The external detector probe can also measure the activity in an area of the lungs and thus can estimate the size of left-to-right intracardiac shunts from the pulmonary time-activity curve generated by an intravascular indicator. It can also estimate the size of peripheral arteriovenous shunts from successive arterial and venous microsphere injections. The instrument has proven useful for the bedside evaluation of cardiopulmonary disorders.

Radionuclide angiocardiology. In radionuclide angiocardiology, the scintillation camera is used to depict the course of an intravenously injected radiopharmaceutical as it passes through the heart and great vessels. Although the structural detail is far inferior to

that of contrast angiography, useful information concerning cardiac anomalies, intracardiac shunts, valve positions, chamber size and location, pericardial effusions, and aneurysms and coarctations of the aorta can be obtained. In addition to providing a graphic display of the passage of a bolus through the heart, great vessels, and lungs, the use of the scintillation camera with computer capabilities permits selection of areas of interest, such as the right and left ventricles, and display of regional time-activity curves. These curves provide quantitative information such as the transit times between various points in the circulation and the magnitude of intracardiac shunts. If the recording system has adequate resolution, the stroke volume and ejection fraction of the ventricles can also be calculated.

Technetium-99m-labeled albumin or red blood cells are the preferred tracers. Per technetate, which is commonly employed, is less desirable since it diffuses rapidly out of the vascular compartment.

Cardiopulmonary activity can be continuously recorded on film, on magnetic tape, or directly into a computer, which is required for quantitative work.

The technique is helpful in the diagnosis of congenital and acquired cardiac and pulmonary conditions and, when done with a portable camera, has proven useful in bedside evaluation of cardiopulmonary function.

Ventricular wall motion and performance. A number of methods have been introduced recently for the study of ventricular performance and regional wall motion. As stated previously, ejection fraction can be measured with a nonimaging detector, but evaluation of ventricular wall motion requires a scintillation camera. Usually, the scintillation camera is activated (gated) to record images only during selected portions of the cardiac cycle. Technetium-99m-albumin or ionic $^{113\text{m}}\text{In}$ are commonly used since these tracers remain within the vascular compartment. Technetium-99m-red blood cells are preferred by some. Both right and left ventricular function can be determined. Serial studies are possible since the technique requires only an intravenous injection.

Simple inspection of the end-systolic and end-diastolic images of the two ventricles in the 45-deg left anterior oblique position often permits estimation of the ejection fraction of each ventricle and the detection of regional contraction abnormalities. Other views, such as the anterior, are often helpful. Alternation of end-systolic and diastolic images on the same viewing screen facilitates perception of hypokinesis, akinesis, and dyskinesis.

Quantification of end-diastolic volume and ejection fraction can be accomplished by geometric projections of ventricular contours using formulas developed for contrast angiography or by analysis of time-activity curves in the flagged area of the left ventricle.

The timing of the events of the cardiac cycle (gating) is usually obtained from the electrocardiogram, al-

though the carotid pulse or the phonocardiogram can also be used. An alternative to gating the scintillation camera is the continuous recording of both cardiac radioactivity and the electrocardiogram on magnetic tape or directly into a computer. Subsequently, the activity at various regions and phases of the cardiac cycle are selected for data processing and display. Usually an image of the tracer distribution is obtained at 0.1-sec intervals during a specific fraction of the R-R interval. Images obtained during the same time intervals after the R waves are summed until 200,000 or more counts have been recorded during systole and diastole. The end-systolic and end-diastolic images are usually recorded in both the left anterior oblique and the anterior position, and each position requires separate recording intervals of perhaps 10 min each. Multiple images of greater frequency throughout the cardiac cycle can also be formed by specially programmed computers. It is essential that the patient lie absolutely still during the data recording.

An important use of these procedures to date has been to differentiate diffuse hypokinesis from localized dysfunction and aneurysm in patients with myocardial infarction and heart failure. This differentiation is vital in selecting patients for subsequent contrast angiography and aneurysmectomy. These procedures are also useful in the evaluation of patients with congestive heart failure and in the differentiation of left, right, and biventricular failure. They are also used to monitor the status of patients with acute myocardial infarcts and to assess the response to pharmacologic intervention as well as to coronary bypass surgery.

Facilities for these studies should be immediately adjacent to a coronary care unit if patients with suspected or proven myocardial infarction are to be studied, particularly those in shock or congestive heart failure. In hospitals with many coronary heart disease patients, a scintillation camera kept in the coronary care unit can be dedicated to these and other studies. This camera may also serve other patients in adjacent medical/surgical intensive care units. In smaller hospitals, portable equipment may be more desirable so that when not in use for patients with coronary heart disease it can be used in other locations.

Evaluation of myocardial perfusion. Regional myocardial perfusion can be determined noninvasively from peripheral intravenous injection of radioactive tracers or by direct injection into the coronary circulation at the time of cardiac catheterization. These techniques are useful for differentiating diffuse and focal myocardial disease and for estimating perfusion deficits associated with stenosis of the coronary arteries. Relative myocardial perfusion can be determined by imaging the distribution of intravenously injected ^{43}K or its analogs, ^{81}Rb , ^{129}Cs , and ^{201}Tl . The location, size, and extent of myocardial infarcts can be estimated in the majority of patients. Regional ischemia can be identified by comparing such studies after exercise and

at rest. During exercise, the myocardium supplied by a stenotic artery becomes ischemic and less tracer is observed in the involved region compared to that of the surrounding nonischemic myocardium. Such changes may not be observed when the tracer is injected at rest, when even major degrees of stenosis may exist without visible focal defects. If acute infarction or scar tissue (old infarction) is present, however, the damaged area does not accumulate radioactivity either during exercise or at rest. When used in combination with radionuclide angiocardiology, and ventricular wall and ventricular performance studies, the noninvasive relative perfusion examination is useful both in identifying patients with heart disease and in differentiating diffuse from focal pathology of the left ventricle.

Relative regional myocardial perfusion can be demonstrated at the time of coronary angiography by the injection of albumin microspheres or macroaggregates tagged with $^{99\text{m}}\text{Tc}$ or other radionuclides directly into the coronary arteries, left ventricle, or aortic root. Such studies reveal the functioning capillary bed in the territory distal to the point of injection. The distribution of radioactivity within the myocardium can be determined for several hours after the patient has left the angiographic laboratory. The safety of this technique has been widely accepted, when appropriate attention is paid to the number and size of particles injected.

Regional myocardial blood flow estimates per unit weight of myocardium are provided by the washout of a diffusible indicator, usually ^{133}Xe injected into the coronary arteries. The technique is particularly useful in that serial measurements can be made before and after a physiologic or pharmacologic intervention, and quantitative measurements of flow can be provided. (Similar serial measurements can also be made with microspheres by using two or more radionuclides.) The interventions employed are usually rapid atrial pacing, drugs such as papaverine, or radiographic contrast material. The data can be displayed as a grid of derived numbers on the cardiac silhouette or as a functional image with intensities proportional to the calculated regional blood flow. This procedure requires a camera in the angiocardiology laboratory.

Acute myocardial infarct visualization. The property of certain technetium-tin chelates to localize in acutely infarcted myocardium has been employed to determine the size, location, and extent of acute damage during the first 3 or 4 days after an infarction. These studies complement those of regional myocardial perfusion and ventricular wall motion, which document the presence and location of myocardial damage but cannot distinguish acute from chronic disease. Agents such as technetium-labeled tetracycline, pyrophosphate, and glucoheptonate that accumulate in regions of acute infarction help solve this problem. Since the studies are positive only in fresh infarcts of 4-8 days' duration, this test also helps identify the extension and recurrence of

infarction. It is of particular value in patients in whom the diagnosis of acute infarction is clinically difficult, those with left bundle branch block, previous infarction, subendocardial infarction, true posterior infarction, and intraoperative infarction.

Either a dedicated or a portable scintillation camera is required since the majority of studies are performed on patients in coronary care units. It is often desirable to determine ventricular function at the same time in a patient with a documented myocardial infarct.

Radionuclide arteriography and venography: *Arteriography.* Following the intravenous injection of ^{99m}Tc -pertechnetate, the activity in the abdominal aorta may be visualized. The presence of suspected abdominal aneurysm and its effects on distal perfusion to extremities or kidneys can be determined. This technique may also be used to determine the vascularity of space-occupying lesions within the liver or kidneys.

The distribution of perfusion in the extremities can be determined during peripheral arteriography by intra-arterial injection of labeled albumin particles or microspheres of albumin. Diffuse disease of the vessels is indicated by a generalized decrease in blood flow to muscle as compared to skin; stenotic lesions of large vessels cause regional decreases in blood flow that are indicated by regional decreases in activity. Healing of skin ulcers can often be predicted on the basis of the degree of associated hyperemia. Quantification of the size of arteriovenous fistulas can be made by measuring pulmonary activity after arterial injection of microspheres. Increased sensitivity of the method can be achieved by injecting microspheres during reactive hyperemia resulting 5–15 sec after injection of radiographic contrast media.

Venography. Radionuclide venography of the legs and pelvis is performed by injecting labeled albumin particles or microspheres into a foot vein and monitoring them as they ascend the leg into the inferior vena cava. An obstruction with collateral flow can be determined by serial scintigrams of the area to evaluate the presence of thrombi. Particles of albumin (especially macroaggregated) easily adhere to thrombi.

Radiiodinated fibrinogen has been used to detect occult thrombosis in the legs, especially in postoperative patients, and to evaluate the efficacy of various anticoagulant regimens. The detector most frequently used is a small hand-held nonimaging crystal probe attached to a rate meter.

The course of large veins (superior and inferior vena cavae) can also be determined by visualization of non-particulate technetium-labeled tracers.

The arterial studies can be imaged in the central nuclear medicine facility because there is ample time after injection while the tagged particles are temporarily blocked. A scintillation camera is needed for the dynamic portion of the venous studies.

Regional pulmonary perfusion and ventilation. These

studies are usually performed as an aid in the differential diagnosis of pulmonary embolism but are also useful for detecting pulmonary venous hypertension, congestive heart failure, and other cardiovascular abnormalities such as hypoplastic pulmonary arteries. Perfusion lung scanning performed after intravenous administration of ^{99m}Tc -microspheres or other particles depicts regional distribution of pulmonary arterial blood flow. When properly interpreted, such information can often help confirm or exclude pulmonary embolism suspected on clinical grounds, particularly when regional ventilation is also measured with ^{133}Xe gas.

To perform a perfusion lung scan, an injection of the radiopharmaceutical is made intravenously and its distribution throughout the lungs is determined by means of either a scintillation camera or rectilinear scanner since the radioactive microspheres or particles remain in situ for a sufficient length of time. Regional pulmonary arterial blood flow can also be estimated following an intravenous injection of ^{133}Xe gas dissolved in saline. In the latter instance, measurements are limited to the first 10 sec after injection, however, and usually only one view can be obtained.

It is necessary to use a scintillation camera to measure regional ventilation since all regions of the lung must be examined simultaneously to monitor the initial arrival of the radioactive gas and its rate of washout during exhalation. The qualitative relationship between regional perfusion and ventilation can be obtained by comparing the distribution of technetium-labeled particles with a single breath of xenon gas. Valuable information can also be obtained by computer and quantification of the distribution, arrival, and/or washout of the tracers. The most precise quantitative relationship is obtained using radioxenon for both perfusion and ventilation measurements, but clinically useful data are obtained by comparing the distribution of radiotechnetium (perfusion) with radioxenon (ventilation). The administration of ^{133}Xe gas requires a spirometer or other delivery system as well as a collection apparatus that can be a self-contained charcoal system, a collection bag, or a vent with an exhaust into a hood.

Experience has shown that it is possible to move patients suspected of pulmonary embolism to the central nuclear facility. Perfusion scanning may also be used to detect pulmonary venous hypertension in certain patients with coronary artery disease so it would be desirable to do such studies at the bedside of critically ill patients as well. Portable equipment can be used but intermediate storage of the recorded data is desirable to permit use of the data processing and display capability in the core facility.

Central nervous system studies. Regional cerebral blood flow can be estimated by recording with a scintillation camera the first passage of an intravenous bolus of sodium pertechnetate through the cerebral

circulation, usually employing the vertex or anterior projection. Interpretation can be based on visual assessment of serial timed images (usually at 1- or 2-sec intervals) or on quantitative analysis of regional time-activity curves. Quantitative analysis requires the use of either a general purpose or a special purpose computer system. If carotid arterial disease is suspected, it is best to visualize the carotid arteries by slightly extending the neck and pointing the camera to this region.

The technique is useful in distinguishing serious cerebrovascular disease from more benign conditions causing neurologic symptoms, in determining the relative vascularity of mass lesions of the brain detected by conventional scanning techniques, and in assessing the size and location of cerebral infarcts. Many patients can be examined in the central facility although it is desirable to combine cerebral, cardiac, and pulmonary studies in a satellite nuclear facility in the vicinity of a medical/surgical intensive care area.

Renal studies. Renal perfusion can be estimated by recording the first passage of an intravenous bolus of a technetium radioindicator used for renal scanning. Interpretation is usually based on visual assessment of serial timed images (usually at 5- or 10-sec intervals) or on quantitative analysis of regional time-activity curves. The procedure is used to estimate the relative blood flow to both kidneys and as an index of obstruction to flow at the arterial, venous, and microcirculatory levels. In the transplanted kidney, it can be used as a qualitative estimate of perfusion and sequentially as a guide to changes in flow with time.

A number of technetium chelates are bound by the kidney and can be used for obtaining structural information. The images can be employed to determine renal size, location, and anatomy; to delineate renal pathology, especially in patients who have demonstrated or suspected sensitivity to iodinated radiographic contrast agents; to supply anatomic information on patients with azotemia in whom radiographic visualization cannot be obtained; to assess the amount of residual functioning tissue in hydronephrotic kidneys; and to assess postrenal patency and obstruction.

In addition to visual methods for assessing perfusion and urinary tract morphology, quantitative methods are available for estimating renal function. A number of substances are excreted primarily or only by the kidneys, so, by labeling one of these substances with a suitable radionuclide and monitoring the pattern of radioactivity over the kidney as a function of time, it is possible to obtain an evaluation of renal function.

Radioactive tracer studies are helpful in assessing relative function of the kidneys in patients with suspected renovascular hypertension and in evaluating the adequacy of renal arterial surgery; in the diagnosis, treatment, and monitoring of patients with obstructive uropathy; in the early diagnosis of disease affecting one kidney, such as pyelonephritis; in the differential diag-

nosis of suspected renal masses, such as cysts, tumors, and fetal lobulation; in decisions regarding steroid therapy or removal of transplanted kidneys; and in serial evaluation of renal function in children with a variety of postrenal obstructive diseases.

Compartmental volumes. Measurements of red blood cell and plasma volumes are based on dilutional measurements in which known volumes and activities of tracer are injected into the circulation and, after an appropriate period of mixing, samples are withdrawn for measurement of radioactivity. Red cells are labeled with ^{51}Cr or $^{99\text{m}}\text{Tc}$. Chromium-51 can also be used to determine red cell survival. Technetium-99m may be employed when simultaneous radionuclide angiocardiology and/or blood pool imaging is to be performed. A number of labeled human plasma proteins can also be used for plasma volume measurements, e.g., ^{131}I -albumin, $^{99\text{m}}\text{Tc}$ -albumin, and $^{113\text{m}}\text{In}$ -transferrin (autologous).

In addition to determining blood volumes, dilutional measurements can be used to study electrolyte and fluid compartments such as exchangeable sodium and total-body water.

Measurements of compartmental volumes, particularly red cell and plasma volumes, are useful in determining the extent of hypo- and hypervolemia in patients in shock, from other than recent blood loss, or with acute congestive heart failure, particularly after surgery.

Drug and hormone assays. The development of radioimmunoassay methodology makes it possible to measure extremely low serum concentrations of biologically active substances, some of which are of importance in the management of patients with cardiovascular disorders.

Digoxin (and digitoxin) serum assays are a reasonable estimate of the drug's pharmacologic activity and reflect variations in bioavailability, compartmental distribution, and rates of metabolism and excretion. The assay, which depends on interaction with an antibody raised by coupling the drug to bovine serum albumin, can be performed with simple clinical chemistry equipment and either a gamma or beta scintillation counter. Several commercial kits are now available.

The digoxin assay's major clinical use is in the differential diagnosis of digitalis toxicity, especially in patients with diminished renal function. It can also be used to investigate the bioavailability of certain pharmaceutical preparations. Facilities for this assay should be available 24 hr a day.

Although it is still not possible to assay renin directly, an indirect estimate can be made by measuring the serum concentration of angiotensin I, an intermediate between the conversion of angiotensinogen and its biologically active form, angiotensin II; renin promotes the conversion of angiotensinogen to angiotensin I. Antibody to angiotensin I is raised by coupling the

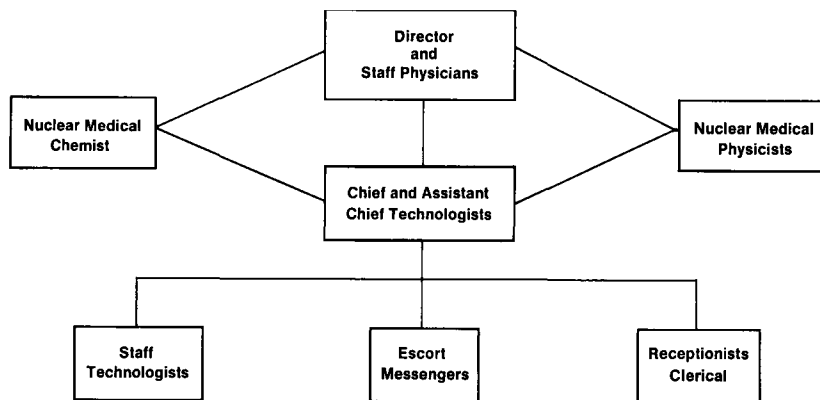


FIG. 1. Staff relationships in central nuclear medicine facility.

peptide hormone to poly-l-lysine to make an effective antibody-producing substance. The antigen-antibody complex is soluble and free antigen must be fixed to an added adsorbent. Commercial kits are available to perform the assay and the basic equipment is essentially that required for digoxin radioimmunoassays.

The angiotensin test is useful in the differential diagnosis of primary aldosteronism and renovascular hypertension. Renal vein assays can be used in the investigation of unilateral renovascular disease.

This assay need not be available in the hospital but can be performed in a reliable and easily accessible outside laboratory.

Although these radioimmunoassays are the principal ones relating to cardiovascular disease in use today, others such as a radioimmunoassay for serotonin and vasopressin are rapidly appearing.

Hospital Resource Guidelines

Because of the complexity and common features of much nuclear diagnostic equipment and the medical and technical expertise required for its proper use, hospitals developing nuclear medicine services should begin by establishing a *central nuclear medicine facility* capable of providing a broad range of diagnostic studies. These will include but will not be limited to cardiovascular studies. As case loads and staff capabilities expand, it may be desirable to establish one or more *satellite nuclear medicine units* remote from the central facility to promote the interaction of nuclear medicine with other diagnostic and therapeutic modalities and to help meet the needs of patients in special care areas—emergency rooms, intensive care units, operating and recovery rooms, catheterization laboratories, and noninvasive cardiac diagnostic laboratories. Satellite units should always be functionally and administratively related to the central facility to facilitate consultation, and to provide for equipment backup and more sophisticated data processing. In small hospitals, and in large institutions during the early phases of program development, an alternative to on-site satellite units is portable diagnostic equipment originating from the central facility.

Central nuclear medicine facility: Administration. The central facility should be established as an independent administrative unit with a separate budget and a physician-director qualified to assume clinical, technologic, and administrative responsibility for the service. Laboratory policy should be developed by the director and his staff, reviewed by appropriate hospital authorities, and published in the written statement of hospital policy.

Professional staff. Figure 1 illustrates staff relationships in the central nuclear medicine facility.

The director should be certified by the American Board of Nuclear Medicine or have the equivalent in training and experience. He must have sufficient background in the clinical, technologic, and administrative aspects of a nuclear medicine service to assume responsibility for—but not necessarily limited to—granting clinical privileges, review and approval of physician performance, establishment of quality controls, training of physicians and laboratory support personnel, development of an annual budget, purchase of equipment, and scheduling of procedures.

Staff physicians should have the same professional qualifications as the director with the exception that they need not necessarily be experienced in the areas of administration and training. If a staff physician restricts his activities to in vivo or in vitro procedures, his competence can be limited to these areas.

The principal functions of a staff nuclear medicine physician will be appropriate patient evaluation before the diagnostic study; supervision of the technical aspects of the study including advising the nuclear medicine technologist on the adequacy of the data obtained; interpretation and reporting of examination results; and consultation with the referring physicians. If a physician's duties are restricted to these activities, he should be able to examine between 12 and 15 patients a day. Other responsibilities such as administration, education, research, and the development and implementation of new diagnostic techniques will reduce this case load capability.

In the development and implementation of cardiovascular procedures, close cooperation between car-

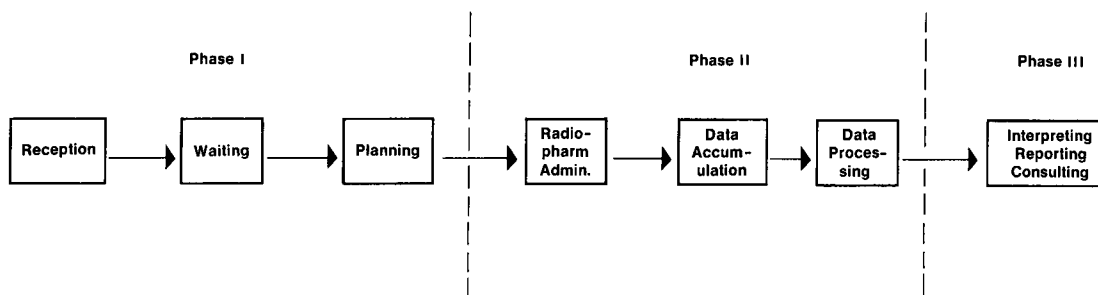


FIG. 2. Nuclear medicine examination flow diagram.

diologists and the nuclear medicine staff is essential for meaningful patient care evaluation.

The *technologist* staff should include a chief technologist and an assistant chief technologist, both skilled in the administrative as well as technologic aspects of nuclear medicine. In collaboration with the physician-director he should develop the technical operational budget and be responsible for its expenditure; develop and maintain statistical records appropriate to budget administration and long-range planning; purchase necessary supplies and approve related invoices for payment; actuate institutional personnel policies for the technical staff; interview, hire, and perform regular evaluations of employee performance and maintain related personnel files.

Technologists should be certified by the American Registry of Radiologic Technologists (ARRT), the American Society of Clinical Pathologists (ASCP), or a conjoint registry currently under consideration.* They should understand the general principles of radiation physics, radiopharmaceutical chemistry, and the function of nuclear instrumentation. They should be familiar with the operation of nuclear instruments and be capable of calibration checks, general quality control, and minor maintenance. They should understand the problems of caring for sick people and of their families, be skilled in patient positioning, and know sufficient anatomy and physiology to understand the morphophysiologic basis of nuclear procedures and the consequences of patient and position variation. They should know sufficient radiation hygiene to minimize the patients' and their own radiation exposures and to perform simple decontamination procedures.

Experience suggests that excessive specialization, such as performing only one type of study, can eventually result in morale problems as well as overdependence on a single individual. To achieve maximum flexibility and to provide services outside the normal working schedule and during vacations and illness, it is preferable that all technologists should be competent in the performance of all procedures. On the average, one

technologist can assume responsibility for 8–10 major *in vivo* procedures per day.

The services of a full-time *radiopharmacist* or *radiopharmaceutical chemist* will be required only by major medical centers although every hospital with a nuclear medicine program will benefit from the consultative services of such professionals. The daily compounding of radiopharmaceuticals from commercial kits can be accomplished by a trained nuclear medicine technologist.

The services of a *nuclear medicine physicist* should be available on a full- or part-time basis. His or her responsibilities include radiation safety, quality control of instrumentation, the teaching of medical radiation physics and nuclear instrumentation to the medical and technical trainees and staff, and the evaluation of new instrumental techniques. Skills in computer programming are particularly desirable. As an alternative, the function of the physicist can be filled by an engineer with special training in nuclear instrumentation.

Location and space. A major characteristic of nuclear medicine procedures is that they are noninvasive. Thus, they are used early in the diagnostic process. Although the majority of patients seen in a central nuclear medicine facility today come from the inpatient medical service, it is likely that increasing numbers of patients in the future will come from the ambulatory outpatient service. Therefore, the central facility should be easily accessible to outpatients. Radiation shielding and structural requirements are minimal and should not be considered obstacles to its being located close to patient areas.

The sequence of events involved in the performance of a nuclear medicine diagnostic examination, illustrated in Fig. 2, can be grouped into three phases: those occurring before the technical performance of the study; the technical performance of the study; and the interpretation and reporting of results to the referring physician. Figure 3 illustrates spatial relationships and staff-patient traffic flow patterns for the central facility.

To accommodate one camera or scanning system, examination table, stretcher, storage area, and small writing desk, the minimum size for an imaging room should be from 250 to 300 sq ft. Arrangement should be such that a technologist can move freely around the

*For information contact the Council on Medical Education, American Medical Association, 535 Dearborn St., Chicago Ill. 60610.

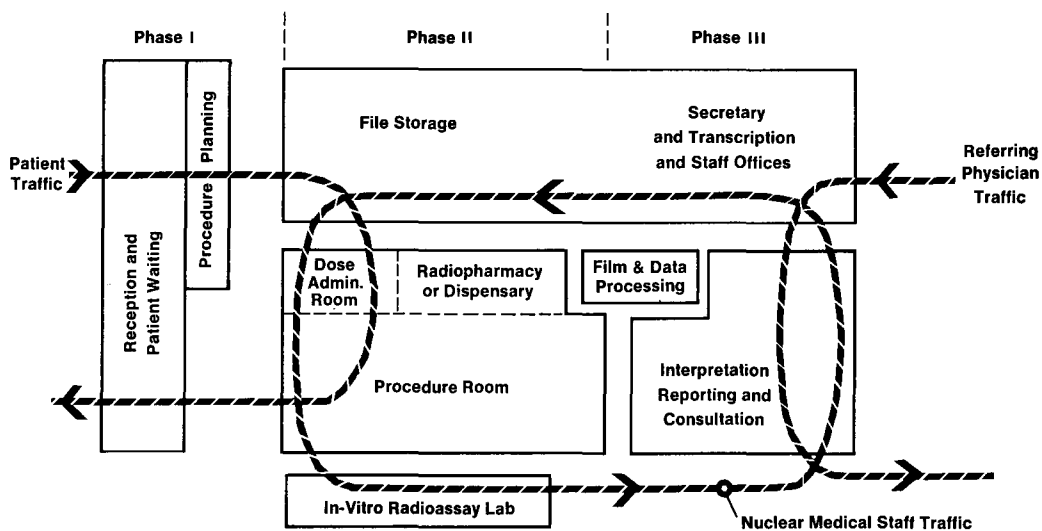


FIG. 3. Spatial relationships and traffic flow in central nuclear medicine facility.

table during the examination procedure. Both oxygen and suction should be available with emergency equipment located close by.

The value of many cardiovascular procedures is greatly enhanced by processing and display of the data by a computer. There are two basic types of computers used in nuclear medicine—general (programmable) and special (*hard wire*) purpose units. The general purpose systems are more flexible and programs can be developed and changed by the users. Special purpose systems have fixed programs and are more limited in capability. Many computer systems are small and can be operated immediately adjacent to the imaging devices, usually in the same room. An additional 50 sq ft should be added to the procedure room to accommodate such devices. Alternatively, an intermediate data storage system may be introduced between the imaging device and the computer. The controls of this intermediate storage device should be in the procedure room to facilitate collection of the data; the computer itself may be located either in the procedure room or in a central data-processing area. The central data-processing unit should be immediately adjacent to, but acoustically isolated from, a consultation room for the nuclear medicine staff and referring physicians. The size of the data-processing and display area will range from 200 to 400 sq ft depending on the complexity of the unit and the number of imaging devices. It should be large enough to contain a central processing unit and peripherals, a writing desk, and a storage area for disks and tapes.

The functions of the radiopharmacy are to store radioactive materials, prepare them for administration, and to assay individual patient doses. The storage room should be approximately 50 sq ft and geographically separated from the preparation area to reduce radiation exposure to the staff. All stored radioactive materials

should be adequately shielded; either built-in lead bins or removable modular containers are acceptable. If hundred-millicurie quantities of radioxenon or radioiodine are to be stored, a hood should be located in the storage room.

Preparation rooms should be 150 sq ft and include a shielded and ventilated radionuclide hood with a face velocity of 100 ft/min, a safely located exhaust, and adequate filtration. A protective barrier with direct (lead glass) or indirect viewing of compounding of radiopharmaceuticals should be provided as well as syringe shields, lead bricks, and pigs. Lead aprons should also be available for personnel who handle large amounts of radioactive substances. Ten square feet of countertop space should be provided for dose calibration. If properly shielded, the preparation room may be within the storage area. Both rooms, however, should be planned in accordance with federal and, where appropriate, state radiation safety standards and in consultation with a qualified health physicist. Access to the radiopharmacy should be limited to those engaged in the preparation and transport of radiopharmaceuticals.

An area should be provided for administration of radiopharmaceuticals to patients when studies do not require patient injection in the procedure room. This area should be large enough to accommodate a stretcher, examining table, counter tops, and two staff members—approximately 150 sq ft. Prepared radiopharmaceuticals will often be stored temporarily in various locations where patient examinations are conducted so there must also be adequate shielding and monitoring instrumentation in these areas.

The size of the in vitro radioassay laboratory will be determined by the number and type of in vitro assays performed. Usually a minimum of 400 sq ft is sufficient.

Adequate space should be provided for patient reception and waiting areas, which may be shared with

other hospital services. It is highly desirable to separate inpatients from outpatients, and children from adults. Since many procedures will require patients to be kept in the central nuclear medicine facility for considerable periods after an injection, the waiting area should be sufficient to contain an adequate number of chairs for ambulatory patients; separate space should be provided for stretcher patients and a receptionist's desk.

The physician's examination room should be close to the reception area where the nuclear medicine physician can evaluate patients in preparation for studies. It should be large enough to contain a chair, small desk, examination table, and instrument cabinet; about 120 sq ft.

For secretarial and transcribing facilities and files, 150–250 sq ft should be allocated.

Many nuclear medicine procedures require simultaneous conventional radiographs for proper interpretation of results. In large departments this may justify a radiographic unit within the central facility while, in other circumstances, these services may be shared with diagnostic radiology. Automatic film processing should be available for both radiographic and nuclear medicine procedures.

A minimum of 350 sq ft should be allocated for a data interpretation and consultation room, which should contain projectors for viewing nuclear medicine data and conventional viewers for radiographic data. It is also desirable that a computer terminal and display unit be available here.

At present, approximately 10,000 studies may be stored in 30 sq ft of file space using conventional x-ray folders. In the future, it is probable that storage of nuclear medicine data will be in the 35–250 mm format so space requirements will be greatly reduced; as many as 150,000 studies in the 35 mm format can be stored in approximately 30 sq ft of floor space. Thus, filing can be conveniently combined with the secretarial and transcribing functions.

There should be adequate office space for staff physicians, nuclear medicine physicists and chemists, radiopharmacists, and supervisory technologists in accordance with the needs of the hospital. Space should also be provided for storing linens and general supplies and for an employees' rest area (toilets, locker space, lounge), janitorial area, and educational facilities (conference rooms, library and study room, teaching aids and files), all of which may be shared with other hospital services.

Equipment. The following specifications relate primarily to equipment required for optimal cardiovascular studies. A useful guide to equipment specifications and maintenance has been published (2).

Area monitors should be located where there is a potential for high radiation exposure, such as the storage and radiopharmaceutical preparation rooms. They should be operated continuously and have an au-

dible signal as well as a rate meter. In addition, there should be survey equipment for monitoring incoming packages, storage space, and contaminated areas (3–5).

Devices known as dose calibrators are available commercially for measuring the activities of different radiopharmaceutical preparations, and such a device must be located in the radiopharmaceutical supply or preparation rooms. Most dose calibrators incorporate a high-pressure ionization chamber, the ionization-current response of which, per unit of activity of a gamma ray emitter placed in the re-entrant cavity of the chamber, is a well-defined and reproducible function of the gamma ray energies. This function is approximately linear, increasing with energy, for 100% abundant monoenergetic gamma rays, except at low energies (below ~ 200 keV). By appropriate electrical circuitry the ionization-current response is converted into a direct reading of activity, in multiples of curies, on a digital voltmeter, which reads the voltage drop across a resistance in the electrical circuit. The response of the dose calibrator is adjusted to different radionuclides by means of different plug-in resistance modules (labeled for the radionuclide in question), or by altering a variable resistor to calibrated values supplied by the manufacturer.

A variant of the ionization-chamber dose calibrator is the plastic scintillator, which, in turn, generates a varying current response from an electron-multiplier phototube.

In using any dose calibrator, great care must be taken to follow the manufacturer's instructions, particularly with regard to geometry corrections for different sizes and shapes of containers, and to possible recombination effects at high gamma ray emission rates. Daily monitoring of the dose calibrator, using a sealed preparation of a long-lived radionuclide, such as ^{137}Cs – $^{137\text{m}}\text{Ba}$, or ^{226}Ra in equilibrium with its daughters, is essential. Periodic recalibration of the dose calibrator, with standards of the radionuclides in general use, is desirable. In the event of unexpectedly large discrepancies between the suppliers' assays stated on the label of the radiopharmaceutical container and the dose calibrator assays, it is essential to make an immediate recalibration with a standard of the radionuclide in question.

Equipment for beta and gamma scintillation counting of liquid samples should be available in the radioassay laboratory. Sample changers should be automated and interfaced to a general or special purpose computer when a large number of samples are processed.

At times, these devices are used instead of scintillation cameras for measurement of cardiac output, ejection fraction, left-to-right shunts, transpulmonary transit time, and arteriovenous shunting in the peripheral circulation. When a probe is to be used for radiocardiography, it must be equipped with special colli-

meters, a short time constant, and high speed strip chart or other recorder or computer interface.

The resolution of currently available scintillation camera systems is 8 mm or better in the range of 120–200 keV when measured from FWHM of line-spread functions at the face of the collimator. Count rates of up to 100,000 cps have been obtained without excessive losses. Spatial linearity measured with a bar source or adsorber shows a deviation of less than 0.5 cm from the center line of the bar. Uniformity, as measured with a 64×64 digitized matrix, usually does not deviate by more than $\pm 10\%$ in the useful field of view. Older cameras, however, cannot achieve this level of performance; therefore, each instrument must be evaluated for its adequacy in performing the desired studies. For example, many older cameras have inadequate special resolution for the low-energy photons of ^{201}Tl ; however, such cameras may be satisfactory for radionuclide angiocardiology and gated studies. Uniformity, spatial resolution, and sensitivity should be checked on a regular basis. Spectral resolution of the crystal should be better than 18% FWHM at 140 keV, and overall sensitivity should also be sustained within 10% of the level set at the time of the purchase of the instrument when measured under identical conditions.

Computers are not necessary for many cardiovascular nuclear medicine procedures but they enhance the quality of most of them. For example, initially only the scintillation camera and cardiac gate are needed for radionuclide angiocardiology and ventricular wall motion and performance studies. The next step should be the addition of computer capabilities. Each imaging device should be interfaced to a data storage system such as magnetic tape, disks, or cassettes. For many studies, special purpose (*hard wire*) computational equipment is adequate but, for maximum flexibility and incorporation of new technology, general purpose (programmable) digital computational equipment is desirable. Ideally, the computer system should have 10,000 or more image cells with a capability of various matrix sizes down to 4,000 image cells (64×64 array) for use when count rates during specific periods of the cardiac cycle are limited. Magnetic tape or disk recording devices should meet industry standards commonly used for larger digital computers. Some of the commercially available imaging systems in nuclear medicine employ a television screen for displaying the data. The advantages of television display include better gray scale, ready adaptability for use with color, and relatively low cost.

The use of rectilinear scanners in cardiovascular nuclear medicine is limited almost entirely to pulmonary perfusion studies with particles and to the diagnosis of cerebral infarction. These studies can also be performed, however, with the scintillation camera. The use of a dual detector rectilinear scanner substantially reduces examination time.

Automatic film processors are highly desirable to fa-

cilitate inspection of results before patients leave the examination area. Varieties available include 35 mm, 70 mm, and 105 mm, as well as those designed to process larger (14×17) radiographic film. Daylight loading systems are available.

A general purpose computer is useful for permanent storage of patient data, such as identification numbers and type and date of study. Permanent storage of images is best achieved photographically using 35 mm, 70 mm, 105 mm, or standard radiographic film sizes with single or multiple format. Direct inspection is possible with 70-mm or larger film; but for viewing 35-mm film, projection is desirable. Recording on Polaroid film has the advantage of immediate availability of each view, but this method is more expensive than celluloid film and less desirable for conference viewing. Automatic processing of conventional celluloid film also permits evaluation of the examination shortly after its completion.

Interpretation of scintigrams frequently requires correlation with radiographs and with ultrasound studies (1, 6). Particularly when studying the lung, isolated interpretation of the scintigram without correlating the study with the roentgenographic appearance of the chest may lead to misinterpretation. Therefore, the location of the scanning rooms and the administrative arrangements concerning inter-relationship with diagnostic radiology and ultrasound should be such that films and ultrasound scans are immediately available for viewing at the time the scintigrams are being interpreted.

Nuclear medicine technologists should perform daily equipment checks including evaluation of uniformity of field, spatial resolution, and sensitivity of cameras. Scanners should be checked daily for sensitivity and monthly for adequacy of contrast. Provision should be made for periodic preventive maintenance for all equipment (Table 1). Monitoring of personnel for radiation exposure should conform with state and federal regulations. There should be weekly checks for radionuclide contamination of all working areas.

Quality control for sterility and pyrogenicity should be available if radiopharmaceuticals are prepared in the laboratory from other than commercial kits.

Emergency resuscitation. Essential patient medications and monitoring and resuscitation equipment should be available.

Satellite nuclear medicine units: *Types of examinations.* Table 2 outlines the cardiovascular nuclear medicine examinations that, under optimal conditions, should be available in each satellite unit. A priority rating has been assigned each examination based on its utility in the satellite under consideration.

Administration. Approaches for managing satellite units will vary, and hospitals must tailor administrative structure to local circumstances. Whatever the arrangement, it is important to emphasize that close working relationships between the professional staff of

TABLE 1. Quality Control for Patients, Radiopharmaceuticals, and Equipment*

What monitored	How monitored	When monitored	Who is responsible
Patient			
Is the correct study being performed?	Consultation with referring physician	Before scheduling	Physician
Satisfactory information	Requisition/report form; clinical evaluation	After study	Physician
Accurate interpretation	Followup	When information becomes available	Physician
Positive identification	Verbal or personal communication, wrist band if available	Before nuclide is administered	Technologist
Correct preparation	Verbal request	Before nuclide is administered	Technologist
Radiopharmaceutical			
Pyrogens	Pyrogen test (USP)		
Micro-organisms	Sterility test (USP)		
Efficacy	Tissue distribution		
Chemical and radiochemical purity	Chromatographic and spectroscopic analysis		
Radionuclidic purity	Beta/gamma spectroscopy		
Physical properties	Microscopy		
Radionuclidic concentration	Ionization chamber assay		
Commercially compounded		Before use	Manufacturer
Commercial kit preparations and generators		Before use	Manufacturer [†] Pharmacist [‡]
In-house preparations		Before use	Pharmacist
Equipment			
Well counters and external detectors			
System resolution	FWHM	Monthly	Technologist
System linearity	Two nuclides with widely separated photopeaks	Monthly	
Background	Background control chart	Daily	
Stability of count rate	Long-lived standard control chart	Daily	
Spectrometer calibration	Peak with nuclide with photopeak near nuclide to be counted	Daily	
Rectilinear scanners			
Photorecorder calibration	Counts/cm ² /film density	Three monthly	
	Effect of contrast enhancement	Three monthly	
	Phantom studies	Initial evaluation only	
Scintillation cameras			
Stability of count rate	Long-lived standard control chart	Daily	
Spectrometer calibration	Peak with nuclide to be used	Daily	
Field uniformity check	Disk source ⁵⁷ Co or ^{99m} Tc	Daily	
Spatial resolution	Lead bar phantom or line source phantom	Daily	
Ionization chambers			
Contamination	Background count	Daily	
Stability of count rate	Long-lived standard count	Daily	

*Modified from Ref. 7.

[†]Responsible for pyrogen- and micro-organism-free radiopharmaceuticals.

[‡]Responsible for efficacy, chemical and radiochemical purity, physical properties, and radionuclidic concentration of radiopharmaceuticals.

TABLE 2. Cardiovascular Nuclear Medicine Examinations in Satellite Facilities

Cardiovascular nuclear medical examinations	Location of satellite nuclear medicine facility					
	Central nuclear medicine lab	CCU/ICU*	Noninvasive cardiac lab	Cath-angio lab	E. R.	Cardiac O. R.
Radiocardiography	+	+	+	+	±	±
Radionuclide angiocardiology	+	+	+	+	+	+
Ventricular wall motion and performance	+	+	+	+	+	+
Acute infarct visualization	+	+	-	-	+	-
Regional myocardial perfusion	+	+	+	+	+	+
Radionuclide arteriography and venography	+	+	±	+	+	+
Pulmonary perfusion and ventilation	+	+	+	-	+	+
CNS studies	+	+	+	+	+	-
Renal studies	+	+	±	+	+	±
Compartmental volumes	+	-†	-	-	±†	±†
Drug and hormone assays	+	-†	-	-	±†	±†

*Includes cardiac surgical ICU.

[†]Studies should be available; equipment need not be.

Priority rating: Based on utility of examination in the area indicated, (+), highly desirable; (±), optional; (-), not desirable.

the central and satellite facilities is essential to ensure high-quality diagnostic examinations and patient safety. Equally important is a clear delineation of administrative, clinical, and technologic responsibility of physicians and technical staff. These should take the form of written policies and should include a mechanism for resolving professional disputes.

A cardiovascular nuclear medicine unit that is located in the coronary care unit or in some other location in the hospital should be administered jointly by a cardiologist and by a nuclear medicine physician. In most institutions the unit should be an administrative satellite of a central nuclear medicine facility while in other institutions alternative administrative arrangements may be made. Regardless of where the cardiovascular nuclear medicine unit is physically or administratively housed, the nuclear medicine physician with his specialized training should be responsible for the safety, technical performance, and quality control of the unit. If either cardiologist or nuclear medicine physician attempt to operate this satellite service independently, it will either fail or, at best, perform ineffectively to the detriment of both the patients and the professional staff.

Equipment. Most in vivo nuclear medicine procedures can be performed in satellite units with a scintillation camera. Interfacing of the camera to a computer-processing system simplifies some procedures and aids in obtaining quantitative data. The operation of the satellite units differs principally in the type and number of patients rather than in the technologic requirements of the study.

Utilization. An average daily case load of at least four major in vivo studies is desirable to maintain the clinical and technical competence of the diagnostic team in a satellite unit. The high cost of equipment and the necessity of amortizing it over a 5-year period (because of rapid technologic developments) also will require this level of utilization in a free-standing satellite. At the present state of technology, eight to ten studies per 8-hr day can be performed with each instrument.

Quality control. Each nuclear medicine service should establish and maintain a quality control program to include adequate records for documentation of continued high-quality performance. Excellent guidelines for quality control are available (7).

A potential danger associated with noninvasive studies with minimal complication rates is that inadequately trained individuals may be tempted to perform these examinations. This can result in improper conduct of the study resulting in inadequate data, faulty retrieval, and misleading results that may lead to inappropriate or even dangerous therapy.

Summary and Conclusions

The use of radioactive tracers for studying the heart and circulation is increasing daily. Procedures for esti-

imating the size and location of acute myocardial infarcts, for delineation of regional ischemia during exercise, and for the evaluation of regional and total right and left ventricular function are rapidly being developed. Special purpose instrumentation specifically designed for patients with cardiovascular disorders will soon be available including lightweight, portable imaging instruments capable of use at the bedside, in the operating room, intensive care and coronary care units; emission and transmission tomographic systems capable of producing transverse sections of the heart to help locate regions of infarction or dyskinesia; and single purpose, hard-wire systems such as a device for radiocardiography with capability for the computation of ejection fraction for use in the cardiac clinic. In addition, efficient computer codes are being developed that, in conjunction with radionuclide angiocardiology, provide a wide range of indices of ventricular function including cardiac output, pulmonary vascular volume, stroke volume, ejection fraction, and shunt flow measurements.

Progress in the development of cardiovascular nuclear medicine will be facilitated by close cooperation between cardiologists and nuclear medicine physicians in the planning, performance, and interpretation of these diagnostic examinations. The special requirements of patients with acute cardiovascular disorders often necessitate supplementation of the central nuclear medicine facility of the hospital with one or more satellite units in or near the coronary care unit, emergency room, and cardiac operating suite. In addition, the newly emerging noninvasive cardiac diagnostic laboratories should be equipped to perform certain nuclear medicine procedures. Moreover, selected nuclear diagnostic procedures will provide useful supplemental information during cardiac catheterization and angiocardiology.

The major instrument involved in the important advances in cardiovascular nuclear medicine is the scintillation camera. Many studies can be performed by using this instrument alone, but their number and quality is increased by interfacing the camera to a digital computer.

We have presented guidelines for planning cardiovascular nuclear medicine procedures both in a central nuclear medicine facility and in satellite units such as the coronary care unit. They are suggested as optimal criteria rather than minimal standards and they should be read with this in mind.

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