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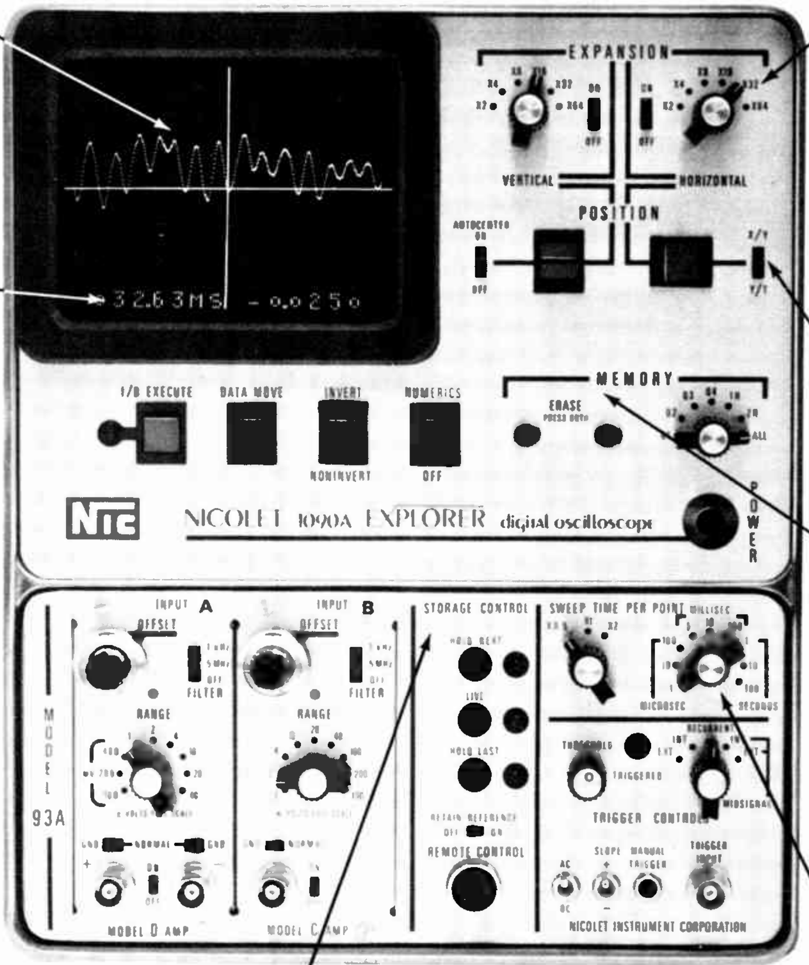
Why You Should Consider a DIGITAL OSCILLOSCOPE Like The NICOLET EXPLORER . . .



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the cover

The latticework of waveguide elements glows in the zoned lens of Lockheed Missile & Space Company's new multibeam spacecraft antenna (Lockheed photo by R. M. Petersen). A report on the state of the art in commercial satellite data communications applications by Norman Abramson of the University of Hawaii and Eugene Cacciamani of American Satellite Corp. begins on page 36.

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spectral lines

The public and nuclear power

Sixty-three percent of the American public favors more nuclear power plants, Louis Harris revealed to an assemblage of journalists at the Engineers Club in New York City on August 5. The new Harris poll findings showed 19 percent opposed and 18 percent not sure. Harris himself thinks this is a clear indication of how the public would vote on issues such as those posed in the California Nuclear Initiative (*Spectrum*, June, p. 26), which provides for a moratorium on the construction of nuclear plants in the State of California.

The Harris study also quizzed specific segments of the populace on their guesses as to how the public at large views the issue of nuclear power. Interestingly, all of these groups vastly underestimated the degree to which nuclear power plant extension is favored. The regulators of public utilities came closest, yet only 45 percent of them guessed that the public endorses more plants. The figure for political leaders was 42 percent; for environmentalists, 38 percent; and for business leaders, 36 percent.

The principal attributes of nuclear power as the public sees them are that it is clean, cheap, and reliable.

On the other hand, the public sees real problems and seeks reassurances that they will be dealt with forthrightly. Harris himself urged industry leaders to "heed carefully and well" the public's concerns. The major concern cited in the poll was the disposal of radioactive waste materials. (See article, p. 56 of this issue.) Others were the escape of radioactivity into the atmosphere, the chance of an explosion in case of an accident, the discharge of warm water into lakes and rivers that could endanger fish and other marine life, the threat of attempts to sabotage nuclear plants, and the possibility that plutonium could be stolen by radical revolutionaries.

Harris interprets the poll's results as indicating that while the public is willing to take risks concerning nuclear power, it is with clear qualifications. People are reluctant or unwilling to accept significant environmental tradeoffs. He feels that the public is reacting more "fiercely" on environmental matters than in the past. For example, the public would be strongly opposed to energy solutions that might jeopardize the cleanliness of the air and water. Only the business community indicates it would accept such a tradeoff.

A revealing aspect of the poll concerns how the public rates its sources of information concerning nuclear power. The single group given high marks are the scientists. In fact, the poll suggests that among the public both those who favor more plants and those opposed have great confidence in the opinions of scientists.

Although the overall results of the poll, taken at face value, would indicate the public is generally well informed on the topic of nuclear energy, such is not necessarily the case. Participation in the poll itself was something of an education to many participants. For example, in unaided, open-end questioning, only 10 percent of the public volunteered waste disposal as a main disadvantage of nuclear energy. Under direct probing, however, waste disposal emerged as the public's biggest concern.

In comparison with oil and coal, the public (53 percent) believes nuclear energy will become cheaper with time. Business leaders (61 percent) are even more convinced of this decline in cost, while only minorities of political leaders (30 percent) and environmentalists (25 percent) share this opinion. Although the public is concerned about thermal pollution, it nevertheless rates nuclear energy as less of a threat to clean water than oil or coal, and rates it far ahead of oil and coal in the matter of clean air.

In general, the public seems to view nuclear plants as far safer than they are dangerous. It does recognize health hazards and dangers, but does not consider coal or oil to be significantly safer. A majority (over 75 percent) feel the risk of building plants worth it if the Government certifies that the plants will not pollute the air and water, the plants meet tough Government standards for waste disposal, the Government inspects the plants regularly to detect radioactive leakage, the Government is satisfied on inspection that an accidental explosion is unlikely to happen, and the plants have security to prevent the theft of plutonium or sabotage by revolutionaries.

A majority of the public favor having nuclear power as the main source of energy for electric power in their own community. The neighbors of nuclear plants appear more convinced than the public at large that nuclear energy is cheaper and cleaner than competitive sources, and are also more willing to rely on nuclear energy as their principal source of power.

It is interesting to note that scientists and/or engineers were not included as one of the subgroups of leaders polled. Harris explained that the task of defining and selecting a sample of "scientists" would have been very difficult. Yet, in view of the public's evident high trust in the opinions of scientists, the omission was unfortunate.

Copies of the Harris study will undoubtedly be widely distributed by Ebasco Services Incorporated, who commissioned it. Some caveats seem in order. First, the study clearly reflects both objective expectations and subjective preferences of its participants. But more important, industry would be mistaken to interpret the public's favorable "vote" as giving carte blanche to proceed without dealing with the merits of the counter-arguments. And therein lies a major challenge to the engineering community.

Donald Christiansen, Editor

Satellites: not just a big cable in the sky

High bit rates, high reliability, low costs, and versatility are features of satellite communications systems

In 1975, the pace of development of communication satellite systems has accelerated markedly. NASA successfully launched three commercial communication satellites from Cape Canaveral during 1974 but, during 1975, from eight to ten such launches are anticipated. Fueling this development are the lower costs and special capabilities that satellite links offer communication users; particularly data communication users. For example, long-haul service provided by satellite is usually more cost-effective than comparable service provided by purely terrestrial links. This is especially true of specialized higher data rate services. Today there is little, if any, terrestrial capacity available to provide long-haul transmission of data at rates of one million bits per second and higher. To provide new services at these rates in most situations will require both large inflexible investments and new construction of terrestrial facilities, which will require long implementation times. Satellite systems can be quickly and inexpensively installed to establish circuit connections wherever the user desires and at the data rates that he needs.

Generally speaking, highly reliable data channels can be achieved using satellite systems. This is particularly true if the service can be provided directly to the user without intervening terrestrial carrier links. Since the system consists of a single transponder, the channel characteristics are well known and can be controlled within certain limits. Unlike terrestrial circuits, which can experience fading due to microwave propagation path anomalies as well as "bursty errors" due to telephone exchange equipment switching, the satellite circuit is affected primarily by additive, white, Gaussian noise. Hence, performance can be controlled by adjusting earth station transmit power, and further performance enhancement can be achieved using forward error-correction techniques.

Some important communications satellite capabilities have yet to be exploited. For example, commercial satellite channels are usually employed as point-to-point links between two earth stations, just as if these stations were linked by a direct cable connection. But a satellite is not just a big cable in the sky; a single satellite channel has a broadcast character that allows it to transmit and receive signals from any earth station in its antenna pattern. This flexibility provides the satellite communication channel with particularly powerful capabilities for use in a digital network composed of a large number of small earth stations. If a destination address is attached to each message transmitted by an earth station in such a system, then it is no longer necessary to devote a separate channel to each pair of earth stations that wish to communicate. Once this flexibility is appreciated, it becomes possible to employ either novel forms of communication systems architecture to allocate voice circuits dynamically (in seconds), or packet broadcasting to allocate data packets dynamically in microseconds. The extent to which these satellite communications capabilities actually come into use depends, in the first place, on their availability.

Norman Abramson University of Hawaii
Eugene R. Cacciamani, Jr.
American Satellite Corp.

Standard and special satellite services

Both the U.S. domestic carriers and INTELSAT now offer a variety of "standardized" tariffed services that the user can order from a "shopping list." COMSAT, as the U.S. representative to, and member of, INTELSAT, acts as a carrier's carrier, providing satellite circuits to the U.S. international carriers, interfacing with them at the COMSAT-operated earth sta-

More and more satellites aloft

The commercial use of communication satellites began with the successful launch of INTELSAT I in April 1965. INTELSAT consists of a consortium of 90 member countries that operates a network of geostationary communication satellites positioned over the Atlantic, Pacific, and Indian Oceans. Since each satellite covers approximately one third of the surface of the earth, such a network is adequate for almost complete earth coverage. Since 1965, INTELSAT has designed three new generations of communication satellites; the latest, INTELSAT IV, was first put into operation in March 1971.

In addition to the INTELSAT system, several national or regional communication satellite systems have been or soon will be launched. By early 1975, five other systems were operational—Molniya (U.S.S.R.), Anik (Canada), and Westar (U.S.A.)—with their own satellites, and RCA and American Satellite Corporation employed the Anik and Westar satellites for their space segment. Other communication satellites expected to be launched during this decade are two additional U.S. systems (in competition with Westar), a European system involving nine stations, an Iranian system, a Japanese system, an Arabian system, an Indonesian system (perhaps involving Malaysia and the Philippines), a Brazilian system, and an Indian system. An international maritime communications satellite (MARISAT) is being launched in 1975, and an international aeronautical satellite (AEROSAT) is scheduled for the late 1970s.

tions. Services in operation today include: video transmission on demand; 4-kHz voice circuits using both preassigned FM/FDMA transmission and the SPADE demand-assigned digital transmission system; teletype; telex; voice band data up to 9600 bits per second; and digital data circuits operating at 50 000 and 56 000 bits per second.

The U.S. domestic carriers, American Satellite Corporation, Western Union, and RCA, can interface at the user premises using terrestrial interconnections from their respective earth stations to the user's facility. In some specialized situations, these carriers may locate their earth station at the user's premises.

Representative tariff rates for domestic services are shown in Table I and the trend INTELSAT satellite tariffs have been taking over the last few years is shown in Table II.

In addition to these more or less standardized services, satellite carriers develop and provide *new* services to meet evolving user requirements previously not easily met using terrestrial lines. The carriers' ability and willingness to do this is of considerable importance to the consumer of data communication services. Specialized tariff services can be developed dynamically as requirements arise, and tariffs can be filed with the U.S. Federal Communications Commission to cover these specific applications on a case-by-case basis.

One example of such new services is the Government network installed in 1974 by the American Satellite Corporation. It consists of five dedicated-user earth stations on U.S. Government facilities. The system is used to transmit and receive five 1.344-Mb data streams over long- and medium-range distances (from 3000 km down to 450 km) to connect remote data collection terminals to a primary computer facility.

This year, American Satellite will install a dedicated broadcast network for Dow Jones. This service will enable digital broadcast of the *Wall Street Journal* to remote printing plants for regional distribution. The initial service will be at 150 000 bits per second and, combined with facsimile data compression equipment provided by Dow Jones, a complete "master" newspaper page can be transmitted in about three minutes. Eventually, when the system data rate is increased to 1.344 Mb/s, the transmission time will be about one minute per page.

Another proposed service includes off-shore oil rig earth terminals such as the Cities Service terminal. Exxon also has a proposed requirement for a gyrostabilized tracking station on board its oil exploration ships. This proposed voice and data service will link the ships to Exxon's central computer located in Houston, Tex.

In the near future, the costs for satellite communications can be expected to decrease. The reasons for this probable trend lie in changes now underway in satellite system design.

Satellite system costs

The cost of the satellite itself is often thought to be the dominant cost in the overall satellite communication system. Actually, in the present generation of systems, the cost of the satellite is rapidly becoming less significant, taking third place behind earth station cost (including multiplexing equipment), and the cost of distribution from the earth station to the user.

Cost estimates for the space segment of a single, full-duplex voice channel on the INTELSAT IV satellite have been estimated at about $600 per year. Comparable cost for the Anik or the Westar satellite is about $300 per voice circuit per year.

From the point of view of satellite communication systems, digital transmission systems are generally more efficient in transmitting both voice and data than are traditional analog FM/frequency-division multiplex systems. In transmitting data, the satellite digital voice circuit is the equivalent of at least six voice circuits in a conventional analog-transmission land line system. A single conventional circuit may achieve a data rate of 9600 bits per second under carefully controlled conditions, but up to 64 000 bits per second of digital data can be transmitted over the equivalent satellite digital voice channel. For example, a 50 000-b/s data circuit, with a tariff comparable to that of a single voice channel and operating over the Pacific Ocean INTELSAT IV satellite, has linked the ALOHA system in Honolulu with the ARPA Computer Network in North America and Europe since December 1972.

The cost of an earth station for a satellite communication system is more difficult to determine than

I. Representative U.S. domestic tariffs in February 1975 (satellite, ground links, and local loops)

Between	And	Satellite Single-Channel Rates	AT&T Single-Channel Rates
Chicago	New York	$ 620	$ 760
Chicago	Los Angeles	820	1674
Dallas	Los Angeles	820	1231
New York	Los Angeles	1120	2300
Washington	San Francisco	1120	2292

II. Satellite rates—U.S. to Europe

Effective Dates	Monthly Half-Circuit Rates
INTELSAT charges to COMSAT	
6/27/65	$ 2 667
1/ 1/66	1 667
1/ 1/71	1 250
1/ 1/72	1 080
1/ 1/73	930
1/ 1/74	750
1/ 1/75	705
COMSAT charges to carriers	
6/27/65	$ 4 200
4/ 4/67	3 800
7/ 1/71	2 850
Carriers' charges to customers	
6/27/65	$10 000
10/ 1/66	8 000
10/ 1/67	6 500
8/ 1/68	6 000
4/ 1/70	4 750
8/15/71	4 625

Note: Carrier, COMSAT, and INTELSAT rates are for circuits to the mid-point (i.e., half-circuit rates). Carrier rates include terrestrial haul from COMSAT earth station to New York.

the cost of the satellite. In analyzing the cost of an earth station, it is necessary to specify the communication capabilities desired of the station. For example, almost all the stations first built in the INTELSAT system were capable of transmitting and receiving color television signals while simultaneously handling voice and data traffic. Furthermore, they were designed to have this capability with satellites transmitting considerably less power than the current generation of satellites. These earth stations typically consist of a 30-meter antenna, cryogenically cooled receivers, and tracking capabilities of questionable utility. The cost of such an installation has been from about $3 000 000 to $5 000 000. The cost estimates for the smaller and simpler earth stations used in the Canadian and U.S. domestic systems have been from $1 000 000 to $2 000 000 for full television and voice-data capabilities. If we consider earth stations with only data communication capabilities, even simpler installations are possible. Earth stations have been installed by U.S. domestic satellite carriers for specialized data applications ranging from $100 000 to $400 000 per station, and even lower costs have been projected for future stations.

Some of the factors that contribute to the lower cost of these earth station installations include: smaller diameter antennas, uncooled low-noise receivers, low-power transmitters, and simplified communication hardware requirements. In many instances, forward-acting error-correction techniques can be effectively added to the system at little additional cost providing significant improvement in performance. Earth station parameters can be adjusted to provide a cost-effective earth station based on capital investment in the earth station and recurring space segment charges.

Increasing equipment redundancy requirements can significantly increase earth station costs. Redundancy implies that additional components are implemented to provide backup in the event of failure of on-line components. User reliability requirements will determine the need for redundancy. For example, assuming unmanned earth station operation, the expected reliability of a nonredundant earth station is 99.4 percent versus 99.9 percent for a redundant system. However, the cost of adding redundant components can amount to a significant portion of the total earth station cost—as much as 40 percent of the total cost of a simple single-data-link earth station. Thus, the user must be careful not to overspecify his reliability requirements.

Other user requirements will affect costs by defining earth stations to be duplex or simplex operating. A simplex operating earth station (receive-only or transmit-only) requires correspondingly less equipment than does the duplex station (receive and transmit) and, hence, is less costly. A typical example of a simplex operating system could be a point-to-multipoint newspaper publishing system whereby the paper is distributed from a central point to a number of printing plants equipped with receive-only terminals. Television and radio distribution networks would be another example of a simplex earth station network.

Reduced costs in earth station design for data communications can be achieved by reduced multiplexor requirements. In some cases, this function (when required) can be replaced by a program in the computer connected to the earth station. This latter possibility is particularly attractive because of the flexibility and added capability of a computer network employing packet-broadcasting architecture. Further decreases in costs, beyond those discussed in this article, can be projected for newer-generation satellites as well as for present-generation satellites, with advanced data transmission-multiplexing techniques.

General distribution earth stations can require extensive ground interconnection circuits to reach the user. This is particularly undesirable to the data user since it can add significantly to the overall service cost. However, many small data-terminal earth stations can be located at the user's premises, thus reducing the ground interconnect costs to zero and insuring high end-to-end performance. The "dedicated user" Government data network mentioned previously, where all stations are located at the user's premises, operates with an overall bit error probability of less than 10^{-8} for 1.344-mb/s data service. These ongoing developments in equipment and systems promise cost reductions for satellite services in the near future, and we can expect them to be followed by more dramatic changes.

As for the future . . .

With the hindsight provided by the ten years since the launch of INTELSAT I, it is easy to forget the revolutionary nature of the satellite telecommunications medium. And it is easy to forget that there was considerable uncertainty before 1965 about incorporating geostationary communication satellites into the existing telecommunications plant. With these uncertainties in mind, satellite communication advocates have tended to minimize the differences between satellite channels and earthbound channels. Actually, until the present time, satellite channels have been used almost exclusively as replacements for cable or microwave channels. This situation now appears to be changing as the special capabilities of satellite channels are becoming more widely recognized.

Because of the greater flexibility of digital data, compared to video or voice signals, the impact of the unique capabilities of satellites is likely to be most visible in satellite data communication systems providing unconventional services. In the U.S., approval for such unconventional data communication services will be necessary from the Federal Communications Commission. But this agency has indicated that it is receptive to proposals that take fuller advantage of the capabilities of satellite channels.

Dynamic channel-sharing

One of these unconventional techniques—the ability to allocate dynamically satellite channel capacity among a number of mobile stations—will be exploited in the planned MARISAT and AEROSAT systems. The first MARISAT satellite is scheduled for launch in 1975 and will be employed for voice and data channels to ships in the Atlantic using L-band frequencies (1.6 GHz). MARISAT will be operated by COMSAT General Corp. and will initially provide one voice channel and 44 teletype channels.

An interesting feature of the MARISAT program is

Communication satellite basics

At an altitude of 36 000 km, a satellite in a circular orbit will have a period of 24 hours. If such a satellite is placed in orbit over the equator, it will appear stationary from any point on the earth. Such a satellite is called geostationary. Three geostationary satellites positioned at roughly equidistant points around the equatorial orbit are sufficient for essentially full communications coverage of the entire earth.

Geostationary satellites are employed as radio repeaters for communication purposes. A signal from one earth station is transmitted up to the satellite (the uplink) and the signal is retransmitted down from the satellite to another earth station (the downlink). In order that the signal transmitted by the satellite not interfere with the signal received by the satellite, the uplink and the downlink signals use different frequency bands. Most of the present generation of geostationary satellites use the 4-GHz band for the downlink and the 6-GHz band for the uplink.

Since the characteristics of most commercial satellite channels match quite well the classical Shannon model of a channel with additive white Gaussian noise, we may calculate the channel capacity by means of the Shannon formula

$$C = W \log (1 + S/N)$$

where C is the channel capacity in bits per second, W is the channel bandwidth in Hz, and S/N is the signal-to-noise power ratio at the receiver. From this equation, we see that the capacity of a satellite to transmit messages depends upon both the bandwidth available and the total effective radiated power of the satellite. But the capacity increases rapidly with the bandwidth while increasing much more slowly with the radiated power.

The upper limits of bandwidth available in the 4-GHz and 6-GHz bands assigned to communication satellites have been reached in present systems, and additional bandwidth will only be obtained by shifting to higher frequencies—frequencies that may require more expensive equipment. The effective radiated power, however, can be expected to increase in the next generation of communication satellites. While this will not lead to large increases in satellite capacity, it will lead to a dramatic decrease in the size and complexity of ground systems necessary to receive satellite signals and it will lead to greater flexibility in satellite communication systems architecture.

Since INTELSAT I was launched in April 1965, almost all of the more than 100 earth stations used in the INTELSAT system have included a 30-meter-diameter antenna, sophisticated tracking and control equipment to point this large antenna, and extremely sensitive, cooled receivers to detect the weak signal from the satellite. Such ambitious earth stations may have been desirable for use with INTELSATs I, II, and III, but they seem overdesigned for use with INTELSAT IV and its successors.

Earth stations designed for use in national and regional satellite systems put into operation in the early 1970s generally employ simpler uncooled amplifiers and smaller diameter antennas—typically 10 to 15 meters. The European satellite system plans to employ antennas with diameters no greater than 15 to 18 meters, and it seems likely that most earth stations in that system will have even smaller diameter antennas. As the diameter of an earth station antenna is decreased, the beam width of its radiation pattern increases, thus leading to the possibility that the signal transmitted to one satellite may interfere with the signal to an adjacent satellite. At the presently planned spacing of geostationary satellites around the equator: it appears that this may limit the minimum antenna diameter to from 3 to 5 meters for the 6-GHz band now used.

that during the first few years of operation much of the satellite channel capacity will be employed in a separate U.S. Navy communications network in the UHF band (240–400 MHz). As the civilian maritime needs increase, the satellite power will be shifted from the UHF transmitter to the L-band transmitter in the satellite, and when the Navy has completely phased out its use of MARISAT, the capacity available to the civilian maritime system will be nine times the initial capacity.

Scheduled channel sharing

The MARISAT and AEROSAT services will use unscheduled sharing of the satellite space-segment portion of a communication system. It is also possible to design special data communication systems that share the space segment in a scheduled manner. For example, a banking or credit card system might be designed with small earth stations located at each of ten or twenty regional centers and those centers might transmit financial data to a national center on a regularly scheduled basis over the same channel.

Land lines or microwave systems could also be used for such systems, of course, but a satellite data service has certain properties that can make it more attractive. A land-based system will usually have to locate the central processing facility near the geographical center of the system in order to minimize leased or dial-up line charges. In a satellite system, the central facility can lie anywhere within the antenna pattern of the satellite. Data transmitted from outlying units may be rerouted to a backup central facility with a minimum of effort, even if the backup facility is located at some considerable distance from the primary center.

The tradeoff of earth station costs versus space segment costs for a scheduled channel-sharing satellite data service is different from the tradeoff in the case of conventional fixed point to fixed point satellite channels. Since with channel-sharing there are many earth stations making use of the same satellite channel resources, the earth stations may be small and inexpensive while satellite channel capacity can be quite freely used in order to minimize the total system cost. In fact, as the number of possible nodes in such a satellite data communication network increases, and as the fraction of the satellite capacity used by each node decreases, the overriding consideration in the system design becomes the design of the many inexpensive earth stations of the network.

Digital broadcasting

The future systems discussed so far employ the traditional point-to-point architecture of ground-based data communications, although the receive or transmit points may be reconfigured in order to utilize the

Multibeam antenna developments

The waveguide-lens spacecraft antenna pictured on *Spectrum*'s cover this month is capable of generating multiple beams that collectively cover the whole earth disk or, instead, generate several isolated beams as small as 2 degrees in diameter.

The antenna was built by Lockheed Missiles and Space Co. for proposed use on the phase III spacecraft of the Defense Satellite Communications System, DSCS-III, the next generation of U.S. military communications satellites.—*Howard Falk*

space segment fully. But, as was pointed out, a satellite is basically a broadcast communications medium, connecting any point in its electromagnetic view to all other points. This property may most easily be exploited in the distribution of identical data from one point to several other points. Examples of such systems are news or financial wire services or the distribution of national newspapers and magazines to regional printing plants—or even to plants located in individual cities. A fully redundant earth station employing a 5-meter antenna dish, with receive-only capabilities at a data rate of 1.344 b/s, could be built at a cost of about $150 000. At this data rate, it takes only one minute to transmit a newspaper page. The advent of such a nationwide system would make it economically feasible to have only a few nationwide newspapers with separate sections produced in each city for local news.

Packet broadcasting

It is a relatively small step from the digital broadcasting concept to packet broadcasting. This is a method of operation that allows efficient transmission of data from many earth stations to one earth station, or even from many to many. Certain kinds of data communication systems operate under extreme conditions of traffic variability. For example, terminal time-sharing networks, data base inquiry systems such as those for airline reservations or stock market quotations, and computer networks with file-transfer capabilities, all tend to operate with high peak-to-average data rates.

In these situations, it is possible to allow each earth station in the data network to share a single high-capacity satellite channel. Data are buffered in each earth station to form packets—typically these are 1000 bits in length. Each packet, together with a header containing address and control information, is transmitted over the common shared satellite channel at the maximum rate of the channel. In such a packet broadcasting data network, it is not necessary to control or synchronize the burst transmissions from the separate earth stations. The header for each packet is received by all the earth stations in the system and the packet is accepted by the station or stations with the proper address. If the average data-rate of each station is low enough, and if there are not too many earth stations, the probability that two packets will be transmitted at the same time—and thus interfere with each other—will be low. If such interference does occur, the two earth stations that transmitted the packets can detect the interference. Fortunately, in a satellite channel, it is possible to monitor your own transmissions. Each station can then repeat the lost packets until a successful transmission occurs.

Packet broadcasting by satellite was first demonstrated in 1973 in a NASA experiment involving the University of Alaska, NASA Ames Research Center, and the ALOHA system at the University of Hawaii. Satellite packet broadcasting experiments using large INTELSAT earth stations (in Etam, W.Va., and Goonhilly, England) and the Atlantic Ocean INTELSAT IV are planned to begin in September 1975.

Packet broadcasting systems are an attractive possibility from the point of view of efficient use of space segment satellite resources, since the satellite transponder need only provide power during the short burst when it is transmitting a packet. Thus, a satellite transponder operating in a packet broadcasting mode at a duty cycle of 10 percent would only transmit 10 percent of its rated power. Alternatively, such a transponder could be adjusted to provide 10 dB more power during its transmission of packets, while keeping its average power output fixed.

An earth station employed for packet broadcasting needs no multiplexor since this function can be carried out by a rather simple software module in the computer system receiving the data. A packet broadcasting earth station using a single transponder at a peak data rate of 1 Mb on a Westar class satellite could be built for about $30 000–$50 000. Such a system could easily handle the data traffic generated by 10 000 computer terminals in a time-sharing or data base inquiry system.

These cost figures for packet broadcasting earth stations are in the same range as, or lower than, the cost of many present-day peripheral devices for medium- and large-scale computer systems. This fact suggests the possibility that such an earth station might very well be marketed as just another computer peripheral device by a large computer manufacturer. In the 1980s, when ordering a large-scale computer, one may well be asked to consider system configurations that include a packet broadcasting earth station with a 5-meter antenna on the roof of the computer center. ◆

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Dr. Cacciamani holds several patents in the field of satellite communications. He received his B.E.E. degree from Union College and the M.E.E. and Ph.D. degrees from the Catholic University of America.

Avoiding midair collisions

This author-developed system puts the pilot in the "driver's seat" and exploits the existing U.S. air traffic control system

Every day, somewhere in the United States, at least one airplane pilot experiences a near miss with another aircraft, and recent history is full of tragic examples of aircraft that did not miss, but collided in midair. Danger is a constant factor in the daily operations of commercial, business, private, and military planes, and the stakes get higher as more jumbo jets take to the air.

Clearly, the problem urgently needs a solution. Not surprisingly, a variety of solutions (see "The promise of air safety," July *Spectrum*, pp. 26–36) have been proffered by electronics and avionics firms, and are being considered by the Federal Aviation Administration (FAA). The best solution should be that which makes the maximum use of the existing air traffic control (ATC) system, and also minimizes the size, weight, complexity, and expense of additional on-board equipment. This is especially true since both the FAA and the Department of Defense (DOD) have designated the air traffic control radar beacon system (ATCRBS) as the primary means of controlling the nation's air traffic. To date, the ATCRBS network represents a massive investment of almost $3 billion in the form of nearly 700 ground stations and 130 000 aircraft transponders, as well as training and maintenance.

Under FAA and DOD contracts, an airborne collision-avoidance system (CAS) is being developed that exploits the existing ATCRBS network by utilizing the signals transmitted between ground stations and aircraft during the ordinary course of air traffic control. With these signals, a pilot in a suitably equipped aircraft can learn of impending danger from other planes in his vicinity. Called Semiactive BCAS (beacon collision-avoidance system) because, for the most part, it operates *passively* using receivers to intercept other aircraft transmissions but, in exceptional cases, can *actively* solicit responses directly from other aircraft, the system imposes minimum and inexpensive changes in the present ATCRBS network, and does not require additional transponders aboard aircraft beyond those already mandated (last January 1) by the FAA.

At present, BCAS is the only CAS system available that passively determines range, range-rate, and bearing angle between the protected and intruder aircraft. To avoid garbling multiple messages, BCAS not only excludes nonthreatening aircraft from its data processing, but selects only those ATCRBS signals it absolutely needs to assess a threat, multiplexing these measurements within the unused "dead time" of the present ATCRBS network.

The present system

A brief review of ATCRBS—or SSR (secondary surveillance radar), as it is internationally known—will aid in understanding Semiactive BCAS. As the beam of an ATCRBS ground station antenna (see Fig. 1) rotates, it interrogates all aircraft in its line of sight. In the present ATCRBS configuration, during the time the interrogation beam intercepts an aircraft carrying a Mode A/C (identity/altitude) transponder, it repeatedly and digitally asks the questions: "Who are you?" and "How high are you?" To ask for aircraft identity, two pulses spaced 8 μs apart are radiated on the 1030-MHz beam, and all transponder-equipped aircraft within the beam automatically reply at 1090 MHz with one of 4096 discrete identity codes.

Alternately, a separate pair of pulses (spaced 21 μs apart) on the beam ask for an uncorrected ("raw") barometric altitude report, to which the aircraft transponder again digitally replies, this time with its altitude in 100-ft increments; the identity and corrected altitude obtained via ATCRBS are then displayed on the air traffic controller's screen, such as the ARTS-III display shown on the July *Spectrum* cover.

Although in its initial stages ATCRBS suffered from operational difficulties such as interference, confused target replies (sidelobe interrogation), and lack of a sufficient number of transponder-equipped planes, interagency and industry cooperation provided the solutions. As an answer to the interference and poor-target problem—probably the most formidable difficulties encountered—a sidelobe suppression (SLS) subsystem was developed to avoid unwanted interrogations by sidelobes to the main beam and reflections from obstacles such as hangers. This was accomplished by radiating a circular "suppression" pattern omnidirectionally in addition to the narrow (4-degree) rotating main beam. Hence, at the same time that interrogation pulses (P_1 and P_3 in Fig. 1) are sent out over the main beam, another interspersed pulse (P_2) is radiated on the omnidirectional broadcast pattern between P_1 and P_3 to set the suppression level. An interrogated plane replies only when the P_1,P_3 pair dominates the P_1,P_2 pair—that is, when the main beam points directly at it.

At the present time, the national ATCRBS standard sidelobe suppression range is about 30 nmi, permitting the most inexpensive receivers to be used (at −72 dBm). With Semiactive BCAS, however, the range will be extended to 100 nmi (using modified receivers to operate at −92 dBm in order to maximize BCAS effectiveness and synchronize with the SLS).

Another development that helped make ATCRBS attractive was the addition of "defruiting" circuitry, which rid the system of nonsynchronous reply errors. Finally, the establishment of national standards and their rigid enforcement greatly enhanced the ultimate performance of the ATCRBS network.

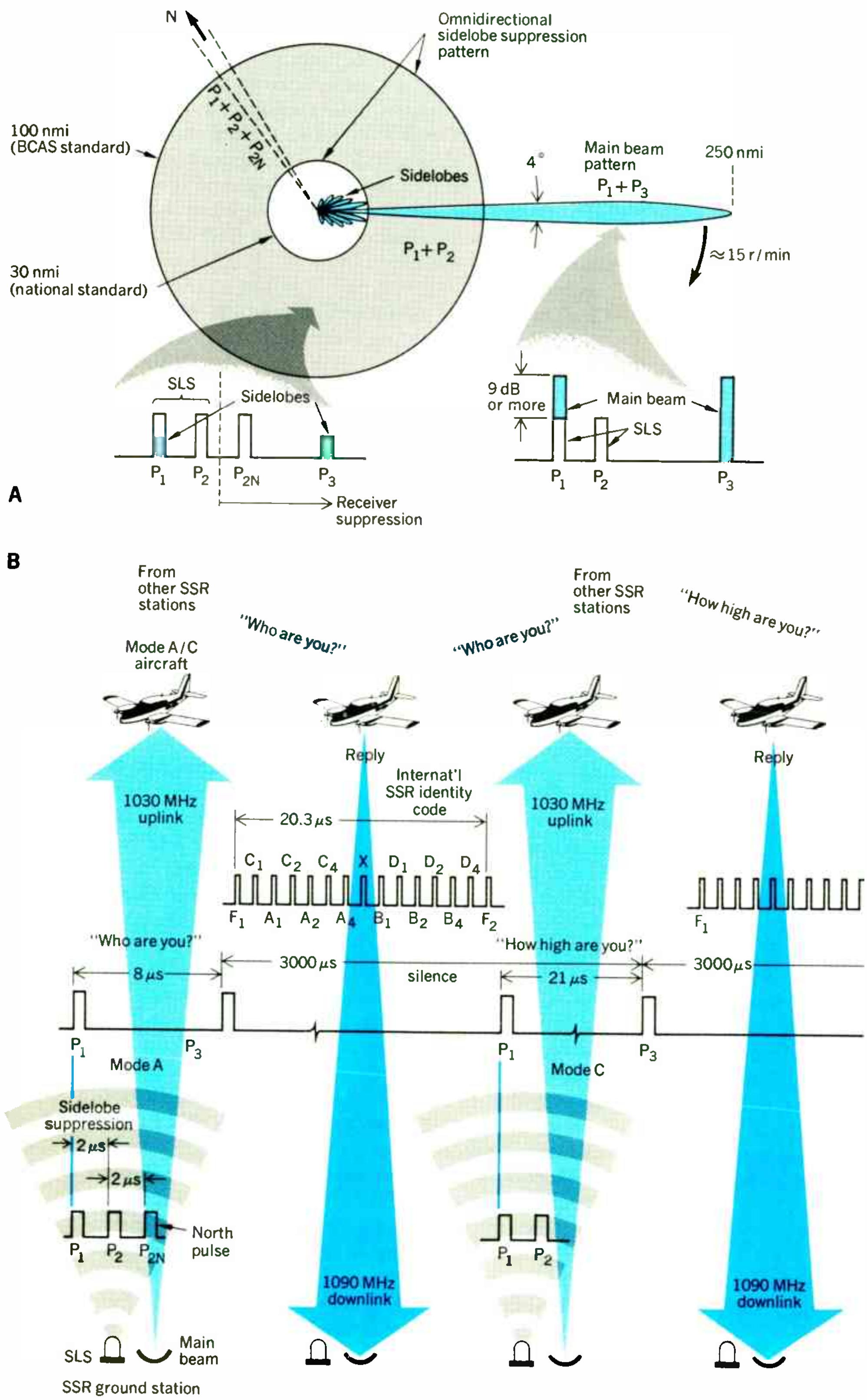
The problem of transponder availability to the large general-aviation fleet was solved when the avionics industry was able to offer moderately priced units.

George B. Litchford   Litchford Electronics

Today, the great success of ATCRBS has led to acceptance among as many as 60 nations through International Civil Aviation Organization agreements.

How Semiactive BCAS works

Semiactive BCAS is a system that allows a protected aircraft to receive ATCRBS replies from transponders on other aircraft in response to either ground ATC interrogation or interrogation directly from the protected aircraft, which then uses the replies to evaluate collision threats. The only operational change that would be required in the present ATCRBS ground hardware to accommodate Semiactive BCAS is the addition of a simple pulse spaced another 2 μs after P_2 to create a "triad" (P_1,P_2,P_{2N}). The triad would be radiated on the circular broadcast pattern whenever the



[1] The national ATCRBS network consists of approximately 700 SSR ground stations that radiate both a narrow interrogation beam and an omnidirectional sidelobe suppression broadcast on a 1030-MHz uplink to almost all aircraft within the nation's controlled airspace. While the present range of the SLS broadcast is and will continue to be about 30 nmi, Semiactive BCAS is capable of a 100-nmi sensitivity. In B, the message–reply sequence (left to right) demonstrates the almost 3000 μs of silence that typically exists between Mode A/C interrogations, providing ample time to handle the numerous 20.3-μs replies expected from the most densely populated airspace. Listening time is further increased by a factor of 100 since a given radar dwells for 1 percent of its rotation period on a given aircraft.

[2, right] Knowledge of when an SSR main beam passes magnetic north is essential for BCAS operation, not only to determine differential azimuths (see A) but to aid in keeping track of a particular SSR station (by rotation period). Once another aircraft enters the protected aircraft's predetermined area gate and altitude band, its potential threat is continually assessed. If the protected aircraft is in range of only one SSR station, it can actively interrogate the identified aircraft's transponder to determine both threat range and bearing angle (D); if in range of two or more SSR stations (E), range and bearing angle are easily determined passively. (It is important to understand the role of the inner ellipse gate [see C]: as a potential threat enters the outer edges of the azimuth gate [±18°], an inner TOA limit of 5 μs is probably sufficient for capture; as the threat proceeds toward 0°, however, the computer selects smaller and smaller TOAs [down to 0.1 μs]. The zone within the 0.1-μs ellipse is a thin area of garble that an intruder traverses but a brief instant, if at all. With more than one SSR station, this garble zone is removed entirely. For ease of conception, all drawings in this article will refrain from showing the jagged inner-ellipse boundary of C.)

Getting more for your money

Although Semiactive BCAS is described here as a solution for midair-collision avoidance, its capabilities extend far beyond this proposed application. For example, BCAS could be used to prevent ground collisions as well. If used as a ground proximity warning system (GPWS), BCAS would detect transponders permanently emplaced on high obstacles within terminal control areas, thus providing pilots with all-weather warnings of such collision hazards.

Not only will BCAS's versatility reduce overall cockpit system cost and size (by eliminating the need for other equipment), but reliance on microprocessing will bring down cost and size even further. According to Robert R. Richards, president of Megadata Corp., Bohemia, N.Y., developers of BCAS hardware: "The BCAS system has evolved around a 16-bit, 3-parallel-processor machine that acquires raw SSR data, tracks and correlates targets, and gives threat determination and display. Cycle times will be in the area of 1 μs, and memory size is expected to be about 24 000 words."

Displays, too, are a versatile area of BCAS, which provides excellent signals for either a simple vertical-escape (dive/climb) display (the present FAA specification), or a more sophisticated pilot plan-position indicator (PPI). The customer can choose according to his needs and pocketbook.

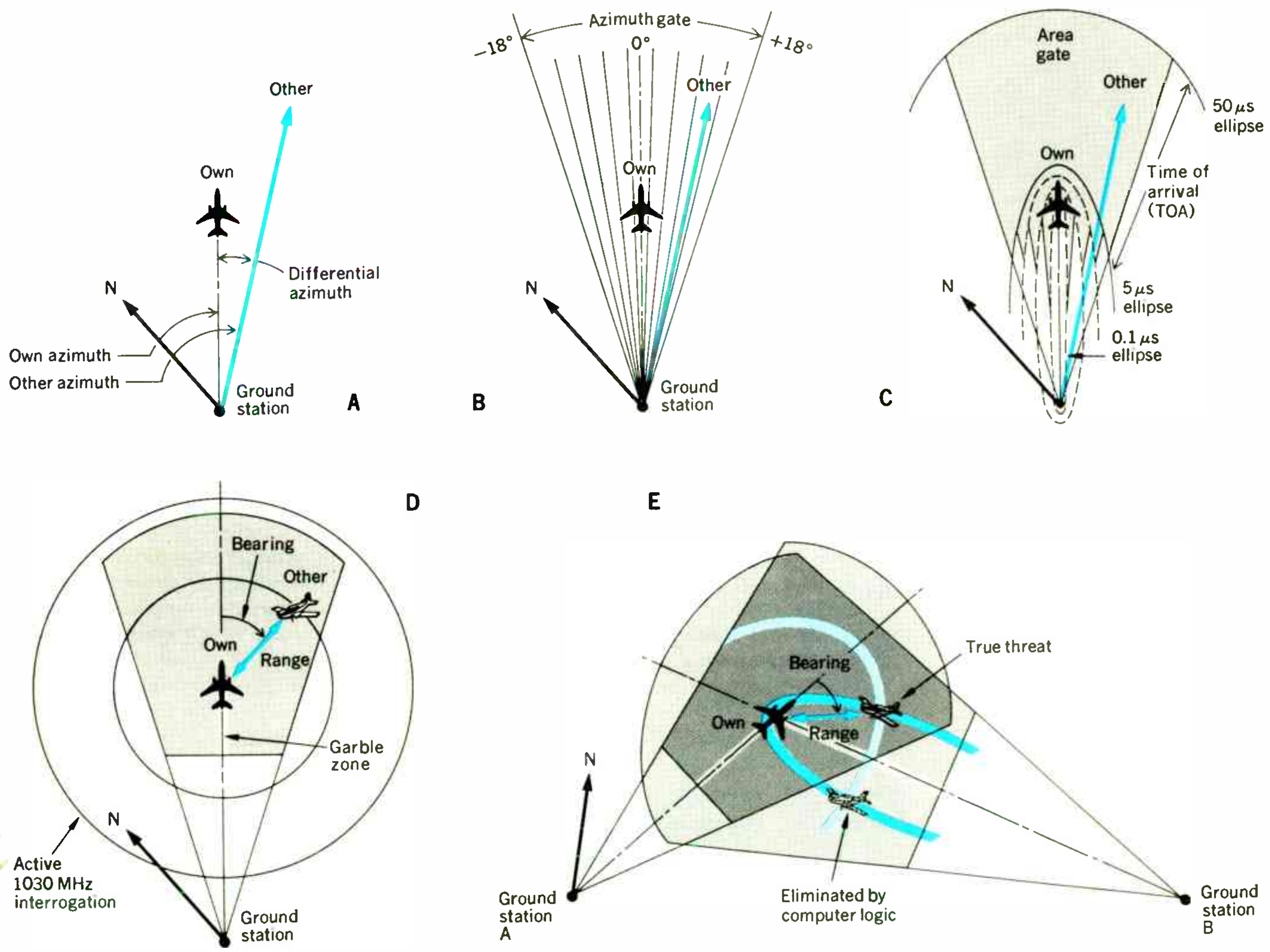
Marce Eleccion

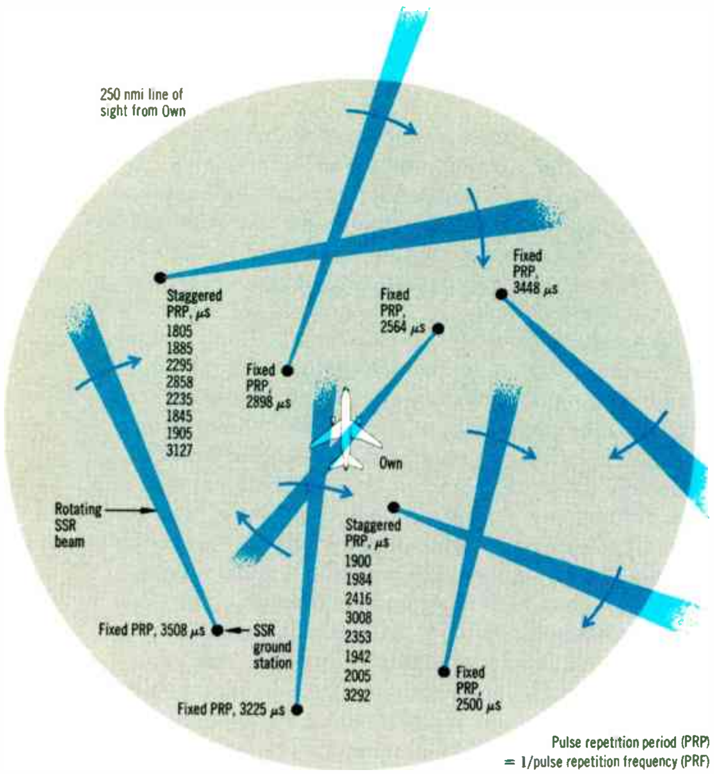
main beam passes through local magnetic north, thereby giving all aircraft receiving the 1030-MHz broadcast an azimuthal reference with respect to the round station (see Fig. 2).

For BCAS protection, two receivers are required on an aircraft: the conventional 1030-MHz receiver already required on transponder-equipped planes for both circular broadcast and main-beam reception (but modified for CAS operation at −92 dBm), and a new 1090-MHz receiver to intercept responses of other aircraft to interrogations.

By measuring the time it takes for a selected ground main beam to rotate from north (indicated by the triad pulse) to the protected aircraft's azimuth position (see Fig. 2A), the plane can continually determine its own azimuth relative to that specific ground SSR station. Similarly, by measuring the time interval between a north triad and the intercepted response of another aircraft to a direct interrogation by the main beam, the protected aircraft can determine the azimuth of another aircraft relative to the ground station. It is then feasible to determine azimuth difference between the protected aircraft and the potential "intruder."

To distinguish among the many SSR beams that may be interrogating aircraft over a densely traveled airspace (see Fig. 3), BCAS measures the unique pulse repetition period (PRP = 1/PRF) characteristic of each ground station's powerful main beam; hence, there can be no confusion in selecting one 1030-MHz

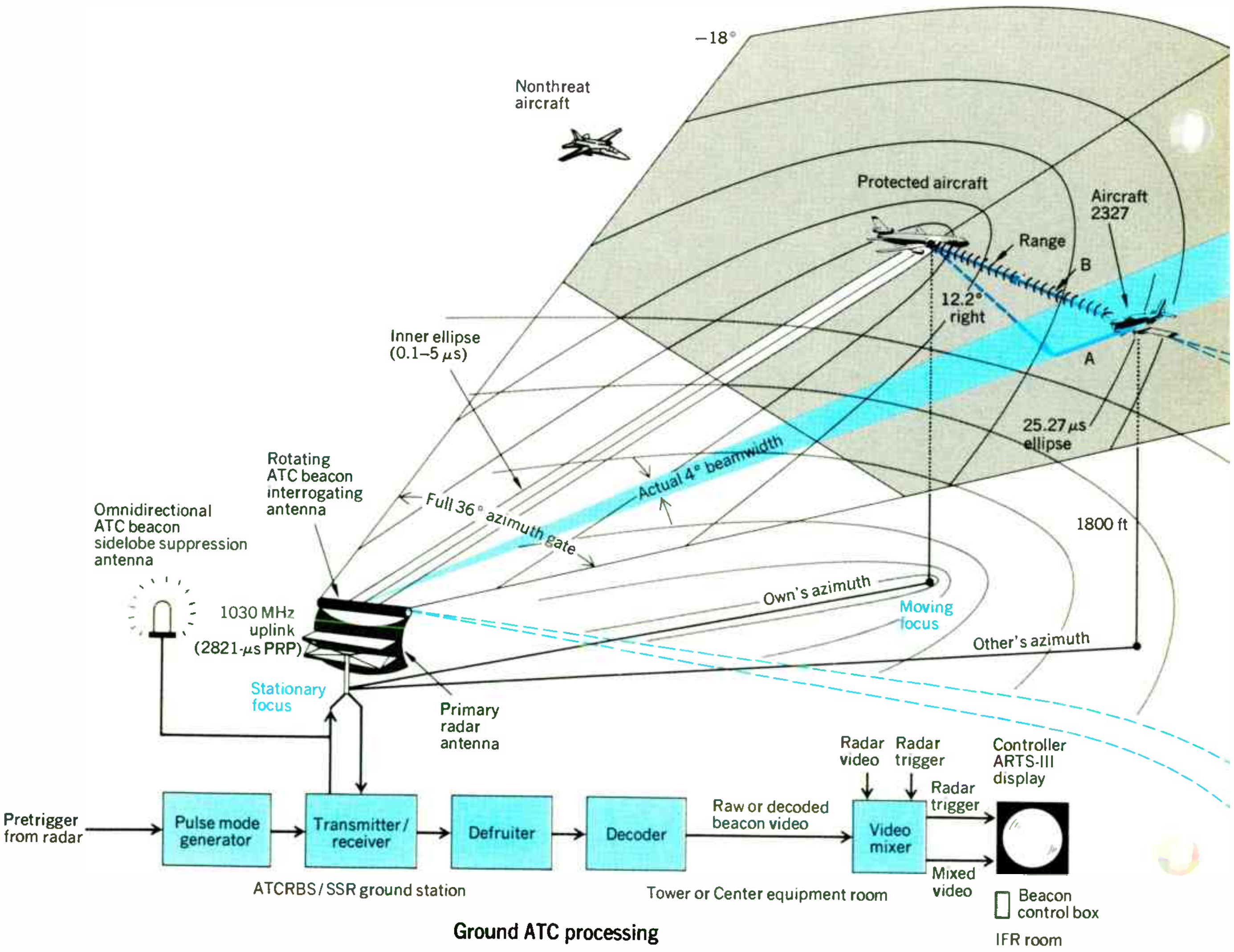




[3] Although rotation period helps in distinguishing one SSR station from another, since as many as 40 stations may be interrogating an aircraft in a dense airspace (some with the same rotation period), a more unique identifier is needed—the PRP. Fixed PRPs in an area are purposely assigned at different periods to prevent mutual interference; some radars, however, have an eight-step stagger, which is associated with a primary-radar solution to an MTI (moving-target indicator) problem. This is another fortunate design feature of the basic SSR system that enhances BCAS operation.

[4] This three-dimensional view of BCAS threat evaluation in a single-SSR situation shows an actual passive-intercept-data readout obtained during a recent testing series. Not only are the intruder's azimuth (12.2° right) and TOA (25.27 μs) displayed, but the BCAS processor also identifies the interrogating radar (2821 PRP) and indicates that, of 36 total replies received in the area gate (not all from the same aircraft), 33 correlated to within a fraction of a μs (indicating they came from the identified aircraft). Since only one SSR is involved, active interrogation from the protected aircraft gives both range and bearing; more than one SSR coverage makes active interrogation unnecessary. Note that both the intruder's identity (Mode A) and altitude (Mode C) are obtained passively, and all 20–40 interrogations received during a main-beam dwell are used to determine TOA and azimuth, a redundancy that increases BCAS accuracy, hence safety. In this diagram, we can assume that the protected aircraft is coaltitude with aircraft 2327 (1800 ft), and therefore a definite threat can exist.

Typical multiple-radar coverage can be seen in the upper right-hand corner, which displays the seven radars emanating near McGuire Air Force Base, N.J., at an altitude of about 8000 ft.



ground signal from among the many other 1030-MHz signals of other interrogators. Moreover, all the 1090-MHz replies of aircraft to a particular ground interrogator possess the same PRP characteristic "signature" as that interrogator. As a rule, BCAS selects only 3–4 SSR main beams for passive target tracking.

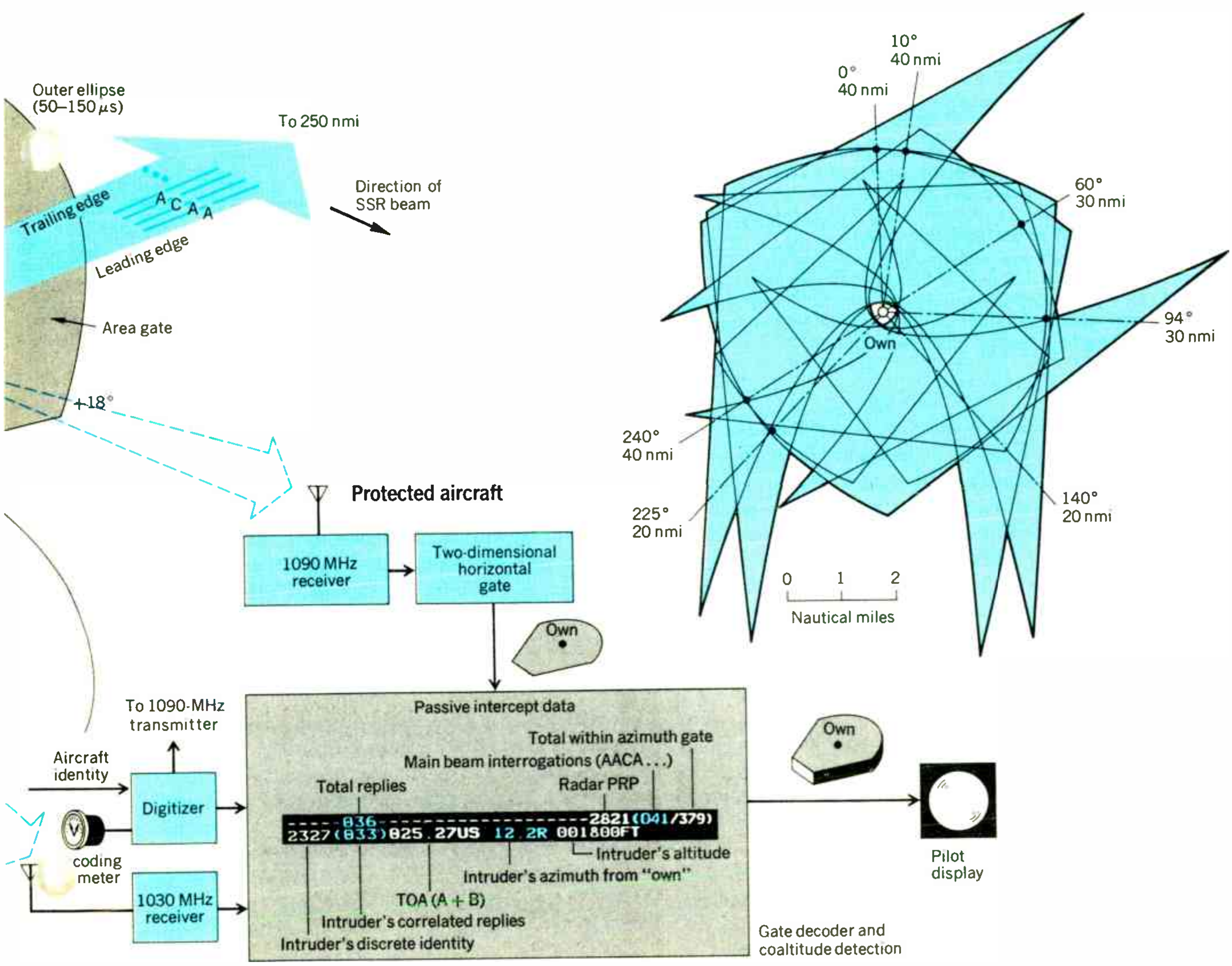
While determining the azimuths of both protected and intruder aircraft, BCAS has already established (by means of a digital counter) an azimuth gate, typically 4½ beamwidths on each side of the protected aircraft. All aircraft found outside of this 36-degree azimuth gate are eliminated from further threat assessment, since they are not an immediate danger to the protected aircraft (see Fig. 2B).

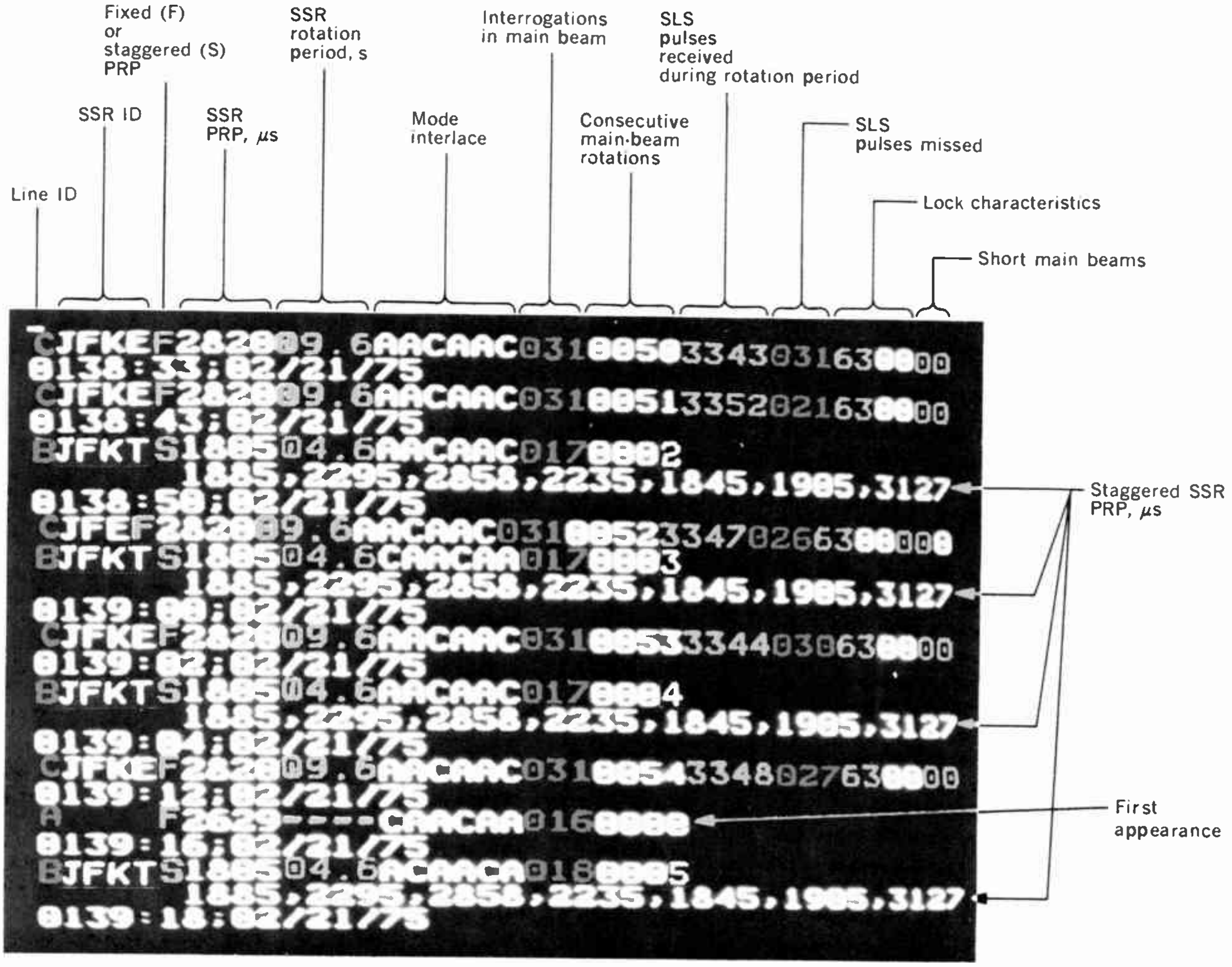
To determine the radial dimension of its plane's protective area, BCAS next measures the time differential of arrival (TOA), defined as the time it takes for a reply signal from another aircraft to reach the protected aircraft *after* the interrogation signal soliciting the reply has been received by the protected aircraft (see Fig. 2C). Since all replies from another plane to the BCAS plane are delayed by the extra path length the replies must travel, all constant-delay contours are found to be ellipses whose foci are the protected aircraft and the ground station. Each such ellipse is very precise and represents a contour in space with real coordinates. Although azimuth is measured in milliseconds (4000 ms typically equaling 360 degrees for one class of FAA radars), the between-aircraft delay is measured to about ±0.1 μs (or even ±0.05 μs) using histogram processing and correlation techniques involving many TOA measurements in a single "burst."

It should be noted that a single pass by a ground station interrogation beam elicits as many as 20 to 40 replies from a single aircraft—usually in the Mode sequence AACAACAAC . . . These highly redundant responses are ideal for BCAS's correlation processes, improving the reliability and integrity of the BCAS data, and avoiding the "one-shot" transmissions common to most communications systems.

To complete the third dimension in the volumetric protective gate surrounding aircraft equipped with BCAS, an altitude band around the craft (determined by the density of traffic) is established by BCAS within which all other aircraft are computed to be potential threats. What BCAS actually does is compare its altitude with the other's decoded altitude (received via the SSR Mode-C interrogation) to determine the vertical separation and the possibility of a collision. If another plane is outside the preestablished altitude band (±1000 ft from the BCAS craft's own altitude, for example), then the computer ceases threat evaluation.

When flying within 95 percent of the controlled airspace over the U.S., a plane will normally be in range





[5] Early BCAS testing demonstrated the feasibility of capturing and locking onto multiple ground radars (JFKE is JFK enroute, JFKT is JFK terminal, and Line A was unknown at the time of computer processing). Note the consistent stagger pattern of JFKT as automatically measured by the computer. As an exercise, if one adds the SLS pulses received (3343 on the top line), the SLS pulses missed (31), and the total interrogations received from the main beam (31), one arrives at the same number derived from dividing the SSR rotation period (9600 ms) by the PRP (2.82 ms).

of two or more SSR beams. At times, however, there will be only one beam or no beam at all. In the case of only one beam (see Figs. 2D and 4), BCAS is able to determine differential azimuth and whether or not another plane is within the protective volumetric gate (i.e., the azimuth, TOA, and altitude gates), but it is unable to measure the actual range from its plane to another. As a result, the BCAS craft must actively interrogate the other craft by means of its 1030-MHz transmitter, which asks the same questions as the ground interrogators: "Who are you?" and "How high are you?" Range and bearing are then easily determined by measuring the time of reply. No interference to ATCRBS can occur in such a low-density airspace.

In the case of no beam at all, BCAS again actively interrogates all aircraft in its vicinity, but this time without the benefit of a differential azimuth or a TOA gate (it does receive Mode-C altitude, however). Hence, in this rarest of all air-control environments, BCAS's capability is reduced to that of most other collision-avoidance systems now competing for FAA approval—that is, threat determination by means of range, range-rate, and altitude. Instead of offering the pilot a more precise escape maneuver (see the July *Spectrum*, p. 29), BCAS only instructs him to "climb," "remain level," or "dive."

When in range of two or more SSR beams—the normal environment—a BCAS-protected aircraft is able to function at its full passive potential, eliminating the need for active BCAS transmissions. As seen in Fig. 2E, the intersection of two ellipses, each of which has both a ground station and its own position at the foci, will describe both a "true" threat and a "virtual" threat. By proper computer analysis, the incorrect virtual threat will be eliminated, thus leaving the computation of both bearing and range as an easy computer exercise. All this is accomplished completely by passive interception of 1030-MHz interrogations from the ground and normal 1090-MHz replies from other aircraft.

If three or more SSR beams address a protected aircraft, the true threat will appear exactly at the intersection of all three or more ellipses.

Fortunately, ground stations in the same area are currently nonsynchronized and purposely randomized to avoid overlapping interrogations. Furthermore, the Mode A/C message reply time is very short—20.3 μs—and the period between interrogations is comparatively long—2500 to 5000 μs. Thus, the protected aircraft is not troubled by overlapping interrogations of a given radar, making over 99 percent of its time avail-

Analyzing a live target over New York

The principle of the Litchford Semiactive BCAS was demonstrated earlier this year when the system was used to measure passing aircraft from atop the Pan Am building in New York.

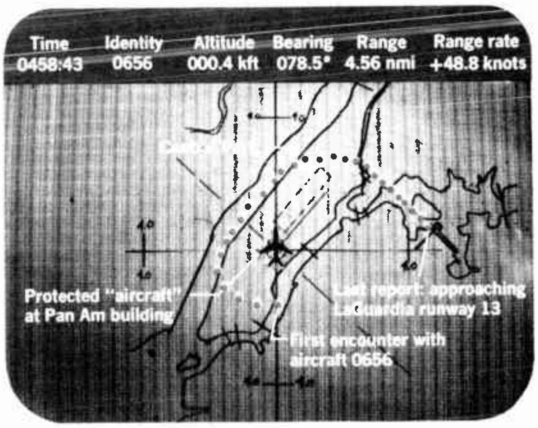
In the photograph (right) of the "pilot's" console at the test site, 800 ft high on the building, the protected "aircraft" is at the center of the display. LaGuardia Airport is visible at about 80 degrees and 4½ miles. Data such as computed range, bearing angle, and range rate are shown at the top of the display.

A transparent overlay shows some of the geographic details of the New York City area. The overlay would not be used in an aircraft, but helps an observer to track an aircraft by eye from the windows of the Pan Am building.

The Pan Am building is surrounded by multipath reflectors of equal or greater height—the World Trade Center towers, the Empire State building, the Chrysler building, the RCA building, and other structures. Despite the fact that the test location has a multipath environment probably worse than any that would be encountered in actual flight, most of the multipath reflections have been removed automatically by the computer. All of this is accomplished without a-priori knowledge of the environment.

The color dots in the photograph are the trail of an actual airliner. The ground station used in this test is the long-range radar at Kennedy Airport, which scans 360 degrees of azimuth in 9.6 seconds; thus, the space between dots represents 9.6 seconds of flight time. The target aircraft (identification number 0656) carries a Mode A/C transponder, as it is required to do by regulations. The transponder was not required specifically for the Semiactive BCAS demonstration; the aircraft equipment was that normally carried during flight and the pilot and controller were unaware of the measurements made by the Semiactive BCAS. Moreover, it is known from other FAA measurements that the airspace occupied by airliner 0656 was covered by many radars so was replying to at least five and perhaps 20 other interrogators.

During the 4½ minutes of flight that is described in the photograph, the target was identified 616 times by its discrete code message and 308 times by its altitude message. This large redundancy is a necessary part of the ATCRBS technical operation, but pays extra dividends when used for collision avoidance. The 924 reports are intercepted responses to the Kennedy ground station; if responses to the Newark Airport ground station had been used too, the reports would total 1300.



The identity tags at the top of the photograph could be displayed directly on the screen; and if desired, every blip of the target could show a tag for bearing angle, range rate (radial velocity), altitude, time, and range. If the 4-second radar at Kennedy or Newark had been used for the measurements, a nearly solid track for the target would have been created on the screen, and a tag could have been provided at given lengths of track.

The computer displays only one aircraft in the photograph because it was instructed through the pilot's keyboard to show only aircraft 0656. All targets, or a limited number of them, can be shown if the pilot so elects. In a dense area, only targets assessed as threats would be shown to the pilot.

This particular target does not have a pattern of range, range rate, or azimuth rate that poses a threat to the protected aircraft, but it illustrates a "live" sample at the same altitude that comes within 1½ mi, passing in front of the "protected" flight path. Aircraft 0656 therefore deserves the pilot's concern and attention to determine if a change in the path of either aircraft will create a new threat condition.

Or 0656 could be the plane that the protected aircraft is to follow into LaGuardia, maintaining the FAA-prescribed 3 nmi separation. The 100-ft range accuracy of the system is more than adequate for this purpose.

able to receiving many more Mode A/C replies from as many other aircraft as may be in the vicinity. In addition, since all ground stations must share the same single frequency channel, the sophisticated pulse multiplexing technique used by the FAA and DOD to minimize interference is also used by BCAS aboard a protected aircraft.

Threat evaluation

As just described, to be considered as a possible threat to a protected aircraft, another aircraft must:

1. Be within a given altitude band containing the BCAS aircraft's own altitude (± barometric altimeter tolerances).

2. Be within a wide azimuthal sector of many SSR beamwidths centered on the BCAS aircraft's azimuth.

3. Be within a given message delay (typically from 0.1 to 50 μs at slower terminal-area speeds, and 5 to 150 μs at faster enroute speeds), as represented by the inner and outer TOA ellipses.

These are physical, volumetric dimensions of a "cocoon" of airspace surrounding and moving with the protected aircraft.

All signals from other aircraft that fall outside of the cocoon are automatically regarded as nonthreats and excluded from further processing. (Signals from multiple ground radars, however, are continually processed, since they are usually situated near higher density airspace.) The exclusion of such "extracocoonal" signals drastically reduces the load on the protected aircraft's computer, allowing a smaller and simpler machine than would otherwise be needed. Other CAS (described in the July *Spectrum*) require nearly continuous exchanges between themselves and the protected aircraft, thus increasing computer workload, a condition other CAS solve by resorting to multiple channels or extremely stable, highly synchronized time references.

As a conservative estimate, the threat-nonthreat discrimination of BCAS may reduce the computer workload by at least 1000 times: a factor of ten through selection of an azimuth gate, another factor of ten through the TOA gate, and yet another factor of ten through altitude gating. Range garbling, an affliction of active forms of BCAS as well as other CAS, can also make excessive—and unrewarding—demands on computer time and software; with BCAS, most of this is eliminated not only by rejection of nonthreat replies, but by computer selection of as few ground radars as needed to evaluate a threat (thus reducing the number of processed replies from each threat). Whenever BCAS becomes "active"—during the absence of ground interrogation or to supplement the few 1030-MHz SSRs that may be present—garbling is virtually nonexistent, since there is not likely to be many aircraft over such low traffic density areas. Moreover, "active" interrogations (typically ten per second) are not apt to cause interference problems if there are no ground stations to interfere with.

Safety in numbers

The mere entrance of a target aircraft into a volumetric gate is not sufficient to define it as a positive threat, only that it bears watching. Suppose a target enters the protective cocoon surrounding a BCAS aircraft (see Fig. 4). As soon as the potential threat is detected, BCAS's threat–nonthreat discrimination capability not only continually measures the changing TOA, but the changing differential azimuth as well—thus doubling the safety factor of BCAS Tau discrimination.* Since rate-of-change is defined as the percentage of deviation over a given time interval, it is much more revealing of a target aircraft's behavior than single measurements of TOA or differential azimuth.

Depending upon the relative trajectories, the separation between the two aircraft and the rate-of-change of this separation are actually assessed according to whether successive TOA and azimuth values are increasing or decreasing in time. A closing rate of separation is considered a *negative* Tau, while an increasing rate of separation is a *positive* Tau. BCAS uses only negative Taus in threat evaluation.

A decrease in any of the three separation criteria that creates a low value of Tau is sufficient for BCAS to continue a threat evaluation; a persistent negative Tau in all three parameters (TOA, differential azimuth, and relative altitude) most assuredly indicates a midair collision course could ensue. Tau, therefore, is simply the displacement value divided by the rate-of-change of displacement between both aircraft.

It is clear then that TOA rate-of-change and differential-azimuth rate-of-change are actually figures of merit much like the Tau concept used in other CAS that follow Air Transport Association specifications (ANTC-117)—specifications that use range divided by range-rate (Tau_R) to assess (along with relative altitude) the degree of danger to a protected aircraft. Similarly, Tau_{TOA} is defined as TOA/TOA-rate, and Tau_{AZ} as differential-azimuth/azimuth-rate.

Once a coaltitude target has been detected, BCAS identifies its Mode-A code so that it cannot be confused with other aircraft. If either TOA-rate or differential/azimuth-rate are positive (indicative of increasing separation), the target is not considered a threat but will be tracked until it leaves the protective cocoon, since it can change its course at any time.

The combined TOA and azimuth data, then, make up a fine-grain coordinate system centered upon the protected aircraft; when differential altitude data is added (target must carry a Mode-C transponder), the system becomes three dimensional—all without knowledge of the distance to the ground interrogator. It has been estimated in demonstrations that azimuthal difference can be measured with an error of approximately ±0.2 degree over an azimuthal sector of nine or ten 4-degree radar beamwidths. Similarly, measurement of TOA can be accurate to within ±0.1 μs.

Azimuth and TOA Taus, therefore, give an exceptional and hitherto unobtainable means of avoiding false alarms, a problem that plagues most other CAS methods based solely on range/range-rate Tau.

Moreover, whenever there exists a highly probable threat, or in the case of only single or dual ground radar coverage, a protected aircraft has the additional prerogative of going active, thus obtaining range/range-rate as still another target discriminant to BCAS threat assessment.

It should be remembered that active BCAS is avoided in environments of more than three SSRs, since serious interference can exist to the ground system. Additionally, severe garbling of many aircraft replies can also occur in dense airspace, making altitude decoding impossible. BCAS passive ranging avoids these two flaws of active interrogation in dense air/ground environments.

Finally, there is another target discriminant that can be obtained whenever BCAS is operating under one or more SSR coverage—*bearing angle* (see Fig. 2). It is a well-known navigational concept that collisions occur only if the bearing-angle rate-of-change of an approaching target (decreasing separation) is zero. If the bearing angle between protected aircraft and intruder is changing in either a clockwise or counterclockwise direction, no collision can ensue. Not only does bearing angle increase the probability of detecting real threats, but it acts as an ultimate fine control to eliminate most of the incidences of false alarms. ◆

* This built-in redundancy—so necessary for air safety—would be tripled if altitude rate-of-change were included. As it is, BCAS constantly monitors relative altitude (at 100-ft increments), and discontinues threat evaluation whenever a detected aricraft leaves the protective coaltitude band.

George B. Litchford (F) has had a long and distinguished career in the development of many of the nation's present aviation systems. One of the few elected a Fellow of both the IEEE and the AIAA, he is active in both electronics and avionics, having performed hundreds of hours of flight research, hence speaks from both an aviation as well as an electronics expertise. A professional engineer in New York State, he is the 1974 corecipient of the Pioneer Award (AES Society) and served in the White House during the Eisenhower Administration as head of the Curtis Committee aviation facilities planning group, which led to a restructuring of the CAA into the FAA and closer civil–military cooperation. He holds about 40 aviation patents, was instrumental in developing the only microwave landing system presently in operation—the Navy's C-SCAN—and has published over 70 professional papers. Mr. Litchford is now President of Litchford Electronics, Inc., of Northport, N.Y.

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Ignition systems go solid state

Standard on all 1975 U.S. cars, electronic ignitions reduce maintenance costs, improve cold starts, and keep engines tuned longer

About 65 years ago, Charles Kettering developed a contact point inductive ignition system for use on Cadillacs. That system, or improved variations of it, has been in use ever since. It is relatively simple, inexpensive, and if properly maintained can provide a satisfactory ignition for most cars. But, as any car owner knows only too well, a conventional ignition system can also be a trouble-prone component of an automobile. Points tend to burn, pit, or simply wear out rapidly; spark voltage may decrease rapidly with increasing engine speeds; and the rubbing block attached to the points tends to wear down from contact with the distributor cam used to open and close the points. These, and other related problems, may cause ignition timing to retard or advance resulting in poor engine performance, decreased fuel economy, and even engine failure if no sparks are produced to ignite the fuel–air mixture in the cylinders.

Electronic ignition systems, on the other hand, eliminate most of the problems associated with the Kettering type of system by either doing away with the points or by so reducing the current flow through them that they last longer. It is perhaps not surprising, then, that electronic ignition systems are standard equipment on all 1975 U.S. automobiles as well as on many import models. A large assortment of electronic ignition systems of various types are also available from many auto parts manufacturers as after-market retrofit kits.

Keep the points, add a transistor

Electronic ignition systems got their start with the addition of a power transistor to a conventional inductive ignition system (Giacoletto, L. J., U.S. Patent 2 878 298). The breaker points in a transistorized ignition of this type, instead of carrying full primary current, merely act as a switch to turn the power transistor on and off. It, in turn, carries the majority of the current flow. In a conventional ignition system, the points carry from 4 to 6 amperes of current whereas, in a simple transistorized system, they carry 300 mA or less. Since no arcing is produced, the capacitor across the breaker points, used in conventional systems to assure a sharp cutoff of current, is also usually eliminated with the added advantage of a larger ignition voltage.

Even though the points carried less current in early transistorized ignitions, higher primary currents of 10 to 12 amperes were required because only low-voltage, high-current transistors were then available for the desired energy levels. Special high-current, high-turns-ratio ignition coils had to be designed to match the transistor limitations. Low current in the points gave longer point life (25 000 to 30 000 miles or more instead of 10 000 to 20 000). Higher current and voltage in the coil, with proper coil design, gave more reliable ignition at both high speeds and at very low cranking speeds.

Pointless ignition systems

More recent electronic ignition systems eliminate the points altogether, as well as the distributor cam, by replacing them with other trigger mechanisms and means for turning primary current on and off. In addition to the use of transistor combinations (a power transistor and a driving transistor, for example), the two most popular trigger systems are magnetic pulse units and interrupted light beams. Magnetic pulse units use sensors which: (1) produce a voltage trigger pulse when the teeth on a trigger wheel mounted on the rotating distributor shaft move past a permanent magnet, or (2) produce a pulse as the result of the position of the teeth in an oscillator coil. In both cases, the sensor output is used to break the primary current flow through the ignition coil thereby creating a spark in the secondary circuit. The interrupted-light-beam type of ignition system uses a light source and either a photodiode or phototransistor. A rotating slotted disk interrupts the light beam. Each time the light beam is broken, an interruption of primary current takes place which then causes a spark to be generated in the secondary circuit.

Capacitor-discharge ignition systems

Another basic type of electronic ignition system, used extensively in retrofit kits, is a capacitor-discharge (CD) ignition. It can use either magnetic-pulse or interrupted-light-beam triggering but, in addition, it contains a capacitor that must be kept charged, discharged, and then recharged. When the triggering signal is received, the capacitor discharges through the primary of a pulse transformer which converts a very high di/dt to a voltage pulse of the required amplitude for firing the spark plugs.

The CD ignition system has extremely fast rise time (about 3 μs) which aids in firing badly fouled plugs and also permits the capacitor to be recharged in sufficient time for the next plug to be fired, even at high engine speeds. CD systems have also been used with breaker points, in which case point life is extended, because full primary current does not flow through the points.

CD systems usually have a much shorter arc dura-

Ronald K. Jurgen Managing Editor

Ignition systems at a glance

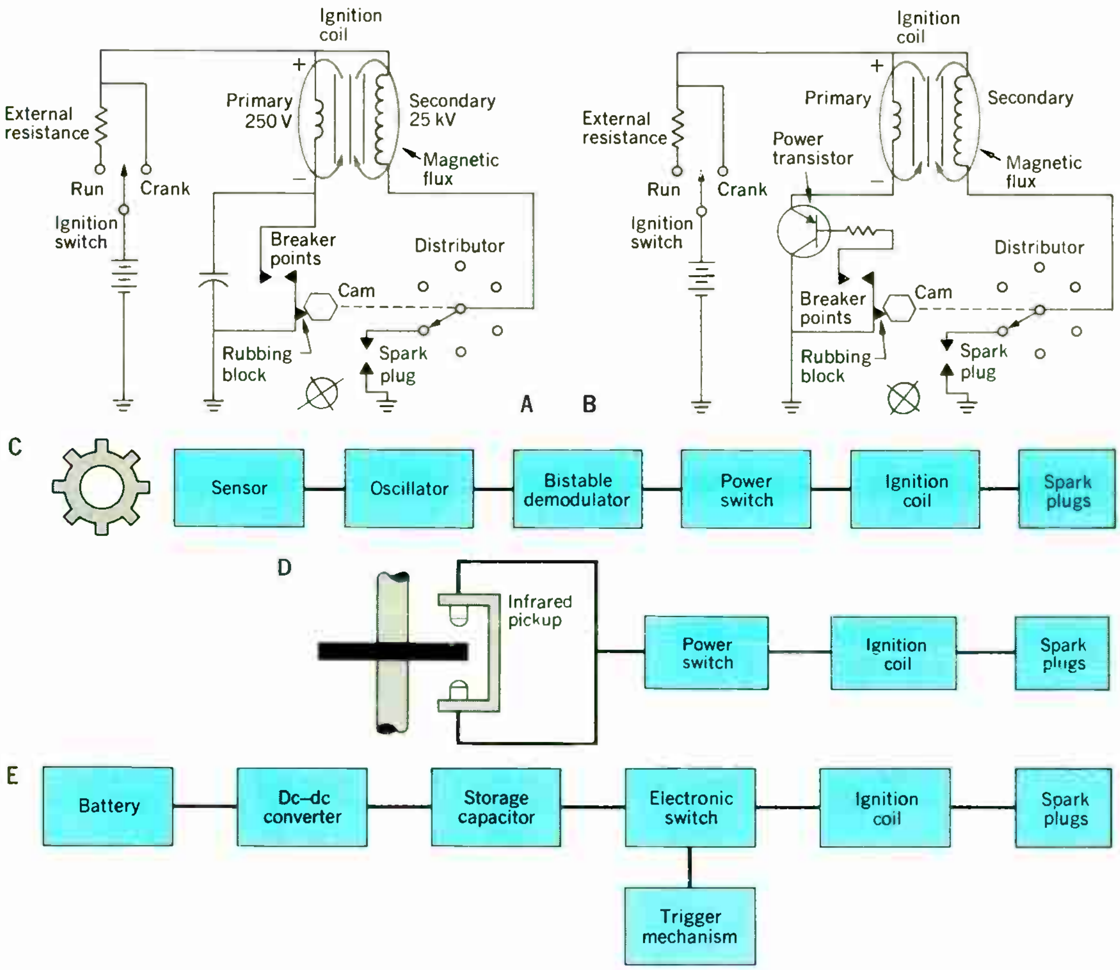
When the ignition switch is closed and the breaker points in the distributor of a conventional (Kettering) system (A) are closed by the rotating cam, current flows from the battery through the primary winding of the ignition coil to produce and maintain a magnetic flux within the iron core of the coil. When ignition of a spark plug is required, the cam opens the breaker points, interrupting the primary current flow. The resulting decay of flux induces a voltage in both the primary and secondary windings of the ignition coil. The voltage induced in the secondary winding is routed by the distributor to the correct spark plug to produce the ignition spark. The points then close again and the cycle is repeated for the next cylinder in the firing sequence. The capacitor across the breaker points helps prevent arcing across them by providing a momentary alternate path for current flow when the points are opening.

In a simple transistorized ignition system (B), when the ignition switch and breaker points are closed, the power transistor switches on, conducting current through the coil. When the points open, the transistor switches off rapidly and the magnetic field collapses, inducing a voltage in both the primary and secondary of the ignition coil. The secondary voltage is used to fire the appropriate spark plug. Although just one transistor is shown in the illustration, some systems use two transistors in series and almost all systems have additional components to protect the power transistors.

In a magnetically triggered breakerless or pointless system (C), the distributor has the conventional advance mechanism but a sensor and trigger wheel are added. In the Prestolite Electrical Division system, for example, an electronic control unit is used. Operation of its circuitry is based on the accurate amplitude modulation of a resonant circuit oscillator in which the inductor acts as a sensor. When the conductive material of a trigger wheel enters the field of a sensor, eddy current losses in the nonmagnetic wheel tooth reduce the *Q* of the resonant circuit and decrease the amplitude of oscillations to a level at which a switching transistor interrupts the coil current and causes the coil to produce a timed high-voltage spark. When oscillator amplitude has decreased below the switching level, a variable feedback system maintains a minimum amplitude of oscillation. This minimum level eliminates timing variations that would occur if the oscillator had to be restarted by random noise.

In an optically triggered, pointless system (only used at present in retrofit systems because of its high cost), a shutter device attached to the distributor shaft interrupts a fixed beam of light. In the Lumenition ignition system (patented by Lumenition Ltd., London, England and produced and marketed in the U.S. by TRW Electronics), infrared radiation from a light-emitting diode (D) is focused on the junction of a phototransistor. A slotted sheet-metal or plastic disk affixed to the distributor shaft interrupts the beam, producing an on-off signal for spark control. The optoelectronic trigger signal (basically a measure of crankshaft position) is amplified and used to control a power transistor which actually switches the coil primary current and so controls the spark energy. Since both the initiation and interruption of the coil current are controlled by the optically generated signal, spark timing is only a function of crankshaft position.

A capacitor-discharge system (E) might use either a magnetic or optical triggering system. A dc-to-dc converter keeps the capacitor charged at 300 volts. Upon receipt of the triggering signal, the capacitor is discharged through an electronic switch into the primary of a pulse transformer. The 300-volt pulse is stepped up to 25 kV by the pulse transformer.



tion (less than 250 μs) than other ignition systems. This decreased arc duration can increase the probability of misfiring of the spark plugs.

"High-Energy Ignition"

An advanced electronic ignition system presently in use is the General Motors "High-Energy Ignition" (HEI) system introduced as standard equipment on all 1975 GM cars. It is a total system in which the distributor, coil, and electronic module are combined into one package.

HEI has a number of interesting features among which are a spark voltage of 35 kV, instead of the conventional 25 kV; a 50-percent longer spark duration (1800 ms vs. 1200 ms); and use of automatic current regulation. The combination of higher spark voltage and longer spark duration permits use of wide-gap spark plugs (0.060–0.080 in) and gives HEI the ability to ignite the fuel–air mixture under a wider range of engine operation than is possible with many ignition systems. Automatic current limiting at 5.5 amperes is accomplished by absorbing excess battery voltage in the switching transistor. This action causes an appreciable power dissipation during the time the current is being limited. A low-resistance coil design with automatic dwell control delays the turn-on of coil current until there is just enough time for the current to reach full value before turn-off to produce the spark. As a result, the time that current limiting is required is reduced to a minimum. This function eliminates excessive power dissipation in the system and increases its temperature tolerance and reliability.

The trigger mechanism used in the HEI system is magnetic. It is a concentric variable reluctance design consisting of a stationary magnet and pickup coil assembly surrounding the distributor shaft and a rotary pole piece fitted to the spark advance mechanism on the shaft. As the distributor shaft rotates and the pickup teeth approach alignment, the output voltage increases in positive polarity. As the teeth pass through alignment, the output voltage suddenly reverses and passes through zero to a negative polarity to produce the spark on the rapid negative-going portion of the voltage waveform. This action gives a precisely located switching point for accurate spark timing.

Ignition systems of the future

Chrysler Corporation has already announced plans to use an electronic spark advance system in conjunction with electronic ignition in some 1976 model cars (see *Spectrum*, June 1975, p. 77). Silicon-controlled rectifiers and power Darlingtons may find more usage in electronic ignitions. And Hall-effect devices are under consideration. Hall-effect devices look promising mainly because they are clean, low-voltage components which are nonspeed sensitive and have inherently high outputs. This combination of characteristics offers advantages over many other sensors.

One of the first automotive applications of Hall-effect devices is in Ford Motor Company's new timing system which will be standard equipment on 1976 Continental Mark IVs. Major components of the system are: the distributor; an electronic spark-timing module; and sensors used to detect instantaneous values of engine r/min, transmission-gear positions, coolant temperature, and manifold vacuum. The distributor has two separate timing pickups (the Hall-effect devices) offset from each other by the desired advance increment. By using one pickup for initial timing and the other for advance, it is possible to obtain an instantaneous shift in advance merely by switching to the second pickup. This switching is controlled by the spark-timing module, essentially a miniature computer that evaluates the various operating conditions to determine when to advance the spark. It advances the spark based on the various sensor inputs. It can also generate a time delay in the signal to retard the spark when warranted by engine operating conditions. This feature is used for engine knock control. Output from the spark-timing module provides the input for an electronic breakerless ignition module.

Now the bad news

High-voltage, solid-state ignition is not without drawbacks. Regardless of trigger or switching means, all systems have a distributor. The higher the voltage, the more sensitive are components to moisture condensation or metallic contamination. Distributor caps having aluminum terminals are particularly prone to sputtering of the terminals which then causes deposits on the inside of the cap. Moisture and metallic contamination can cause arc-over or leakage inside the distributor cap which, in turn, prevents the engine from starting. At very high voltages, corona, RFI, and possibly X-radiation become problems.

The economics of solid-state ignition are also interesting to consider. Electronic ignitions are higher priced, nonrepairable (to a large extent), and complex to diagnose. They are being substituted for cheap, easily understood, but inevitable wear-out systems. Since one of the fundamental rules of reliability is more parts, more failures, it will be interesting to view the long-term results. The forcing function for the automobile manufacturers appears to be a system that keeps the engine in tune for pollution control. Service costs, when failures occur, will be up to the consumer once the warranty period has ended. ◆

For further reading

A basic discussion of automotive ignition systems is contained in the article, "Electronic ignition" by Sam Florie in *Machine Design*, pp. 73–77, March 6, 1975.

For the home mechanic interested in retrofit kits for replacing conventional ignition systems with electronic systems, an informative discussion of ignition systems, a how-to-install guide, and a rundown on commercially available retrofit kits can all be found in an article by John Fuchs, "Electronic ignition systems," in *Motor Trend*, pp. 110–120, May 1975. Also worth looking at for retrofit kit information is "Electronic ignition buyer's guide," by Don Fuller, *Road Test*, pp. 38–44, July 1975.

In-depth engineering information on General Motors HEI system is contained in a paper, "HEI—a new ignition system through new technology," by G. O. Huntzinger and G. E. Rigsby presented at the Automotive Engineering Congress and Exposition, Detroit, Mich., February 24–28, 1975. The paper is available as paper 750346 from the Society of Automotive Engineers, Inc 400 Commonwealth Drive, Warrendale, Pa. 15096.

WESCON '75

The week in brief

Over 25 000 members of the electronics industry are expected to attend this year's 24th annual WESCON, September 16 through 19. The four-day product exposition and professional technical program will be held under one roof: the product exposition in Brooks Hall, and the professional program in the Civic Auditorium, San Francisco, Calif. Over 300 exhibitors are expected.

The schedule

WESCON's product exhibits will be open each day, Tuesday through Friday, at 9:30 a.m., and will close at 5 p.m. on Tuesday and Thursday, 9 p.m. on Wednesday, and 4 p.m. on Friday. The professional program, to be held in the Civic Auditorium, one level above the product exposition in Brooks Hall, is comprised of 32 half-day sessions starting at 10:30 a.m. and 1:30 p.m., daily, except Friday, when there will be no afternoon sessions. The program will also include a Friday morning session devoted exclusively to IEEE Region 6 student technical papers. A special Wednesday night session on "Psychotronics," the science of parapsychology, will be held at 7 p.m. Further details about the professional program are on page 53.

Registration hours are 8:30 a.m. daily at the Civic Auditorium. No advance registration is required. As in last year's WESCON, the computerized Jacquard registration system will provide each registrant with an embossed plastic inquiry badge.

Touring the product exhibits

Brooks Hall will be divided into four major product sections: components and microelectronics; instruments and instrumentation; computers, peripherals, and communications; and electronics packaging and production. It is anticipated that the Hall will be fully occupied—a total of 489 exhibit spaces contracted by over 300 exhibitors. About 10 percent of the WESCON exhibitors will be manufacturer representatives and distributors who will be exhibiting the products and services of several manufacturers in one booth. More details about product highlights at the show start on page 54.

Roger Allan Associate Editor

Special events

A number of special events will take place at the St. Francis Hotel on San Francisco's Union Square. The St. Francis Hotel has been designated the official WESCON headquarters hotel. The events include a luncheon on Tuesday the 16th, a reception that evening, and a conference on Thursday the 18th.

The WESCON luncheon will feature a keynote address by Daniel McMillan, publisher of *Electronics* magazine. That evening, the WESCON All-Industry Reception will be held (tickets are $10 per person) with live music, food, and refreshments. The Thursday distributor-manufacturer-representative conference will have as its theme "Distribution in the Next Thousand Days."

For the ladies, there will be a hospitality suite at the St. Francis Hotel.

Transportation

As was the case in 1973 (the last time WESCON was in San Francisco), WESCON will offer "Bayshore Flyer" bus commuter service from Palo Alto on the Peninsula to the WESCON site at the Civic Center (Polk and Grove Streets and back). Buses will start and return from the Cabana Hyatt House Hotel in Palo Alto and will operate during all show hours. Free parking will be available to WESCON attendees, at the Cabana Hyatt Hotel.

Additional transportation within San Francisco will include shuttle bus service linking the St. Francis Hotel and the BART train system to the Civic Center.

WESCON is a nonprofit activity cosponsored by the San Francisco Bay Area Council and the Los Angeles Council of IEEE, and the Northern and Southern California Chapters of the Electronic Representatives Association. WESCON's parent organization, Electrical and Electronics Exhibitions, Inc., is a nonprofit California corporation.

Scanning the sessions

Thirty-two morning and afternoon sessions—from Tuesday through Friday noon—highlight the WESCON technical program. Covering a wide range of topics in electrical and electronics technology, the papers fall into six major areas of interest—microprocessors, electronic devices and consumer electronics, instrumentation and communications, finance and marketing, packaging and production, and energy. Characteristic of most WESCON sessions this year is the balance of both manufacturers and users as speakers. Whether the subject is pocket calculators or data links, sessions tend to offer a range of viewpoints.

Full reprints of most of the WESCON papers will be available for each session.

Microprocessors go public

Six of the 32 technical sessions are devoted to the microprocessor and its peripheral components, reflecting the continuing growth of LSI-processor applications.

Designers are introduced to the microprocessor in Session 1, which focuses on the experiences of four new users. Each speaker will stress *real* hardware, software, systems, and training aids that they have used or developed. Session 6 examines another aspect of the microprocessor boom: methods for generating and testing software and firmware, along with the pros and cons of each technique. The discussion will concentrate on features for future support systems to minimize development time and money.

Three popular commercial microprocessors—the Intel 8080, National Semiconductor's GP/CP 16-bit chip, and Motorola's M6800—are the subject of Session 10, but it's the user, rather than the manufacturer, doing the talking. Three of the speakers will tell how they started with an idea and a handful of parts, and ended up with a working system. A fourth speaker, with the aid of a live demonstration, will offer tips to designers with the know-how to use microprocessors, but not the money.

New developments in microcomputer design aids and logic analyzers and recorders are the concerns of Session 15. Intel's Intellec MDS, Motorola's EXORciser, and logic analyzers and recorders from Hewlett-Packard and Biomation are among the devices to be discussed.

Want a printer for your microcomputer system? Session 21 gets to the heart of the differences in printing peripherals and includes a demonstration of the first microprocessor-controlled serial printer.

Medical instrumentation applications for microprocessors are explored in Session 24, which considers the applications of the microcomputer in patient monitoring and diagnostic health care.

Consumer electronics

The electronic watch, one of the largest and fastest growing segments of the electronics industry, is the subject of two sessions, 12 and 17. Quartz watch crystals, CMOS circuits, batteries, LEDs, and liquid crystals are among the topics to be considered.

Another popular consumer product, the pocket calculator, is the subject of session 29, which presents the viewpoints of both user and manufacturer, as well as an analysis of the market for hand-held dedicated calculators.

Neither of these products would have been practical had it not been for advances in electronic devices such as I^2L (a high-density, bipolar IC device). I^2L and CCDs will be reviewed in Session 19.

Session 26 offers an applications overview of field-programmable logic arrays (FPLAs). The FPLA is finding increasing use in microprocessor and memory circuits as a low-cost and flexible replacement for non-standard logic functions.

Instrumentation and communications

Instrument manufacturers and users have long needed a common method for interconnecting programmable instrumentation. Session 3 reviews the interface system concepts contained in IEEE Standard 488-1975, which describes the IEEE standard digital instrument bus.

Programming costs for bringing automatic test equipment (ATE) on line are also industry concerns. Session 13 describes hardware and software that have been introduced to lower the programming and related startup costs of automatic testing. Session 22 explores the impact of ATE at various stages in the manufacturing process. And Session 27 looks at ATE as applied to LSI device testing.

From blood pressure monitoring to ultrasonic cardiac measurements—medical electronics must be developed to provide the highest standard of health care at the lowest possible cost. Session 20 summarizes new engineering concepts that will influence electronic instrumentation and hospital electrical safety.

Communications technology is covered by several sessions. Electronic PBXs, for example, are examined in Session 5, which outlines a design philosophy and its effect on marketing considerations. Extraterrestrial applications are the focus of Sessions 9 and 32. Session 9 describes satellite laser ranging, and 32 concentrates on communications satellite systems and their impact on spacecraft configurations and ground networks.

Session 18 brings together two manufacturers and two users of synchronous data link control (SDLC) systems. Each of the four participants will speak on the pros and cons of SDLC relative to his specific field—in this instance, banking and insurance. A fifth speaker, a market-research analyst, will forecast the marketing impact of SDLC on teleprocessing equipment and related components.

Electronic identification systems are yet another application of instrumentation covered by a WESCON session. Session 31 defines three approaches based on fingerprints, speech, and handwriting. The presentations have a technical, rather than a marketing orientation, yet are aimed at professionals not directly involved in the area.

Dollars and sense

As in previous WESCON technical programs, several sessions are devoted to the business side of electrical and electronics engineering—recognition of the fact that today's designer must be aware of the financial aspects of his profession.

How do you get a loan when times are tough? Session 2 provides some answers. A panel representing the financial community and the Small Business Administration will discuss how an entrepreneur or growing company can obtain alternate sources of capital. Need a sales team? Session 11 offers suggestions for choosing a winning team—be it "reps," a direct sales force, or distributors. The purchasing agent—what's his role in the business organization? Session 16 touches on topics like quality adherence, meeting time requirements, sourcing, and vendor contacts. How to protect your company's interests abroad? Session 28 presents an international business cookbook, with up-to-date information in four critical areas: foreign legal protection, market size determination, techniques for cutting red tape, and site selection.

The Employee Stock Ownership Plan (ESOP), as amended by the Income Security Act of 1974, contains provisions of interest to manager and employee alike. Session 7 looks at the use and misuse of ESOPs, as well as the practical aspects of administering such a plan.

And much more . . .

That's not all. Packaging and production are covered by Sessions 4, 8, and 25, which examine computer-aided LSI design, IC interconnection considerations, and beam-leaded devices, respectively.

Session 14 explores energy policy decisions and their implications for the electronics industry. Among the topics: energy consumption and economic growth, the case for conservation, and the effect of new legislation on energy policy.

A different sort of energy is described in Wednesday evening's special session on "psychotronics," a repeat of last year's presentation by U.C.L.A. researchers on work in Kirlian photography, bioenergy phenomena, and unorthodox therapeutic techniques—all related to the parapsychological phenomena of external energy fields in human beings.

The Program Committee for WESCON is headed by Alan Mitchell and Andrew Nalbandian.

Products at the show

Programmable synthesizer offers flexible performance

Model 3100 0- to 200-kHz programmable frequency synthesizer achieves a new high in versatility by offering 0.1-degree dual phase-adjustable outputs, and programmable attenuation, sweeps, markers, and carrier modulation, in any combination, by the proper selection of accessory-function plug-in modules. This 8-digit-resolution instrument features excellent accuracy of 5 ppm/day.

The 3100 comprises a mainframe synthesizer with not only dual-output channels in phase quadrature but also a front-panel compartment that accepts any one-, two-, or three-auxiliary-function plug-in modules, selected from five such modules currently available. The modules are equipped with front and rear connectors that permit routing and interconnection of signals between each other, the mainframe, and external equipment, in a variety of configurations.

The mainframe provides eight frequency selection decades, programmable from 0.01 Hz to 199 999.9 Hz in 0.01-Hz steps, either manually by panel switches, or remotely by parallel-entry, digital TTL BCD signals. Frequency switching is done in less than 2 ms and is transient-free.

Of the two output channels (A and B), the former, a reference channel, provides push-button selection of sinewave, positive, negative, or symmetrical squarewave, and TTL squarewave output waveforms. It includes a 0- to −70-dB attenuator, adjustable in 10-dB steps. Channel B output is a sinewave in phase quadrature (90° ± 0.5°) with channel A output, and it does not include an attenuator.

Both channels provide push-button-selectable fixed (7 volts) or adjustable (0 to 10 volts) peak output voltages, and selectable output impedance at either 5 or 50 ohms. Each channel has a peak current rating of 100 mA.

Optional accessory modules include the 3111 programmable attenuator (three attenuation decades of 0.1, 1, and 10 dB) with a total attenuation range of 0.0 to 79.9 dB; model 3112 high-resolution programmable phase control; model 3113 phase-angle detector; model 3114 sweep, search, and marker module; and model 3115 carrier modulation module.

The 3100 frequency synthesizer is available in bench- or rack-mounting styles. It is priced at $3550 for the basic instrument. Module prices range from $475 to $1175 each.

For further information, contact Adret Corp., 1887 Lititz Pike, Lancaster, Penn. 17601.

Booths 1211, 1213

Circle No. 85 on Reader Service Card

5-MHz miniscope has a low price of $495

This single-trace miniscope, model PS121A, features a dc to 5-MHz bandwidth, 50-mV/division sensitivity, and a sweep rate up to 100 ns/division. All of this is offered at a price of only $495.

The compact oscilloscope weighs less than 5 lb (2.27 kg), and is small enough to fit into a tool kit or briefcase. Front-panel dimensions are only 3 by 5 in (7.62 by 12.7 cm). The oscilloscope operates from 115 volts, 50 to 400 Hz.

Featuring automatic triggered sweep, the easy-to-operate PS121A includes external

triggering and an 8- by 10-division (0.5 cm/division) display. Its input impedance is 1 MΩ paralleled by 47 pF, and input risetime is 70 ns. Several options are available. These include a $100 rack-mounting kit, $25 rearpanel input connectors, a $25 10:1 probe kit, and $10 viewing and front-panel protective hoods.

Delivery is from stock to 30 days. The PS121A is warranteed for one year.

For further details, contact Vu-data Corp., 7170 Convoy Ct., San Diego, Calif. 92111.

Booth 1529

Circle No. 86 on Reader Service Card

Bugs in the nuclear fuel cycle

Stalled in its "back end" because of economic and safeguarding uncertainties, the cycle hinges on disposal of high-level nuclear waste

Unless prompt and effective actions are taken for the safeguarding and handling of nuclear fuels, the use of nuclear fission energy will be limited. This is the conclusion of the U.S. Energy Research and Development Administration in a report (ERDA-33) published in March. Whereas risks associated with nuclear reactors have been quantified and put in perspective, questions remain about risks associated with the safeguarding and handling of the nuclear fuels themselves. As a result, little progress is being made in the "back end" of the fuel cycle—that which includes temporary storage of spent fuel, reprocessing of spent fuel, and waste storage and/or disposal. ERDA cites these additional reasons for its concern:

- The availability of adequate uranium resources to allow continued growth over the next 20–25 years is in doubt.
- It is not clear if adequate enrichment capacity will be made available over the same period.
- Certain aspects of reprocessing of spent fuel have not been demonstrated, and the question of whether to allow recycling of the recovered plutonium has not been resolved.
- Program delays have postponed the time when the liquid-metal fast breeder reactor will remove the constraints of uranium resources and separative work on nuclear growth. Further, the breeder system requires that the reprocessing of fuel and the recycling of plutonium be licensed and demonstrated.

In ERDA's view, industry alone simply cannot be expected to solve problems of the back-end fuel cycle, and the Government must accept a greatly increased role if the problems presently threatening to impede nuclear progress are to be overcome. Among the back-end problems mentioned in the ERDA report: acceptable safeguard systems for separated plutonium have yet to be established and permanent disposal of the radioactive waste has not yet been demonstrated.

This article addresses problems and risks involved in the storage of spent reactor fuel, the reprocessing of the spent fuel for the recovery of plutonium and unused uranium, the disposal of high-level radioactive waste, and the shipment of nuclear material, predominantly that of spent fuel and high-level waste.

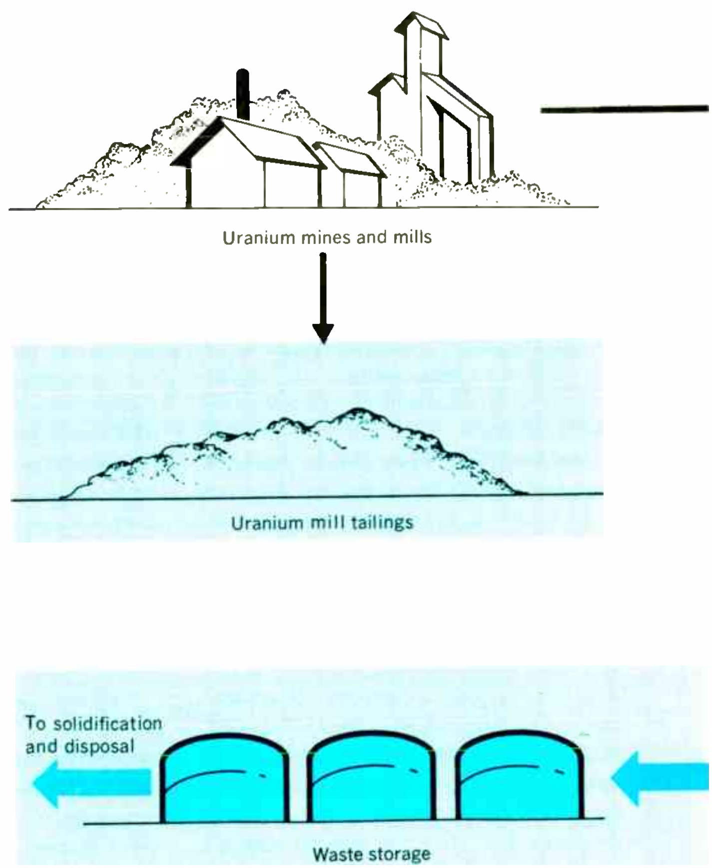
Spent-fuel storage

The facing illustration shows the principal steps of the nuclear fuel cycle. In two recent articles (June, pp. 46–55, and August, pp. 46–55), *Spectrum* took up the overridingly important question of nuclear reactor safety. In this article, *Spectrum* takes a hard look at the back end of the cycle beginning with spent-fuel storage and proceeding to waste disposal.

Gadi Kaplan Associate Editor

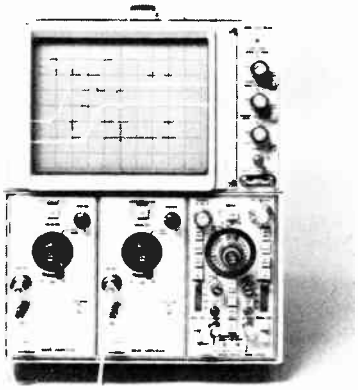
The first step in the nuclear cycle's back end is known as spent-fuel storage. Spent-fuel assemblies, which are typically stored in temporary basins located on reactor sites, will soon be filled to capacity. In the U.S. for example, it appears likely that about five temporary storage basins for spent fuel at reactor sites will be completely filled by 1976 unless steps can be taken to transfer some of their spent fuel to other locations. Similarly, a number of additional reactor basins will become completely filled in 1977 and subsequent years. The obvious questions arising from these circumstances are: Why are the basins being allowed to

The nuclear fuel cycle for light water reactors is comprised of a "front end," the reactor itself, and a "back end." Front-end services include the portion of the cycle before the fuel reaches the reactor (not discussed in this article)—stages that include the mining and milling of uranium ore, conversion into uranium hexafluoride, enrichment in the fissile uranium-235 isotope contents to about 3–4 percent (as against 0.7 percent in the natural uranium ore), and conversion to reactor fuel. While the risks from the reactor itself were already discussed, (see *Spectrum,* August 1975, pp. 46–55), hazards in the back end of the cycle—that is, temporary storage of spent reactor fuel, reprocessing of this fuel for recovery of plutonium and unused uranium, and temporary liquid high-



Dual-beam oscilloscope provides waveform versatility

Model 5444 true-dual-beam oscilloscope allows the comparison of any two signals easily and accurately, even that of rapid, single-shot events. Its two gun structures—two electron sources, two vertical-deflection systems, and two horizontal-deflection systems—provide completely independent operation and full-beam overlapping that allows positioning of either vertical-channel



signal over the entire eight-division CRT area. By combining the 5444 oscilloscope with two appropriate amplifiers and with the 5B44 dual-time-base unit with separate and independent circuits, two oscilloscopes in one instrument case can be had.

The 5444 allows the display of one signal at two sweep speeds, two signals at the same or different sweep speeds, the comparison of as many as four repetitive waveforms at 60 MHz in the alternate or chop mode (or up to eight waveforms at reduced bandwidth), and the comparison of multiple-trace, single-shot events at sweep speeds up to 100 μs/division, in the chop mode. The use of the 5B44 time-base unit permis a detailed look at a portion of the signal displayed. This detailed and delayed portion will appear as an intensified zone in the first sweep. The second sweep will trigger at the beginning of the delay, allowing the magnification of the waveform by increasing the sweep speed.

The 5444 uses three plug-ins from the Tektronix 5000 series of plug-ins. A choice of 13 amplifiers, including high-gain differential, dual-trace, and multitrace plug-ins, is possible.

The 5444's display is easy to photograph. The CRT screen, measuring 6½ in (16.51 cm) diagonally, is internally illuminated and is over twice as bright as screens of comparable single-beam oscilloscopes. The CRT readout automatically documents the sweep speed and vertical-deflection factor for each beam. A user-addressable readout option programs the 5444 to write photograph number, device under test, and other pertinent information (up to two 10-character words) on the CRT screen.

It is possible to photograph the display to the 5444's full bandwidth of 60 MHz by using the Tektronix C27 option 1 camera with 10 000-speed film and the Writing Speed Enhancer or P-11 optional phosphor.

The 5444 true-dual-beam oscilloscope weighs about 26 lbs (11.79 kg), stands 5¼ in (13.34 cm) high when rack-mounted, and dissipates less than 100 watts typically, including its plug-ins.

For further information, contact Tektronix, P.O. Box 500, Beaverton, Oreg. 97005.

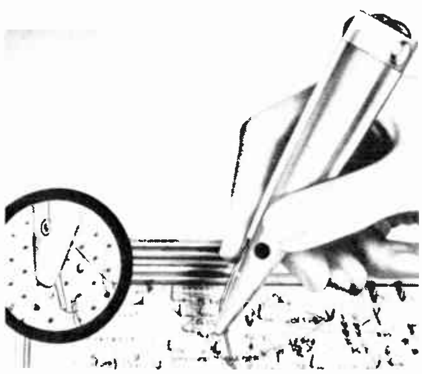
Booths 1423–1426

Circle No. 87 on Reader Service Card

Low-cost wiring pencil speeds interconnections

This new and economical wiring pencil almost completely eliminates wire measuring, stripping, and forming. The P173 pencil-like tool consists of a light plastic housing, a replaceable spool of wire, and an extended tip to guide and cut the wire. The average time required to make a connection is only seconds—about three times faster than conventional soldering or conventional manual wrapped-wiring techniques.

The tool accommodates interconnections



between sockets or IC tabs, component leads, and terminals. The 36-gauge wire used is routed directly between terminals or component leads making three to five wraps wherever a connection is to be made. Correct tension is maintained by finger pressure on the wire as it emerges from the plastic body and enters the metal tip. The wire may be cut with the tip when the run is completed. Because the wire is insulated with nylon and polyurethane, routing may be point-to-point, if care is taken to leave slack when going around sharp corners.

P179WS nylon wire spacers, which press on to "tenth-tenth-spaced Vectorbords" having 0.041-in (0.104-cm) holes, are available to hold wires in good order and greatly reduce the chance of short circuits or accidental damage by hot irons. When heat is applied to the wrapped-connection points with a fine-tipped soldering iron, the insulation melts, producing a solder bond.

The wiring tip is angled to facilitate wrapping and provide a clear view of operations. Lightweight for easy wiring, the pencil tool is suitable for moderate-production, as well as breadboard, and prototype-construction applications. Circuit wiring is easily reparable with a minimum of inconvenience.

The P173 wiring pencil, with two 250-foot (76.2-meter) spools of green and red wire, and instructions, sells for $9.50. Extra packages of three spools, in choices of blue, green, red, or clear insulated wire, sell for $2.50 per package. Delivery is off-the-shelf.

For further details, contact Vector Electronic Co., Inc., 12460 Gladstone Ave., Sylmar, Calif. 91342.

Booth 1444

Circle No. 88 on Reader Service Card

Fractional-horsepower motors are OEM priced at under $10

The CL series of fractional-horsepower dc motors can be supplied in OEM quantities within a price range of $5 to $10 each.

They are designed for 5000 hours of service life. Stall torque ratings cover the range of 2 to 20 oz–in. The operating voltage range is from 3 to 24 volts dc, maximum rated speed is 10 000 r/min, and efficiency is as high as 70 percent.

All motors in the series are available with either ball or sintered-bronze oilless bearings. The shafts may be single- or double-ended, and can be supplied with flat, tapered, knurled, or drilled ends, or be custom finished to customer specifications.

Three basic models are presently available in the CL series: the CL26, with a 1-in (2.54-cm) diameter; the CL32, with a 1.25-in (3.175-cm) diameter; and the CL38, with a 1.5-in (3.81-cm) diameter. The length is supplied to suit the application. Each size is also available as a motor-tachometer, in gear-head versions, and as a motor-tachometer with a gear head.

More information may be obtained from Canon USA, Inc., 123 Paularino Ave. East, Costa Mesa, Calif. 92626.

Booths 1152, 1154

Circle No. 89 on Reader Service Card

reach capacity and how should this spent fuel be dealt with?

Spent-fuel reprocessing

The original intent of the nuclear industry was to take the spent fuel to a nearby site and reprocess it. Unlike spent fossil fuels, which have no residual fuel content, fuel discharges from nuclear power reactors contain appreciable quantities of "unburned" uranium-235 and plutonium. The technology has already been developed, and is constantly being improved, to recover unused uranium and plutonium and to recycle it into the front end of the nuclear cycle. However, as of today, commercial fuel reprocessing in the U.S. is virtually at a standstill (the reason why spent-fuel basins are approaching capacity).

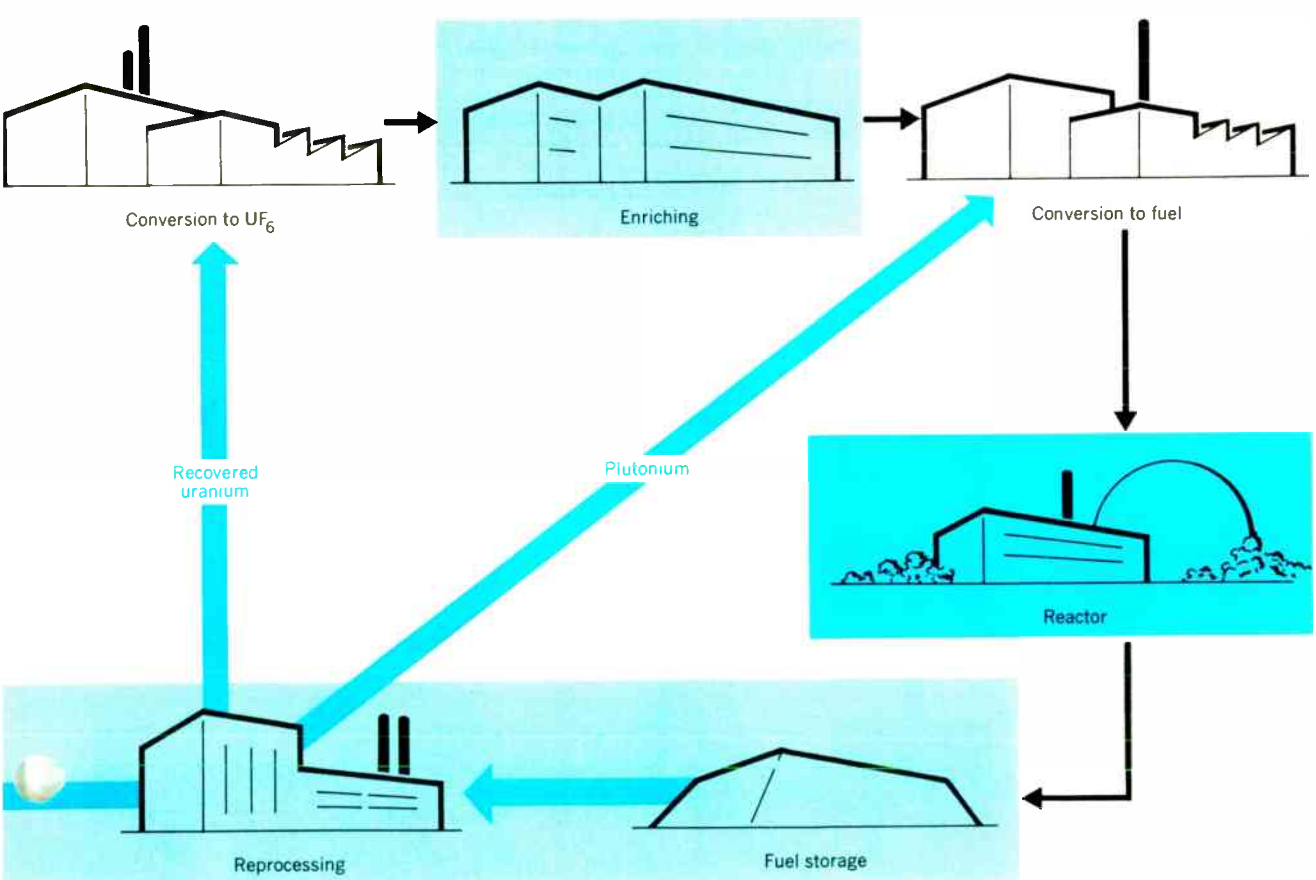
It's not as if no reprocessing plants exist in the United States. To the contrary, one plant, Nuclear Fuel Services (NFS) in West Valley, N.Y., was actually operational for six years until 1972 when it was closed for modification and expansion. It is still closed today.

Another plant, a General Electric project sited in Morris, Ill., has already been completed but is not operational at press time due to technical problems—during "cold" startup procedures (that is, before radioactive materials have been fed into the facility) some pipes showed a tendency to plug. After a thorough technical audit of the plant, GE decided, in July 1974, that the plant was inoperable in its present configuration. According to an ERDA expert, some difficulties in the GE reprocessing plant have to do with conceptual design. For example, it has been mentioned that fully irradiated fuel cannot be processed in it due to a lack of remote control operation features.

A third reprocessing plant was to have been built by the Exxon Nuclear Company of Bellevue, Wash., in Loudon, Tenn. Sadly, the company has decided to let its option on the proposed property expire. It seems the geology of the proposed site was deemed unsatisfactory and no alternative site has as yet been announced by Exxon Nuclear.

Only an Allied-General Nuclear Services facility, to be located in Barnwell, S.C.—a plant with more than twice the capacity of the once-operational NFS—

level waste storage, as well as the final disposal of the solidified waste—are taken up in this article. It should be noted that reprocessing, a key element in the back end of the cycle, is currently inoperative in the U.S. (see text, pp. 57–61). In the meantime, spent reactor fuel accumulates mainly in temporary storage basins on reactor sites. High-level waste from reprocessing, in liquid form (up to now, this type of waste is mainly from weapons programs), is stored in tanks. Within five years of its generation, this type of waste must be solidified, as mandated by the Nuclear Regulatory Commission, and within ten years, it must be shipped to a Federal site for its eventual disposal (see Fig., pp. 60–61). The color shading indicates roughly relative risks of each step in the cycle. Misuse of mill tailings, for example, a sandlike waste material from the milling stage, also may cause radiation hazards, as in a notorious case occurring in Grand Junction, Colo. There radioactive tailings were used for construction purposes, thereby exposing a portion of the town's citizenry to a significant amount of radiation. The problem is now being corrected, but its occurrence points up the kind of risk that exists in the front end of the cycle. Another front-end potential hazard involves enrichment technology. Developments in laser isotope separation are expected, when this technique has matured, to have a substantial impact on the cost of uranium enrichment, even up to weapon-grade levels—a potential safeguarding problem.



seems to be on schedule. It is expected to be operational as of July 1976.

This rather dismal record in getting spent-fuel reprocessing plants operational gives rise to a whole series of concerns—technical, environmental, and even economic—that have yet to be obviated. Marvin Resnikoff, a scientist at the Rachel Carson College of Environmental Studies of the State University of N.Y., Amherst, N.Y., points out that one has to begin by differentiating between normal operation of reprocessing facilities and accident conditions. Under normal operation, low-level radioactive effluents, containing iodine and ruthenium, are expected to be released in the evaporation process and in cleaning up nitric acid and solvents for reuse. Other hazardous releases include those of the radioactive noble gases krypton and xenon, whose distribution patterns in the environment are believed to be well known, and that of tritium in the gaseous state.

With a ten-year half-life, krypton is known to remain highly radioactive even after the six months needed for the cooling of spent-fuel prior to reprocessing. Krypton's radioactivity at this point measures about 11 000 curie (see box on facing page) per one (metric) tonne of uranium fuel (Ci/MTU) fed to the reactor. Tritium gas, at the same stage, measures about 600 Ci/MTU.

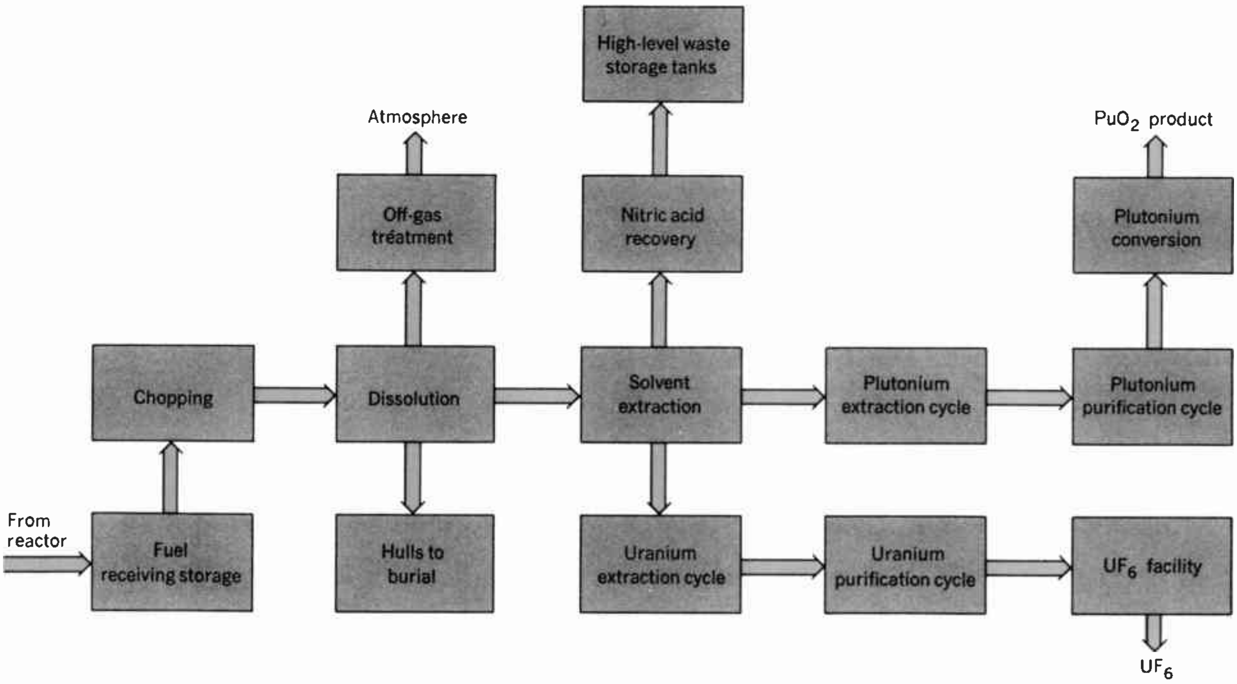
The question, here, is whether special—and perhaps costly—measures need to be taken to protect the atmosphere against the consequent buildup of radionuclides. According to a recent standard proposed by the Environmental Protection Agency, reprocessing plants may be required to install krypton removing equipment. And *Spectrum* has learned, that this feature is already included in the designs of prospective plants. But according to experts from General Electric, such measures are unnecessary. It is the GE experts' view, for example, that, compared to existing background radiation, krypton release into the atmosphere from all projected reprocessing plants in the year 2000 would have a negligible effect on the public—even presuming a substantial number of such plants is on line in the year 2000.

This sort of debate is only one of many surrounding the reprocessing stage of the nuclear fuel cycle. Another question relates to the health effects on workers during routine operation of reprocessing facilities. Dr. Resnikoff points to the shut-down NFS plant as a prime example. The radioactivity dosage being received by NFS workers was found to be about ten times higher than the average dose to workers in the nuclear industry in the U.S. Also, the dose was increasing every year after 1968 (the third year of the plant's operation), and almost reached the top dose permitted by the NRC.

With regard to the environment of the NFS plant, the N.Y. State Department of Environmental Conservation had stated in its 1970 annual report, according to the Union of Concerned Scientists, that the amounts of radioactivity detected in water and fish remained at levels that confirmed the need to install liquid waste treatment facilities to hold discharges as low as practicable. Following this and earlier criticisms, a low-level waste treatment plant was installed in NFS and began operation in 1971. This, along with burial of contaminated waste sludge and spent resins in the onsite burial ground, resulted, according to UCS, in the lower levels of strontium-90 and cesium released by the plant relative to earlier years.

Apart from risks at normal operation, the conse-

In a typical reprocessing plant, the spent fuel elements are received and put in a storage pool. When ready, they are chopped and dissolved in nitric acid. The zircalloy metal hulls—the tubes which contain the fuel pellets—are not dissolved by the nitric acid; furthermore, they are buried. An organic solvent dissolves the uranium and plutonium which are later separated, purified, and further converted into plutonium oxide and uranium hexafluoride. The nitric acid containing the fission product solution goes to an evaporator where the acid, along with some fission products, is boiled off. The remaining high-level waste is condensed and put into storage tanks where it is cooled.



quences from potential accidents in nuclear fuel reprocessing have also been evaluated. Although the probability of such accidents is believed to be very low, no definite quantitative estimate of these probabilities can yet be made. As far as the consequences are concerned, it is believed that there are possibilities for accidents at reprocessing plants, the effects of which could be comparable to a loss-of-coolant accident in a nuclear power plant (see *Spectrum*, June, pp. 46–55). However, this belief is not shared by the entire industry, and further, it is generally accepted that, except for a few possibilities, most potential accidents would occur in slow motion and could possibly be avoided with proper design and operation.

The most serious accident would be caused by a loss of cooling to the high-level waste storage tanks, assuming no engineered safeguard system is operating. Based on a report by Oak Ridge National Laboratory (ORNL 4451), the water in these tanks could boil off in a week in such an accident, and the radioactive material could then melt through the stainless steel tank and concrete vault. Eventually, in a typical case portrayed in the report, a molten ball could be formed, about 21 meters in radius, including the radioactive material itself as well as surrounding soil. This scenario goes on to suggest that the ball would stay molten for some 150 years. The estimated dose at the boundary of the plant's site would be in the order of 100 000 rems (see box on p.

Radiation units; radiation effects looked at

Radiation units are numerous. So are, sometimes, their interpretations. In an attempt to create order out of chaos, the International Commission on Radiation Units and Measurements (ICRU) located in Washington, D.C., has devoted much effort, since its inception in 1925, to the development of internationally acceptable recommendations regarding quantities and units of radiation and radioactivity. For example, the *activity* of a quantity of radioactive nuclide has been defined by the ICRU as the number of spontaneous nuclear transformations that occur in this quantity per unit of time. This activity is measured in *curie* (Ci), where one Ci equals 3.7×10^{10} transformations per second. The *roentgen*, another useful unit, suggested by ICRU, measures *exposure*, as the quotient of charge to mass. (The charge is taken as an absolute value of the total charge of the ions of one sign, produced in a volume element of air, when all the electrons liberated by photons in that volume element are completely stopped in the air. The mass is that of the volume element.) One R (roentgen) is 2.5×10^{-4} coulomb/kg.

Another unit, the *rad* (rd), is that of *absorbed dose*. The unit indicates the mean energy imparted by ionizing radiation to the matter in a volume element, divided by the mass of that volume element. One rd is 10^{-2} J/kg. And a quantity directly related to the presumed radiation risk, the *dose equivalent*, is measured in *rems,* and is in fact the absorbed dose multiplied by two dimensionless factors—the radiation quality factor and the product of all other modifying factors. This latter product was, at the time (1973) of recommendation of the rem by the ICRU, assigned a value of 1 for all irradiation by external sources. However, for sources deposited in the bone, the International Commission on Radiological Protection (ICRP) has recommended specific values for that product.

How are these units implemented, particularly the last two units that relate to radiation risks? In a paper discussing medical aspects of power generation, Roger Linnemann, president of Radiation Management Corporation, Philadelphia, Pa., has indicated that the estimated average whole body dose to the entire U.S. population from some 30 nuclear power reactors operating at the time the paper was written was 0.01–0.001 mrd per year, whereas for people living close to nuclear power reactors the doses may average a few mrd per year. In analyzing genetic effects of radiation as well as its cancer-producing potential, he indicates, for example, that the evidence that radiation bears a cause and effect relationship to cancer lies above a level of about 30 000 mrd and that the most convincing evidence is from exposures above 100 000 mrd. According to Dr. Linnemann, it has been estimated that to see a statistically significant increase in the incidence of cancer at low doses, at least five million people would have to be somehow exposed to about 5000 mrd (5 rd), and that no such exposure, except perhaps in a nuclear war, can be envisioned. Similarly, says Dr. Linnemann, in studying genetic effects of radiation as the dose is lowered below about 37 000 mrd, the increased incidence of genetic mutation due to radiation is so small that extremely large numbers (many millions) of experimental animals (mice, for example) must be exposed to show a statistically significant difference. Based upon comparative results of epidemiological, clinical, and laboratory studies, Dr. Linnemann has concluded that radiation dose equivalents from emissions from nuclear power plants under normal operations are small compared to those from natural background radiation and from other man-made sources. For example, the east coast of the U.S. is exposed to about 110 mrem annually, and this includes contributions from the sky, buildings, air, ground, and food. Population exposure is larger for people living at high altitudes than for those at sea level, according to Dr. Linnemann. For example, in Denver, Colo., the population is exposed to about 175 mrem annually. Other sources of radiation to the population—like medical X-rays (see *Spectrum*, August 1975, pp. 46–55), high-altitude flight, and television sets—have also been mentioned in this context. For example, it has been indicated by other sources that the dose to the entire U.S. population from all nuclear power plants in the U.S. in the year 2000 will be about twice that now received from television sets.

Recently, effects of moderate radiation doses other than those related to genetic effects or cancer have been discovered and looked into. In one study, although not necessarily representative of many other studies in this area, it was shown that a protracted mild radiation dose by radioactive sodium-22 or cesium-137 gamma rays, on a model of a cell membrane, was more effective in damaging the membrane than a shorter, more intense irradiation amounting to the same dosage. This phenomenon has been explained in terms of an indirect chemical effect, involving slowly progressing, long chain reactions, initiated by ionizing radiation but sustained without it. The membrane models used in the experiments, reported by A. Petkau of the Medical Biophysics Branch of the Atomic Energy of Canada, Pinawa, Manitoba, were reconstituted from a fresh beef brain and from plant lipids. The author stresses, however, that the model structures used for his study were unlike that of living cells in that they did not contain the protein particles that are present in a living cell membrane whose presence may alter the chain reaction. Also, his model, unlike the living cell, contained highly unsaturated "fatty acids" to help the detection of chemical effects. As a complement to these findings, Dr. Petkau reports that a remedy which completely wipes out the "dose rate effects" reported in his experiments, was found in the form of an enzyme, whose "radioprotective" action helps to reduce O_2^-, a "superoxide anion" generated in the course of irradiating the membranes, into ordinary molecular oxygen.

In addition to mounting interest in low-level radiation, needs have also been expressed for resolving uncertainties related to the effects of background radiation on the public. In particular, there are extremely limited data on gamma radiation and airborne radon levels in indoor environments and their dependence on properties and radionuclide contents of building materials. Also, possible inadequacies are mentioned in models used to relate radiation or radionuclide measurements to human organ dose. Additional areas that need more clarification relate to contributions from charged particles from cosmic rays and to fluctuations in background radiation levels resulting from man-made radionuclides stemming from sources like nuclear power plants or reprocessing plants.

59), or about 200 000 times the dose presently accepted by the NRC for *normal* operation of a plant. Worse still, it was pointed out that, should the EPA's recently proposed standard for boundary dosage during normal operation of a reprocessing plant be implemented, the ratio would be 20 times higher.

A few nuclear fuel experts, however, maintain that the forecasts of the size and longevity of the molten ball are unrealistically large. For example, theoretical and experimental studies conducted by Sandia Laboratories, Albuquerque, N.Mex., on a scaled-down model of a storage tank, are said to have shown that the molten ball would completely solidify in 10 to 15 years.

Apart from a loss-of-cooling accident, another potential accident that is weighed is that of nuclear criticality in the fuel storage pool. Also believed to be a low-probability event, this accident could occur due to the "jamming" together of fuel elements either by operator error or by some natural occurrence.

A criticality of three to six spent-fuel assemblies (about one metric tonne of fuel) could, according to one scenario, result in a production of highly active iodine (some 2500 Ci of radioactivity), within the fuel cladding. (A worse situation could develop in the case of defective cladding, where the iodine could be released into the storage pool.) Still, in the case of the undamaged cladding, the fence dose resulting from such an accident is expected to be in the order of 10 mrem, a relatively low dose.

Other types of fuel reprocessing accidents that have been evaluated include loss of coolant in the fuel storage pool, overpressurization or the development of leaks in the dissolver, and explosions due to the presence of hydrogen gas or some other explosive material.

Considering the fact that no reprocessing is taking place at the moment, and the myriad of problems foreseen in connection with reprocessing, the very need of reprocessing, from an economic point of view, has also been seriously questioned. According to one such view by an environmental scientist, it costs more to reprocess spent fuel than the materials, uranium and plutonium, are worth. In connection with this view, it is argued that alternative methods of storing, or disposing of the fuel elements should be sought. Eventually, however, uranium will admittedly become scarcer, and it may then make sense to reprocess, extract, and use the recovered uranium and plutonium.

Opposition to this viewpoint comes from nuclear fuel experts who maintain that economical justification for reprocessing already exists. According to reprocessing proponents, in addition to the important recovery of uranium and plutonium resources, reprocessing will also diminish the waste disposal problem

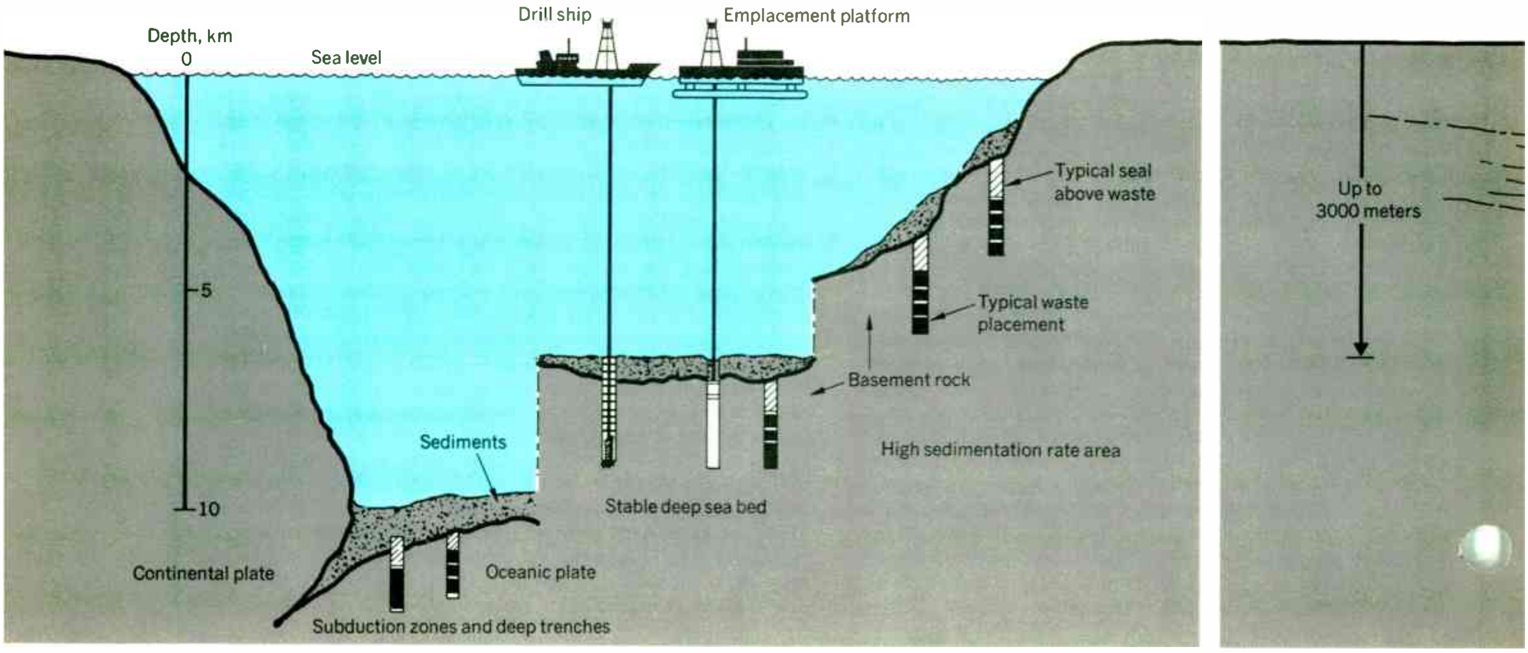
Among high-level waste disposal concepts that have been looked into, at least in theory, are (left to right, but not in order of importance):

• Seabed disposal, which includes: disposal in stable deep sea floor; in deep-sea trenches where the waste will eventually be subducted, it is believed, into the earth's mantle; or in high sedimentation rate areas, where major rivers are building deltas into the oceans.

• Emplacement of the waste in rooms or tunnels that have been excavated in a stable geologic formation which can be reached by conventional mining methods. This seems to be the only practical disposal concept in the foreseeable future. (Bedded salt disposal was extensively studied as one possibility in this category.)

• Extraterrestrial disposal. Although disposal of total waste has been considered, space disposal of transuranics only (elements with atomic numbers higher than that of uranium—e.g., plutonium) may be the most practical scheme due to high cost per unit weight.

• Disposal in ice sheets—large permanent masses of ice overlying continental land masses. It is believed that the Antarctic ice sheet, which is international territory, has the potential to provide an international repository. Three potential disposal concepts were developed for the ice sheet areas: The *"meltdown,"* or the *"free flow,"* concept, where the waste canister is placed in a shallow drilled hole and allowed to melt down through the ice sheet to the bedrock; the *anchored emplacement* concept, where the canister is anchored in position for an extended period—on the order of a 100 years; and the *surface storage/disposal* where canisters are placed in a shielded cell storage facility for up to approximately 50 years, after which the facility will be allowed to become covered by snow and eventually be buried in the ice sheet.



in that the volume of high-level waste (see further on in this article) from reprocessing would be less than that of the original amount of spent-reactor fuel being processed. However, uneasiness is reported even within the reprocessing industry as to a lack of ground rules and an inadequacy of regulations which could impact the industry's current economic underpinnings.

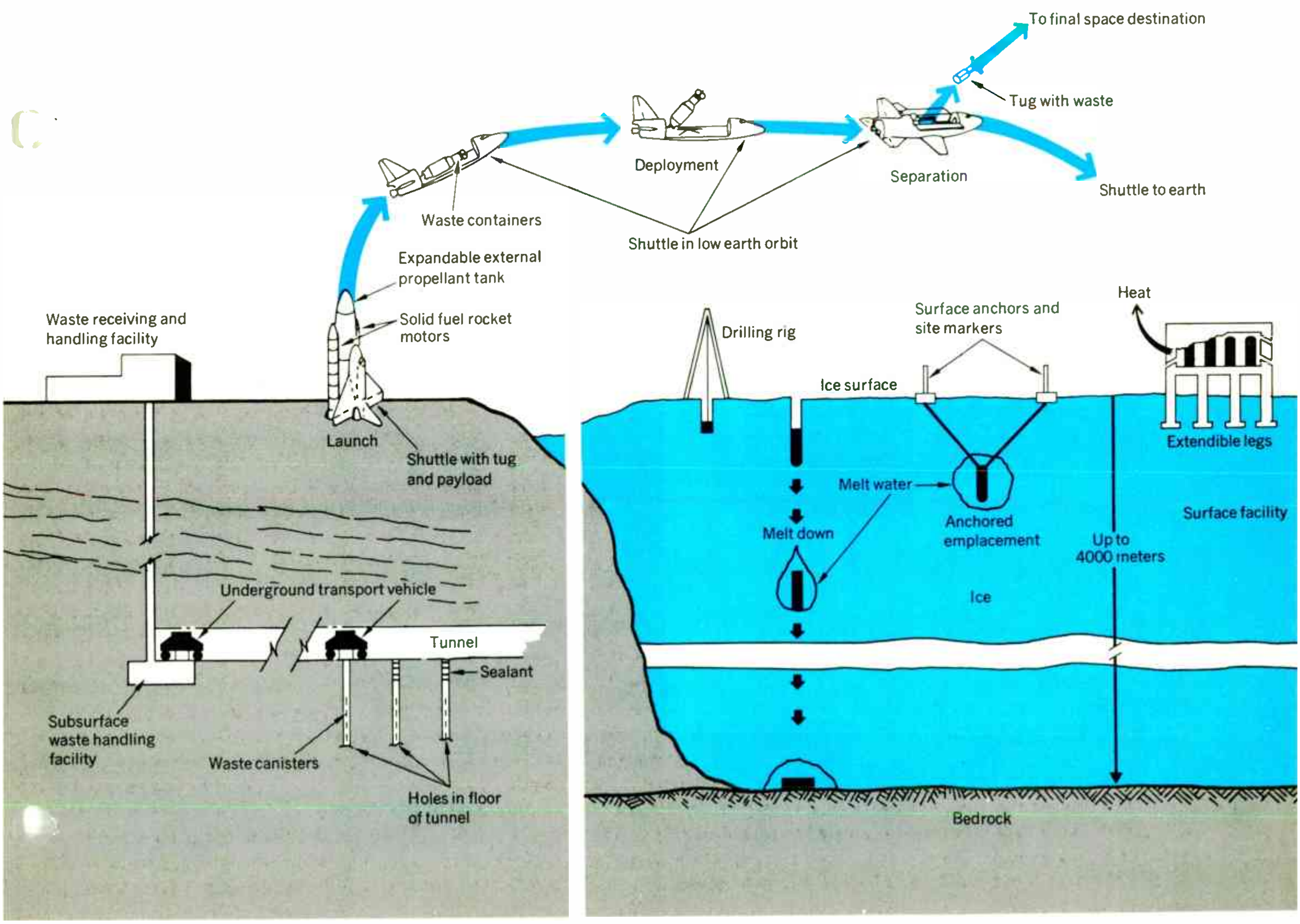
High-level waste

With or without reprocessing, perhaps the key element in the nuclear fuel cycle is the question of disposal of *high-level waste*. Unlike some types of radioactive wastes, which may be safely discharged as air or water effluents after relatively simple treatment, high-level waste is characterized by high levels of penetrating radiation and high radiotoxicity per unit volume. In addition, high-level radioactive waste also emits significant amounts of radioactive decay heat. This type of waste can be in liquid form, as a by-product of spent fuel reprocessing, or it can be converted into solid form.

The penetrating radiation, the decay heat, and most of the ingestion toxicity at the time the waste is generated are due to fission products. The longest-lived abundant fission products (strontiom-90 and cesium-137) have half-lives of about 30 years, and the fission product activity in typical high-level waste would decay to innocuous levels in about 800 to 1000 years. According to a recent publication by the Division of Waste Management and Transportation (WMT) of ERDA, such a period of storage is not unreasonable to expect for a single man-made structure of very high quality. However, the ERDA paper points out that under today's spent-fuel processing technology, the high-level waste also contains about one half of one percent of the plutonium-239 generated in the fuel, and this element not only has a high radiotoxicity per unit weight but a 24 000 year half-life. It is because of the plutonium content that high-level waste needs to be isolated from the environment for a period of time that is very long compared to the expected useful life of any man-made confinement system.

The topic of high-level waste can best be discussed by dividing it into considerations of liquid and solid waste products. In the U.S., experience has been accumulated from the weapons program with interim storage (in tanks) of liquid high-level wastes. And this experience has not been highly successful. One significant criticism, for example, has involved reported leaks in the tanks.

In this regard, *Spectrum* has been informed that the newer, double-walled tanks, implemented in the last five to eight years, have not developed any leaks. But to be absolutely secure, one critic of high-level liquid-



waste storage has suggested the possibility of solidification of the "hot" liquids immediately after reprocessing. Current regulations require solidification within five years and shipment of the solidified waste to a Government facility within ten years.

As a temporary solution to the high-level radioactive waste problem, until acceptable ultimate disposal schemes will be approved, ERDA"s program for waste management includes, as a first phase, the development of a repository for fully retrievable storage of solidified commercial high-level waste, using existing radioactive materials handling technology. As possible alternative locations for such a retrievable surface storage facility (RSSF), existing ERDA nuclear sites, like the ones in Hanford Reservation, Richland, Wash., or the Idaho National Engineering Laboratory (INEL), or the Nevada Test Site outside of Las Vegas, are mentioned.

These ERDA proposals have strong precedent. In the United Kingdom, such "controlled" storage of high-level solidified fission product waste was accepted as the best practicable interim solution to the waste problem as early as 1948. Today, this policy is still favored by the British. They maintain that this system allows them to take advantage of technological improvements as they emerge. The control is exercised in high-level nuclear waste storage in the U.K., according to two principles:

- Negligible leakage of radioactivity to the environment is allowed, and hence there is no risk to the general public.
- The radioactive waste is in such a physicochemical form that man can retrieve it and reprocess it into other, more advantageous forms, and carry out maintenance on, or make improvements to, the storage system. In addition, the volume of the stored waste is minimized.

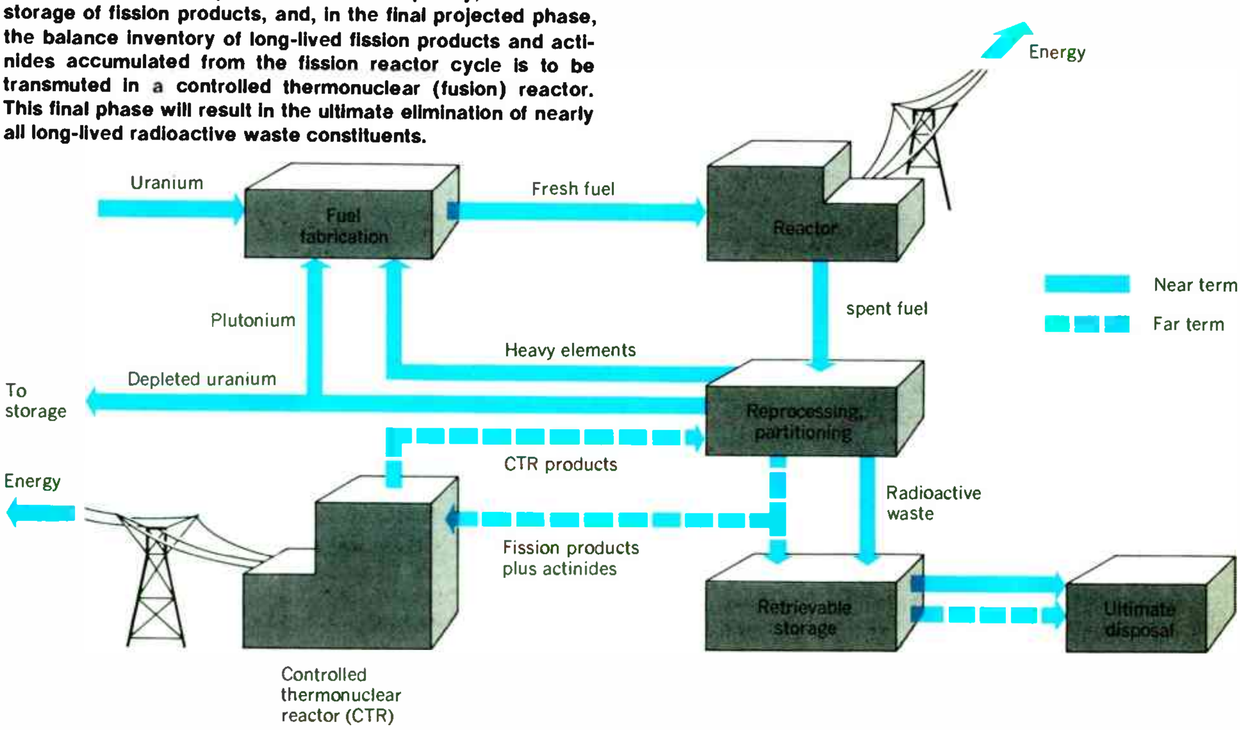
Disposal

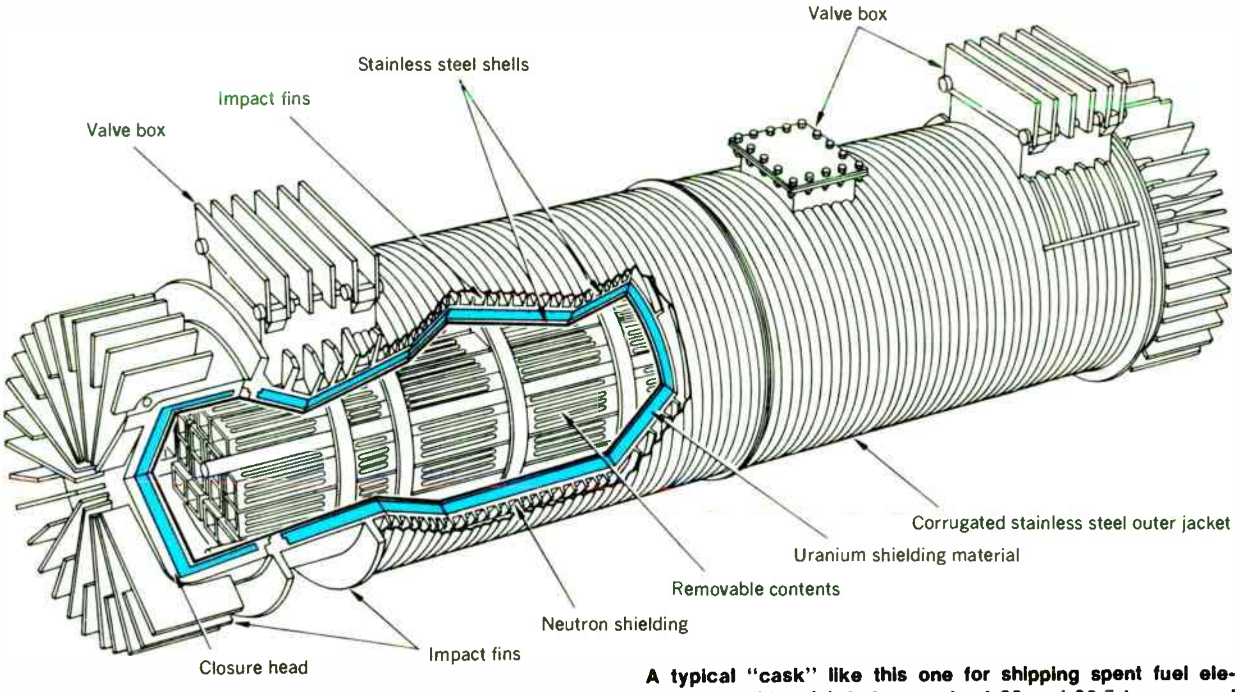
But in the end, however the high-level wastes are stored, they still must be disposed of. Various methods of management of high-level radioactive waste have been studied by the Pacific Northwest Laboratory of Battelle Memorial Institute, in Richland, Wash.—disposal in terrestrial locations (including disposal in geological settings, in ice sheets, or in the seabed), disposal into space, and elimination of long-lived high-level waste by transmutation (nuclear transformation of certain waste constituents into nuclides having less long-term toxicity).

Disposal of high-level nuclear waste in bedded salt, a subcategory of the terrestrial disposal methods, had previously been extensively studied. One pilot repository in this category was proposed in a salt mine in Lyons, Kans. But the idea was later abandoned, when doubts arose as to the integrity of the formation, due to nearby salt mining and to the presence of old and possibly unplugged oil and gas exploration wells nearby. However, the Waste Management and Transportation Division of ERDA considers that the problems at Lyons were related to the specific site and do not invalidate the general rationale for geologic disposal.

The key consideration in determining which of the foregoing options for disposal will prove best is, of course, safety. In a Battelle Memorial Institute study, safety considerations include failure mode analysis for the various disposal concepts as well as an estimation of probabilities of the release of radioactivity associated with each of the geological disposal concepts. One interesting conclusion in the study is that the failure events associated with man's activity are not impor-

Transmutation, or the changing of one isotope into another, preferably less toxic isotope with a shorter half-life, is also a possibility considered in waste management. Using the normal nuclear fuel cycle of fission reactors, long-lived actinides (elements in the periodic table beginning with and following actinium, including uranium, plutonium, and americium) are to be converted, according to this scheme, to short-lived fission products. A second phase involves temporary, retrievable storage of fission products, and, in the final projected phase, the balance inventory of long-lived fission products and actinides accumulated from the fission reactor cycle is to be transmuted in a controlled thermonuclear (fusion) reactor. This final phase will result in the ultimate elimination of nearly all long-lived radioactive waste constituents.





A typical "cask" like this one for shipping spent fuel elements, would weigh between about 22 and 82.5 tonnes, and it would be constructed of thick steel walls, and include dense shielding material such as lead, tungsten, or depleted uranium. Apart from heavy radiation shielding, the 4.5 to 5.4 meter long and 1.5 meter in diameter cask will have to dissipate power (about 22.5 kW) produced by radioactive decay. For some of the larger casks, air may be forced over the fins by blowers to increase the cooling. In other casks, heat exchanges with cooling coils running into the body of the cask will literally pump the heat out and into the atmosphere.

tant safety considerations. In addition, radiation dose and risk to man were evaluated for each disposal concept. For example, the maximum measure of risk to an individual from the given failure mechanisms and pathways in geological disposal would be in the range of 10^{-14} to 10^{-10} mrem/year to the whole body during the operation period, 10^{-10} to 10^{-6} mrem/year at 1000 years after disposal, and 10^{-6} to 10^{-3} mrem/year at 1 000 000 years after disposal. The fault tree analysis technique (see *Spectrum*, August 1975, pp. 46–55), the method adopted in the study for failure mode analysis, was also applied to disposal concepts other than the geological one.

As to the seabed disposal concept, it was concluded in the study that, due to lack of adequate data, this disposal method is uncertain. The same is true, according to the Battelle study, of the ice sheet environment except that more known mechanisms for release of waste can be identified.

But how can safety in extraterrestrial disposal be assessed? The study indicates that experience accumulated by the National Aeronautics and Space Administration (NASA) with manned space flights can serve as a basis for estimating the level of safety that can be achieved. Failures on the launch pad, burnup in the atmosphere, or meltdown after loss on the earth's surface are the failure elements of greatest concern and can be estimated with improved confidence as the number of launches accumulates.

Long-term hazards from disposal of high-level radioactive wastes in salt formations were recently computed by Bernard Cohen, while at the Institute for Energy Analysis, a division of Oak Ridge Associated Universities, in work that was done under contract to the Federal Energy Administration. According to Dr. Cohen, the number of cancer deaths per year in the U.S., expected after 1000 years of burial of waste generated in one year from production of 400 million kW-years of electrical energy (somewhat above present annual U.S. consumption), is less than one over one million.

Lower figures than that are expected after longer burial periods, according to Dr. Cohen's calculations. And, integrated over time, less than one eventual death is expected.

In his disposal model, wastes are assumed to be buried at random locations throughout the United States at a depth of 600 meters and the probability that an atom of waste reaches people and irradiates them by ingestion is then computed.

According to Dr. Cohen, his considerations were limited to the dangers from ingestion of radiopoisons with food or drink, since essentially all scenarios in which high-level wastes might do great damage to the public depend on this pathway to man. Another assumption was that there was no monitoring or guarding of the waste.

Human intervention within the burial area is expected to bring the death figure up. According to Dr. Cohen, he computed a total of 0.003 deaths if the region is explored for oil 500 years after burial. Mining for salt (assuming the storage site is forgotten) may be expected to cause, according to Dr. Cohen, an average of less than 0.1 eventual deaths if current methods are used in the mining.

Nuclear shipments risks

Much public concern has been expressed about transportation of nuclear material. In our illustration of the nuclear fuel cycle (pp. 56–57), *Spectrum* has attempted to pinpoint the areas of greatest concern by printing the arrows between certain stages in color. Also very much aware of such concerns, the Transpor-

For further reading

Literature on topics discussed in this article is voluminous. In the *Transactions of the European Nuclear Conference*, held in Paris, France, April 21–25, 1975, and published jointly by the European and American Nuclear Societies, a complete section is devoted to reprocessing, transportation, and waste (pp. 623–690). A brief discussion of new enrichment methods is also included (pp. 799–802).

Another source of insight into the current situation of nuclear fuel technology is the *Proceedings of the Joint Topical Meeting on Commercial Nuclear Fuel Technology Today*, held in Toronto, Canada, April 28–30, 1975. The meeting was sponsored by the American Nuclear Society and the Canadian Nuclear Association. In the meeting, one session was devoted to reprocessing technology and waste management (pp. 3-2 to 3-108 in the *Proceedings*); another focused on recycle fuel fabrication (pp. 4-2 to 4-78); and a third covered shipment of spent fuel and recovered products (pp. 5-3 to 5-40).

On shipments of nuclear fuel and waste, much information is included in a publication, numbered WASH-1339, of the Atomic Energy Commission (AEC) and issued in August 1974. High-level radioactive waste management alternatives are summarized in publication WASH-1297, issued by the AEC in May 1974.

A booklet by the Union of Concerned Scientists entitled, *The Nuclear Fuel Cycle*, discusses various public health environmental and national security aspects of the cycle. And the status of fuel for electric power to 1984 was discussed in the 1974 Summer Meeting of the IEEE Power Engineering Society in Anaheim, Calif. The proceedings of the meeting were issued as publication number 74 CHO 945-6 PWR by the IEEE. The IEEE also cooperated in the 1975 Carnahan Conference on Crime Countermeasures, where papers on nuclear materials security and on the application of crime counter-measures for the protection of nuclear materials were delivered. The Proceedings of the Carnahan Conference are available from the IEEE as publication number 75 CHO 958-9 AES.

Finally, more on nuclear safeguards can be learned from a paper, "More on nuclear safeguards," by L. M. Brenner and W. C. Bartels of the division of safeguards and security of the NRC, delivered at the 1974 Nuclear Science, and Scintillation and Semiconductor Counter Symposium in Washington, D.C.

tation Branch of the Division of Waste Management and Transportation of ERDA (previously a branch within the Atomic Energy Commission) has concluded, on the basis of other studies, that the probability of death, injury, or massive property loss due to transportation of radioactive material can be determined, and that this probability is very small. In reaching these conclusions, ERDA's WMT Division has examined various aspects of shipment of nuclear materials—the nature of shipment (fresh fuel, spent fuel, waste), government regulations, types of packages, as well as the pattern and projected number of nuclear shipments up the year 2000.

How many shipments of nuclear material are made in a year, in the U.S.? The U.S. Department of Transportation (DOT) has estimated that there are nearly 1 000 000 shipments of nuclear materials each year. About 95 percent of the shipments involve small quantities of nuclear isotopes for use in industry, medicine, agriculture, and education. In 1971, nuclear shipments associated with power plants, numbered only a few thousand. And most of these shipments were low-level waste and new fuel, the latter with a relatively low radioactivity which is effectively shielded by the zircalloy fuel cladding tubes. By the year 2000, the shipments associated with nuclear power plants are expected to increase about 100-fold. A little over half the total number of these projected shipments will involve highly radioactive, heat-generating spent reactor fuel, that requires highly shielded, heat-dissipating packages. Various shipping packages are used to accommodate various types of nuclear materials and the requirements for various packages become more vigorous. For example, the impact of missiles and/or bullets on a cask for spent fuel shipments is also being considered as an incident a designer should consider, in addition to such other requirements as radiation shielding and cooling. Also, requirements are made for additional shielding and special operational procedures to achieve "as low as practicable" radiation exposure levels to workers.

Some transportation problems related to safety resulted from a host of rules and regulations encountered in 1974. For example, on March 29, 1974, the Association of American Railroads unanimously approved a recommendation to its members that spent fuel be hauled only in *special trains* at speeds not to exceed 56 km/h, and with additional operating restrictions to control passing situations and to avoid interference with regular freight and passenger trains.

In addition to special trains, a number of railroads in the U.S. have announced that they will require contracts for carriage of spent fuel completely relieving them of all liability for any and all damage. And they have proposed to set their own rates. Also, in many areas in the U.S., the physical condition of railroad track and roadbed has deteriorated to the point that the question of general safety has come up.

Other transportation difficulties are encountered with state regulations regarding the transportation of radioactive materials on top of Federal ones. And prohibition of transportation of radioactive materials over many bridges and turnpikes and through nearly all tunnels was reiterated. A nuclear shipping expert has even argued that, in spite of the unprecedented safety record in the U.S. in transportation of nuclear materials over the last 25 years, broad compliance with the Federal government's safety regulations on the packaging and transportation of radioactive materials has not been achieved.

But things are expected to improve, and a research and development effort is currently in progress at the WMT Division of ERDA with the ultimate objective of developing a new technology and a comprehensive body of standards encompassing the needs for packaging, materials handling equipment, and procedures and systems related to the safe transport of radioactive materials. Among other aims of the research effort, ERDA undertook to examine critically the adequacy of existing standards to assure safe transports without excessive and expensive conservatism. ◆

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