The Renaissance in Submarine Communications

PART III
THE ELF ODYSSEY
1958-1979

by Roland J. Starkey, Jr.

The Polaris Special Projects Office (PSPO), a planning group delegated to solve the myriad of problems associated with the embryonic fleet ballistic missile (FBM) submarine force, was organized in 1955, 2 years before the first SSBN was scheduled to be laid down.

Designed to conduct extended deterrent patrols and complement nuclear attack submarines entering service, the cold war took an insidious turn as intelligence reports began to suggest the Russians were converting a number of Zulu IV-type patrol submarines to carry ballistic missiles. Within a year the first Zulu Vs became operational with an 11 m section spliced amidships to accommodate N-4 tubes and Sark missiles. This was a monumental milestone in naval history as it marks the beginning of the race between the US and the Soviet Union to gain strategic advantage over the other with long-range submarine-launched ballistic missiles (SLBM) as a mobile deterrent to first-strike capability.

For either of the principals to maintain extended covert operations under the control of shore-based command authorities, development of secure jam-proof communications systems became an urgent requirement. Broad spectrum specifications formulated by PSPO and the Polaris Command Communications Committee (PCCC) to ensure SSBN survivability and immediate responsiveness of submarine commanders to nuclear command authority, placed a staggering burden on mid-1950s designers and state-of-the-art technology. The most significant of these included: (A) Nuclear-hardened transmission facilities in CONUS; (B) One-way/error-free communications from National Command Authorities to submerged submarines on station; (C) Acceptable data rates and hard copy aboard submarines; (D) Freedom to maneuver without restriction on depth and speed; (E) Freedom from detection and interception by antisubmarine warfare (ASW) forces; and (F) Freedom from countermeasures.

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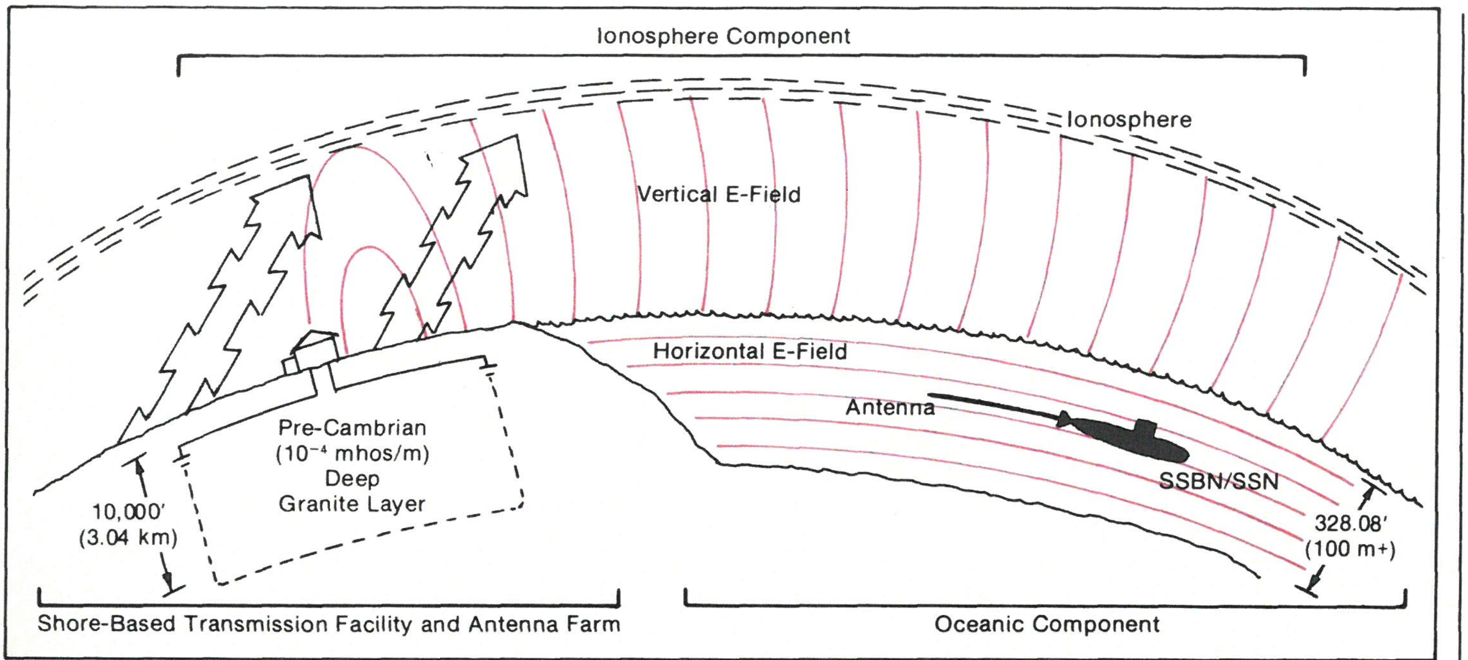
The Dawn of ELF

During the summer of 1958 a Navy team reviewed Polaris communications problems and priorities with staff members at UC, Livermore. From this evolved Nicholas Christofilos' proposal to resonate the earth-ionosphere with extremely low carrier-frequencies in the range of 30-100 Hz. This was based on the well-known fact that energy penetration into a conducting medium as sea water is inversely proportional to wavelength. Thus, whereas transmissions from LF through UHF and SHF would require a submarine to extend its antenna mast above the surface to receive a message, VLF (14-30 kHz) penetration would be restricted to the upper layer of the water column (10-15 m), but long waves approximating extremely low frequencies could theoretically be received at depths >100 m. Structure of the medium would not be expected to appreciably attenuate the signal or modify wavefronts at maximum depths anticipated for SSBNs and SSNs throughout the remainder of the century.

Christofilos' theory gave the PSSO a glimmer of hope for a viable FBM submarine communications system and began to receive funding from the Office of Naval Research. The following June the Institute of Defense Analysis (IDA) convened to renew Christofilos' ELF concept and the ongoing program at Livermore. Prevailing agreement and enthusiasm of the participants provided impetus for the Bureau of Ships (BUSHIPS) to award RCA a contract under the code name PANGLOSS for developing not only prototype hardware but also to examine current and future Polaris submarine communications requirements.

By 1960 PSPO called for a number of priority studies to be conducted concurrently in order to fill obvious data voids and ensure early systems optimization. Paramount to this were unresolved questions regarding, quite understandably, antenna system requirements where exceptionally long wavelengths were involved. Thus,



Global extremely low-frequency (ELF) strategic submarine communications system. Shore-based center-drive end-grounded antenna approximately 62.5 km in length, ELF is operated at 100-300 A with the transmission circuit completed by an underlying strata of low conductivity pre-Cambrian granite. The ELF signal is transmitted into the atmosphere via the vertical E-field, becomes trapped in the ionosphere and spreads around the earth. Reflected signals ($\lambda = 3 \times 10$ at 100 Hz) enters the conducting medium and can be detected at great depths (>100 m) by submarines with a trailing receiving antenna.

since $\lambda = 3 \times 10^6$ at 100 Hz, projected global performance characteristics and cost trade-offs were considered very early in the program. Designs requiring loading with dielectric and magnetic materials were rejected as being economically unsound in favor of more cost-effective strategies. Conceptualized systems, including non-linear mixing in the ionosphere; earth satellite trailing antenna; excitation of the magneto-ionic duct; helicopter-suspended wire; spiral top-loaded antenna; island slot and mountain loop, gave way to the center-fed end-grounded "beverage antenna."

Preliminary propagation and attenuation studies were conducted from March-June 1960 at the Navy's 120 kW VLF "Jim Creek" (Oso, Washington) transmission station. Operated at power levels of 1-100 W, the system's catenary antenna, acting as a capacitive load to the transmitter, was excited from 600-4000 Hz. Data analysis strongly suggested performance of a loop-type ELF transmitting antenna would exceed capacitive impedance and short vertical types.

By mid-June, MIT's Lincoln Laboratory, after completing radio noise measurements from 5-45 Hz, reported Q values of the earth-ionosphere cavity as ~4 at the fundamental mode. Generally agreeing with data collected at Jim Creek, the Navy abandoned plans in August for earth-ionosphere resonance methods in favor of traveling excitation coupled with a horizontal wire antenna extending over poorly conducting earth and grounded at either end.

Christofilos, agreeing with the decision, proceeded to design a center-driven end-grounded horizontal grid antenna. Following detailed analysis by the Livermore group and RCA's David Sarnoff Research Center, Princeton, NJ, the concept was recommended for continued evaluation as the most feasible solution to the problem.

Early in 1961 an ELF committee was organized by PCCC to review program status and coordinate future R&D efforts with the goal of expediently evaluating Christofilos' design in the field.

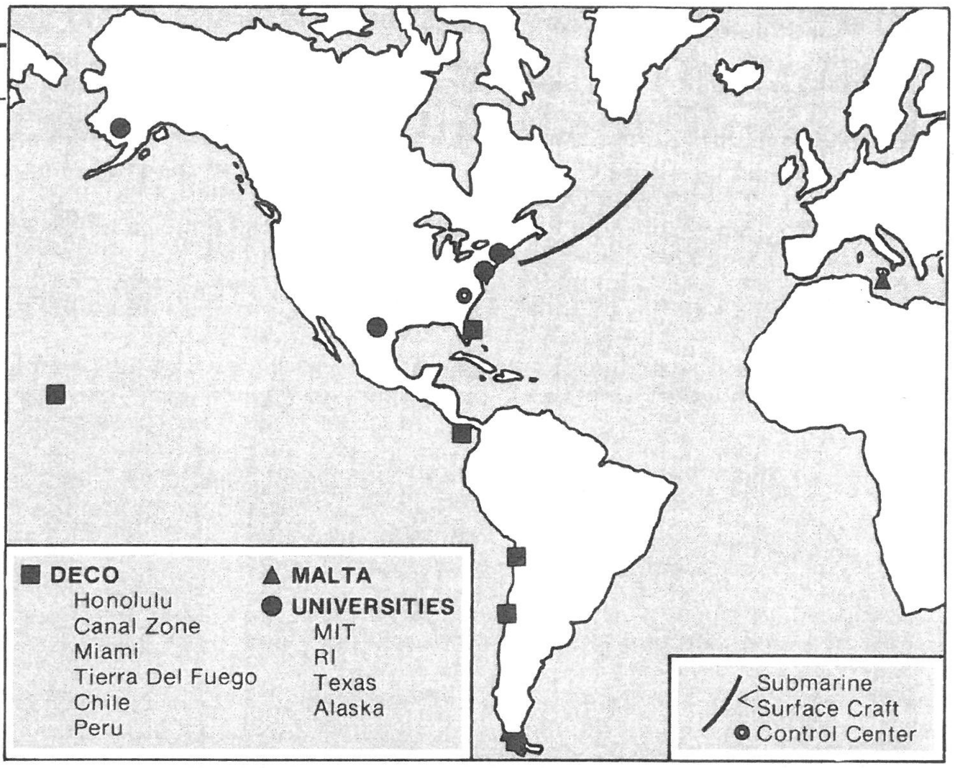
The Decisive Experiment

By mid-spring a "decisive experiment" was recommended which would provide an electric field of ~58 μV/m at a distance of 1000 km. This would require a 62.5 km antenna with the center-fed transmitter located in an area where ground conductivity approximated 2.5×10^{-4} Ω/m.

RCA's PANGLOSS contract was extended to include surveys of sites suitable for transmitter and antenna installations. In the interim period (June-August 1962), the Office of Naval Research sponsored a propagation study utilizing a leased 60 Hz high-voltage transmission line extending 70.0 km from Cheyenne to Laramie, WY. Disconnected from service in the evening hours and grounded at either end, the "improvised" antenna was driven at 60 Hz. Far-field measurements were made 1500 km away at a receiving station in the Padres National Forest, CA. Supplementary near-field measurements at the transmission site provided valuable insight into the relationship between conductivity and ELF radiation.

RCA's search for an optimum site required verification of low-earth conductivity (10^{-4} to 10^{-5} mho/m) to a depth of several meters along the antenna tract in an area of high-surface conductivity (>10^{-2} mho/m) suitable for grounding. Relative proximity to the coast, i.e., within 100-200 km, was similarly a mandatory requirement if successful contact was to be made with submerged submarines via a medium-powered transmitter and a single ELF antenna.

Based on these specifications, a 68.75 km antenna was installed from the southern most point at Lookout Shoals, NC to Algoma, VA. Designated Site Alpha, the antenna was center-fed with a 10 kW (vibration table) amplifier-driven by a minimum phase shift keyer and modulator located in Ararat, NC. Producing carrier frequencies in the 15-260 Hz range, local interferences included slight lamp flicker at lower carrier frequencies and intermittent activation of telephone ringer circuits. Severity of the latter problem varied considerably but was generally minimized by reducing power above 150 Hz and restricting operation to low-use periods.



Site of 1963 ELF "intensive test" in the North Atlantic and location of atmospheric noise monitoring stations in CONUS and overseas.

The Intensive Test

The transmission facility was complete in December 1962. The Intensive Test authorized by the ELF Committee proceeded to collect data required to verify Christofilos' and RCA's theoretical predictions and optimize design parameters. This was accomplished with three customized receivers (RCA) deployed at fixed sites, in mobile vans and aboard surface ships and submarines in the North Atlantic. Atmospheric noise measurements were made throughout North and South America, as far west as Honolulu and to Malta in the mid-Mediterranean. These studies not only validated the zero order propagation model at frequencies <600 Hz but generated reliable attenuation data as low as 78 Hz.

With this information available, the 6-week Intensive Test began in January 1963 following outfitting of SSN-575 (USS Sea Wolf) with a receiver and a trailing antenna. The latter consisted of a 304.8 m cable terminating in a sensor pair separated by only 12 areas in CONUS and one in Alaska which were identified with deep earth conductivity approximating 10^{-4} mhos/m. More often CONUS conductivity was closer to 10^{-2} mhos/m and less frequently approached 10^{-3} mhos/m. By 1965 RCA recommended the northern portion of Wisconsin for the ELF transmission facility based on tentative systems operational requirements.

In 1967 extensive criteria were developed for Project Sanguine and RCA was redirected to evaluate the sites in more detail. Remember, this had been going on since 1961 and it was a well-known fact there was a direct relationship between conductivity, anticipated systems performance and cost. RCA again recommended Wisconsin in 1968 following extensive trade-off studies indicating the site would constitute the lowest cost to the government in consideration of construction, operation, maintenance and indirect costs. The report further concluded that Sanguine would have "no irrepressible impact on the community" and "could have a mild, favorable effect on the local economy."

The secondary or back-up area identified by RCA was dispersed throughout portions of Virginia, North Carolina, South Carolina and Alabama. Disadvantages suggesting significantly higher installation costs included, among others, areas of low conductivity interspersed 75 m. Considering the modest transmission facilities, the results were highly gratifying: (1) Keyed test signals (minimum phase-shift) were received at a depth of 100 m approximately 400-500 km from the antenna; (2) Transmissions made at carrier frequencies of 78, 125, 156 and 250 Hz were received at a maximum range of 3200 km with the antenna at keel depth. This dropped off to 850 km when the antenna was taken into deeper water; (3) Attenuation was shown to increase directly as a function of frequency but significantly decreased during the evening hours; and (4) Transmissions to the Sea Wolf, similarly monitored by sferic monitoring stations in Florida, New Jersey and Maine, provided additional insight into the system's performance and global ELF propagation characteristics.

By late 1963, the Director of Defense Research and Engineering (DDR&E), enthusiastically endorsing the ELF concept (code name SANGUINE), directed RCA to survey CONUS for candidate transmission facility sites. Criteria, including the basic specification for low-ground conductivity, required a relatively large, undeveloped and sparsely inhabited area to minimize electromagnetic interferences during 24-hour/day operations. The optimum site additionally would be characterized by flat terrain devoid of major impediments to facilitate access and minimize overall construction costs. Availability of support services and unemployed labor pool adjacent to the site were important economic considerations but were secondary to technical considerations if a worldwide submarine communications system was to materialize.

By 1965, more than 3000 measurements had been made with high conductivity ground. This was rugged terrain, representing accessibility and maintenance problems and relatively higher labor rates than those prevailing in Wisconsin.

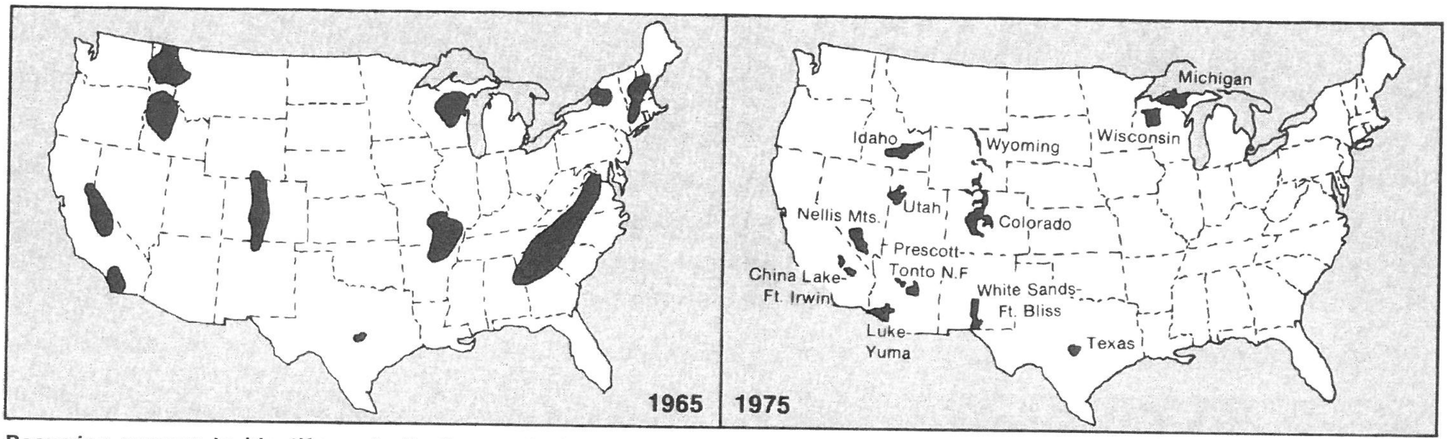
The Sanguine Project

The Sanguine Project, as envisioned in 1965 and 1968, would have consisted of ~100 buried transmitters and an antenna complex covering an area of 13,750 km^2. Such an expansive system would ensure uninterrupted communications with submerged FBM submarines and guarantee survivability in the event a large portion of the transmission facility was impacted by nuclear warheads. Considering estimated Soviet ICBM and SLBM inventories in 1968, complete Sanguine destruction would have required attack by nearly one-third of their strategic weapons.

At this point, implementation of Sanguine by the Navy and Congress would have significantly enhanced deterrent capability of the nuclear submarine force and extended range Trident boats in the planning stages into the 1990s-plus time frame. The key of course would have been a nuclear-hardened system capable of unrestricted and instantaneous contact with submarines by National Command Authorities (ashore, afloat, airborne) regardless of position and operational profile.

Unfortunately the late 1960's climate was anything but favorable for Sanguine after Congress had authorized expansion of the TACAMO VLF submarine communications system. In retrospect, politics were being unintentionally pitted against national security interests; understandably there was considerable concern about the advisability of investing in a redundant system estimated to cost in excess of $1 billion. There were extenuating problems developing which would influence the course of the program to the present time. Probably the most important of these was the massiveness of the antenna farm with thousands of miles of cables buried to a depth of 1.0-1.8 m encroaching on a broad spectrum of political subdivisions. Unlike a secure facility that can be installed on a military reservation without attracting public attention, Sanguine was being closely scrutinized after RCA's earlier site surveys recommending Wisconsin for the transmission facility.

In the intervening period, notable advances in ELF signal reception and message-processing occurring between 1968 and 1970 significantly reduced estimated systems cost and antenna requirements by a factor of ~5-6. Alternate design and site studies were ordered to include a variety of environmental parameters to ameliorate opposition to Sanguine and



Recurring surveys to identify cost-effective geological and environmentally compatible site for ELF transmission facility based on shifting design criteria for Sanguine (1965/1970) and Seafarer (1975). Each becomes more refined as deep earth conductivity is mapped to determine the extent of 10^{-4} mho/m pre-Cambrian strata.

develop a firmer base for gaining public acceptance. Of 17 geographic locales investigated, all were reported unacceptable from the standpoint of deep earth conductivity, cost and environmental impact, except Wisconsin.

From 1970 through 1973 Wisconsin was caught up in the miscellaneous environmental, anti-war, anti-nuclear, anti-military movements sweeping the country. This obviously placed the Navy and DoD in a highly awkward position and they became the *cause celēbré* of the collective opposition. With the Viet Nam war winding down, environmentalists and anti-Sanguine factions maintained tenacious and sustained visibility while continuing to gain support at the grass-roots level. Their efforts culminated in 1973 when then Secretary of Defense Melvin R. Laird, former Wisconsin Congressman and member of the Wisconsin State Senate, eliminated Wisconsin from further consideration as the Sanguine site as he was about to resign from office. At this time he further directed the Navy to investigate the feasibility of installing the ELF transmission complex in the hilly countryside around Llano, TX.

This was strenuously objected to by ranchers, in particular local environmentalists and splinter groups from Wisconsin continuing the battle against Sanguine. The scenario didn't change and the Navy and DoD finally acquiesced to these pressures, withdrawing into their Pentagon cocoon to develop a new strategy consistent with the post-Viet Nam war climate.

Seafarer

Resurfacing as Seafarer in the 1974-75 time frame, another alternative site survey was authorized by Congress consistent with requirements for a modest-sized system designed to reduce cost and obliviate many of the objections to its infamous predecessor.

Of 12 areas studied in detail for deep-earth conductivity as well as environmental and socio-economic compatibility, three were located in National Forests (Colorado, Wyoming, Arizona), five represented DoD facilities (Nevada, Arizona, New Mexico, California, Utah) and four were on a combination of private and public lands (Upper Peninsula of Michigan, Wisconsin, Texas). Eight of the 12 sites were rejected strictly from the standpoint that system's performance, based on conductivity and geographic limitations, would not be comparable to identical installations in Michigan or Wisconsin. Additionally, the Utah site was disqualified because power required for ELF was not available regionally and in California (China Lake/Ft. Irwin) ELF power requirements were approximately equal to that of the region. DoD facilities were not evaluated in respect to land-use incompatibilities and potential EMI problems after it became evident conductivity criteria couldn't be met.

Considerably more detailed assessment of the Wisconsin-Michigan region reconfirmed their superiority in meeting cost-effective design specifications. Systems and regional characteristics for the 1975 version of Seafarer varied modestly between the two states. Basically the Wisconsin design specified a total antenna length of 750 km to be installed within a 3368.75 km² low-conductivity area of mixed land ownership (federal, state, private). Vertical and horizontal antenna limbs were to be spaced 0.96 km apart with 40 terminal grounds installed throughout the entire complex. Four transmitter stations requiring 5 MW of commercial power would be operated from a single control center.

The modified Michigan ELF system called for 649.37 km of buried antenna (13.4% shorter than Wisconsin) on an irregular parcel of 4550 km² representing private and state ownership. Adjacent antennas spaced 5.2 mi apart would require a total of 66 terminal grounds (65% more than Wisconsin). Transmitter and control station specifications were identical to the Wisconsin site except commercial power requirements were reduced to 5 MW.

As the Navy was looking into the possibility of using federal facilities in New Mexico and Nevada, word was passed down that DoD was interested in conducting an environmental impact study (EIS) in one of the Upper Great Lakes States to determine its overall suitability for installation of a Seafarer-sized system. The Upper Peninsula of Michigan, experiencing a variety of economic and unemployment problems, with the backing of local legislators, businesses and other interested groups, besieged Gov Milliken to accept the invitation. After receiving the assurance of his science advisor and an *ad hoc* committee that Seafarer's radiation levels were safe, Milliken gave the go-ahead for the EIS with the proviso the National Academy of Sciences' pending study on the biological effects of ELF would have to be incorporated into the final report.

Still bothered by the Sanguine episode in Wisconsin and perhaps considering the political ramifications and the course of his own career, Gov Milliken obtained a highly unusual and unprecedented concession from Deputy Secretary of Defense William P. Clements, Jr., in 1976. This amounted to an agreement, although completely contrary to the national security interests of the US and its multi-billion dollar nuclear deterrent submarine force, giving the governor "veto" power on the Michigan site regardless of whether the environmental impact study was favorable or not. The ultimate course of action to be taken by Milliken was forecast in the spring when Seafarer was rejected in a series of referenda held in the Upper Peninsula. As the noose drew tighter, presidential-candidate Jimmy Carter delivered a pre-election speech promising not to install an ELF system in Michigan. On Nov. 2 the Seafarer issue was soundly defeated on a special ballot in the general election. The following spring, not surprisingly, Gov Milliken notified Secretary Brown and the president that he was exercising his "veto" against a Michigan siting.

Conclusion

Without considering the multi-faceted philosophical aspects of the issue, there are several provocative questions to be asked. How could then Deputy Secretary of Defense Clements legally offer "veto power" to Gov Milliken without incurring the wrath and indignation of Congress? The Navy had an urgent requirement for a communications system freeing SSBNs and SSNs from towing a VLF antenna in the upper layer of the water column, yet this overt act and the promise of an ex-submariner and presidential candidate on election eve succeeded in scuttling a vital command-link to the nuclear deterrent force. At this point ELF passed into a state of limbo as Mr. Carter continued to procrastinate and withhold the funding requested to develop a redesigned "austere" system.

Secondly, if the Navy wanted ELF as much as they claimed to ensure communications with Trident-class boats operating beyond the range of Polaris-Poseidon predecessors, why didn't they fight for it? Why didn't Congress fight for it? How could the CIC jeopardize survivability of a multi-billion dollar weapons system when limitations of VLF communications are well-known?

Next month these questions will be considered in relation to the Navy's requirements and a General Accounting Office (GAO) report recommending abandonment of ELF communications altogether, based on an investigation of technical and intelligence realities. The fifth article in this series will report on the DARPA-funded blue-green laser submarine communications system.

A copy of Mr. Starkey's bibliography may be obtained by calling ICDM of North America, Inc., outside California (800) 538-9700 or inside California (408) 727-3330.