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The 22 September 1979 Vela Incident: Radionuclide and Hydroacoustic Evidence for a Nuclear Explosion

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ABSTRACT

This article offers a new analysis of radionuclide and hydroacoustic data to support a low-yield nuclear weapon test as a plausible explanation for the still contentious 22 September 1979 Vela Incident, in which U.S. satellite Vela 6911 detected an optical signal characteristic of an atmospheric nuclear explosion over the Southern Indian or Atlantic Ocean. Based on documents not previously widely available, as well as recently declassified papers and letters, this article concludes that iodine-131 found in the thyroids of some Australian sheep would be consistent with them having grazed in the path of a potential radioactive fallout plume from a 22 September low-yield nuclear test in the Southern Indian Ocean. Further, several declassified letters and reports which describe aspects of still classified hydroacoustic reports and data favor the test scenario. The radionuclide and hydroacoustic data taken together with the analysis of the double-flash optical signal picked up by Vela 6911 that was described in a companion 2017 article ("The 22 September 1979 Vela Incident: The Detected Double-Flash") can be traced back to sources with similar spatial and temporal origins and serve as a strong indicator for a nuclear explosion being responsible for the 22 September 1979 Vela Incident.

ARTICLE HISTORY

Introduction

Just after midnight, at 00:52:43, on 22 September 1979 UTC, a U.S. surveillance satellite, Vela 6911,[1] equipped with special sensors called bhangmeters that record double light flashes typical of atmospheric nuclear explosions, picked up a signal that strongly indicated such an event. Based on the data, the explosion would have occurred somewhere in the South Atlantic or South Indian Ocean, and the signal became known variously as the Vela Incident, Alert 747, or Event 747. Following analysis of hydroacoustic signals detected by the Ascension Island array 110 minutes after the flash, the most probable test location was assessed to have been above

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Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/GSGS.

shallow waters close to the remote South African Prince Edward Islands, some 2,200 km southeast of Cape Town. The satellite detection information remained secret for about one month, before being leaked and reported by ABC TV on 25 October 1979.[2]

According to a National Security Council (NSC) document declassified in 2003, the U.S. Intelligence Community on 22 October 1979 had "high confidence, after intense technical scrutiny of satellite data, that a low-yield atmospheric nuclear explosion occurred in the early morning hours of 22 September 1979." In another document from the NSC dated 7 January 1980, different options were spelled out for what the Government's public posture on the Vela event should be and among three options one was to "emphasize that one cannot tell whether September 22 event was nuclear or non-nuclear."[3] Given its obvious proliferation implications, and the discrepancy in the amplitude of the optical signal's second peak between the two independent sensors on 6911,[4] an expert panel was set up in October 1979 to assess the original double flash and possible corroborative signals. This panel was chaired by Dr. Jack Ruina, a former director of the Advanced Research Projects Agency, and included eight respected physics, engineering, and technology professors, among them the Nobel laureate Luis Alvarez, Dr. Richard Garwin, and Dr. Wolfgang Panofsky.

The Ruina Panel's mandate focused on whether the double flash could have been "of natural origin, possibly resulting from the coincidence of two or more natural phenomena." The conclusion drawn in their 23 May 1980 final report was that, "although the Panel is not able to compute the likelihood of the September 22, 1979 event being a nuclear explosion, based on our experience in related scientific assessments, it is our collective judgment that the September 22 signal was probably not from a nuclear explosion."[5] The statistical inferences in this statement are important, as they left very much open the possibility that a nuclear test was responsible for the signal, put at about a 1-in-4 chance by one of the Panel members interviewed shortly after release of their report.[6] Even so, the Panel stated that "we consider the alternative explanation of the September 22 signal as light reflected from debris ejected from the spacecraft as reasonable, but we do not maintain that this particular explanation is necessarily correct." Again, the nuancing in the Panel's words is important, as it suggests that, if it wasn't an explosion, the Panel had little idea what phenomenon produced the signal. Indeed, their task was not to come up with a precise explanation, but rather to examine qualitatively possible alternatives to a nuclear explosion.

The Panel relied heavily on Vela bhangmeter data of previous confirmed nuclear explosions as well as on about 100 other optical signals for which no explanation existed at the time. This was provided by the Air Force Technical Applications Center (AFTAC), whose mission is the detection of non-U.S. nuclear detonations anywhere in the world at any time. Known as the Vela zoo, or zoo-ons, none of the unexplained signals had a light curve like Alert 747. Especially no zoo-on had a first maximum like Alert 747, in either rise time or pulse shape. While a few zoo-ons had a second maximum, in no case did the trace of the two bhangmeters approach anywhere near the similarity observed in the Alert 747 case. In other words, Alert 747 looked more like the previous nuclear explosions than anything else.[7]

In classifying Alert 747 as a zoo-on, the anecdotal evidence is that the Ruina Panel rejected the opposing explanation put forward by government agencies and/or contractors. Further, the Panel largely dismissed corroborative evidence of a nuclear explosion. This included a 300-page report from the NRL, which contained an analysis of a hydroacoustic signature, the temporal and spatial origins of which were consistent with those of the optical signal.[8] The NRL report remains classified to this date. Additional corroborative evidence concerned a possible detection of a short-lived fission product. The Panel wrote in their report that "detection of radioactive fallout can be immediately confirmatory for a nuclear event" and "positive results from the debris collection effort would provide conclusive evidence of a nuclear explosion." Despite this, the Panel appeared to not give due consideration to potential corroborative evidence from existing radionuclide data that needed a thorough analysis to be fully credible.

This paper sets out to do exactly that. It finds that the radionuclide information, plus the hydroacoustic signals, dismissed by the Ruina Panel bear heavily on the conclusion of whether the 22 September 1979 event was a nuclear test. This paper and its companion paper, "The 22 September 1979 Vela Incident: The Detected Double-Flash" published in 2017, are restricted to technical analyses of the data.[9] Other non-technical information that might be relevant is not considered such as speculation about possible responsible parties. Such claims are typically ambiguous, poorly documented, or attributed to sources that cannot be independently verified.[10] Also not examined are suggestions of a "cover-up" and obfuscation by the U.S. government down-playing the event and making a sustained effort to find non-nuclear explanations that would "cloud" the issue. These have been covered extensively in other works and overlook the vast resources invested by U.S. agencies in finding confirming data. In any case, such allegations can only contribute to the story once the technical case for a nuclear test has been made.[11]

The paper begins with an analysis of the iodine-131 fresh fission product found in the thyroids of slaughtered sheep from southeast Australia. Then an analysis of the hydroacoustic investigation undertaken by the NRL is presented, followed by some brief surveys of other possibly corroborative evidence. It ends with a discussion and a summary of the conclusions. Supplementary material relevant to the iodine-131 detections is provided in the online Appendix.[12]

Iodine-131 detected in Southeastern Australian sheep

In October and November of 1979, low levels of iodine-131, with a half-life of 8.025 days, were detected in sheep thyroids from southeast Australia. Since 1956, and at least through 1986, thyroid glands from southeast Australian sheep slaughtered in Melbourne were regularly analyzed for radioactivity, primarily for the presence of iodine-131. Samples were sent by Dr. Roger Melick (University of Melbourne and Royal Melbourne Hospital) about once per month in 1979 and more often during the French atmospheric tests at and around Mururoa and Fangataufa from 1966 to 1974. The analyses were conducted in the United States by Prof. Lester VanMiddlesworth at the University of Tennessee (Memphis). By 1979, it had long been established that thyroid glands of grazing animals, and especially sheep, efficiently concentrate radioactive iodine-131 from atmospheric nuclear weapon tests.

Since VanMiddlesworth did not publish his Alert 747 findings, it is difficult, but not impossible, to make an independent technical analysis of his results. Several documents exist in which he explains his methodology, both for this finding and more generally for findings during his four decades of research into iodine fallout and thyroid monitoring. Some are located at the National Security Archive at George Washington University (Washington, D.C.), having been declassified by Freedom of Information Act (FOIA) requests. Others are at the Nuclear Testing Archive in Las Vegas, where VanMiddlesworth's remaining papers, including reports, notebooks, and miscellaneous notes, are archived. Hereinafter, these documents will be referred to as "LVM" followed by a running number, such as LVM-1.[13]

Procedures of VanMiddlesworth's iodine-131 surveillance with focus on Australia

VanMiddlesworth's methodology is central to the reliability of the October/November 1979 thyroid data. Therefore, and because it is relevant to refuting some objections encountered later, it is reviewed in detail here.

About ten thyroid glands from sheep were dissected at the Melbourne abattoir and delivered to a laboratory, presumably at the University of Melbourne, where they were packed with 5–8 grams of paraformaldehyde and dispatched to VanMiddlesworth in containers provided by him (LVM-1). Care was taken at all stages to ensure that the thyroids were not exposed to radioactivity. Upon arrival at VanMiddlesworth's laboratory, the glands were trimmed from non-thyroid tissue, weighed, placed in a cup or beaker, and the gamma radiation in the energy range 300–400 keV, i.e., encompassing the iodine-131 364.5 keV primary gamma line, was measured using a single channel pulse height analyzer (SCA) connected to a sodium iodide scintillation crystal with a diameter of 5 inches and a 1-inch well.[14] The setup was shielded by four inches of lead. Measurements were made at least twice on each sample for 40–80 minutes, a background count was subtracted, and the result compared to an iodine-131 reference solution measured with similar experimental parameters. Any detected radioactivity was corrected for decay back to the date of slaughter and expressed in units of pico-Curie per gram (pCi/g).[15]

The detection limit for iodine-131 was usually in the range of 0.05–1.00 pCi/g (2–37 mBq/g) with the spread much depending on the different transit times in the mail (LVM-1, LVM-2). If the result was less than about 0.5 pCi/g, it was considered to be consistent with background, whereas a result of 0.5–1.0 pCi/g indicated the possible presence of intrinsic radioactivity. Levels above 1 pCi/g were considered significant, with a 90% probability that the derived value was within ±10% of the true figure, at least if the measurement was not conducted more than two or three iodine-131 half-lives post-slaughter.

When the radioactivity inferred by the SCA exceeded 0.5 pCi/g, the sample was subjected to gamma-ray spectroscopy to confirm the presence or absence of iodine-131. An integration time of 1,000 minutes (16.67 h) was typically used to acquire the spectrum, with the specimen inside a shielded 5″ × 5″ NaI(Tl) detector with a 1″ diameter well coupled to a multichannel analyzer (MCA). This detector was probably the same detector as used for the SCA scans, but if not, it used a crystal with identical specifications. Anywhere from a few hundred to several hundred channels were used to cover gamma energies up to 1,000 keV. Subsequently, a background spectrum—or an average of many background spectra—taken under the same experimental conditions was subtracted.

VanMiddlesworth was aware of possible contamination and/or background issues that could lead to a false positive. This is evident from several published papers. For instance, when low-level quantities of iodine-131 were detected in Welsh sheep thyroids in late 1978 and 1979, checks were done to determine if any abattoir workers had undergone a medical treatment with iodine-131, if there had been an iodine-131 release from regional nuclear power reactors, and if iodine-131 had been found in milk.[16] In other publications, circumstances were described under which natural radioactive isotopes, such as those of radium and their decay daughter products, could mimic the presence of iodine-131.[17] In these cases, the same thyroids were re-measured weeks and months later to determine if the activity decreased, indicating iodine-131, or remained constant, indicating much longer-lived uranium and/or thorium series isotopes. While VanMiddlesworth did occasionally find radium or its daughter products in cattle thyroids, at least up to 1979 these isotopes were never found in sheep thyroids. All of this provides confidence that VanMiddlesworth was meticulous in pursuing options for explaining unusually elevated iodine-131 readings.

The iodine-131 detections from Southeast Australia, October–November 1979

A thyroid sample collected at the Melbourne slaughterhouse on 22 October 1979 revealed a possible signal of iodine-131 in the SCA count (LVM-3). Its implied specific activity on the slaughter day, based on a total counting time of $7 \times 40 = 280$ minutes on 12 November 1979, was around 0.67 ± 0.25 (counting uncertainty) pCi/g. The measurement was made 2.6 half-lives post-slaughter due to a delay in the mail from Melbourne. From VanMiddlesworth's ledger notes for 12 November 1979 the calibration used for the primary iodine-line at 364.5 keV can be deduced to be 1.04 (= 0.67/0.644) pCi/cpm (counts per minute) (LVM-3, pages 132 and 133 with a correction for an obvious calculation error). The calibration factor, cf, expressed in pCi/cpm can also be given as the detectors efficiency, $\varepsilon(\%)$, for the primary gamma ray, which for the 364.5 keV line of iodine-131 is $\varepsilon(\%) = 27 \times 100/(60 \times 0.815 \times \text{cf})$. Here 27 is the number of pCi per Bq, 60 is the number of seconds per minute, and 0.815 is the 364.5 keV gamma intensity per beta decay in iodine-131. For cf = 1.04 this gives an efficiency of 53%.[18]

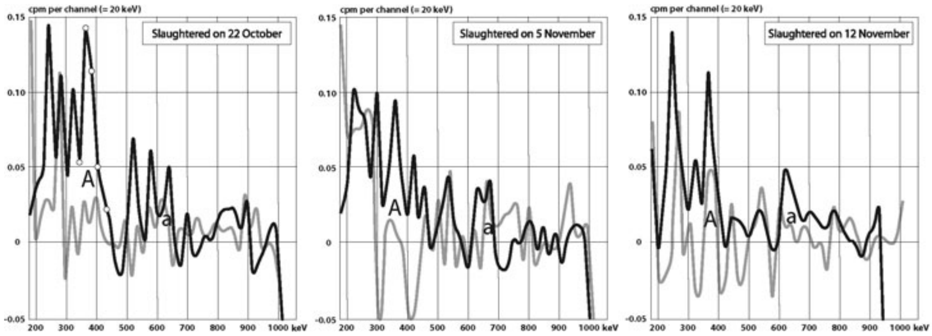

Figure 1. NaI(Tl) spectra of the sheep thyroid glands slaughtered in Melbourne on 22 October, 5 November, and 12 November 1979. The spectra drawn by thick lines were measured on 12, 13, and 28 November 1979 respectively (LVM-4, Frames 17, 23 and 24), and the ones drawn by thinner lines are spectra counted of the same samples nine months later in August 1980 (LVM-4, Frames 22, 27 and 25). The peaks marked A and a are the candidate iodine-131 peaks at 364.5 keV and 637.0 keV. The white circles show the content of the compressed channels around the major iodine peak in the 22 October 1979 sample.

VanMiddlesworth acquired a gamma spectrum of the 22 October 1979 sample. He also analyzed two subsequent samples (5 and 12 November 1979), even though these two showed little indication of iodine in the SCA data. The three spectra acquired on 12, 13, and 28 November 1979 are displayed in Figure 1 after a background spectrum has been subtracted. (LVM-4). Despite the delayed mail delivery, there is a clear detection in the 22 October 1979 sample of iodine-131 by its major gamma line at 364.5 keV (81.5% emission probability) and with less confidence another one at 637.0 keV (7.2%). The 364.5-keV line is probably also present in the other two samples but with lower amplitude and significance. Figure 1 also shows counts taken of the samples nine months later, which effectively show zero net counts and thus demonstrates that the original measurements did reveal iodine-131 activity. To our knowledge, none of these spectra found among VanMiddlesworth´s remaining papers at the Nuclear Testing Archive in Las Vegas have been published before. The original spectra had 2-keV wide channels while in Figure 1 "channel" refers to ten times compressed 20 keV channels, which are the ones depicted. The counting time of each gross spectrum was 1,000 minutes (LVM-4).

To enhance the overall signal-to-noise ratio (SNR) in the net results, the three individual net spectra have been summed, and the result is displayed in Figure 2 with the most prominent peaks marked. Here, one can clearly note the presence of iodine-131 (364.5 keV and 637.0 keV), lead-212 (238.6 keV), and possibly thallium-208 (583.2 keV). The latter two are decay products of radon-220 (thoron gas) that probably entered the counting cave from nearby building materials or from the underground. The interpretations of these four lines gain credibility from the fact that the linear channel-to-energy calibration through them was fitted with a coefficient of determination as close to 1 as 0.9999. A crucial point to be made from this co-added spectrum is that, by minimizing the noise, it provides incontrovertible evidence from the primary 364.5 keV peak, supported by the 637.0 one, that

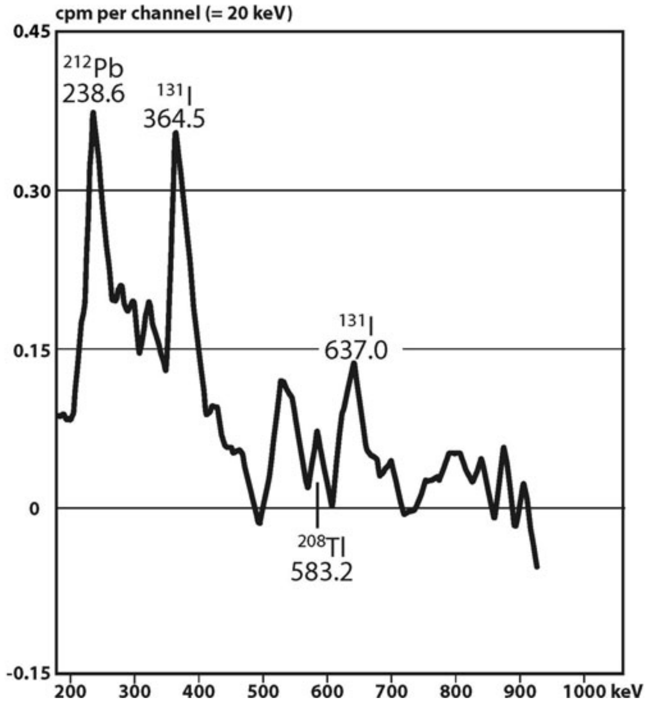

Figure 2. Summed spectrum of the background-subtracted 22 October, 5 November, and 12 November 1979 sheep thyroid gland samples.

the thyroids did contain iodine-131. The noise is, however, most probably the reason that the area of the latter peak appears to be larger than what is expected from the area of the former one and that, what reasonably is the 511 keV annihilation peak, shows up around 10 keV too high.

The pertinent iodine-131 concentrations obtained by VanMiddlesworth from the spectra have not been found in his archived notes. However, in Figure 1 the 364.5 keV peak can be estimated to be 0.3 ± 0.1 cpm (integrated) and with the calibration factor 1.04 pCi/cpm as given above and a correction for decay 21 days back to 22 October 1979 that corresponds to 1.9 ± 0.6 pCi/g at slaughter, almost 3 times higher than the SCA estimate. That is not surprising as the dominant background varied with time, probably due to differing contributions of radon daughters.

To check the efficiency, a simulation was made in the Monte-Carlo-based code VGSL (Virtual Gamma Spectroscopy Laboratory) developed at the Provisional Technical Secretariat of the Comprehensive Nuclear-Test-Ban Treaty Organization in Vienna.[19] Although the sample and its holder are not described in detail, the efficiency can be calculated to be approximately 55%, very close to the 53% from the physical calibration.[20]

The background count at 364.5 keV was about 1,100 counts per 20 keV channel (LVM-4, Frame 9). A peak area of some 300 counts within 4 channels implies a signal of about $300/\sqrt{2 \times 4 \times 1100} = 3.2$ standard deviations.

A meteorological analysis

Given the clear presence of iodine-131 in southeastern Australia, the next step is to analyze whether there is a straightforward way to meteorologically connect a suspected source with the detection. Without any calculation, it can be expected that such a connection exists, since the prevailing winds at the relevant southerly latitudes are westerly, peaking in strength in the southern spring, and known as the roaring forties. Even so, such a study was carried out by the U.S. National Oceanic and Atmospheric Administration (NOAA) together with the NRL.[21] The study determined the trajectory of a possible cloud from a near surface/sea test close to Marion Island early on 22 September 1979 for the 500-mbar-pressure surface (around 5 km altitude). It found that any residual debris after the local washout around the test site would probably have hit and passed southeastern Australia during 26 September UTC, 1979 (Figure 3). The black areas mark regions of rainfall on 26 September that could have produced the contaminated pasture for sheep. The 5 mm of rain on that day in the major sheep-grazing region of Victoria, Tasmania, and New South Wales is notable as the Melbourne abattoir mainly slaughtered sheep from these regions.

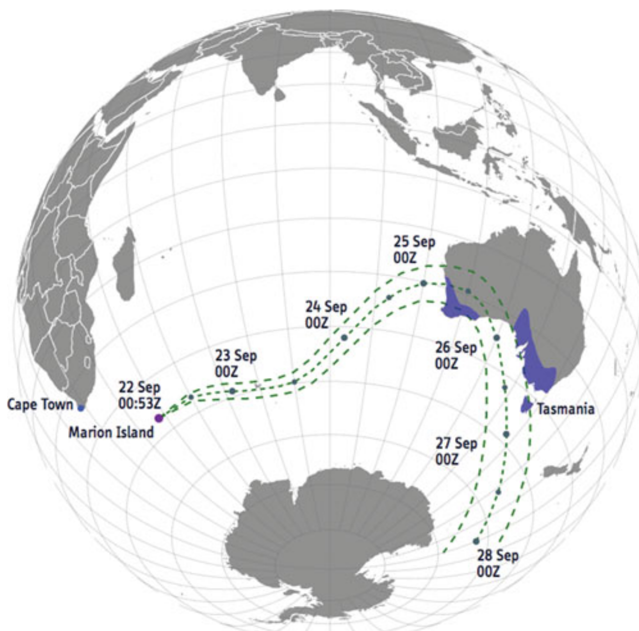

Figure 3. Meteorological trajectories at the 500-mbar-pressure level starting at the area of Marion and Prince Edward islands (South African territory) and extending for nearly 6 days. A central track and two $\pm 1\sigma$ lines of the trajectory are shown. The black areas in South East Australia mark areas where there was some 5-mm rainfall during the cloud passage that produced the contaminated pasture that caused the concentrations of iodine-131 in sheep thyroids that were later detected in mid-October. Marion Island is believed to be close to the detonation point, and Melbourne is the location of the abattoir that provided thyroid glands to VanMiddlesworth. All time values are UTC.

Further details on the iodine-131 detections are contained in the online supplementary material. On-line Appendix A examines the possibility that the iodine-131 could have been of civilian origin, but concludes that the only realistic source of the iodine-131 detections is indeed the suspected nuclear explosion on 22 September 1979. In online Appendix B, a few “false alarms” and/or ambiguous radionuclide detections are reviewed. The purpose of this analysis is to scan published data for detections in the southern hemisphere in 1979 and 1980 that could possibly corroborate the Australian thyroid data. No such data are found. In online Appendix C, it is shown that the detection of iodine-131 in Australian sheep thyroids is fully consistent with the non-detection of iodine-131 in air the Australian ground level air surveillance network at the time. Appendix C also describes briefly the effort by AFTAC to find the cloud.

Reactions to the iodine-131 sheep thyroid detections

On 8 December 2016, the Nuclear Security Archive published about 50 declassified documents from the files of Ambassador Gerard C. Smith.[22] The documents contain scant technical data, but some provide insights into when the U.S. Government became aware of and reacted to possible evidence corroborating the Vela detection. Among the declassified documents, the first reference to VanMiddlesworth's analyses appears in a note written for Secretary Cyrus Vance or President Carter dated 19 November 1979.[23] In that note, VanMiddlesworth was not prepared to conclude that a nuclear explosion had taken place.

VanMiddlesworth had probably become aware of the 25 October 1979 report of a possible nuclear explosion on 22 September in the southern hemisphere and realized that his Australian sheep thyroid monitoring program could potentially detect iodine-131. The regular October sample was taken on 22 October, however he must have asked his contact in Australia, Dr. Roger Melick at the Royal Melbourne Hospital, to provide an extra sample in early November and to take the monthly sample a bit earlier than scheduled. After analyzing the 22 October, 5 November, and 12 November 1979 samples, VanMiddlesworth was not ready to conclude the presence of any iodine-131 in these samples, writing “my first impression was that we had not observed 131-I in those sheep thyroids” (LVM-5). Such a conclusion was probably related to his previous experience of detecting very high levels of sheep thyroid iodine-131, in the range of 100–1,000 pCi/g, after the French nuclear tests in the late 1960s and early 1970s (LVM-1). The no-detection conclusion led to the formulation in the note for the President and Secretary of State that the analysis (most probably based on the 22 October sample) “revealed no abnormal radioactivity.”

Another document showed that in February 1980 VanMiddlesworth remeasured the October/November 1979 samples and compared the original measurements with the corresponding aged ones. At that point, he completely changed his view and concluded that there had in fact been quite clear signals of iodine-131 in the October/November 1979 thyroid samples (LVM-5). He then wrote, “our evidence showed a high probability of iodine-131 having been present and then decayed." He further claimed that the probability of a false positive was less than 0.1%, which implies a net signal of 3.3 standard deviations above the background.

In the same document (LVM-5), VanMiddlesworth described how he was "visited by representatives from the Air Force Technical Applications Center (AFTAC) and the data were presented to a special committee at the White House Office Building." Presumably the visitors from AFTAC were joined by at least a subset of the Ruina Panel, and the special committee he mentioned was the Ruina Panel. In his memoirs, Wolfgang Panofsky, the director of the Stanford Linear Accelerator Centre and a Panel member, wrote: "An amusing incident originated from a U.S. Department of Energy (DOE) funded research installation that examined sheep thyroids from New Zealand (sic)" and " …when visiting the research installation in question, we found the detector used to analyze the sheep thyroids to be completely unshielded, and it was further reported that elevations in counting rates from that detector were not only due to contaminated specimens, but would also be triggered by the packages of passers-by!"[24]

This is not correct. VanMiddlesworth described his detector as a shielded $5'' \times 5''$ NaI(Tl)-crystal with a $1''$ well for the sample, all shielded by 4 inches of lead. The detector with an empty well showed a count rate of about 0.3 counts per second, which is 3–4 orders of magnitude lower than the expected count rate for an unshielded $5'' \times 5''$ crystal. Dr. Panofsky had mistaken a large unshielded sodium iodide detector in the laboratory that alarmed if unexpected radioactivity was brought into the counting room for the detector used to measure thyroids.

Nobel laureate Luis Alvarez, another member of the Ruina Panel, demonstrated a similar lack of appreciation for all possible corroborative evidence when he wrote about the work of the Ruina Panel in his 1987 autobiography: "In our DIA (Defense Intelligence Agency) briefings we were shown, and quickly discarded, confirming evidence from a wild assemblage of sensors: radioactive Australian sheep thyroids, radio telescopic ionospheric wind analyses, recording from the Navy's sonic submarine-detection arrays that supposedly precisely located the blast from patterns of sound reflected from bays and promontories on the coast of Antarctica."[25]

A declassified version of the Ruina report was published on 17 July 1980. Regarding VanMiddlesworth's detections and the NRL analyses, the report concluded: "The search for nuclear debris and for geophysical evidence that might support the hypothesis that a nuclear explosion was the source of the September 22 event has so far only produced data that is ambiguous and noisy. At this date, there is no persuasive evidence to corroborate the occurrence of a nuclear explosion on September 22." Following the release of the report, VanMiddlesworth repeated his measurements in August 1980 to confirm that there were no long-lived signals at the iodine-131 energies (see Figure 1). In a letter received on 25 September 1980, VanMiddlesworth wrote about his analyses and concerns to the NRL Research Director, Dr. Alan Berman, someone who had vociferously protested the Ruina Panel's ignorance of possible corroborative evidence.[26] Dr. Berman then asked Dr. Keith Marlow, the Head of the Radiation Survivability and Detection Branch at NRL, to review the data. The conclusion of Marlow and his staff was that at least the 22 October 1979 sample contained iodine-131 at a level five times the standard deviation of the background and that "Dr. VanMiddlesworth's data constitute a positive case for the proposition that Australian sheep ingested the fission product iodine-131 in October 1979."[27]

Two important enclosures were expunged; the original letter from VanMiddlesworth to Dr. Berman and the internal review by Dr. Marlow's group. An African activist organization, The Africa Educational Fund, claimed in a 1985 report that they had viewed the VanMiddlesworth and Marlow enclosures secured by FOIA requests. Copies could not be obtained for this analysis despite FOIA requests.[28]

The day Dr. Berman received Van Middlesworth's correspondence, Van Middlesworth also wrote a reply to Dr. Harold Beck at the DOE Environmental Measurements Laboratory (EML) in New York City.[29] VanMiddlesworth had obviously been in contact with EML earlier, and Dr. Beck had given a review of VanMiddlesworth's measurements that concluded that EML could not support the detections of iodine-131. Dr. Beck repeated his concerns on 2 October 1980, when he reiterated the risk that the signals could actually have been due to radon-222 decay products.[30] On 8 Dec 1980, in a letter to John Marcum, Beck expressed his concerns, which indicated that he earlier had been called as an expert before the Ruina Panel and thus explaining why VanMiddlesworth contacted Dr. Beck after the Panel's final report was publicly released.[31] A central issue in the discussions between VanMiddlesworth, Beck, and Marlow during the winter of 1980–81 was the statistical strength of the iodine-131 364.5 keV gamma peak. VanMiddlesworth had initially claimed 6 standard deviations (σ) of the background, Marlow 5 σ and Beck 1 σ. Part of the discussion had been about the background measurements VanMiddlesworth had used in his analysis, the average of some 20 readings spread over a year or a single background taken close to the actual thyroid measurements. After clearing some misunderstandings, all three of them agreed in February 1981 on the value 3.1 σ.[32] This value agrees well with the analysis above, which finds 3.2 σ based on a background of some 1,100 counts per channel, a 4-channel wide region of interest, and a net signal of some 300 counts.

Hydroacoustics

A nuclear airburst could potentially have many more, and stronger, corroborating signals than an underground nuclear explosion (UNE). Besides radioactive fallout, a non-exhaustive list includes: electromagnetic pulse (EMP); acoustic gravity and infrasonic waves, where the explosion couples directly to the atmosphere; seismic or hydroacoustic waves if conducted at low enough altitude for the explosion to couple to the surface; subsequent seismic waves (T-waves) when a hydroacoustic wave propagates onto land; and traveling ionospheric disturbances (TIDs).[33]

Many or all were searched for after Alert 747 with varying degrees of success, as briefly discussed in a following section.[34] Perhaps the strongest corroborative evidence was the detection of hydroacoustic waves by sensors of the U.S. Missile

Impact Location System (MILS) and/or Sound Surveillance System (SOSUS) network and analyzed in detail by a team of up to 75 personnel from the NRL.[35] The several-hundred-page report was forwarded to the White House on 30 June 1980. The report remains classified and is only superficially discussed in the numerous publications on the Vela signal. Several specific findings have been summarized, however, in a declassified letter from the NRL Research Director (NRLRD), Alan Berman, to the Executive Office of the President, Office of Science and Technology Policy (OSTP) on 11 December 1980 (hereafter referred to as NRLRD-80).[36] This letter was sent after a presentation by NRL on 3 December 1980 to the Ruina Panel, and appeared to be a follow-up to what the Director perceived as misunderstandings and/or confusion among the Panel members about the NRL's findings.

Utility of hydroacoustic observations

Hydroacoustic observation should be an effective means of detecting nuclear explosions below, on, and even above the surface of the ocean (within limits). A strong endorsement of the efficacy of hydroacoustic monitoring is the fact that the Comprehensive Nuclear-Test-Ban Treaty International Monitoring System (IMS) only uses six hydrophone stations (plus another five T-phase seismic stations on remote islands), despite oceans covering 71% of the Earth's surface.[37] This is to be compared with 170 seismic stations (50 primary and 120 auxiliary) dispersed throughout the continents, 80 radionuclide stations, and 40 infrasound stations.

Hydroacoustic surveillance is a powerful monitoring technique because sound waves can travel thousands of kilometers in the ocean with relatively minor attenuation, through what is called the Sound Fixing and Ranging (SOFAR) channel. The ocean sound speed is a function of water temperature, pressure, and salinity, and thus varies with depth. The SOFAR channel is a consequence of this variation. Decreasing with increasing depth from the surface for several hundred meters, the magnitude of the acoustic velocity then reverses and begins increasing with increasing depth. The depth at which the reversal occurs, i.e., where speed is a minimum, is termed the *sound channel axis* and is responsible for SOFAR propagation. Sound produced from a source located on the axis, typically at a depth of 700–1300 m, will follow paths which are refracted back toward the axis.[38]

The SOFAR channel is effectively a waveguide, such that a large portion of the acoustic energy is confined to the plane of the velocity minimum, not undergoing reflections at the ocean surface or bottom which could otherwise result in attenuation. Losses are therefore relatively low in the SOFAR channel and very long ranges are possible, up to and beyond 10,000 km for even relatively small explosions, as demonstrated in many studies.[39] A good example was the detection of explosions from charges equivalent to 34 kg of TNT, not even exploded in the sound channel but rather at a shallower depth of 60 m, at a range of 16,300 km between the east coast of Japan and the IMS station Juan Fernandez off the coast of Chile.[40]

Hydroacoustic detections potentially associated with Alert 747

According to NRLRD-80, at 02:43:00 UTC on 22 September, and at an SNR of over 300, three wide-band hydrophones near Ascension Island, part of the MILS, detected a signal indicative of a "large impulsive release of energy which coupled acoustic energy into the deep South Atlantic sound channel," most likely referring to the SOFAR.[41] The temporal sequence of signals on the three hydrophones allowed a bearing to the source of 198 $\pm$10 degrees to be inferred, i.e., to the south-southwest. Based on experience with French nuclear tests in the Pacific, the dispersion of the signals indicated a path length to Ascension of about 10,000 km.[42] With a propagation velocity of 1.5 km/s, a standard value for hydroacoustic signals travelling through the SOFAR, the origin time is then around 00:52:00 UTC, extremely close to the Vela signal time.

In addition to the detection at Ascension Island, according to a recently posted document dated 17 June 1980, a signal was also observed from the SOSUS installation at Argentia, Newfoundland.[43] This is consistent with several other documents that mention the NRL study, including the Ruina Panel's report; the second site had never been publicly identified however.[44] Unfortunately, the precise details of the signals at the two locations remain unknown. According to the 17 June 1980 document, the Ascension Island signal was a direct arrival, while the Argentia signal was received after a reflection from a point in Antarctica.[45] The information in NRLRD-80, specifically the bearing and travel path, shows that Ascension must also have received a reflected signal, and thus it detected both direct and reflected arrivals.[46] For the latter, with the aforementioned bearing and travel distance, and if the source was somewhere near the Prince Edward and Marion Islands (hereafter PE&M), a fitting reflection area is the South Sandwich Ridge, part of the East Scotia Ridge, at a bearing of 189 degrees from Ascension.[47] This scenario is depicted in Figure 4.[48]

Fine structure in the hydroacoustic signals from French nuclear tests, propagated over a similar range (9,500 km, possibly to Guam), was replicated in the Ascension Island data. This fine structure was characteristic of an "explosion on, near, or in water 10 to 20 meters above a thin sediment layer overlying basalt." The fine structure, referred to as a "line frequency" in the letter, possibly points to the existence of peaks at 7.5 and 12 Hz in the hydroacoustic spectra of two French atmospheric nuclear tests.[49] These can be identified with the Dragon and Licorne tests on 30 May and 3 July 1970 that exploded at 500 m ASL with yields of 945 kt and 914 kt at the Fangataufa and Mururoa atolls, respectively.[50]

Over the years, Dr. Berman has stood firmly by the findings, even arguing that the analysis could be used by itself to identify an explosion at about the time and place of the 1979 event.[51] He was adamant that characteristics of the data were consistent with observations of French nuclear tests in the South Pacific, indeed "unique to nuclear shots in a maritime environment."[52] The continued classified nature of the NRL report makes a completely independent judgment impossible, but even so, by placing the detections in the context of hydroacoustic signals from known nuclear tests and other explosions, the next section reviews NRL's work and the Ruina Panel's

Figure 4. The tracks for the two arrivals detected by the hydrophones just south of Ascension Island. A reflection from the East Scotia Ridge with a band of seven approximately equidistant small islands over 380 km fits very well the information given in NRLRD-80.

response. Following sections examine aspects of the detected signals not provided in NRLRD-80 or the few other articles which refer to the NRL work. These include discrimination of the signal as explosive and coupling of acoustic energy into the ocean and subsequently the SOFAR channel. Thereafter other potentially corroborative data are briefly discussed, as are the logistics of performing a nuclear test at or near PE&M.

Comparing Ruina Panel and NRL assessments of Alert 747 hydroacoustic data

The hydroacoustic analysis of the NRL provides strong corroborating evidence for an explosion as the origin of Alert 747. The signals were detected by three Ascension Island MILS hydrophones and the Argentia SOSUS array.[53] Estimating the range and bearing of the signal origin the NRL utilized well-established techniques that continue to be practiced today. For instance, the time delay between hydrophones, which provide a bearing (or azimuth) to the source, was likely determined by calculating the cross-correlation of each hydrophone pair of the Ascension triplet.[54] This is evidenced by the statement in NRLRD-80 of "pairwise, statistically significant cross-correlation coefficients for all possible pair combinations."[55] The range estimate was made using the temporal dispersion of multipath arrivals and well known relations between signal duration and distance. Finally, at the long ranges considered here and given the SOFAR is effectively a waveguide, cylindrical vice spherical spreading for the decrease of the signal energy with distance is appropriate.[56] Yet, the dismissal of the hydroacoustic evidence by the Ruina Panel starkly contrasts with that of the NRL experts.

Although the published literature on hydroacoustic detections of nuclear tests conducted on or above the surface is limited, the following discussion provides an independent technical assessment. To the authors' knowledge, only two papers with data have been published, one for two French atmospheric tests in the South Pacific and another for two U.S. barge tests of the Hardtack series in the Marshall Islands.[57] The latter can be identified as the 20 May 1958 5.9 kt Holly and 26 May 1958 57 kt Magnolia shots, both detonated at the Eniwetok atoll. Other cases must have produced hydroacoustic waves, including megaton-level tests at burst heights of 1500–4300 m during Operation Dominic at Christmas Island in 1962, but were instead detected via T-waves at 2,300 km distant Papeete (shots Rinconada, Bluestone, Sunset, and Pamlico).[58]

The Ruina Panel described the putative Alert 747 hydroacoustic readings as "weak signals" and implied they were "only a few decibels above background noise." On the other hand, the NRL states their SNR as being about 25 dB, or 317 to 1, and were immediately obvious from a visual inspection of the record. A similar SNR of approximately 20 dB has been reported for a small accidental underwater explosion, which occurred 175 km south-east of New York at a depth of less than 100 m. Detected about 8,000 km away by the IMS hydroacoustic sensors at Ascension Island, the spectrogram shows an obvious and clearly apparent structure.[59] Further, the Panel criticized the NRL's method of extracting the signal, specifically the filtering process for which they infer that a central frequency of 16 Hz and a bandwidth of 1 Hz were utilized. But in NRLRD-80 it is instead stated that 12.5 ± 1.5 Hz was used, a figure consistent with that observed for other nuclear explosions at Mururoa and Eniwetok.[60]

NRL Research Director Berman was quoted as saying it was the strongest hydroacoustic pulse he had ever seen, only comparable to those from nuclear tests in the Pacific.[61] In NRLRD-80 the signal is described as being much stronger, 25 dB versus 13 dB above background, than from a confirmed 35–40 kt French shot at a similar range. With cube root scaling of the acoustic yield of an explosion, this apparent 12 dB difference is actually increased to around 15 dB assuming yields of 2 kt and 35-40 kt respectively for the Alert 747 and French explosions. This difference between the two cases was said to be probably due to the higher yield French shot being an airburst at several hundred meters as opposed to a much lower altitude (even surface) burst presumed for Alert 747.

There was a disagreement between the Panel and the NRL on the hydroacoustic background, or at least its level and interpretation. About a site where recordings were made (but not identified as Ascension or Argentia), the Panel stated that 176 signals occurred above background during a 156-hour (6.5-day) period, presumably referring to anything more than 3-sigma or 3 times the noise. In contrast the NRL notes that, for Ascension Island itself, they searched 30 days before and after the putative Vela signal and found no other signal with similar characteristics). These include i) detections on all 3 hydrophones within travel time constraints to the area of the Vela satellite coverage, ii) statistically significant cross-correlation for all hydrophone pairs, iii) duration of 8–32 seconds, iv) a consistent “line structure” (probably meaning the frequency spectrum), and v) SNR $>$ 22 dB in the 12.5 $\pm$ 1.5 Hz frequency band on all 3 hydrophones.

Taken at face value this disagreement over the size of the signal and background is a serious disconnect between the two groups. They appear to be referring to two completely different data sets and analyses, and it would not be surprising that they came to different conclusions.[62] But why? One possible reason could be that the two groups were referring to the different locations at which hydroacoustic signals were detected. The Panel may have been referring to Argentia. Being much closer to population centers on the east coast of North America, as well as probably shipping traffic, it is potentially hydroacoustically noisier than the more isolated Ascension Island. Its longer travel path, compared to Ascension, also suggests the signal would be weaker. If it was a direct arrival along a great circle path it would have encountered several bathymetric (hence attenuating) structures between source and receiver.[63] From PE&M and in order of increasing distance these include the continental margin of the African land mass near the Cape of Good Hope, the Walvis Ridge with several seamounts rising to within several hundred meters of the surface, and again the African continental margin off its westernmost part.[64] At the relevant latitudes of the Walvis Ridge the SOFAR axis is at a depth of 900–1000 m, so that the seamounts cross through it.[65] This would preferentially attenuate the more numerous axial rays and thus result in a weaker signal at the receiving station.

Alternatively, the two groups may have been referring to the same receiving location but to different arrivals, i.e., the Ascension Island direct and reflected signals in the case of the Panel and the NRL respectively. In literature on the Vela Incident these are stated to be of different strengths. One article quotes a White House staff member as saying the data consist of two signals, “a weak one, which came first, and then a strong one.”[66] Assuming they were from the same source “the first had to be a direct signal, and the second, reflected.” In other words, the reflected signal was stronger than the direct one, and according to the same person “most of the mathematical analysis was based on the second signal.” This then cast doubt on the overall reliability of the data and NRL’s analysis.

But this is not an unusual situation in hydroacoustics. Reflected signals contain the same structure, both temporal (duration) and spectral (frequency), as the direct arrival and can have a similar amplitude.[67] Indeed reflected signals enhance the coverage of the IMS hydrophone network, including from Antarctica, for those regions of the Earth that might be in the shadow of one or more of the six stations.[68] A resolution of this discrepant strengths problem between the direct and reflected arrivals at Ascension may be inferred from an exchange between the NRL’s Director Berman and a journalist.[69] It was noted that along a direct path, presumably from PE&M, around 6,500 km from Ascension, the signal would encounter scattering and/or blockage by bathymetric features. NRL’s computations could predict the observed behavior, taken here to mean the respective signals’ arrival times and relative amplitudes. Though not specified, in order of increasing range from PE&M

the scattering/blocking structures could feasibly be the Vema Seamount, Walvis Ridge, island of St. Helena and even the Mid-Atlantic Ridge south-east of Ascension Island.[70] The Vema Seamount is particularly noteworthy as it lies on a great circle path between PE&M and Ascension and rises to within tens of meters of the ocean surface. It most definitely cuts through the SOFAR axis and would be a significant source of attenuation.

Discrimination of the Alert 747 hydroacoustic signal

One issue not addressed in NRLRD-80 is the identification of the Ascension Island signal as explosive in nature rather than one of several other possible sources, including an undersea earthquake or volcano eruption and even ice movements in Antarctica. From the description of the signal being representative of "a large impulsive release of energy" such discrimination work was almost certainly undertaken. The term "impulsive" suggests an abrupt onset of the signal, consistent with previous data on the French and U.S. explosions and expectation from calculations.[71] Further, it is strongly implied in NRLRD-80, though not explicitly stated, that the putative Vela signal was of a short duration, perhaps between about 8–32 seconds, also consistent with the previous data.[72] Further discrimination was likely to have been a straightforward process.

The Prince Edward and Marion Islands, near which the suspected nuclear explosion occurred, have a volcanic origin. However, the first eruption in the recorded history of Marion Island occurred between February and October 1980, detected only because of a new lava field rather than any explosion or Earth tremor.[73] Occurring only about 6 months after Alert 747, it is possible that some precursor underground or undersea activity occurred leading up to the eruption. But no evidence could be found in the literature of any such observations for the region around that time. Other volcanic systems in nearby areas have been observed hydroacoustically, including from the Walvis Ridge fracture zone west of southern Africa.[74] However, potential signals from these would not satisfy the path length and bearing criteria of the putative Vela signal. A similar consideration, at least for the path length, holds for the several active volcanoes near the Antarctic Peninsula such as Deception Island.

The properties of the signal detected by NRL are almost certainly not characteristic of volcanic activity. Observed frequencies in the spectrum of volcano eruptions are typically below 10 Hz, with a range of 4–12 Hz.[75] Perhaps more significantly, in contrast to a nuclear explosion, submarine volcano signals, like undersea earthquake signals, typically have a longer duration, and/or occur in swarms detected over hours and days.[76] Submarine volcano signals might also contain an overtone structure indicative of a resonance in the conduit from magma chamber to vent, and exhibit a bubble pulse signature like the one from an underwater explosion.[77]

The ISC (International Seismological Centre) Event Bulletin showed only two earthquakes within a 7.5 degree radius of PE&M for the month prior to and after Alert 747, with body-wave magnitudes (mb) of 4.4 and 4.7 on 29 September and 16 October 1979, respectively.[78] But hydroacoustic signals can be detected from undersea or near-ocean earthquakes of much lower magnitude, e.g., 2.0 mb. Such an earthquake in a remote location would probably not be detected by conventional land-based seismic networks.[79] But even if one did occur, and coupled energy into the deep sound channel, both its duration and signal onset would probably be longer than for an explosion and thus be easily distinguished.

Icebergs can generate sound in the ocean via a multitude of mechanisms. These include collisions (impacts, grinding), calving, breakup (cracking), and grounding on the sea bottom.[80] These are characterized by relatively long durations of tens of seconds to tens of minutes, a frequency content from a few Hz to at least 100 Hz (including monochromaticity but which fluctuates during a single emission sequence), and the presence of overtones. Hydroacoustic signatures from icebergs can be well discriminated from explosions. Also, given their large number icebergs probably form a source of background noise, and would be unlikely to generate a signal as large as that detected at Ascension and putatively originating from Alert 747. This background is seasonal, and for Ascension Island exhibits low activity between August and October, bracketing the time of the Vela event.[81]

Coupling of Alert 747 acoustic energy into the ocean

The final issue not covered in NRLRD-80, and perhaps the most important in the context of a possible nuclear test, is the mechanism by which the explosion coupled acoustic energy into the SOFAR channel. Based on the "line frequency" structure and its similarity to French Pacific shots, the authors concluded that the explosion took place in shallow water, 10 to 20 m deep, "underlain with sedimentary deposits over a hard rock [basaltic] basement." At first glance, this scenario carries several potential problems, including the difficulty of finding such an environment at the presumed explosion location or even anywhere nearby.

A cursory glance at the Mururoa and/or Fangataufa atolls, where France conducted atmospheric tests, shows how very different these are compared to PE&M (or indeed Clarence Island, also mentioned in NRLRD-80). Both Pacific atolls have an interior lagoon, around 20 km × 10 km (8 km × 6 km) in size, with a relatively narrow main opening to the ocean, about 4.5 km (0.1 km) wide and up to 9 m (8 m) deep for Mururoa (Fangataufa), plus numerous other but much narrower openings.[82] The average depths of the lagoons are 33 m (ranging up to 55 m) for Mururoa and 15 m (up to 45 m) for Fangataufa. Similar properties hold for Eniwetok and Bikini atolls.

The hydroacoustic signals described in the literature from French atmospheric and U.S. barge nuclear tests within the Pacific atolls were assessed to have been T-phases. In other words, they were not excited by direct coupling of the explosion's airblast from the atmosphere into the water and then into the deep SOFAR channel. Instead, the French shots were postulated to have been produced when the explosive energy was refracted into the atoll's lagoon at the critical angle, then refracted into the atoll itself as a compressional (P) wave, which could then insonify the SOFAR channel wherever the seismic waves impinged upon it.[83] For the U.S. shots it was concluded that energy first coupled directly into the solid earth (i.e., the atoll), then entered the ocean at a solid/water interface and energized the SOFAR after multiple reflections between the ocean surface and down-sloping bottom.[84]

The implication is that energy from the explosion had to be transmitted through up to three interfaces, air/water, water/solid and solid/water, and be converted from acoustic to elastic and back again. It is possible that some of the properties of a long-range-detected hydroacoustic signal could change between the different coupling scenarios just outlined. For instance, while the dominant frequency band, broadly separated into low and high (1–25 and 26–50 Hz) would probably not change, it may be that the spectral shape within the bands might be modified. The coupling mechanism of the putative Vela explosion to the deep sound channel may well be different to the French and U.S. cases. Since they are two volcanic outcrops the PE&M may be considered younger versions of the Pacific atolls. There is a steeply sloping ocean bottom, rising from a depth of around 3,000 m, much like the Pacific atolls. But the approximately 20 km wide relatively shallow plateau, 50–200 m deep, between the islands can hardly be considered a lagoon.[85] Thus, using French Pacific shots as a template, as in NRLRD-80, may not be entirely appropriate.[86] Whatever the case, regardless of the precise coupling process it seems that the hydroacoustic signal from an atmospheric explosion will have an abrupt onset, short duration, and relatively low frequency content (little energy beyond about 20–30 Hz), demonstrated by both observations and calculations.[87]

Literature on the coupling of an atmospheric explosion into the SOFAR channel is rare, and that which exists is brief. But as noted above, the question of the precise coupling mechanism may not be a problem, as demonstrated by a series of calculations for a 1 kt explosion conducted in, on, or above deep water.[88] These calculations show that, despite the energy coupled into the deep ocean being sharply reduced for explosions near or above the surface (compared to sub-surface explosions), there is still sufficient energy to give an easily detectable hydroacoustic signature. It would be distinguished by a short duration and relatively low frequency content (peaking at around 5 Hz at a range of 10 km), consistent with the putative Vela signal at Ascension. For instance, even a burst height at 50 m would be equivalent to a 10–50 kg explosion on the SOFAR axis. A similar case holds for such an explosion over a steeply sloping bottom. On the other hand, for a burst conducted above 200 m deep, flat-bottomed water, the energy coupling is reduced by about an order of magnitude. These simulations were conducted for a mid-latitude ocean sound speed profile, while the profile at the more southern putative Alert 747 location may well be different, e.g., a shallower SOFAR axis. Indeed, the SOFAR axis depth may be 200 m or even less at PE&M's latitude, in which case it is possible that insonification of the SOFAR channel would be more efficient than the calculations suggest.[89]

Bache et al. made a similar hypothesis about the spectral character and duration of a nuclear explosion near the ocean surface.[90] In this case the hypothetical explosion appears to be tailored to the characteristics of Alert 747. Bache calculated a hydroacoustic signature at a range of 6,600 km, notably the distance between

PE&M and Ascension Island, for a 1-kt nuclear explosion at the surface of a deep ocean with the sound speed profile of the South Atlantic. Included were two mechanisms by which the explosion energy couples into the ocean, being the dominant air blast-induced pressure loading on the surface plus direct coupling of thermal energy into the water. The observed spectrum was found to depend almost entirely on the source properties, while its duration was determined by the propagation, i.e., the travel path characteristics.[91]

The frequency at which the spectrum peaked at this 1 kt yield was found to be around 22 Hz, for other yields the peak frequency scales with the cube root of the yield. The authors of the report mention two French airbursts (though do not identify their dates), but are uncertain about whether an analogue can be drawn between these high yield, high burst altitude explosions and their simulation of a low yield near surface explosion. Nonetheless, they note that their calculations for both signal frequency content and duration are consistent with the French data. The two U.S. barge tests previously mentioned may be more relevant, and broadband spectra were published for the 57-kt Magnolia shot.[92] The peak of around 6–7 Hz for the deeper hydrophone, which recorded the largest signal, is in agreement with the predicted cube root scaling.[93]

The shapes of the calculated and observed frequency spectra are very similar, with no discernible fine structure. They are also broadly consistent with independent simulations in that the amplitude has a broad peak but decreases steeply on either side.[94] The latter, calculated at a range of 10 km for a 1 kt burst at an altitude of 50 m, do however, contain distinct, though not particularly sharp, peaks and troughs. For both sloping and flat ocean bottom cases a peak occurs at around 12.5 Hz, like that used by the NRL for the Alert 747 signal, while the deep-water case instead has a shallow trough at 12.5 Hz (the peak moves to 15 Hz but which would then move back to about 12 Hz under cube-root scaling for a 2–3 kt explosion).

For all three simulations, there is more energy in the 2.5–10 Hz frequency interval, which the NRL did not use in their analysis. But such considerations would also need to account for the frequency response of the hydrophones and/or the dominant frequency of noise sources. The NRLRD-80 does note that the ambient noise at 10 Hz is about 70 dB referenced to 1 micropascal, rapidly increasing below 8 Hz due to surface waves and above 18 Hz due to the acoustic signals generated by marine mammals. These figures continue to be borne out by observations.[95] For instance, the upper bound is almost certainly a reference to vocalizations by fin and blue whales.[96]

Other potential corroborative or related data

Some other potentially corroborating data for Alert 747 exist but they were not of sufficient quality and/or uniqueness to be considered definitive evidence of a nuclear explosion. This includes unusual aurorae observed in Antarctica and a so-called electron precipitation event sensed by the TIROS-N weather satellite.[97] Either type of event could have been the consequence of an EMP from a surface nuclear burst. The TIROS-N observation was ultimately attributed to natural causes. While broadly coinciding in time with the Vela signal, it was not sufficiently simultaneous to be unambiguously connected to Alert 747.

On the other hand, the sudden brightening of an aurora observed at the Japanese Syowa Antarctic research station, almost due south of PE&M, occurred within seconds of the Vela signal. While not necessarily unique, it was considered plausible that the two were related. Furthermore, and relevant to criticism raised by the Ruina Panel, in a very thorough assessment of all accessible geophysical data, nothing was found that conflicted with the occurrence of a nuclear explosion.[98]

Another possible corroborative observation was a traveling ionospheric disturbance detected at the Arecibo radio telescope in Puerto Rico, which had the right velocity and originated from the right direction, and which would otherwise only have a 1-in-50 chance of occurring randomly.[99] The responsible scientists never claimed it to be unambiguously associated with the Vela signal, and the NRL also dismissed the idea that the two were related.[100]

A curious piece of evidence concerns ionosonde data, described in a 23 July 1980 memorandum to NRL Director Berman from its head of the Ionospheric Effects branch of the Space Science Division.[101] A so-called "bite-out," or depletion, of the ionospheric electron density was found in the ionosonde data from Marion Island beginning between 00:45:00 and 01:00:00 UTC on 22 September 1979 (i.e., bracketing the origin time of Alert 747) and extending to 02:30:00 UTC, but was not seen in data from Johannesburg, Kerguelen Island, or Grahamstown (South Africa). Despite the data being described as "exceedingly poor quality" the depletion was characterized as a "rather striking anomaly" that had been previously observed following low-yield nuclear bursts conducted near ground level.

Given the remote location in which Alert 747 is thought to have occurred, there is really no surprise that data corroborating the optical flash, levels of iodine-131, and the hydroacoustic detections were difficult to find. Having occurred almost 40 years ago, there were fewer observatories with sensors capable of detecting the event, and sensitivity was also lower. Even today, the southern Indian Ocean is not well monitored compared to other areas.[102]

Given the elapsed time since Alert 747, new information could possibly be acquired by looking at more recent and the September 1979 data sets. Better statistics, such as time, location, strength and number, would now be available for natural events which could mimic those of a surface nuclear burst. Also, a fresh look at each possible (civilian) corroborative data set, using more sophisticated algorithms and software, could possibly yield new insights. There is no guarantee that the original data have survived in a useful format, however, since much was possibly recorded on analog equipment and/or stored on magnetic tape. Unless it has been archived in a modern format it may well be irrecoverable. A significant investment of time and resources would be required just to stage the analysis.

Logistics of a nuclear test near Prince Edward and Marion Islands

Atoll lagoons like Mururoa are logical locations for conducting nuclear tests since they are protected from the open ocean. If nothing else, the timing of a test would be less dependent on weather conditions, although wind speed and direction are important for fallout predictions. They also provide a stable platform, important for diagnostic instrumentation, personnel safety, and protection of the device.

The waters around PE&M provide none of these advantages. There is no safe harbor. Further, with a storm approaching the island group on 22 September 1979, with one report citing cyclone conditions, it seems likely the seas would have been running a large swell. Conducting a controlled experiment within the roaring forties would present a significant logistical challenge.

Marion is inhabited by the staff of a civilian weather observatory and a biological research station on the northeastern side of the island. These facilities were reportedly occupied at the time by a team of twelve scientists and technicians. As can be seen in Figure 5 there were realistically only two locations around the islands where a small nuclear test could be carried out without being noted by the station staff: off the southwestern part of Marion behind the 1,200-meter volcano, or north of Prince Edward Island behind the 600-meter volcano on that island.[103] Offshore from both sites is about 1.5 km of shallow water. The distances to the station are a little more than 20 and 30 km, respectively. That would presumably shield the station from much of the light and the sound of the explosion. The local time at the island group is UTC+3 hours and most staff should have been asleep at 3:53. This is 2 hours and 24 minutes before sunrise and for someone awake potential explosion effects could presumably have been taken for lightning and thunder given there was heavy storm activity in the vicinity.[104] Of course, the explosion could have occurred tens of kilometers from the islands, to preclude any possibility of being seen or heard by station staff. The Vela 6911 optical flash, south-east Australian sheep thyroid iodine-131,

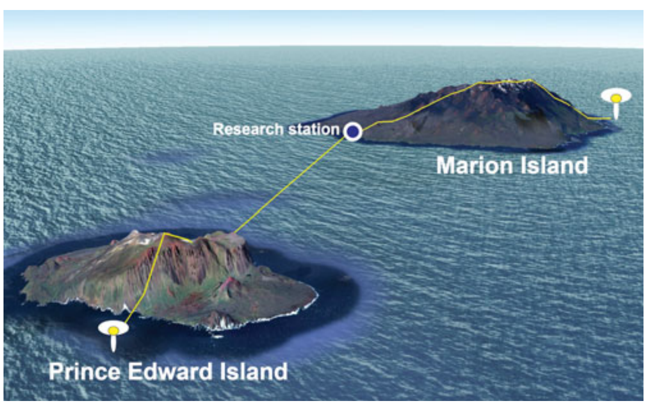

Figure 5. Prince Edward and Marion Islands seen from the north. The two marked test points are the ones most likely to avoid disclosure of an explosion by the staff at the research station. From there the near Marion potential test point is 23 km away behind the 1,230 m *State President Swart Peak* and near Prince Edward Island the optimum point is 32 km away behind the 672 m Van Zinderen Bakker Peak (Google Earth).

and Ascension Island hydroacoustic data would still be consistent with each other for such an uncertainty in the event location.

Finally, if the 1979 Vela incident was a nuclear test then those responsible prepared very well in choosing a time and place that would make detection extremely difficult. If not a nuclear test, and instead a member of the Vela zoo population, then the fact that the only uniquely nuclear-like zoo event could be tracked back to such a remote location is remarkable.

Discussion and conclusions

Through forensic analysis of relevant radionuclide and hydroacoustic data, this paper considerably strengthens the argument that Alert 747 of 22 September 1979, otherwise known as the Vela Incident, was in fact a nuclear explosion. The main technical results can be summarized as follows:

Professor Lester VanMiddlesworth's claim to have detected iodine-131 in the thyroids of southeastern Australian sheep slaughtered in late October and early November 1979 has been vindicated and strengthened. These sheep had been grazing in an area hit by rain on 26 September 1979, when a plume from the potential explosion site near PE&M was passing. Three spectra from different thyroid samples of sheep slaughtered on three different dates are published here for the first time. These spectra show two signature gamma-ray emission lines of iodine-131.

The concentrations in air corresponding to the thyroid concentrations are well below the detection limit of two airborne radionuclide particulate surveillance systems then operating in Australia and New Zealand. These consequently could not see any iodine-131 in the pertinent time window. The very low concentration in the cloud blowing across southern Australia is consistent with a low-yield nuclear explosion of a few kilotons near the ocean surface, where the ejected water together with precipitation within a cyclonic storm, which passed the islands at the time, caused the bulk of the debris to rain out close to the event.

A clear hydroacoustic signal was detected at two sites. The signal had properties consistent with an explosive source and was like that observed from French nuclear tests at their Pacific atoll test sites. The assessments showed that the signals had originated at the same time and at a location consistent with the location inferred from the Vela satellite flash detection. Further, the time and location are compatible with the dissemination and the detection in Australia of the fission product iodine-131 from the suspected site.

The case for a nuclear explosion being responsible for the 22 September 1979 Vela Incident is now founded upon three pillars, which include the original optical signal, the iodine-131 evidence, and the hydroacoustic signal. Each one, even by itself, is a strong indicator of a nuclear explosion. Indeed, analysts have previously argued that the optical and hydroacoustic signals are definitive indicators for a nuclear test, while the iodine-131 detections provide robust and credible evidence for a nuclear fission event shortly before ingestion by the grazing sheep. All three data sets have high SNRs and can be traced back to similar spatial and temporal origins, even within a few minutes for the optical and hydroacoustic signals. It would be an unlikely coincidence if these phenomena did not have a common cause.

These conclusions should be contrasted with the findings of the Ruina Panel, which concluded that "the signal was probably not from a nuclear explosion" given the lack of "persuasive corroborative evidence" and, focusing on the double flash instead, the slight difference in the optical signal seen by two independent bhangmeters aboard the same Vela satellite. This difference was only in the second pulse of the time history and had another credible explanation. On the other hand, the first pulse was entirely consistent between the two sensors and with previous nuclear tests, but inconsistent with the population of a few hundred or so unexplained signals detected by Vela, and since then by other satellite bhangmeters, from which the Ruina Panel suggested Alert 747 was drawn. The Panel was premature in dismissing the hydroacoustic data and its analysis, which provide a strong prima facie endorsement of a nuclear explosion scenario. Also, although not specifically addressed in the Panel's declassified written report, comments made by a few members afterwards were incorrectly dismissive of the iodine-131 data and its implications.

This independent analysis is based on documentation that has only become accessible over the last decade – an important NRL hydroacoustic report remains classified, however. The analysis serves to demonstrate the need for open access to additional technical hydroacoustic data. Such data will be useful in particular to strengthen the International Monitoring System associated with the Comprehensive Nuclear Test-Ban-Treaty.

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Notes and References

1. In total, six pairs of Vela satellites were launched. The satellites are called Vela 1A, 1B, 2A, 2B, 6A, 6B or, alternatively, Vela 1, 2, …12. Vela 6911 is therefore also referred to as Vela 5B or Vela 10. The two satellites moved as a pair in antipodal positions to optimize their common field of view. Only Vela 7–12, launched pairwise on 28 April 1968, 23 May 1969, and 8 April 1970, carried Earth facing bhangmeters.
2. John Scali, ABC News, 25 October 1979, after having been briefed by contacts at the Pentagon. Nuclear Weapons Archive. Carey Sublette, Report on the 1979 Vela Incident.

3. Christine Dodson, Staff Secretary at the National Security Council, "Memorandum for the Secretary of State and others on the South Atlantic Nuclear Event," (22 October 1979), National Security Archive Electronic Briefing Book No. 190 (2006); Christine Dodson, Staff Secretary at the National Security Council, "Discussion paper for the mini-SCC meeting on January 9 on the September 22 event in the South Atlantic" (7 January 1980), National Security Archive Electronic Briefing Book No. 190 (2006).
4. Christopher M. Wright, and Lars-Erik De Geer, "The 22 September 1979 Vela Incident: The Detected Double-Flash," *Science & Global Security* 25 (2017): 95–124.
5. Jack Ruina et al., "Ad Hoc Panel Report on The September 22 Event," Executive Office of the President, OSTP (17 July 1980). A declassified (redacted) version is available at nsarchive.gwu.edu/NSAEBB/NSAEBB190/09.pdf. An unredacted version issued on 17 July 1980 is available at fas.org/rlg/800717-vela.pdf.
6. Eliot Marshall, "Debate Continues on the Bomb That Wasn't," *Science* 209 (1980): 572–573.
7. Christopher M. Wright, and Lars-Erik De Geer, "The 22 September 1979 Vela Incident: The Detected Double-Flash."
8. Leonard Weiss, "Israel's 1979 Nuclear Test and the U.S Cover-Up," *Middle East Policy Council* 18 (2011): 83–85.
9. Christopher M. Wright, and Lars-Erik De Geer, "The 22 September 1979 Vela Incident: The Detected Double-Flash."
10. Richard Rhodes, *The Twilight of the Bombs* (New York: Random House, 2010); Sasha Polakaw-Suransky, *The Unspoken Alliance: Israel's Secret Relationship with Apartheid South Africa* (New York: Pantheon Books, 2010); Jeffrey Richelson, *Spying on the Bomb* (New York: W. W. Norton & Company, 2006); Seymour M. Hersh, *The Samson Option: Israel, America and the Bomb* (New York: Random House, 1991); J. D. L. Moore, *South Africa and Nuclear Proliferation: South Africa's Nuclear Capabilities and Intentions in the Context of International Non-Proliferation Policies* (Palgrave Macmillan, 2014); Ronald W. Walters, *South Africa and the Bomb: Responsibility and Deterrence* (Lexington, Mass: Lexington Books, 1987).
11. Leonard Weiss, "Flash from the Past: Why an Apparent Israeli Nuclear Test in 1979 Matters Today," *Bulletin of the Atomic Scientists* (8 September 2015), thebulletin.org/flash-past-why-apparent-israeli-nuclear-test-1979-matter-today8734; Leonard Weiss, "The Vela Event of 1979 (or the Israeli Nuclear Test of 1979)," Proceedings from The Historical Dimensions of South Africa's Nuclear Weapons Program," Intundia Game Lodge, Pretoria, South Africa, 9–11 December 2012, cisac.fsi.stanford.edu; Leonard Weiss, "The 1979 South Atlantic Flash: The Case for an Israeli Nuclear Test," in H. Sokolski (ed.), *Nuclear Proliferation: Moving Beyond Pretense: Preliminary Findings of NPEC's Project on Nuclear Nonproliferation Policy* (Washington, D.C: Nonproliferation Policy Education Center, 2012) 117–140, www.npolicy.org; Leonard Weiss, "Israel's 1979 Nuclear Test and the U.S. Cover-Up," *Middle East Policy* 18 (2011) 83–95.
12. Online Appendices A, B, & C, "The 22 September 1979 Vela Incident: Radionuclide and Hydroacoustic Evidence for a Nuclear Explosion," http://scienceandglobalsecurity.org/archive/sgs26degeer_app.pdf.
13. The following documents are available from the Nuclear Testing Archive in Las Vegas, where VanMiddlesworth's remaining papers are stored. They are labeled in the text as LVM-x, where x, see previous LVM-x is a running number referring to the accession numbers in brackets. They include: LVM-1 "World-Wide 131-I Fallout in Animal Thyroids, 1954–1987" [350399]; LVM-2 "Studies in Iodine Metabolism, 1980" [350420]; LVM-3 "#9 LEDGER 1975–1979" [350201]; LVM-4 "Sheep & Goats, Australia, NaI(Tl) spectra 1979" [350440], including Slaughter 22 October 1979 and counting 12 Nov 1979: Frame 9 (2 keV/ch), Slaughter 22 October 1979 and counting 12 November 1979:

Frame 17 (20 keV/ch), Slaughter 22 October 1979 and counting 4 August 1980: Frame 22 (20 keV/ch), Slaughter 5 November 1979 and counting 13 November 1979: Frame 23 (20 keV/ch), Slaughter 5 November 1979 and counting 18 August 1980: Frame 27 (20 keV/ch), Slaughter 12 November 1979 and counting 28 November 1979: Frame 24 (20 keV/ch), Slaughter 12 November 1979 and counting August 1980: Frame 25 (20 keV/ch); LVM 5 "Studies in Iodine Metabolism–33 Year Summary 1948–1979 with Appendix 1979–1982." [350453].

14. An older crystal used in the 1960s had a smaller diameter of 2 inches.
15. L. VanMiddlesworth, "Long-life Radioactivity in Occasional Thyroids," *Nature* 203 (1964): 200–201; R. Melick and L. VanMiddlesworth, "Radioiodine Fallout in Australian Sheep," *The Medical Journal of Australia* (12 November 1966): 930–932; L. VanMiddlesworth, "Radioiodine in the Biosphere During 1968," *Nature* 221 (1969): 1041–1042; R. Melick and L. VanMiddlesworth, "Radioiodine in Animal Thyroid Glands from 1966–1972," *Medical Journal of Australia* (2 March 1974): 298–301; L. VanMiddlesworth, "Radioiodine I-131 in Animal Thyroids during Nuclear Tests in Both Hemispheres," *Health Physics* 29 (1975): 861–863; L. VanMiddlesworth, "Small Quantities of I-131 in Thyroids of Sheep from Wales," *Health Physics* 40 (1981): 525–527.
16. L. VanMiddlesworth, "Small Quantities of I-131 in 930 Thyroids of Sheep from Wales."
17. Long-life Radioactivity in Occasional Thyroids; L. VanMiddlesworth, P. Correa, R. W. Perkins, and A. T. Keane, "Radium Isotope Accumulation in Animal Thyroids," *Science* 151 (1966): 453–454.
18. Note that neither the 364.5 keV nor the 637.0 keV gamma rays of iodine-131 suffer from any true coincidence summation effects, which otherwise can be significant in a well detector for many other nuclides.
19. R. Plenteda, "A Monte Carlo Based Virtual Gamma Spectrometry Laboratory," PhD Thesis, Universitätsbibliothek der Technischen Universität Wien, Austria (2002); Lars-Erik De Geer, "VGSL, The Virtual Gamma Spectrometry Laboratory," Presentation at the ICRM Gamma Spectroscopy Meeting, Paris, 23 February 2009, www.nucleide.org/ICRM_GSWG/Workshop_2009/WS_2009_Presentations.htm.
20. The source is approximated by paraformaldehyde, OH(CH2O) nH (n = 8–100) (with high n and density of 1.5 g/cm3) packed into a 2-mm thick cylindrical aluminum container.
21. Alan Berman, "Re: Evidence of possible detection of fission products related to VELA event of 22 September 1979," U.S. NRL, letter to John Marcum, Executive Office of the President, OSTP, 3 November 1980, National Security Archive, South Africa, Document No. 01104.
22. National Security Archive, Electronic Briefing Book No. 570, Document 27, posted 8 December 2016.
23. National Security Archive, Electronic Briefing Book No. 570.
24. Wolfgang Panofsky, *Panofsky on Physics, Politics, and Peace: Pief Remembers* (New York: Springer, 2011).
25. Luis Alvarez, *Alvarez: Adventures of a Physicist* (New York: Basic Books, 1989).
26. Alan Berman, "Re: Evidence of possible detection of fission products related to VELA event on 22 September 1979."
27. De Geer knew Marlow and several of his colleagues, having visited each other's laboratory many times during the 1970s and 1980s. Marlow and his colleagues were/are experts in the field of nuclear spectroscopy.
28. Ronald Walters, and Kenneth S. Zinn, "The September 22, 1979 Mystery Flash: Did South Africa Detonate a Nuclear Bomb?" The Washington Office of The Africa Educational Fund (21 May 1985).

29. Letter from L. VanMiddlesworth to Harold Beck at the DOE/EML in New York, 25 September 1980, accession number 350990, Nuclear Testing Archive, Las Vegas, United States.
30. Letter from Harold Beck, DOE/EML in New York, to L. VanMiddlesworth, 2 October 1980, accession number 350990, Nuclear Testing Archive, Las Vegas, United States.
31. Letter from Harold Beck, DOE/EML in New York, to John Marcum, Executive Office of the President, OSTP, 8 December 1980, accession number 351123, Nuclear Testing Archive, Las Vegas, United States.
32. Ronald Walters and Kenneth S. Zinn, "The September 22, 1979 Mystery Flash."
33. T-waves are seismic waves which have travelled an extended path as an oceanic acoustic wave, before being converted into a seismic wave at a shoreline. They are the third, or tertiary, seismic wave detected, since the hydroacoustic velocity is only about 1.5 km/s compared to around 8 and 3.5 km/s for the P and S waves. They are typically observed as a product of undersea disturbances, such as earthquakes, volcanic eruptions, and man-made explosions, after conversion of elastic to acoustic energy at the sea bottom. A T-phase signal detected from an in-water explosion may instead be called an H-phase.
34. *Spying on the bomb: American nuclear intelligence from Nazi Germany to Iran and North Korea*; Marshall, Eliot, "Navy Lab Concludes the Vela Saw a Bomb," *Science* 209 (1980): 996–997; David Albright, and Gay Corey, "A Flash from the Past," *Bulletin of the Atomic Scientists* 53 (1997): 15–17; Kathy DeLucas, "Blast from the Past: Lab Scientists Receive Vindication," *LASL Daily News Bulletin* (11 July 1997), http://nuclearweaponarchive.org/Safrica/071197.html.
35. In the normal operations of MILS, it was not the surface impact of the re-entry vehicle (RV) that produced the hydroacoustic detection at long-range, as it had insufficient energy to insonify the SOFAR channel, but rather that from an explosive charge released from the RV set to detonate close to the SOFAR axis. Hydrophones located on the ocean bottom close to the splashdown point were however able to detect the direct signal and provide a more accurate fix. See H. H. Baker, "Missile Impact Locating System," *Bell Laboratories Record* (June 1961): 195–200.
36. "Hydroacoustic Evidence on the Vela Incident," letter from U.S. NRL Director Berman to John Marcum, Senior Advisor for Technology and Arms Control, Executive Office of the President, OSTP, 11 December 1980, Wilson Center Digital Archive, http://digitalarchive.wilsoncenter.org/document/116758.
37. Martin W, Lawrence, "Acoustic Monitoring of the Global Ocean for the CTBT," In Proceedings of 2004 Annual Conference of the Australian Acoustical Society, 3–5 November 2004, Gold Coast, Australia, 213–220, 455–460.
38. This is a simplified description. There are both geographic (principally latitude) and seasonal variations in the velocity profile as a function of depth, which may alter the depth of the SOFAR axis and the associated Deep Sound Channel. In low and mid-latitude waters, for example between about ±40 degrees, there is a surface layer in contact with the air which responds to day/night and weather variations. Even within this diurnal layer there can be significant structure in the depth-temperature-velocity relationship. Processes such as surface heating by sun, cooling by evaporation, and lower night time temperatures, as well as wind-induced wave action, can lead to convection and turbulence, thereby mixing water from different depths. This can result in a quasi-isothermal layer a few to several tens of meters thick, seasonally dependent, which can also trap acoustic energy and is known as the mixed layer or surface duct. Below the diurnal layer is the seasonal thermocline, extending for a few hundred meters, which responds to temperature variations through the year. This is followed by the main thermocline in which the largest change in temperature, and thus velocity, occurs, and in which the velocity decreases with depth. At greater depths the temperature reaches a constant value of around 2–4 °C, the

velocity gradient reverses, and so the velocity increases with depth (due to the increasing pressure) through this deep isothermal layer. The SOFAR axis is where the velocity is a minimum, at a typical depth of around 1,000 m, while the Deep Sound Channel is that region between the shallow (300–400 m) and deep points (3,000–4,000 m) where the velocities are equal, and its thickness can be a few thousand meters. Above the axis, rays are refracted down while below the axis they are refracted up, analogous to geometric optics and Snell's law. At higher latitudes, where the oceans are cooler, the thickness of the main thermocline shrinks and the minimum acoustic wave speed (and thus SOFAR axis) gets progressively shallower. Approaching the poles, the entire water column can be isothermal, so that the minimum velocity and SOFAR axis is at the surface. In this case, all rays are refracted up, to undergo reflection at the surface. For low frequencies, the reflection is essentially perfect, but rough seas can obviously result in non-specular reflection and thus acoustic energy will scatter in different directions. For further details see R. J. Urick, "Sound Propagation in the Sea," Defence Advanced Research Projects Agency (1979), Reprint from the collection of the University of California Libraries; and M. J. Sheey, "SOFAR Propagation," in R. J. Urick, and A. W Pryce, "A Summary of Underwater Acoustic Data, Part I, Introduction," Office of Naval Research (1953), http://oai.dtic.mil/oai/oai?&verb=getRecord&metadataPrefix=html&identifier=AD0030750>. R. J. Urick, and A. W Pryce, "A Summary of Underwater Acoustic Data. Part VII. Transmission Loss," Office of Naval Research (1956). <http://oai.dtic.mil/oai/oai?&verb=getRecord&metadataPrefix=html&identifier=AD0115204>.

39. M. K. Prior, R. Chapman, and A. Newhall, "The Long-range Detection of an Accidental Underwater Explosion," proceedings of the European Conference on Underwater Acoustics, 2–6 July 2012, Edinburgh, Scotland; C. De Groot-Hedlin, Donna K. Blackman, and C. S. Jenkins, "Hydroacoustic Propagation Through the Antarctic Convergence Zone: Study of Errors in Yield and Location Estimates for Explosive Charges," Ft. Belvoir: Defense Technical Information Center, 2007, http://handle.dtic.mil/100.2/ADA519212; "Hydroacoustic Propagation and Reflection Loss Using Explosions Found in the Indian Ocean," in Marvin A Wetovsky and Jody Benson, "Proceedings of the 29th Monitoring Research Review: Ground-Based Nuclear Explosion Monitoring Technologies," 25–27 September, 2007, Denver, Colorado, (LA-UR-07-5613): 697–706; W. H., Munk, W. C. O'Reilly, and J. L. Reid, "Australia-Bermuda Sound Transmission Experiment (1960) Revisited," *Journal of Physical Oceanography* 18 (1988): 1876–1898; A. C. Kibblewhite, R. N. Denham, and P. H. Barker, "Long-Range Sound-Propagation Study in the Southern Ocean–Project Neptune," *The Journal of the Acoustical Society of America* 38 (1965): 629–643; George M. Bryan, Marek Truchan, and John I. Ewing, "Long-Range SOFAR Studies in the South Atlantic Ocean," *The Journal of the Acoustical Society of America* 35 (1963): 273–278.
40. M. K. Prior, O. Meless, P. Bittner, and H. Sugioka, "Long-range Detection and Location of Shallow Underwater Explosions Using Deep-Sound-Channel Hydrophones," *IEEE Journal of Oceanic Engineering* 36 (2011): 703–715.
41. The MILS system at Ascension had already been successfully used to detect man-made signals originating from both the northern and southern Atlantic Ocean, as well as the southern Indian ocean. The hydrophone locations are provided in several publications that discuss these detections, and that bracket the time of the putative Alert 747 case. These include the Chase 21 and Chase 22 ship scuttling explosions off the coast of New Jersey in 1970 and the Heard Island Feasibility Test (HIFT) in 1991. Another publication reports Ascension MILS detections in 1959–60 of 48 lbs. TNT charges exploded at various depths along a track which passes close to the Prince Edward and Marion Island group. The Chase case suggests the presence of 5 hydrophones and the HIFT 8–11 (some may be in pairs). Presumably the system did change over the years, but assuming a minimum of 5 phones begs the question of why only 3 registered a signal. Only declassification of the

full NRL report can answer this question definitively, but it is possible that one or more of the phones were in the island's "shadow" along the signal bearing. Relevant references are: Bryan, et al., "Long-Range SOFAR Studies in the South Atlantic Ocean"; Walter H Munk, Robert C. Spindel, Arthur Baggeroer, and Theodore G. Birdsall, "The Heard Island Feasibility Test," *The Journal of the Acoustical Society of America* 96 (1994): 2330–2342; D. R. Palmer et al., "Reception at Ascension of the Heard Island feasibility test transmissions," *The Journal of the Acoustical Society of America* 96 (1994): 2432–2440; T. M. Georges, R. Boden, and D. R. Palmer, "Features of the Heard Island Signals Received at Ascension," *The Journal of the Acoustical Society of America* 96 (1994): 2441–2447; Department of Energy, Office of Nonproliferation and National Security, "Hydroacoustic Monitoring System" in *Arms Control and Non-Proliferation Technologies*, (Second Quarter 1994): 22–29, https://fas.org/sgp/othergov/doe/acnt/1994b.pdf.

42. In this case the dispersion refers to the duration of the detected pulses. Even a short duration event, or even an instantaneous event like an explosion, will be spread out in time at the receiver end. Broadly speaking, this is due to rays leaving the source at different angles to the SOFAR axis, thus following slightly different refracted paths to encounter regions (depths) with different velocities, and therefore arriving at the receiver at slightly different times. An ideal signal (i.e., with both source and receiver on the SOFAR axis) would show a slow buildup to a peak amplitude, the latter representing ray paths near the SOFAR axis, typically more numerous as they have suffered the least attenuation (e.g., from bottom reflections), which are the slowest and thus arrive last. Despite having travelled further, steep rays arrive first since they have travelled faster (in the deep and shallow parts of the SOFAR channel). But they have also encountered more obstacles (such as the sea bottom), subsequently suffered greater attenuation and therefore register a smaller amplitude at the receiver. See for example M. J. Sheehy, "SOFAR Propagation."
43. U.S. Department of State, Memorandum to Paul Hare from Robert Martin, "U.S. NRL analysis of data relevant to 22 September 1979 possible nuclear event," 17 June 1980, National Security Archive Electronic Briefing Book 570, posted 8 December 2016, Document #39, http://nsarchive.gwu.edu/nukevault/ebb570-The-22-September-1979-Vela-Satellite-Incident
44. Marshall, Eliot, "Navy Lab Concludes the Vela Saw a Bomb." Kathy DeLucas, "Blast from the Past."
45. Detections at Ascension and Argentia raise the question of whether a signal at the Bermuda MILS facility was detected. In hand-written notes accompanying a letter to the NRL Director Berman, dated 9 June 1980, an arrival time was predicted for Bermuda (Tudor Hill) of about 03:23 GMT. The author of the notes, which are rough calculations of the time and place of possible arrivals from a source at 00:53:00 at the Prince Edward and Marion Islands, cannot be established. The Bermuda possibility was based on a great circle path from the presumed source, about 13,500 km. Only declassification of the NRL report could answer the Bermuda detection question, and if no, then why. The path does intersect several bathymetric features, crossing orthogonally the Richardson Seamount, the ridge connecting the Schmidt-Ott and Erica Seamounts, a particularly complex part of the western Walvis Ridge comprising three prongs of a fork-like structure, and the Mid Atlantic Ridge itself. See Letter from L. H. Ruhnke to Director Berman, U.S. Government Memorandum, 9 June 1980, Document #SA01064, National Security Archive at The George Washington University.
46. It would be interesting to know if the reflected and direct arrivals at Ascension were detected on the same three hydrophones, and/or whether the direct arrivals had sufficient SNR to provide a bearing and travel path range. Only declassification of the NRL report could address this question.

47. Considering only the reflected signal at Ascension, the approximately 10,000 km path suggests that a source could also be placed to the west of the reflection point, instead of to the east and the PE&M group. A single signal could not differentiate between the two scenarios and may be the reason why in NRLRD-80, "the vicinity of Clarence Island" is mentioned as a possible source region. This is perhaps also one reason why the Palmer Peninsula (more commonly known as the Antarctic Peninsula) was mentioned as a possible source region in one article (see Phillip J. Klass, "Clandestine Nuclear Test Doubted," *Aviation Week and Space Technology* (11 August 1980): 67–72.) Clarence Island is the easternmost of the South Shetland islands, which follow the coastline of the Antarctic Peninsula at a separation of approximately 120 km. However, a reflected path from Clarence to the East Scotia Ridge to Ascension would be little more than 7,000 km, inconsistent with the length estimate from the signal duration. The reflection would instead have to be from Antarctica itself, probably the Ronne Ice Shelf in the Weddell Sea, to remain consistent with the observed bearing of 198 $\pm$10 degrees. Clarence Island lies along a bearing from Ascension of around 201 degrees, well within the uncertainty bounds given in NRLRD-80, but the length of such a direct path is only about 6,750 km. A 10,000-km path along a bearing of 198 degrees from Ascension that passes through the Antarctic continent itself is impossible. A bearing of around 204 degrees for 10,000 km takes the path through the Drake Passage (between Cape Horn and the South Shetland Islands) and into the southern Pacific Ocean at 64.5 S and 121.5 W. But there are no islands charted there, or within 10 degrees or more. Also, any such source would be unlikely to produce a signal at Argentia without travelling a long path, which would likely require more than one reflection (e.g., bouncing off Africa then South America). Instead it would likely produce a signal at one or more of the several Integrated Undersea Surveillance System facilities along the west coast of the United States. Finally, neither Clarence Island nor any part of the Palmer Peninsula or the Ronne Ice Shelf could provide a direct path to the Argentia SOSUS array, and it is also difficult to see how a reflected signal could arrive at Argentia without making multiple reflections. In summary, for detections to be recorded at both Ascension and Argentia, direct and/or reflected, demands a source east of any Antarctic reflection point, with the PE&M vicinity providing the best overall consistency with the data.
48. Another possible reflection point, also part of the Scotia Ridge and at a bearing of almost 198 degrees, would be South Georgia Island. The longer distance implies an explosion at 00:47:00 UTC, which is still close to the time of the Vela flash. This region has recently been suggested to be a suitable reflection point for hydroacoustic signals following the probable explosion of the Argentine submarine on 15 November 2017 and analysis released on the CTBTO web site. Following a reflection at either point, the signal's path to Ascension would essentially be unimpeded. Unfortunately, either reflection point would be inconsistent with the Argentia signal being reflected from the same region, as it would be blocked by the easternmost South American continent (i.e., Brazil). Assuming a great circle path, a direct arrival at Argentia from PE&M is also problematic as the signal would encounter several bathymetric features acting to block and/or scatter it. In order of increasing distance from PE&M these include the continental margin of the African land mass near the Cape of Good Hope, the Walvis Ridge with many seamounts rising to within a kilometer or so of the surface (i.e., likely intersecting the SOFAR axis), and again the African continental margin off its westernmost part. Some geodesic paths, which account for the ellipticity of the Earth, and/or laterally refracted paths, may not be as adversely affected and it is feasible a weak direct arrival could be observed at Argentia. Otherwise the Argentia signal would have to be reflected from a different point near Antarctica than the Ascension signal, a clue which is given in the handwritten notes accompanying a letter to the NRLRD dated 9 June 1980. A travel distance of 24.7 degrees is given between PE&M and Antarctica. The point in Antarctica corresponding to such a distance is at 69.00 S and

15.75 E respectively. The path from there to Argentia could then feasibly produce the detected arrival, implied to have been at 03:59:00 UTC in the notes, though it would pass very close to the continental margin of South America at its most eastern point in Brazil. See Letter from L. H. Ruhnke to Alan Berman, Document #SA01064.

49. J. Northrop, and M. F. Morrison, "Underwater Sound Signals from Some Atmospheric Explosions," *The Journal of the Acoustical Society of America* 49 part 2 (1971): 1682–1683.
50. International Atomic Energy Agency, "The Radiological Situation at the Atolls of Mururoa and Fangataufa: Main Report," STI/PUB/1028, Vienna, 1998.
51. Leonard Weiss, "Flash from the past: Why an apparent Israeli nuclear test in 1979 matters today"; Leonard Weiss, "The Vela Event of 1979"; Leonard Weiss, "The 1979 South Atlantic Flash"; L. Weiss, "The South Atlantic Flash: The Case for an Israeli Nuclear Test," *The Spokesman Journal* 123 (2014): 25–42; Leonard Weiss, "Israel's 1979 Nuclear Test and the U.S. Cover-Up"; Marshall, Eliot, "Navy Lab Concludes the Vela Saw a Bomb."
52. Memorandum to Paul Hare from Robert Martin. The precise origin of the quote is unknown. Martin relays it from Jack Varona at the DIA and is preceded by the words "thought by NRL to be."
53. Leonard Weiss, "Israel's 1979 Nuclear Test and the U.S. Cover-Up"; Memorandum to Paul Hare from Robert Martin; Executive Office of the President, OSTP, J. P. Ruina et al., "Ad Hoc Panel Report on the September 22 Event," (17 July 1980), http://fas.org/rlg/800717-vela.pdf; "Ad Hoc Panel Report on the September 22 Event," (23 May 1980), http://nsarchive.gwu.edu/NSAEBB/NSAEBB190./
54. C. de Groot-Hedlin, "Estimation of the Rupture Length and Velocity of the Great Sumatra Earthquake of Dec 26, 2004 using Hydroacoustic Signals," *Geophysical Research Letters* 32 (2005): L11303; Z. M. Upton, J. Jay Pulli, Brian Myhre, and David Blau, "A Reflected Energy Prediction Model for Long-range Hydroacoustic Reflection in the ceans," *The Journal of the Acoustical Society of America* 119 (2006): 153–160.
55. Note also that the CTBT IMS uses hydrophone triplets.
56. D. E. Weston, and P. B. Rowlands, "Guided Acoustic Waves in the Ocean," *Reports on Progress in Physics* 42 (1979): 347–387; A. C. Kibblewhite and R. N. Denham, "Hydroacoustic Signals from the CHASE V Explosion," *The Journal of the Acoustical Society of America* 45 (1969): 944–956; Bryan, et al., "Long-Range SOFAR Studies in the South Atlantic Ocean."
57. J. Northrop, and M. F. Morrison, "Underwater Sound Signals from Some Atmospheric Explosions"; A. R. Milne, "Comparison of Spectra of an Earthquake T-phase with Similar Signals from Nuclear Explosions," *Bulletin of the Seismological Society of America* 49 (1959): 317–329.
58. J. Talandier, and E. A. Okal, "Identification Criteria for Sources of T Waves Recorded in French Polynesia," *Pure and Applied Geophysics* 158 (2001): 567–603.
59. M. K. Prior, R. Chapman, and A. Newhall, "The Long-range Detection of an Accidental Underwater Explosion."
60. J. Northrop, and M. F. Morrison, "Underwater Sound Signals from Some Atmospheric Explosions"; A. R. Milne, "Comparison of spectra of an earthquake T-phase with similar signals from nuclear explosions."
61. Marshall, Eliot, "Navy Lab Concludes the Vela Saw a Bomb."
62. It must be remembered that the "information cut-off date" for the Ruina Panel's report was 3 April 1980, the date of their final meeting, at which time the NRL had not completed its analysis (its report was submitted on 30 June 1980, almost 3 months later). Even so, the fact that the NRLRD felt compelled to write this letter (NRLRD-80) in December 1980, after meeting the Panel earlier that month, suggests that the Panel was not swayed from their original position.

63. Assuming a spherical Earth, a great circle is the shortest distance between two points. But the Earth is not perfectly spherical, but rather has a minor amount of ellipticity and is slightly flattened at the poles. Corrections for this provide geodesic paths as the shortest path between two points. The difference may only be a few kilometers over the entire path length, but nearer the poles the two paths increasingly diverge and so a real geodesic path may encounter different oceanographic conditions (e.g., sound speed, bathymetry) than would be suggested by a great circle path assumption. Lateral refraction, due to a horizontal rather than vertical gradient in the sound speed, or even by islands or seamounts, may also alter the path from a great circle or geodesic, and detailed calculations must be performed to reliably associate a received signal with a source, e.g., ensuring consistency of calculated and observed arrival times assuming (or given) a shot time and location. See W.H. Munk, and F. Zachariasen, "Refraction of Sound by Islands and Seamounts." *Journal of Atmospheric and Oceanic Technology* 8 (1991): 554–574; W. H. Munk, W. C. O'Reilly, and J. L. Reid, "Australia-Bermuda Sound Transmission Experiment."
64. Although the Argentia signal is stated to be a reflected rather than direct arrival in the 17 June 1980 Martin to Hare memorandum, allowance is made here for this to be a misstatement. As explained in a previous note, if Argentia did receive a reflected signal it could not have been reflected from the same point (Scotia Ridge) as the Ascension Island signal. It would have been blocked by the eastern point of Brazil.
65. John Northrop, and J. G. Colborn, "SOFAR Channel Axial Sound Speed and Depth in the Atlantic Ocean," *Journal of Geophysical Research* 79 (1974): 5633–5641.
66. Marshall, Eliot, "Navy Lab Concludes the Vela Saw a Bomb."
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slides http://noiselab.ucsd.edu/view/intro2hydro.pdf. A hydroacoustic signal is shown on slide 44 (of 92) as a time series in several frequency bands, said to be from an atmospheric nuclear explosion. No details are provided, e.g., if it is real data or a model calculation, nuclear or chemical, height of burst, depth of water. But it does show a short duration and low frequency content.

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83. J. Northrop, and M. F. Morrison, "Underwater Sound Signals from Some Atmospheric Explosions"; It is presumed here that the "critical angle" is analogous to that of Snell's Law in geometric optics. For a wave to be transmitted from one medium to another, each with different acoustic velocities (optical refractive indices), the angle of incidence of the ray

(measured from the interface between the two media) must be greater than some critical value for there to be transmission into the second medium. Otherwise total reflection occurs. For the two U.S. barge explosions, in "Comparison of Spectra of an Earthquake T-phase with similar Signals from Nuclear Explosions," Milne concludes the tests were conducted either on land or in a land-locked area, which is obviously incorrect for the first option and not strictly true for the second.

84. Calculations have shown that where the ocean bottom is sloping downwards steep ray paths can indeed be converted to horizontal ones, and when the SOFAR channel is traversed the acoustic energy can be trapped and propagated to long distance. This may occur tens of kilometers from the atoll itself, as such "mismatches" of the "receiver-to-calculated-source-distance" (or travel time) versus the "receiver-to-ground-truth-source-distance" are common. Notably, such a sloping bottom does exist around the Pacific nuclear testing atolls, which are thought to essentially be the tip of extinct volcanoes rising from the surrounding 4000 m deep-sea bed. Marvin A Wetovsky and Jody Benson, "Hydroacoustic Propagation and Reflection Loss Using Explosions Found in the Indian Ocean," 707–716; M. K. Prior, O. Meless, P. Bittner, and H. Sugioka, "Long-range Detection and Location of Shallow Underwater Explosions"; International Atomic Energy Agency, "The Radiological Situation at the Atolls of Mururoa and Fangataufa: Main Report."
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89. J. Northrop, and J. G. Colborn, "SOFAR Channel Axial Sound Speed and Depth in the Atlantic Ocean" *Journal of Geophysical Research* 79 (1974): 5633–5641.
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91. The signal duration over a 6,600-km propagation path was in the range of 4–38 seconds for the grid of models calculated, extremely close to the 8–32 second range implied in NRLRD-80 for the putative Vela signal. However, the models did not include SOFAR propagation, which according to the author's "crude" estimates would increase the durations to 33–55 seconds. They conclude that "20 to 60 seconds seems reasonable for a range of about 6,600 kilometers."

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104. https://www.timeanddate.com/sun/south-africa/marion-island-prince-edward-islands?month=9&year=1979; An interesting observation was made by NRL Director Berman in an interview (*Spying on the Bomb*, 309), stating that experimenters preferred to test just before sunrise to allow the blast to be observed against a dark background and for sampling aircraft to take off in daylight shortly thereafter, presumably to be able to see the debris cloud. Sunrise on 22 September 1979 was around 06:19:00, such that Alert 747 occurred when the sun was still 25 degrees below the horizon and 44 minutes before astronomical twilight (when the sun is 18 degrees below the horizon). Thus, the timing of the test was likely not related to diagnostic aircraft sampling, and more to do with making it almost impossible for the staff to notice the explosion or its aftereffects (e.g., the mushroom cloud, which would presumably have sufficiently dispersed and/or merged with the storm clouds to make it indistinguishable). Note that this is different than the statement in Richelson's *Spying on the Bomb*, where it is claimed that Alert 747 occurred 10 minutes before sunrise.