The Development of Over-the-Horizon Radar in Australia

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This monograph contains the personal views of the author. These views should not be construed as the official position of the Defence Science and Technology Organisation.

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Preface

The development of over-the-horizon radar (OTHR) in Australia is so closely tied to the word JINDALEE in the minds of most people that one might imagine that the history of DSTO's Project JINDALEE, spanning the years 1975 to 1985, is the total history of OTHR in Australia. Not so.

Whilst JINDALEE saw the development of OTHR technology and the commissioning and trialling of two experimental OTHR systems, the history extends in both directions outside the decade in which Project JINDALEE was running.

In this monograph, I seek to set out the story of OTHR in Australia from its origins in ionospheric soundings in the 1950s to the present. Necessarily much of the story is that of JINDALEE but, fascinating though this is, the earlier work which laid the basis for DSTO's enormously successful project is equally interesting. For it is a record of work which advanced with little official support or recognition and which required the force of several major personalities to keep up its momentum.

OTHR has been and continues to be an important and high-profile area of DSTO research. It is very apt that, in the Bicentennial year, a record of Australian OTHR research should be published. It is the hope of this monograph that the record might prove to be not just a history of events which made up the story of the development of OTHR but also convey something of the flavour of defence research in this country.

2. Why Over-The-Horizon Radar?

Over-the-horizon radar technology has grown out of a number of related technologies and, before embarking on the history in more detail, it is appropriate to establish the basis of how OTHR operates and what advances were required to make it feasible.

All radar operates by transmitting radio frequency energy to a distant "target" which scatters the energy. Part of the scattered energy returns in the direction from which it came. By comparing the returned energy with that sent out, and in particular by measuring the time taken for the energy to go and return, the target range can be determined. The direction of the target corresponds to the radar's direction of look, so both direction and range are determined. Hence the acronym RADAR, RAdio Detection And Ranging. Radio frequency energy, like light, travels in a straight line in free space so the distance over which a radar is effective is limited by obstacles and, in particular, by the bulge of the earth. Raising the height of a radar, as for an optical instrument or observer, allows you to see further around the bulge—the distance to the horizon is increased—but it is a square root relationship. Doubling the horizon distance calls for a quadrupling of radar height.

As an alternative to increasing the radar height, use of ionospheric reflection to bounce radar signals well beyond the horizon is an obvious and attractive proposition for long range radar detection. A shell of ionisation called the ionosphere surrounds the earth in a number of more-or-less distinct layers at heights between 70 and 350km. It has been known for many years that these layers affect radio frequency transmissions and that for a range of frequencies the ionosphere has the effect of bending back radio transmissions as if by reflection. Thus, the ionosphere is, crudely, a mirror in the sky for the frequency band for which it is effective. So-called shortwave communication has since the earliest days of radio used these reflective properties—signals are bounced between the ionosphere and the earth's surface a number of times to communicate between points on the surface which can be on opposite sides of the globe. It is hardly surprising that radar workers should also contemplate the ionosphere as an aid to greatly increased range and to seek ways of implementing radar in the high frequency (shortwave) band to capitalise on ionospheric reflection.

3. Early Work Outside Australia

For reasons quite unrelated to ionospheric considerations, the earliest radars operational on a large scale used the high frequency (HF) band.

It has been conventional wisdom in British accounts of the history of radar that Watson-Watt and Wilkins of the Radio Department of the British National Physical Laboratory may be credited with the first demonstration of radar. In February 1935 they carried out a basic experiment that demonstrated aircraft detection and later that year measured the range to an aircraft. A recent history points to earlier British work (ref. 2): following short-range tests Butement and Pollard proposed to the British War Office in 1931 a coastal defence radar system. The seed fell on barren ground in 1931. But by 1935 the looming prospect of war resulted in a very different reception for the report of the results of the Watson-Watt/Wilkins experiment. Implementation of British coastal defence radars on a large scale became a priority. The point of this discussion into the pre-war history of radar is not to make or support claims as to who actually "invented" radar—very clearly parallel developments occurred in a number of countries—but to highlight two significant points in the record of UK radar development. One is the name Butement: he reappears as the Chief Scientist within Australia's Department of Supply in the early 1950s when the first Australian steps along the path to OTHR were being taken. The second point is the frequency adopted by the first British radars: it was in the same band as is currently used for OTHR.

The highest frequency at which then-current technology allowed substantial power to be generated was about 30MHz, the top end of the HF band. UK radar development proceeded rapidly from 1935 so that by 1937 the first operational (HF) radars of the Chain Home series were demonstrated. They were in place at the outbreak of World War II and played a decisive role in the air defence of Britain during the War. Wartime radar development quickly moved on to shorter wavelengths as devices were developed to allow generation and control of the power, but the Chain Home radars remained in service, as originally installed. The Chain Home radars, operating between 25 to 30MHz, on occasions indicated returns from extreme ranges, due to ionospheric reflection beyond the horizon. But they were intended as line-of-sight radars and long-range returns from the distant ground via an ionospheric reflection were generally only a source of confusion. During the War some attempts were made to use the ionospherically propagated signal for long range detections of convoys but no success was achieved (or could be expected) and tests were dropped.

Following World War II, US workers at the US Naval Research Laboratory experimented in HF radar with ionospheric propagation in mind. They recognised that, for such a radar to be useful, discrimination of targets against the inevitable ground return—clutter—must be provided through signal processing. Target movement against the stationary background allows separation of target and ground returns on the basis of the Doppler effect. Christian Doppler first analysed this effect in 1842. A moving source or scatterer of waves, be they acoustic or electromagnetic, causes a received signal to vary in frequency depending on the motion of the source or scatterer. The rise in the apparent note of a vehicle horn as it approaches and the fall as it recedes is the acoustic analogue of the effect used for radar discrimination of moving targets. But for the Doppler technique to be applicable to ionospheric radar, the ionosphere must be stable enough not to confuse small frequency-shifted signal returns. Thus, research into ionospheric stability was an essential step in the development of OTHR and is the point at which the Australian story can be taken up. However, the US work at the Naval Research Laboratory needs to be noted: through the late 1950s then classified work proceeded to demonstrate ionospheric stability and, towards the end of 1961, resulted in the first OTHR detections of air targets.

Australian workers were later to have access to much of this and subsequent US work on OTHR, allowing Australian OTHR research to advance much more rapidly than would otherwise have been the case. But we are getting ahead of the story.

4. Early Australian Work

By the early 1950s in Australia, the then Electronics Research Division (ERD) of the Department of Supply and Development's Long Range Weapons Base Establishment at Salisbury, SA, had a small program of research aimed at determining the stability of the ionosphere with an eye to OTHR. The practical aspects of the project were the responsibility of George Carter and involved the monitoring of HF transmissions on three frequencies between Salisbury and Melbourne. At the Melbourne end, at the Defence Standards Laboratory, Maribyrnong, Stan Lott and John Farrands were involved.

John Farrands later became Chief Defence Scientist during the turbulent years of "selling" JINDALEE to the Australian Services. George Carter subsequently built a large HF pulse transmitter out of disposal parts and a complex of rhombic antennas in support of ionospheric probing experiments. Bob Edgar (ref. 3), who was a member of Carter's team, recalls the transmitter as a 'lethal contraption', but it appears that all workers lived to tell the tale (ref. 3).

John Clegg joined the Salisbury establishment in 1952 and began studying the concepts of ionospheric radar. He developed receiving equipment which would complement Carter's transmitter to produce a very basic OTHR. He mounted a series of experiments in detection of aircraft by ionospheric radar at ranges which appeared to be extravagantly large for the time—up to 800km. Results were uniformly disappointing. Clegg calculated that his system was deficient by a factor of about 1000 in sensitivity and conducted further experiments in which the aircraft return was synthetically augmented by this factor by use of a transponder carried aboard the aircraft. He was able to detect the augmented returns and thereby vindicate his calculations.

Interestingly, John Strath, who figures so large in later developments, was at this stage (1953) otherwise engaged in ERD but was asked by one of Clegg's people to check the calculations predicting a 1000-fold shortfall in sensitivity. This was the first time his attention was drawn to the possibility of OTHR. Making up the factor of 1000 in the radar design so that aircraft could be detected when they were not so obliging as to provide what amounted to a beacon signal return was not so easy. Clegg's proposals to construct pulse transmitters even more powerful than the "lethal contraption" and array antennas of dimensions approaching those to be used by JINDALEE twenty years later were clearly unlikely to be supported at the time. So the work lapsed in about 1955.

With the benefit of hindsight it is interesting to speculate as to why these experiments failed to produce better results. Certainly the average power from the pulse transmitter was not large. And undoubtedly a major factor was the relative unsophistication of the signal generation and the receiver, which relied exclusively on analogue processing techniques. Advances in both areas were required before the real potential of OTHR could be realised and these advances relied on a digital approach to signal generation and processing. Advances in digital computing were a prerequisite for further progress and it was still very early days in the digital revolution. John Farrands, reflecting later on the reasons for failure at this time, felt "it was an attempt to repeat the success of (microwave) radar without any significant changes having taken place in HF technology" (ref. 4). New wine in old wineskins?

Interestingly, the US Naval Research Laboratory work on OTHR at about the same time had isolated the computing requirement as the major problem area and had pushed ahead a dedicated processor design. This involved a "magnetic drum integrator". As Headrick and Skolnik of the US Naval Research Laboratory have subsequently remarked "The (digital) signal processor has been the key element in the success achieved with OTHR" (ref. 5).

5. Experiments Using Vertical Launch Rocket Firings

With no promise of success in OTHR aircraft detection, attention had shifted, by 1958, to detection of rather larger targets. At that time the Joint UK–Australia program of Black Knight firings was in progress, aimed at studying the physics of reentering bodies. UK authorities suggested that opportunity might be taken to carry out some measurements on the "radar echoing area of rocket flames" as a study separate from the reentry measurements. George Carter in due course set up a vertical-looking HF antenna at Woomera, operating at about 6MHz, to observe the radar echo from the Black Knight firings. He was in place for the Black Knight Number 3 firing and directed his pulse HF radar towards it as it was launched in its near-vertical trajectory. He discovered, to his surprise, a bloom or large enhancement in the radar echo as the rocket left the earth's atmosphere. The result was so unexpected and the implications for ICBM launch detection so significant that Deputy Director, Weapons Research and Development, Don Woods, and Department of Supply Chief Scientist Butement called for a committee to be set up to review critically the results and oversee further experiments. The contribution of senior management in this way, calling for a concerted effort on the parts of scientists and experimentalists, is easy to overlook in an account of this sort. John Farrands makes the point that Butement's enthusiastic call for further investigation of surprising results was typical of his support for imaginative concepts. Butement ensured that a real note of urgency appeared in his call for a committee to investigate and report.

The committee was to be led by John Strath and comprised George Carter, Graham Bird (who subsequently became Professor of Aeronautical Engineering in the University of Sydney) and Bob Edgar. (Bob had left the OTHR scene several years before and joined with John Strath in unrelated but equally-interesting work including the monitoring of UK Monte Bello and Maralinga nuclear explosions. But that is another story.) The committee's terms of reference were to study the Black Knight No 3 results, examine possible explanations and propose more comprehensive measurements during future firings in a planned sequence. John Strath's initial tasking was for his committee to present its findings and recommendations to senior management within 10 days! John Strath (ref. 6) recalls the misgivings he had in view of his total lack of experience to that time in OTHR and ionospheric physics. A red herring helped not at all: the favoured interpretation of the time was that there was a hitherto undiscovered layer in the ionosphere responsible for the radar reflection bloom. There were uncharitable suggestions that various senior officers of the Department might claim discovery of this layer and attach their name to it for posterity. Such hopes of enduring fame were dashed, however—it transpired that, through an ambiguity in reporting radar range, both the height and size of the disturbance caused by the missile had been wrongly reported and a new ionospheric layer could not be responsible for the observed behaviour. The actual mechanism was not deduced within 10 days—indeed it took several years to achieve some understanding of what was involved. Further measurements were carried out by Carter and theoretical deliberations continued in parallel.

In neither endeavour was it plain sailing. Results were certainly obtained but the interpretation of them was difficult on account of the rather crude fixed-frequency pulse radar employed. By mid-1959 John Strath and Bob Edgar were pressing for improved instrumentation through development of a Doppler radar using continuous wave transmission. The subject of Doppler will recur in this account: the radar proposed by Strath and Edgar was to radiate a continuous wave whose characteristics when received after scattering would give an accurate measure of the velocity of the target which would supplement the optical position fix.

Clearly the limited resources available could not support parallel ionospheric radar approaches—one by Carter and one by Strath—so in mid-1959 the two efforts were coalesced with John Strath in charge. The Group was given the title "Special Projects" in accordance with the high degree of secrecy then surrounding the work and its potential application. Subsequently it changed its title to the more representative "Ionospheric Physics" Group.

John Strath travelled to the UK in early 1960. He reported to UK authorities on measurements carried out to that time and theories advanced to explain the radar echo enhancement. UK workers had theories of their own and also access to some rather anecdotal evidence of similar HF radar effects noted during US rocket firings. The outcome of the discussions, in which competing hypotheses were examined critically, was a degree of agreement that the bloom in radar echo was probably established by gas escaping from the missile, launching a wave disturbance in the ionosphere. To test this hypothesis Strath proposed release of a known quantity of gas from the Black Knight vehicle, as well as simultaneous observation of the disturbance from sites displaced from the launch point. To support this further work proposed by Strath, as part of the Joint Program, the UK shipped to Australia a low-power Cossor pulse ionosonde sounder. The intent was for the Australians to augment the sounder output by feeding its output into a following high power amplifier.

The program of work proposed by Strath was an ambitious one. To measure the rocket echo phenomenon with greater certainty he proposed not only introducing a continuous wave (CW) radar but setting up a number of additional receiving sites which would, by triangulation, provide for an accurate position fix. It would also reveal the asymmetry expected if the favoured hypothesis were correct. In the event, his plans were deemed to be too expansive and he was instructed to undertake a very much cut-down program involving multiple receiving sites. The arguments over the scope of the work and who would pay for what occupied most of 1960 and into 1961, during which time Strath’s staff spent most of their time working on equipment development and collecting data as best they could while he carried on alone with data reduction and analysis of measurements made on further Black Knight firings.

The key to OTHR, as has been noted, was the ability to use Doppler to separate radar returns, caused by moving targets, from returns caused by the stationary background. The development of continuous wave Doppler radars was aimed at allowing experimentation in Doppler measurements and by June 1960 the experimental equipment was sufficiently developed to allow the first Doppler trial. The "bistatic" (separated transmitter and receiver) continuous wave radar was set up at Salisbury and a passing Comet aircraft provided a target of opportunity. The Doppler record was, in Bob Edgar’s words "magnificent". The skills being exercised in equipment development were slowly but surely establishing the base which would be required to implement an OTHR, where processing of the Doppler returns is so central.

The bulk of the experimental HF radar work, however, centred around pulse radar measurements on the Woomera rocket firings, where the increased radar return as rockets penetrated the ionosphere continued to be studied. Bob Edgar’s developmental work with continuous wave radar, aiming at aircraft OTHR detection, was in the background—the emphasis was on the rocket experiments with their implications for ICBM launch monitoring. The equipment used for the pulse radar work was considerably improved in 1962 when work was completed on marrying the UK-supplied Cossor low-power pulse ionosonde (designed for low power sounding of the ionosphere) to a 1kW wide band amplifier which allowed a quite healthy signal to be transmitted. The amplifier was built at Weapons Research Establishment (WRE) under contract by Hawker Siddeley.

One of their technicians, Angus Massie, was thereby introduced to Australia’s fledgling OTHR research community. Angus subsequently left Hawker Siddeley to join the OTHR team. His technical expertise was a continuing asset throughout the course of OTHR work from that point. Another addition to the team at this stage was Bruce Francis; Bruce developed an impressive 45m tall antenna to be driven by the high power transmitter.

The Group’s experimental data-gathering activity was intense in the early 1960s, "riding the buffers"* as John Strath called it, of the Joint Project firings.

*A reviewer has expressed puzzlement over this phrase. At one time all railway carriages, including passenger carriages, had a pair of "buffers" at each end to absorb the shock of collision between carriages. "Riding the buffers" was a dangerous but effective means of railway transport if one did not wish to pay the fare required to enter the carriage.

There was little official support for the multiple site triangulation plan but the work was carried on despite this. Strath’s team set up various radar receiving sites over widely-spaced geographical areas to monitor firings. Hands and feet were in exceedingly short supply and the various observation sites, at Salisbury, Port Wakefield, Woomera, Oodnadatta, were frequently manned by only one person, who had to tend the whole range of equipment as well as make very exacting measurements during the brief period of the firing. With equipment ranging from a diesel generator to developmental electronics there was no room for narrow specialisation. John Strath, although Group Leader and carrying the responsibility for data analysis and reduction, nevertheless regularly found himself as an operator of equipment in a remote location.

At this point we need to discuss a major area of technical difficulty which OTHR workers had to overcome. For a continuous wave radar, the transmitter and receiver need to be separated. You cannot receive faint echoes at the same location from which you are transmitting a high power signal. A receiver separated from the transmitter needs some way of knowing what was transmitted so that comparisons can be made with signals returned. If the separation is not too large (as in the case of the 1960 Comet aircraft experiment), a sample of the transmitted signal can simply be provided over a cable link to the receiver. But if, as was now being planned, receiver and transmitter were to be separated by up to hundreds of kilometres, another approach was required. This approach was, obviously enough, to provide an autonomous signal source at the receiver which accurately reproduced the signal transmitted at the remote transmitter. The problem was that, up until the early 1960s, signal sources were simply not good enough: the stability of sources was such that the ionospheric and Doppler effects being studied would be lost in the random drift and fluctuations between the signals from two sources.

In 1962 Rhode and Schwartz released their first synthesised signal sources, promising hitherto unattainable levels of stability. Bob Edgar and John Strath were quick to act and, before the year was out, a pair of the new sources had been purchased. A true bistatic continuous wave radar was built, using the new sources, and deployed in time for the October 1963 Black Knight No 11 firing. John Strath’s Ionospheric Physics Group had quite an armoury of equipment in use at the time of the firing: as well as the recently constructed continuous wave radar, they ran a vertical ionospheric sounder, two fixed frequency pulse radars and receivers located 40km north and south of the point at which the rocket would leave the atmosphere.

It would have been surprising if the US had not been engaged in similar work on rocket/ionospheric interactions and such proved to be the case. Indeed, it has been reported that the US did field a system for monitoring launches, designated program 440-L, using forward scatter from ionospheric disturbances, which was decommissioned in the mid 1970s (ref. 7,8). The experiments with which Strath's Group had been engaged were supported by the UK–Australian Joint Program but there were also some tenuous US links with the program. A more substantial US involvement was to emerge towards the end of the 1960s. However, as early as 1961, some Australian–US comparing of notes was going on and, under the auspices of the three-country (US/UK/Australia) Sparta program of reentry physics, there was scope for this to happen in a more formal manner.

6. Experiments With Longer Range Vehicles

With the running down of the Black Knight program about 1964, European Launcher Development Organisation (ELDO) firings of the former Blue Streak missile were planned for Woomera. This missile was to have an intermediate-range ballistic trajectory, rather than the essentially up-and-down Black Knight trajectory. Blue Streak thus presented the opportunity for wide ranging deployment of the continuous wave radar, to carry out both forward and backscatter experiments including an extended ionospheric path—experiments much more representative of OTHR as we currently understand it. Bob Edgar proposed to conduct a forward and back scatter experiment over a long path—Talgarno, WA, to Salisbury, SA—to coincide with the launching of an ELDO vehicle in 1965. Talgarno was up to that time a control point for the Woomera Range but, by the time the Edgar team arrived to reconnoitre in September 1964, it was being decommissioned and dismantled. It offered no particular advantage over sites closer to facilities so Bob decided to use Broome as his transmit site and the Mowanjum mission property south of Derby airport as a receiver site. The radar equipment developed for the work was duly despatched from Salisbury and set up at the two sites in the northwest corner of the continent. Other equipment was at St Kilda, near Salisbury SA, and at Giles Meteorology Station, WA. It was experimentation on a grand scale as far as distance was concerned, but with very few people: at St Kilda Bruce Francis and Malcolm Golley operated the equipment, Angus Massie and Mick Michael were at Broome, and Bob Edgar was at Derby. Some team members spent up to 3 months at such remote localities during the preparation and conduct of the trial, working long hours under appalling conditions. Bob Edgar recalls 14 hour days, 7 days a week and the difficulties of keeping fuel up to and servicing the diesel generators at Broome and Derby. As luck would have it, the ELDO firing date required preparations during the north-western wet season and rain and mud were constant companions as equipment, antennas and support equipment were readied and tested.

Came the day of the ELDO firing—March 1965. As is often the case when very extended preparations are made for a "great event", the event assumed less significance, in retrospect, than the preparations. The HF radar operations were judged a qualified success, with a great deal of data recorded but, disappointingly, no backscatter results from the Broome–Derby set up. Despite this disappointment, the long pre-trial testing and monitoring returned data that was of more significant import. With the benefit of the stable signal sources, it was possible to assess the phase stability of the ionospheric path between St Kilda and Derby. Stability was excellent. This is another key factor on which OTHR relies—if a stable ionospheric reflection could not be obtained, one could forget about aircraft detection by Doppler processing of OTHR signals. The ionosphere appeared to be sufficiently stable and repeated measurements were carried out over the next few months. Bob Edgar's belief in the potential of OTHR for aircraft detection was reinforced but he had to convince John Strath. The convincing came in December 1965 when both Bob Edgar and John Strath travelled to Derby to record signals transmitted from St Kilda and compare them with locally-generated signals. They fed the signals to be compared to an oscilloscope and viewed the resulting plot, known as a Lissajous figure. This is a sensitive test of phase stability—lack of stability shows itself in a rapid rotation of the figure or a complete break-up. The figure rotated very slowly—figure 1 shows an actual display, reconstructed from tape-recorded signals made at that time. John Strath was convinced, and another piece of the OTHR jigsaw slotted into place, though at this stage John Strath could not see how serious development of such a radar for aircraft detection could possible be undertaken while still travelling on the buffers without a ticket!

The 1965 firing proved to be the last successful firing to the north-west (apart from a Black Arrow firing in 1970 which was monitored with pulse equipment at Giles). So the continuous wave radar equipment lay idle in the north-west until its withdrawal in 1968. Meanwhile, the SPARTA series of near-vertical firings was under way at Woomera and, in the absence of the more sophisticated equipment, the Group was hard pressed to maintain continuous wave radar monitoring. Nevertheless, enough equipment was lashed together, some of it Angus Massie's personal "ham" gear, and observations continued through the period of SPARTA firings.

It is interesting to note that the ionospheric disturbance effects which were the basis of so much effort by the Australian team proved ultimately to be somewhat of a byway in the story of OTHR. As has been noted, a US system was reported as having been fielded for missile launch monitoring (program 440L) but used for only a relatively short time before being decommissioned in favour of more reliable launch monitoring technologies (ref. 8). What was of enduring value in the Australian effort was the experience gained in actually fielding and carrying out ionospheric radar measurements. This not only created the nucleus of a base of skill and experience which subsequently could be built on but also established credibility. It turned out that, before significant further development of indigenous OTHR technology could proceed, there was a need for exposure to related work in the US. This exposure would never had occurred had not it been clear that Australia had some maturity in the field.

7. The US Connection

Since 1965 Australia has been involved in a program of defence technology cooperation known as The Technical Cooperation Program (TTCP). Other participants include the US, UK, Canada and, since 1970, New Zealand. The program is organised via Subgroups along technology lines. One early Subgroup, long since disbanded, was Subgroup F, having responsibility for ballistic missile studies. John Strath was nominated as the Australian representative.

At this stage, during the late 1960s, Strath was also responsible for the analysis in Australia of the reentry data derived from the Joint US–Australia DAZZLE and SPARTA trials. These trials were quite unrelated to the ionospheric radar work of Strath and his Group. Strath could not fail to notice and be impressed by the strong support accorded the DAZZLE and SPARTA reentry work in Australia, which contrasted sharply with the indifference or even hostility which seemed the official attitude towards the ionospheric observations. Riding the buffers would never see OTHR attacked purposefully, Strath reasoned; a joint OTHR program with the US would perhaps allow him in off the buffers and encourage some real support. With this end in view, he resolved to attempt to stimulate some US interest by revealing some of the Australian missile work to US researchers. Even if it failed to stimulate a US response, it seemed there was nothing to lose. Subgroup F provided an opportunity.

At a TTCP Subgroup F meeting in September 1968, John Strath presented a paper "Radar Cross Section Enhancement of a Ballistic Vehicle at Mid Course in the F-layer of the Ionosphere" in which Australian work in modelling the observed effects was reported. The report stimulated considerable discussion. After the Subgroup F meeting, Strath visited contacts at the US Advanced Research Projects Agency (ARPA) and somewhat tentatively suggested that the US may care to cooperate in an aircraft detection program. To his immense surprise the suggestion was enthusiastically supported. A formal request from Australia would be required to initiate such a program, but the US was keen to cooperate. In view of Australia’s obvious interest and proven competence in pursuing the technology, the US proposed that aspects of then-classified US OTHR work should be made available to Australia. Strath appeared to have the response he sought. The immediate hurdle he then had to overcome, on his return to Australia, was to convince the Chief Defence Scientist, Arthur Wills, to agree to pursuing the idea of a cooperative US–Australia R&D program. The agreement came quite quickly.

But even before any agreement was reached, the US had made a most significant contribution. They had confirmed with John Strath that OTHR had indeed been trialled by the US and that detection of aircraft at long range had been achieved. The "prophets in their own country" in Australia, pushing OTHR as an air surveillance approach, were thereby vindicated and the Australian Department of Defence began to take much more notice. John Strath produced a series of "Information Papers on an Australian Early Warning Ionospheric Radar System" during 1969 which caught the eye of many key Australian Defence planners. At the request of the Department of Air, a presentation on the subject of OTHR for air defence was made by John Strath in March 1969 and subsequently Chief Defence Scientist Arthur Wills met with US officials to seek cooperation in OTHR. Further briefings to Australian Departments of Defence, Air, Navy and Supply were made by Strath later that year.

In October 1969 a specialist mission consisting of John Strath, Bob Edgar, Des Lamb and Ralph Cartwright visited the US to meet with US OTHR workers. A key US contact was Al Van Every, OHD* Project Manager in ARPA. ARPA was at that time a major funding agency for OTHR work in the US and the personal friendship which developed between John Strath and Al Van Every was to prove an important adjunct to US–Australia OTHR cooperation as subsequently formalised. The formal cooperative research and development agreement, which was not signed until 1974, was subsequently extended to take it through to 1985. It provided for cooperation between the countries, loan to Australia of some specialist equipment necessary for an Australian OTHR Research Project and Australian access to significant areas of the technology and results which the US had developed over the period of their research in OTHR.

As a result of the 1969 mission to the US, the Australian Department of Defence was convinced that Australia should initiate serious work on OTHR. In July 1970 agreement was secured to commence a period of OTHR studies to define the way ahead. Out of this came a proposal. Future work was conceived as being in three phases. The first phase aimed at defining operational requirements and studying applicable technologies and techniques; the second phase proposed a feasibility study and costed plan for an Australian OTHR and phase 3 was the implementation of the plan. In retrospect, the plan was overly ambitious but the zeal of its proponents was commendable. Although they had a strong background in theoretical and practical ionospheric research, there is no doubt that the difficulty and cost of phases 2 and 3 were only dimly perceived at the time. Indeed, it may be said that phase 2 was not concluded until the end of Project JINDALEE in 1985, 15 years and $40m later, and phase 3, in terms of a network of OTHRs, is now planned for completion by 1997, at a total projected cost of $500m. Nevertheless, to their credit, the authorities saw the potential and phase 1, calling for deployment of some 19 man years effort over a 16 month period, was agreed. At this stage, it is clear, senior Service officers saw only "potential". Later OTHR was to emerge as a threat to Service paradigms, as John Farrands has labelled them, and considerable Service resistance developed. But in 1970 studies by Defence scientists hardly constituted a threat to established Service thinking so the program was agreed.

8. GEEBUNG

Phase 1 of the OTHR studies, which the Minister of Defence approved in November 1970, was designated GEEBUNG. Because of the value of the US connection, and the importance thereby attached to avoiding any exposure which could compromise it, great attention was devoted to security in this stage of Australia's OTHR work. At WRE in Salisbury the "need-to-know" principle was enforced rigorously and access to the US-provided information was restricted to a small and controlled group of workers. This meant that the project was denied the valuable diversity of viewpoint which comes from exposure to a wider group of experts and critics, but the price was considered an inevitable consequence of the need to ensure total safeguarding of the US information. A major declassification of US work was reflected in the 1974 publication of a paper by Headrick and Skolnik (ref. 4) but that, in 1970, was well in the future.

A variety of designations have been used for over the horizon radar. OHD (over-the-horizon detection) was once common but has fallen into disuse. OTHR is by far the most common, sometimes OTH-B where the terminal -B designates "backscatter".

John Strath, promoted in 1969 from his position as Group Leader to Senior Principal Research Scientist, Electronics Division, Applied Physics Wing, led the Project team engaged on GEEBUNG. Bob Edgar had a major role in formulating the proposal for GEEBUNG, laid out the experimental sites and designed and directed the path loss experiment, about which more will be said. This was Bob's last direct involvement in the area of OTHR in Australia; he chose not to join the subsequent JINDALEE work. He went on to other work in very low frequency (VLF) radio navigation and finished up writing a book, begun many years previously, on the mathematical foundations of electromagnetic theory (ref. 10). His contribution to OTHR in Australia was of the greatest significance.

GEEBUNG brought other personalities into the OTHR work, personalities who would bring their own stamp to parts of the work. Malcolm Golley and Fred Earl joined John Strath's team in 1970 and 1971 respectively, having just completed PhDs on Departmental Scholarships. Both Malcolm and Fred had some prior exposure to OTHR work: Malcolm spent almost three years (1963–1966) in John Strath's Ionospheric Physics Group before leaving to pursue PhD studies and Fred was a 1963–64 vacation student in the Group.

Other additions to the team at this time were Bill Mettyear and Bob Greig and they, with John Strath, were to assume a central role in plotting the future course of OTHR in Australia. Bill was a physicist who had spent four years in charge of the Island Lagoon Deep Space Station during a joint US–Australia program. Whilst lacking any experience in ionospheric physics he brought to the GEEBUNG team a broad base of knowledge and experience and an organisational flair. Bob Greig was a sound practical man, energetic and with a keen eye for detail. An earlier stint in Australia's Research and Development Attaché's office in Washington gave him invaluable insights into how the interfaces between US and Australian Defence Research and Development communities were managed. His practical training and experience were put to good use in the planning and execution of what was to be the substantial site works component of JINDALEE.

In Mettyear and Greig, Strath had his management team. The triumvirate persisted as an ad-hoc long-term arrangement within the formal structure of Electronics Division right through to the approval of JINDALEE Stage A in April 1974. To many of the larger team which was assembled over the next few years the triumvirate was too much a closed shop, the cards held too close to the chest, confidentiality over-stressed to the point of pettiness. And yet it worked -solid planning, attention to detail and firm budgetary control became hallmarks of GEEBUNG and JINDALEE under John Strath with his two close advisors.

GEEBUNG called for both studies and experimental work. The studies were further divided into technical updates, for which contributions from many in WRE's Electronics Division would be sought, and operational research to define the role and requirement for OTHR. In those days WRE was in Department of Supply, the Chief Defence Scientist in Defence and the Services each had their own Department. The operational research studies were led by Department of Air, with Department of Supply (Central Studies Establishment) providing input. The experimental work was, of course, the responsibility of Electronics Division of WRE.

Coordination of Defence R&D at that time was vested in a committee chaired by the Chief Defence Scientist, the Defence Research and Development Policy Committee (DRDPC). It included members from Defence, Supply, Army, Navy, Air and Treasury. Securing agreement on any subject across the range of interests reflected by such a breadth of membership was no easy matter.

The DRDPC, in recommending approval for GEEBUNG Phase 1 in July 1970, was cautious in approving commitment of half a million dollars to pursue OTHR studies. They called for a progress report each six months—the first by February 1971. John Strath was on his mettle to see that they got reports which encouraged continuing high level support for the Project.

Bob Dippy, as Superintendent Electronics Division, was John Strath's boss. Bob Dippy, with his retirement not too many years ahead (he retired in 1973), seems to have deliberately stepped back from involving himself in the detail of the work although he supported it and provided substantial resources from his Division. He clearly saw that the future of his Division was very much tied up with OTHR but that it would need to be left to others to pursue over an extended period. Above Dippy was Emlyn Jones, as Deputy Director Applied Physics Wing, and Don Woods, Director WRE. There was generally consistent management support for "Strath's Project" through this line, but that did not always guarantee an untroubled passage of proposals through the corridors of Canberra. Nor was the Salisbury hierarchy unanimous in directing scarce resources to the Project. When John Farrands became Chief Defence Scientist in 1971, he recalls that a major early difficulty he encountered was to convince the Salisbury management to put more effort into the Project.

The technology studies initiated under GEEBUNG called on a diversity of expertise within Electronics Division. Mostly the contributors were called to work on the GEEBUNG studies "part time"—they were selected as experts in relevant technologies and called on to carry out a study without becoming a full-time member of the small GEEBUNG team. There were some exceptions: mention has been made of Malcolm Golley and Fred Earl who contributed as fulltime members and of Bill Mettyear. Bill's contribution to the GEEBUNG studies was system design of HF radars and he recorded his evolving thoughts in a series of papers during GEEBUNG. Stage A of JINDALEE was largely an implementation of the OTHR design developed by Bill Mettyear during the GEEBUNG Studies, influenced by the studies produced by individual specialists participating in GEEBUNG and by advice from US experts.

The use, for the most part, of "contributing experts" to GEEBUNG studies provoked some heat. A project which cuts across management lines in this way runs the risk of stepping on a few toes. Group Leaders within Electronics Division found their staff being committed to tasking over which they had neither responsibility nor control. There were inevitable conflicts about deployment of effort and some huffing end puffing between GEEBUNG management and Group Leaders. But this had minor impact on the rate of progress. A more significant factor was that the technology required for OTHR was in some cases so far removed from the experience of Australian research workers that progress was much more dearly bought than had been anticipated. The flavour of both these difficulties was conveyed in John Strath's July 1971 report to the DRDPC, which read in part, "The progress of the studies has been rather slower than anticipated, in part, it is considered, because of the inherent technical difficulty experienced in coming to terms in the studies with the advanced conceptions; in part, it is suspected, through difficulty in establishing the necessary singleness of purpose in the study groups as required in the face of other conflicting demands on effort."

The operational research studies under Department of Air progressed reasonably well but soon a chicken-and-egg situation emerged. Operational studies depended on access to the results of technical capability studies. But those engaged on the latter felt some justification in seeking answers to questions of the type "what do you want to achieve" before they investigated how well or badly OTHR might deliver against that requirement. Despite such difficulties, with some crosslinking between the operational studies team and the technical studies contributors, the story began to become clear. In May 1971 Bill Mettyear crystallised thinking to that point by issue of a paper defining a "Possible System"—an OTHR system which technical studies indicated could be built to meet a requirement which operational studies indicated existed.

Only passing reference has been made to the experimental side of GEEBUNG and we need now to pick up that thread.

The GEEBUNG measurements proposal involved establishing an ionospheric path between two ground sites and monitoring various parameters of the path over a planned 15-month period. The equipment required was a frequency-modulated continuous wave transmitter and receiver, both of US design, plus communications equipment and antennas, of local design. Siting was a matter of some debate but ultimately sites at Mirikata near Woomera (Transmit) and Broome (Receive) were selected. The equipment was eventually purchased, installed and set to work in December 1971. The major source of delay was the acquisition of equipment, much of it from overseas, and in order to make up some time the program was contracted to 11 months.

The real questions to be addressed during the measurement program related to how well or badly the ionosphere would support OTHR operations in the Australian environment. Some data was available in the form of computer programs which provided a mathematical model of the ionosphere, and the Australian Ionospheric Prediction Service had data of particular Australian relevance. Malcolm Golley took charge of a study of available predictive tools and developed some broad conclusions concerning siting, coverage and operating frequencies. The experimental work was led by both Malcolm Golley and Fred Earl. Malcolm's part involved one-way measurements of both path loss and ionospheric stability. Under Bob Edgar's oversight, Malcolm collected path loss data for 11 months on the 1850km Mirikata–Broome path. The Mirikata transmit site was unattended for three weeks out of four as data were routinely logged but for the fourth week the site was manned and less routine measurements were conducted. Among these measurements were those to determine ionospheric stability and field strengths. The general conclusions of this part of the measurement program were highly favourable to OTHR operations.

Meanwhile, Fred Earl took charge of that part of the experimental program devoted to two-way (backscatter) path evaluation. It was known that signals backscattered from the moving wave structure of the sea would have a particular Doppler characteristic, different from that of land backscatter and one object of the investigation was to assess whether, given the contamination expected from the ionospheric path, the transition between land and sea returns could be determined. The other object was to measure in an absolute sense the backscatter characteristics: as aircraft detection by an OTHR is always in the presence of land or sea backscatter, the surface scattering characteristics are of fundamental importance in design of the system.

Before joining WRE Fred Earl had completed PhD studies at Melbourne University in a field closely related to that in which he now found himself. Indeed, he had put together equipment which the University graciously allowed him to transfer to his new work area. So the Mirikata site was augmented to include an array of Yagi antennas and sounding equipment from Earl’s PhD studies and suitable data recording equipment was developed. As for the Golley work, one week in four was the manning schedule for the Mirikata site. Mutual interference between the one-way and backscatter measurements meant that they had to operate alternately rather than simultaneously but this was not a major difficulty.

The conclusions of the backscatter measurements program were not quite as clear-cut as those of Golley’s one-way propagation measurements. The coastline could frequently be discerned—but not always. And the measurement of surface backscatter coefficients, while it generally confirmed previously reported figures, opened some new questions. All these were grist for the mill in terms of planning the next move in the OTHR program. The experimental sites were decommissioned by the end of 1972. A fitting epitaph to this phase of work appears as the last sentence in an overview report prepared by Bill Mettyear at the conclusion of GEEBUNG: "No evidence has been found to suggest that the operational value of an (OTHR) in Australia would be reduced to an unacceptable level by inherent physical limitations imposed by the ionosphere."

In pursuing a continuous narrative of the experimental work, we have jumped ahead of other events. As noted, Bill Mettyear’s May 1971 paper had provided a technical description for an OTHR which might satisfy emerging operational requirements and which, studies indicated, could be developed with the available technologies. With the benefit of hindsight it seems clear that the next step would have to be some sort of pilot radar constructed in Australia. But this was a by-no-means obvious way forward at the time. Bill Mettyear recollects that he and John Strath came to the view gradually that hands-on experience had to be the next step. The technology was of such complexity and the Australian knowledge base so fragile that a hands-on learning experience was essential. There were also concerns that, notwithstanding the positive experimental results of GEEBUNG, Australian ionospheric conditions were central to any decision to implement operational OTHRs. It would be foolish to assume that US ionospheric conditions would be the same as Australian.

So the concept of an Australian pilot radar was born as an essential component of the broader plan. John Strath wanted to call it the "Workhorse" and internal papers of the time refer to the project by this name. But it never caught on, probably because the project name JINDALEE was soon allocated. Part of the plan included a proposal for a US mission to visit Australia to evaluate the state of local knowledge of OTHR generally and to comment on plans for the Workhorse.

John Strath well-appreciated the fragility of the Australian knowledge base and the almost total lack of OTHR experience at the level required to design an OTHR system. He counselled senior management that a cooperative US–Australia program was vital to the success of Australian OTHR and that without such a cooperative address Australia should not pursue the subject further. Strong words indeed, for a man who had invested so much of himself in OTHR: he advised senior management at the time,

"Should it be impossible to secure (a cooperative program), it is believed that the time scale required to implement a peculiarly Australian Workhorse program would be such as to render its ultimate cost prohibitive as an initial down-payment on a future operational system. Further, the delay so incurred would probably be such as to render this ultimate system obsolete before completion."

The US visit to Australia took place in February 1972. Out of the meeting, working level plans began to firm up as to a cooperative US–Australia program of OTHR research in which the proposed Workhorse radar would be the initial stage. The concept was that, with US assistance through access to results of its programs of OTHR research, Australia should aim to be at a point of self-sufficiency in OTHR within a three-year term. But in the interim, US advice and assistance should be sought in refining plans for the Workhorse radar. Indeed, the plans, such as they existed, were modified to some degree as a result of interactions during the February 1972 meeting.

John Strath and Bill Mettyear were invited to attend a US OTHR meeting later that year at which further details were negotiated concerning the Workhorse proposal. In particular, a three-phase program of OTHR development began to emerge, designated at the time Stages A, B and C, with a progressive escalation in complexity, capability and cost from one stage to the next. The commencement of Stages B and C, escalating in expenditure, was intended to be conditional on attaining the technical objectives of the previous stage so that, in the event of failure to achieve objectives, costs were minimised.

Stage C was to be the basis from which a feasibility study for an operational Australian Defence System could be prepared. The total program was contemplated as running until about mid 1977. Some items of equipment required to address the proposed Australian OTHR program were identified for loan by the US to Australia. In all, it was a particularly useful collaborative planning visit and John Strath and Bill Mettyear returned to Australia to attack with enthusiasm the Development Cost Plan, (DCP) for the proposed work, against which the Australian funds would be sought. The document would also provide the basis for US cooperation. It was to be the JINDALEE Blueprint.

9. JINDALEE—Stage A

So, after a long gestation period JINDALEE was born. Not in a flash of inspiration but as the result of a long series of experimental and theoretical studies, negotiations with authorities in Australia and the US and a good deal of wheeling and dealing. Phase 2 of the OTHR studies conceived in 1970 and now developed to the point of being a Workhorse radar was hereafter to be known as JINDALEE; so said the Department of Supply minute of 19 July 1972 from Alan Sharpe, Controller Research and Development to Director WRE. The minute also noted that JINDALEE means "bare bones". Whilst Alan Sharpe went no further than advising the meaning of the word, John Strath seized on the interpretation "bare bones" to drive home to his troops the need for strict economy in cost. Whilst in retrospect funding of the Project may be considered modest, it was clear to Strath that, by the standards of the day, the sums to be sought were large and paid totally by the Australian tax payer, without the 50% British contribution which applied during the UK–Australian Joint Project. "Bare bones" was to mean that there was no fat for senior management to cut! John Strath's management of the Project was characterised by tight and effective monetary control—the Project was well-named!

The Project had a name, but that was about all. No significant work could proceed until a plan was developed and approved. A pop had to be produced, and produced quickly. A meeting was called on 15 August 1972 of a "Task Force". A three-stage development project along the lines thrashed out in the US was exposed to the group of Electronics Division professionals who would be asked to develop the technical detail of how it might be implemented and at what time and cost. Bill Mettyear was the architect of much of the outline technical proposal as it was then developed. The "Task Force" at that DCP planning meeting was an interesting one; some of the attendees have been identified as "JINDALEE-men" ever since, but at the time OTHR was far from familiar to many of them. John Strath was in the chair, with Bob Greig and Bill Mettyear as the other parties to the Project triumvirate of the time. Around the table were Malcolm Golley, Fred Earl, Reg Phipps, Don Sinnott, Alan Tickner, Bill Rundle and Neil Bryans from Electronics Division; Dick Trenam and John Ellershaw came from outside the Division to provide particular inputs.

Papers were distributed and the rules explained. The meeting broke up and a busy few weeks ensued in which the Task Force members, in many ways quite inexperienced (most were in their twenties), set about trying to estimate for a task projected as running for 6 years over three phases, calling for extensive building and earth works in a remote central Australian location and the integration of technologies on a scale few of them had any concept of. Bill Mettyear was responsible for assembling the technical proposal, pulling together the inputs from Task Force members and US-source information. Cost estimates came, in raw form, from Task Force members and were massaged by Bob Greig who understood rather better than those providing the estimates the complexities of estimating, costing and phasing by financial years. The author was one of those contributing estimates and, as one totally without experience in such work, recalls the chastening experience of seeing his crude estimates of the "man and a half for a day and a half" type turned into departmentally acceptable tables of figures, phased by financial years, under the disciplined pen of Bob Greig. John Strath, of course, provided the "glue" to hold it all together and, he hoped, sell it to senior management. The document was produced and printed within 12 weeks. The total projected cost was $6.4m—a frighteningly large sum at the time.

The pop was duly cleared through Department of Supply Central Office in November 1972. John Strath now began canvassing seriously for staff, aware that the ad hoc team plus "consultants" from a number of discipline-oriented Groups as used in GEEBUNG would not suffice to address the more ambitious JINDALEE program. A team dedicated to the Project was required, although he recognised that there would be a continuing need for "consultants" on specific topics, including the considerable engineering work foreseen. His calls seem to have fallen on somewhat deaf ears as the team was slow in forming—there were competing claims for staff and the Project, whose planning document had been produced so speedily that it was reflected in no forward staff and financial estimates, had a credibility problem in some areas.

Meanwhile, the plan was passed to the US Advanced Research Projects Agency for comment. They generally supported the plan but felt it was overly extended in time. They recommended an accelerated plan, in two phases not three, with some changes in technical planning where US experience indicated the Australian proposals would only re-till old furrows or worse, wander into blind alleys. Bill Mettyear visited the US in April–May of 1973 and followed up points of detail relating to the revisions recommended to the plan. The US–Australia Cooperative Arrangement on OTHR, although not formally agreed until mid 1974, provided for such technical assistance and advice from the US: it also provided for loan of some key items of equipment and during his time in the US Bill Mettyear negotiated tentative arrangements for such loans.

Back in Australia attention turned to identifying sites for the radar. The plan had been developed on the basis of sites near Alice Springs because Alice Springs lay on an international air route (A76) offering a source of targets of opportunity, was sufficiently isolated to be electrically quiet and was logistically supportable. (Giles was considered at one Stage but wisely rejected on the basis of logistics.) The sites were crosses on a survey map—no-one from WRE had ever visited them. In May 1973 this situation was remedied. John Strath and Bob Greig flew to Alice Springs and rented a vehicle. In John Strath's words, it was to be an "unostentatious survey"—there would be no point in alerting locals as to plans for the JINDALEE stations before any sort of formal approval for the Project had been given. They drove to the proposed transmitter site and found that the point selected on the map, 160km from Alice Springs on the road to Harts Range, was indeed a suitable site though at the time located in dense scrub. Closer in to Alice Springs, the site selected for the receiver proved nowhere near as suitable. Although the map showed it as suitably flat country, over the area required for an antenna array there were many creeks and washaways with swampy land on one side. This would not do. So an alternative site was selected—this became the Mt Everard site. John Strath and Bob Greig returned and the long process of land acquisition of the two sites began.

In October 1973 the DRDPC considered the revised pop: a six year program of two stages, to cost $8.5m. 1 January 1974 was the proposed start date. Committees seldom make inspired or heroic decisions and the DRDPC was not about to do so—it made a half decision. Stage A only was agreed, with an "extended hold" between Stages A and B. During this hold, the results of Stage A would be critically reviewed and assessed before agreement was given for Stage B to proceed. More redrafting was done by Strath's people, to come up with a plan for Stage A: 4 years, to cost $3.4m. It was late 1973 before this cleared the DRDPC and, finally, in April 1974 Minister of Defence Lance Barnard was able to announce in a Press Release that he had approved the Australian OTHR Project, JINDALEE. The first of many major JINDALEE paper wars was won!

With the approval of Stage A there were considerable changes to the internal structure of Electronics Division. Bob Dippy retired in 1973 and John Strath became Superintendent in his place. A new Group, JINDALEE Project Group, headed by Bill Mettyear, reflected the increased status of the work, as compared with the ad-hoc arrangements used to that time. There were also physical moves of staff that were not without their drama as John Strath sought—and succeeded—in collocating as much as possible of his growing team under one roof at Salisbury. Bill Mettyear's JINDALEE Project Group was charged with implementation of the Stage A radar design and execution of the experimental program.

The organisational and physical changes at Salisbury were mirrored by changes in perception in Canberra. John Farrands, in reflecting on this period in which he was Chief Defence Scientist, has pointed to Service opposition to OTHR which began to mount in the mid '70s. In a 1986 address to the Australian Academy of Technological Sciences (ref. 8) he remarked that "over-the-horizon radar was bitterly opposed here because it offended at least two Service paradigms". In subsequent correspondence (ref. 3), John Farrands has expanded on this, to include three paradigms which, in his view, accounted for Service resistance to the idea of OTHR:

"All good navies have carriers, all good air forces have airborne early warning and supersonic fighters. All good navies and all good air forces control their own affairs. These are just three of the paradigms I referred to in my talk."

The Canberra paper wars were but dimly perceived by the "workers" at Salisbury, who saw only delays to their plans because of apparently leisurely progressing of approvals in Canberra. But there were very substantial head office battles involved in which various Service points of view and vested interest were traded. The concept of joint operations of all three uniformed Services was a new one in the early 1970s and over-the-horizon radar is, by its nature, a joint operations tool. The paradigms identified by Farrands were at war with the concept of Joint operations. The civilian head office people had a hard row to hoe to secure adequate Service support for OTHR to allow work to continue.

The paper war was significant but an equally significant war was the technical one. It was recognised and planned that some key items of electronic equipment would be developed in Australia. Indeed, one of the objects of the exercise was to develop, independently of the US, some of the technologies underlying OTHR. This was not just to keep the Australian team busy, but to encourage novel approaches in areas where the Americans felt that work to date was deficient. It was also essential to establish an Australian technology base in OTHR. The waveform generator and the signal processor were particular items on which design teams began to work. The signal processor was an adaptation of the Programmable Signal Processor developed initially in the sonar program which led to the Barra system. The processor was developed and integrated under the oversight of Peter Drewer. Neil Bryans took charge of the waveform generator development. This proved to be a particularly challenging task. The search for extreme purity in the generated signals exercised his team to the limit. It is a tribute to the team's skill and persistence that the waveform generator (the Linear Sweep Generator) was not only delivered and used in JINDALEE Stage A but was one of few items of Australian-developed "original equipment" retained into Stage B.

The antenna systems also called for an Australian contribution. The receiving array was modelled closely on a US experimental OTHR system, the Wide Aperture Research Facility at the Stanford Research Institute, but some development and improvements to the design were made by Don Sinnott. He also contributed to decisions as to the siting and spacing of the transmitter antennas, which were provided on loan as part of the US assistance to the project. The transmitter array was to remain throughout Stages A and B (figure 3).

Then came the difficulty of software. Nowadays it is facetiously suggested that to estimate for software one arrives at figures of time and effort by earnest estimating techniques—then multiplies all figures by a digit between 2 and 10. And prepares for an overrun! In 1974 the JINDALEE team had no such rules of thumb and expected no particular difficulty in integrating several minicomputers with purpose-built hardware and standard peripherals. There were indeed difficulties and delays—it all took longer than planned and proved to be more difficult than expected. But steady progress was made through 1974 and 1975.

Cyclone Tracy even conspired to hinder progress. Following the disastrous cyclone damage to Darwin in December 1974, much of the heavy earth-moving equipment in the Northern Territory was required in Darwin, just at the time when earth works were to begin at the Alice Springs sites. Some delay ensued. Then there was the problem of Alice Springs housing. A team of six was intended for location in Alice Springs and John Strath was dismayed to learn that the standard waiting period for a government house in Alice Springs was 22 months. There were some unsuccessful negotiations to try to shorten the waiting period for WRE staff. The delay was eventually terminated by John Strath and Bob Greig visiting Alice Springs and arranging for the lease of private accommodation—much to the dismay of WRE's administration which was obliged to arrange funding in retrospect.

Recruitment of the site team was a difficulty in itself. The expectation of a queue of young scientists and technicians, keen to undertake a challenging stint of development and experimentation at Alice Springs, proved illusory. Young volunteers were not so easy to come by and in the end it was a team marked largely by seniority rather than the flush of youth. Of the six who moved to Alice Springs four, Frank Cleggett, Tom Suttie, Roy Woods and Jack Commander were entering positions which they expected to see them through to retirement within a few years. Such proved to be the case for all four. The other two, David Warren-Smith and Peter Hattam provided a more youthful balance and are still with DSTO's OTHR program.

The relative seniority of the site team was noticed by Sir Arthur Tange, Secretary of Defence, when he visited the site. "What are all those old men doing around here?", John Strath recalls him as asking. Strath's rejoinder, fortunately taken with good grace, was to point out that neither he nor the Secretary, by visiting the site, had reduced the average age.

Frank Cleggett became the Station Director. David Warren-Smith, the other professional officer, was his deputy. Tom Suttie and Roy Woods were the technical complement and Jack Commander the resident officer-in-charge at the remote Harts Range site. It had been recognised early in planning that the sites, once set up, would need to be manned 24 hours a day. At Mt Everard this was done by use of a Duty Officer arrangement whereby one of the team, on a rotation, (occasionally relieved by someone up from Salisbury for a few days) would sleep overnight at the site. At Harts Range this was not practicable so Jack Commander found himself as the sole permanent custodian of a remote facility a 3 hour drive out from Alice Springs. His duties included everything from maintaining the diesel generators to acting as mine-host to the steady stream of visitors coming to install and check out equipment and, later, to conduct experiments.

Jack arranged for provisions, prepared meals for the visitors and generally ran a ship-shape camp. What many would see as a lonely life Jack found much to his liking and, in so doing, made a very significant contribution to the success of the Project.

Not the least of the difficulties in getting the team established was transport to Alice Springs. The team and their families proposed travelling from Adelaide to Alice Springs in January 1976, except for Frank Cleggett who was a commuter for some months more. Some chose to fly but most used the "Ghan", at that time the "Old Ghan" which used the flood-prone narrow gauge line. It happened that January 1976 began a period of wet weather in Central Australia and part of the site team found themselves floodbound in the Ghan for several weeks. Tom Suttie and Roy Woods and their families whiled away 10 days as the rain continued to fall and the train's supplies dwindled. Finally they, and their fellow passengers, had to be lifted out by helicopter to the nearest sizeable (dry) airstrip and continued their trip to Alice Springs by air. It was some months before their baggage caught up with them.

The rain also played havoc with shipments of equipment. Some was on the stranded train, some was in Adelaide awaiting shipment. Air transport for the equipment was a costly option but with time ticking away and the risks of serious Project delay mounting some equipment was shipped by air.

Frank Cleggett moved to Alice Springs in April 1976. His small team had to be adaptable to cope with the high technology equipment arriving from Salisbury, on the one hand, and the realities of installing cable runs to antennas and attending to the housekeeping of the site. David Warren-Smith recalls an occasion when a team from Salisbury had concluded a visit to the receiver site during which major items of electronic equipment had been delivered and partially installed. The site team was to complete the installation and check it out. As soon as the visitors had left, the site team was keen to get to work on the electronics. But Frank Cleggett, as Station Director, had other priorities—first the vinyl-tiled floor had to be cleaned and polished and the evidence of recently-unpacked equipment cleared away. Only when the place was in a satisfactory state of cleanliness could the team get to work on the electronics. This firm attention to detail and priorities was a Cleggett hallmark apparent throughout the conduct of Stage A—without it the small team faced with a daunting task would have been floundering.

Through the first half of 1976, the Project Team at Salisbury laboured with unexpected difficulties. Quite apart from the transport problems early in the year, which disrupted and delayed the planned phased equipment delivery program, there were a number of technical difficulties being encountered in developing some items of equipment. Repeated delays occurred, for which the schedule had to be adjusted. Part of the plan for JINDALEE had been that frequent and close contact would be maintained with US workers through visits of Australian members to the US. But the realities of the Public Service environment were that the Project Manager had no control over overseas travel funds and funds could not be released to cover overseas travel at this point. So there was much correspondence, with Australian workers seeking advice, which was often slow in coming and a poor substitute for face-to-face discussions. As a result, mistakes were made and time was wasted.

By June 1976 the Alice Springs sites, transmitters, antennas, cables and equipment ancillary to the radar were all in a state of readiness, only awaiting arrival of the actual radar receiving equipment and computers. At Salisbury this equipment was going through final checking out.

Over the succeeding few months, the equipment was shipped to Alice Springs and reassembled on site, interfacing with the previously-installed equipment. On many occasions, the equipment developers travelled to the sites to oversee the installation of their equipment but the site team was charged with overall responsibility for equipment integration. In September 1976 the final consignment arrived—the radar was complete.

In stressing the activity at Salisbury and the Alice Springs sites, we have overlooked activity surrounding another site. At Derby, near the point at which Bob Edgar had made his ionospheric stability measurements a decade earlier, a remote beacon site was being established as part of JINDALEE. Although known as the Derby Beacon, designed to re-radiate to the JINDALEE radar a known, target-like signal as a calibration and location aid, the facility established at Derby fulfilled a number of measurement and calibration functions. Warwick Kemp was responsible for developing and commissioning the equipment and installing it, by arrangement, at the Telecom communications compound at Derby. Throughout Stage A Warwick made repeated solo visits to Derby to calibrate and maintain the equipment, which otherwise was unmanned.

The tropical environment of Derby presented some interesting problems. A bushfire went through the compound on one occasion, taking out all the antenna cable runs. Vines grew prolifically, especially when provided with an antenna to act as a trellis: propagation of radio waves through foliage-encrusted antennas was not an area of study planned for JINDALEE. Lightning strikes were frequent and occasionally damaging and field work was hampered by snakes, lizards and heat. One gecko even got a free trip south by stowing away in an equipment box returned to Salisbury. He emerged from the box in a Salisbury laboratory some weeks later, apparently none the worse for his trip.

October 1976. The JINDALEE Stage A radar was turned on. After all the years of development and preparation, it was very fitting that during the checkout phase, to the great satisfaction of those present, an aircraft target was detected. Over the two years that the Stage A equipment was to run, many more targets would be detected and a large amount of environmental data relevant to future OTHR planning would be collected. There were also to be recurring problems and difficulties with equipment which hampered to some extent the orderly collection of a data base of detections and environmental data. Offline replay facilities were part of the plan and these were located back in Electronics Division at Salisbury. Once the radar equipment had been delivered to the site and the bulk of the teething troubles sorted out, effort at Salisbury shifted to off-line analysis of taped radar data, recorded at the Alice Springs receiving site. As results poured in, and were analysed and reported, the attention of senior officers of the Department of Defence was attracted and various experiments were proposed, beyond the routine logging of commercial aircraft detections which was the radar's bread-and-butter tasking. In particular, although it was not part of the plan, and expected to be beyond the capabilities of the Stage A equipment, ship detection trials were run in December 1977. These demonstrated that OTHR detection of ships in the waters off the northwest of Australia was feasible.

John Farrands recalls that, in the corridors of Canberra, many difficulties, some real, most imaginary, were contrived at this stage to explain that JINDALEE would not work, would be easily countered, would prove unreliable and would tee generally unsuited for application to defence. The Service paradigms were alive and well. Farrands needed "convincing demonstrations" more than reports of steady progress with a research project and routine logging of commercial aircraft detections. He was astonished and dismayed to find that his call for convincing demonstrations met with considerable obstruction from Salisbury.

He encountered the researcher with the bit between his teeth, dedicated to the scientific task in hand and impatient with anything which might impede progress. Against great reluctance on the part of some of the JINDALEE researchers, the Chief Defence Scientist had his way and several demonstrations were run for high-ranking officers of the Department.

Not all details of these demonstrations can be discussed openly, to this day. But one in particular can be sketched. In April 1977 John Strath, under some pressure, arranged for a visit to the Stage A receiver site of a high-level delegation, to witness operations in real time. Secretary of Defence Sir Arthur Tange, Chief Defence Scientist John Farrands and Chief of Air Staff Air Marshall James (later Sir James) Rowland travelled to the site and the radar was set to work searching for an aircraft off the north-west coast. The aircraft had been commissioned specifically for the trial—the first time an air movement other than a scheduled commercial flight was to be used as a JINDALEE target. The RAAF navigator of the aircraft had instructions to call for a pre-planned manoeuvre at a specific time and the hope was that the characteristics of the manoeuvre would be apparent to the high-ranking observers at the Alice Springs site. There was an element of risk in exposing the radar operations to such a senior group as the radar had to that time never been used to log other than straight-and-steady commercial aircraft tracks.

After some technical teething troubles, the radar was run up and, by the time the visitors arrived, the aircraft target had been acquired. The aircraft tracked as expected but, at the time appointed for the manoeuvre, no change was noted. There were some furrowed brows. A few minutes later the JINDALEE scientists present heaved a collective sigh of relief as the expected manoeuvre occurred. There had been, it transpired, some confusion over times.

This was the first, one of the simplest, but quite possibly the most important, of very many air trials arranged specifically to evaluate JINDALEE performance. The importance of this trial lay not in the scale of resources employed—in later years, during Stage B, quite large numbers of Service aircraft were marshalled for trials. Rather, the significance of the trial lay in the fact that some of the most senior officers of the Department could witness at first hand the capability of an over-the-horizon radar. John Farrands and George Barlow in Canberra won a couple of influential allies among senior officers as a result of such demonstrations. But the "head office battle" continued. To the researchers engaged in their demanding technical work, such considerations appeared relatively unimportant. Yet even they were forced to concede from time to time that the hardest battle was ever the battle against scepticism and vested interests.

The Stage A program ran through to December 1978, when the radar was closed down as planned. Several months were allowed to formally run down the activities and the records show that February 1979 marked the end date for Stage A. By any measure it was a great success. A small Australian team, with recourse to the US experience and advice, had been able to put together a pilot OTHR with quite a significant capability and to run it over a two year period of data gathering. They had demonstrated that the ionosphere over north-western Australia was suitable for supporting OTHR as a real-time surveillance system and had collected statistics in detections of aircraft which gave every reason for encouragement towards the planned subsequent Stage B and, beyond that, operational radars.

Every success story has known its moments of despair and certainly those close to John Strath in the times of anxious waiting for crucial results recall his ruminations as to whether he had sent "boys to do men's jobs". Yet it did succeed. Bill Mettyear in subsequent correspondence with the author has suggested some key factors which might have been at work.

(a) The plan was modest, devoid of frills, of relatively low risk.

(b) The team was right—skilled and motivated.

(c) The team was small—communications were close and effective.

(d) The working team was largely sheltered from concerns outside the task in hand.

It is interesting to note that some of these key factors working to ensure that Stage A succeeded ran counter to the interests of long-term development of OTHR and its promotion as a viable defence surveillance tool. For example, the low risk approach was costly, in the overall OTHR context in development time and the smallness of the team, with few links into the wider world of engineering and science made for a late entry of industry into OTHR in Australia. And John Farrand's difficulty in prevailing upon the experimental scientist to take time off from his experimenting to demonstrate his toy to the customer has already been noted. Yet if the long-term view had been taken consistently the short-term objective may not have been achieved. It needs to be remembered that failure with JINDALEE Stage A would have been the end of OTHR development in Australia. There can be no doubt that the general thrust was right for the times, taking account of the scepticism accorded defence science in this country: the climate was not, and is not, that which encourages risk taking.

10. JINDALEE—Stage B

The two stages of JINDALEE were not disjointed. As part of the approved Stage A program, a schedule of trade-off studies was planned, to map out and cost the Stage B program and propose it for approval through the Defence Committees. It needs to be recalled that, back in 1973 when the JINDALEE pop was considered by the DRDPC, the cautious decision was to approve Stage A, then have an "extended hold" while the next step—Stage B or nothing—was considered in the light of Stage A experience. But this was not to be. Far from an "extended hold", the Stage B program was to overlap the conclusion of Stage A. For a time there was to be an uncomfortable division of effort between attempting to complete analysis of the hard-won Stage A data and getting on with the design and development of the Stage B equipment. Indeed, to this day the Stage A data has been inadequately analysed.

We need to go back to relatively early days of Stage A to see the genesis of Stage B. The Trade-off Studies Team began to be assembled in the latter half of 1974. Cyril Carson, recently returned from a stint in academia as Associate Professor of Electrical Engineering at Monash University, was the Principal Research Scientist in charge of the small team. In the team were Bob Jarrott, Bren Colegrove, Don Sinnott, Steve Tucker and Stuart Anderson. Their brief: to develop an outline design and costed Task Plan (the terminology had changed by now—"DCP" was passé). The team was set apart from the main Stage A team which was under Bill Mettyear's direction and set about its task.

By the end of April 1975 a good deal of outline technical detail for Stage B had been developed and a US team visited Australia for another OTHR workshop. The intention was for the Stage B outline plans and Stage A results to be exposed to a critical and knowledgeable audience. The US team was a strong one, including government, defence, university and US-industry representatives. In opening the Workshop John Strath promised the visitors a week in which they would "work hard and play hard". Such proved to be the case. Figure 2 includes most of the workshop participants.

As a result of the interaction with the US team, plans firmed in some areas and were re-thought in others. The Trade-Off Studies Team continued with their work and by February 1976 completed a draft technical proposal. This was provided to the US experts for comments. US response to the Stage B technical proposal was favourable and, in the light of successes being achieved by the Stage A equipment during 1976 and 1977, there was some enthusiasm for the Stage B program in Canberra. The Minister concluded that high priority should be accorded to the overall JINDALEE program and all thought of a twelve-month "extended hold" was abandoned.

May 1977 saw another US delegation visit Australia and further fine-tuning of the technical and costing details was made. Cyril Carson and his team completed their task in August 1977 and the Task Plan for JINDALEE Stage B was submitted for consideration by the Defence Committees soon after. John Strath's intention was to complete the Stage A data gathering as planned in November 1977 and press on as soon as possible with Stage B. But too little data and experience had been gathered to satisfy the people in Canberra. All sorts of different, previously unplanned, experiments were now being proposed by senior Defence managers. So Stage A was extended, to run to December 1978, at an additional cost of $2.6m justified by "cost escalations and extension of data collection to include other tasks (eg ships)". This looked like making life difficult for John Strath's small team. How could they run a data collection and analysis exercise calling for expert technical and scientific support whilst at the same time attacking with purposeful vigour the development of a new OTHR of complexity orders of magnitude greater than Stage A?

Worse was to come. The Canberra committees did not want to close down Stage A now they had it operating: how about running it until mid-1980, "without penalty to Stage B"? John Strath argued hard against this and was supported by the Defence R&D Committee which put to Cabinet the submission for Stage B in April 1978. The preferred option put to Cabinet was to conclude Stage A in December 1978. Other options, not recommended, included running the Stage A equipment through to the Stage B turn-on date. Cabinet took the Department’s advice and chose the preferred option. Interestingly, this 1978 Cabinet submission included reference to an ultimate network of up to three radars with appropriate command, control and communications. Almost a decade later this thinking reemerged in Minister Kim Beazley’s October 1986 press release as to plans for a network of OTHRs (ref. 1).

With Stage B approved by Cabinet in May 1978, the official start date became 6 July 1978. This part of the Project was planned to run for 6 years at a total estimated cost of $24.6m. Some long-lead items needed to be ordered before the start date so approval was sought and obtained for such items to be progressed early. These included things like the 200km of coaxial cable to be manufactured to exacting specifications and buried in trenches as part of the early earthworks for Stage B. Clearly, contractual arrangements needed a long lead time if all progress was not to be held up pending the delivery and installation of cables.

In the second half of 1978 the major work got under way. There were some significant organisational problems to be resolved. For one, there were now two distinct groups of workers involved. The "Stage A" group, elated by their success had, as Malcolm Golley has put it, "the runs on the board". The "Stage B" group was seen by the old hands of Stage A as untried, bursting with great ideas which might or might not succeed and liberated from much of the conservatism adopted in Stage A to ensure success. To the Stage B group the "triumphs" of the Stage A group were but stations on the way. Time saw to a blurring of the division, especially once the Stage B newcomers served their own apprenticeship in recording results against difficulties and privations. But it took time.

Stage B was a bigger, a much bigger, project. Planners wearied of hearing "this is how we did it in Stage A" because new ways of managing the larger project were now required. Contractors were to be involved, RAAF was playing a much more central role and a tight, single Group such as ran Stage A, could no longer address the whole range of activities. Two Groups were set up, organised broadly according to the "Transmitter Site" and "Receiver Site" functions. One Group, mostly responsible for "Receiver Site" development was under Bill Mettyear and included most of the Stage A team. The other Group, under Cyril Carson, included most of the Trade-Off Studies team plus some additional recruits to the Project. This second Group, in addition to specifically "Transmitter Site" development, was responsible for research and development into detection and tracking, displays, radar control and signal processing. Bill Mettyear’s Group included a heavy emphasis on frequency management. Some perpetuation of the Stage A/Stage B polarisation was preserved in the membership of the Groups and there was potential for ambiguity of responsibility for some areas of project-wide scope. It is much to the credit of Cyril Carson and Bill Mettyear as leaders of the Groups that the common good prevailed, that the inevitable rivalries which arose from time to time were not permitted to escalate and that not too many problem areas close to the "borders" of Group interests were duplicated or omitted.

Other Groups in the Division (renamed Radar Division, in place of Electronics Division, in July 1978) contributed in their areas of specialisation, including such areas as antennas, digital computing and signal generation. In place of a Project Manager to handle day-to-day management of the project and oversee the matrix of contributing Groups there were set up non-executive Panels. The top level Panel was the Radar Development Panel, chaired by Bill Mettyear. Other Panels, committees and working parties were set up—some official, others ad hoc groupings of necessity. A commentary on how this rule-by-committee was perceived by the workers was a widely circulated set of purported minutes dated 1 April 1980 for a meeting of the "Panel on Panels". In addition to some bitingly accurate caricatures of some of the key players in the project these minutes record some of the frustrations felt by the proliferation of committees. The minutes record that a subcommittee was proposed to investigate whether the decisions of panels should be accepted, that a report was accepted from a subcommittee on the desirability of accepting reports and a good deal of discussion was recorded in the subject of whether the door should be open or closed during Panel business.

Nevertheless, there was a will to make it all work which cut through the apparent tangle of committees. The committees did, however, also cut through some of the boundaries of minor empires and there was some heat generated as a result from time to time. Despite some complaints from line managers about loss of control of their staff there was one great advantage of this mode of working: JINDALEE team members retained their scientific and technological roots. Computer experts remained in the computing specialist Group, antenna experts remained in the antenna specialist Group. Had they been simply pooled as a dedicated Project Team, as the good management books advise, there may have been short-term advantage. But the project has been a long-term one; the technological isolation of the Project Team approach would have left many experts out of touch with advances in their specialisation.

Early in the Stage B program, the question of signal processing demands presented a dilemma. Whereas the Stage A processing load had been handled by a couple of mini-computers, each with an attached in-house-developed high-speed processor, Stage B called for much more powerful computing machinery. The dilemma was build or buy. Commercial mini-computers would be used to control the general data flow, as in Stage A, but the question of a suitable processor to handle the "number-crunching" load had to be resolved. One school of thought held that a suitable processor existed in the US and there were glossy brochures to prove it. The other school held that the brochures were not to be believed and that progress with JINDALEE required that a custom designed processor should be developed in-house. Interestingly, in the event, the favoured "glossy brochure" design was years away from being available and, had the JINDALEE signal processing architecture depended on its availability, a major project crisis would have ensued. John Strath wisely, in the view of the author, opted to support the development of an in-house design, tailored specifically for OTHR. The decision has been unfairly criticised in retrospect because, by the time the processor was complete, other commercial designs were available that probably would have served the purpose. But the point is that these commercial machines were not available at the time the JINDALEE Stage B computing system was designed—the obvious choice, on published specifications, at the time of the design, would never have been available on time. It is also worth noting that the in-house processor, designed ten years ago, is of performance comparable with processors only recently available for OTHR applications. The realisation of such performance was not easy.

It transpired that the in-house design and implementation of the signal processor was a task more challenging than had been realised. Significant delays were incurred which ultimately were held to have delayed the project. Despite this, there is no doubt, at least in the mind of the present author, that the correct decision was made and that the development of the signal processor was an essential step to realising the Stage B radar.

When Peter Drewer, as a coopted attachee to the Trade-Off Studies Team, presented to the 1975 US visiting contingent his proposal for the Stage B Data Handling System, he already had plans for the locally-made processor. Out of these thoughts came the ARO—the ARithmetically Oriented processor. Peter Drewer had a sizeable design team in the work of developing and having constructed ten of these very capable and complex signal processors on which the JINDALEE Stage B data handling system relies. It was an ambitious and wide-ranging exercise, calling for the development of a suitable language and software operating system as well as the processor digital hardware. Initial plans were for the ARO to be available, fully supported, by September 1980. To allow software development to proceed in the absence of the ARO hardware, a software simulator was developed and used to allow software development to proceed and be checked out in the absence of the actual hardware.

From what has been said it must be clear that Stage B was a much more capable radar than was Stage A. Although this is a history not a technical paper it is useful to contrast some of the parameters of the radars of Stages A and B to set in context the change in the scale of difficulty in progressing from one Stage to the next. Stage A had a limited sector of coverage—a few degrees—and was designed as an essentially staring beam, down the commercial aircraft corridor for flights entering Australian airspace from the northwest. By contrast, the Stage B radar had a scanning beam which covered sequentially a sector of at least 60°. So the space surveyed by Stage B was very much larger, calling for much greater computation in real time. Displays approaching those which Service operators would find useful needed to be developed, to replace the limited display capability of Stage A. Sensitivity was increased by use of more powerful transmitters and a larger receive array: whereas the Stage A array was 640m long and comprised 128 simple whip antennas, the Stage B array was 2.8km long, comprising 924 more complex antennas. Figure 4 shows the difference in scale of Stages A and B arrays. The Stage B array remains the longest OTHR antenna known. The so called Frequency Management System, used to advise the radar as to what frequencies it should use to make optimal use of the ionosphere and to avoid interference with other users of the spectrum was expanded greatly to match the increased radar capability. All these capability expansions were reflected in the scale and complexity of the equipment to be assembled and put to work.

A wise decision made early in the project was to minimise, desirably totally remove, manual setting up of the radar and its parameters through switch settings and plugging of cables. The radar was to be, as much as possible, under computer control so that all settings of parameters and connections would be totally reproducible and logged by the computing system, leaving no room for questions of the type, "was that switch up or down when we did that measurement". Although wise in the long term the decision caused pain in the short term because it magnified an already difficult software development task. The software development team grew, forced to recruit to its numbers many whose skills and training lay in other areas. Few would claim to be software experts and calls for recruitment of computer professionals to ease the load on those whose skills were better deployed elsewhere appear to have had no result.

JINDALEE Stage B took longer than expected. The problems and delays ascribable to difficulties in realising the ARO processor were, although the most public, but one aspect of the difficulties encountered. Other technical difficulties contributed their share of delay but, under the cover of the ARO-ascribable delay, had no occasion to be brought to account. Technical difficulties and delays on account of the inherent uncertainty of progress in technologically uncharted areas can be understood—JINDALEE Stage B did, after all, set out to be the most capable OTHR built to that time and the technical difficulties were formidable. Less easy to understand are the non-technical reasons for delay: the project was always understaffed, particularly as regards computer professionals, although the staff requirements were defined in the approved Task Plan, and horrendous delays occurred in letting of contracts. At times it appeared to John Strath that all the pettifogging constraints of the Public Service were arrayed against him to frustrate his plans. By February 1981 program slippage was acute and a major reschedule was submitted to the Canberra authorities, accounting for a 15-month delay.

Nevertheless, work pressed on. Through 1980 and 1981 equipment was reaching a point close to functionality and, after the long haul, it finally began to appear that the equipment would, after all, finally be shipped to Alice Springs, installed and set to work. At the sites, major works and extensions to the existing facilities were going on in parallel with the equipment development. The Stage B transmitting complex, while retaining the antenna used for Stage A, called for much larger buildings to house the more powerful and more numerous transmitters, an expanded power house to meet the increased demands and greater crew accommodation. Four houses were moved from Woomera to the transmitter site and re-established to provide for the accommodation requirements of the permanent transmitter site complement. At the receiver site, the Stage A antenna and facilities were decommissioned and a new start was made, after studies proved that plans to reuse the Stage A facilities would result in added cost. A 3km by 100m strip was cleared for the receiving array, a smaller strip for the Frequency Management array, and the locations for 980 individual antennas were surveyed. At the same time, local Alice Springs contractors were busy with buildings, air conditioning, power reticulation and the myriad of engineering tasks associated with the site works.

The most prominent feature of the JINDALEE receiving site is the array. Visitors are always taken to the array to drink in its proportions. At 2.8km in length (figure 5), it is difficult to be sure, when standing at its centre point, that one can see either end. It is also difficult to believe that a man and his wife set up the whole array in a month. The story is worth repeating.

The erection of the receiver antennas was subcontracted by the manufacturers, Hills, to a rigger, Jim MacMillan. Jim drove up to the Mt Everard receiving site with his caravan, his wife, two small children, a dog and a couple of cats, and set up camp at the Stage A site in August 1980.

It was obvious from the start that he was going to waste no time in erecting the array and he and his wife worked from sun up to sundown each day completing the installation of the 980 array antennas in 32 days, an average of 30 per day.

When two members of Radar Division visited the site in September for acceptance checks on the array, the only fault they could find was that the outer guy rope pegs were not as far into the ground as the specification called for. Without hesitation, Jim set off with a large hammer. There were about 1000 pegs affected and each had to be driven in an additional few centimetres. Up one side of the array and down the other, Jim worked steadily through the day and then, by the light of the moon, through a good deal of the night. By the next day it was done, found acceptable and Jim and family moved on.

During Stage A of the project there had been a single Beacon site at Derby. For Stage B, with its wide arc of coverage, more beacons were required. The main beacon installation was at Darwin within the confines of HMAS Coonawarra and, building on the experience of Stage A, a more capable set of equipment was developed and installed during 1980 and 1981. Warwick Kemp, Angus Massie and John Lane were involved in the work, putting together a set of hardware which provided extensive support to the JINDALEE radar in calibration and frequency management.

Other beacons were designed and located at a number of points in the radar's coverage area. The Derby beacon was retained, though its primary role in Stage A was passed to the Darwin beacon for Stage B. Other secondary beacons, using a solar power supply to allow them to be set up in areas not served by power, were designed to be of low cost and limited life. Three months was the design requirement. Such was the quality of the design that the first two such beacons, installed in September 1983, are still operating.

John Strath retired in September 1981, the day before his 65th birthday. He had no desire to leave, with the culmination of the Stage B development just months away. John's contribution to defence science, and OTHR in particular, was recognised by his 1980 award of the Order of Australia. But the real recognition of the worth of an endeavour must be a personal sense of achievement that may be quite unrelated to public recognition. And John Strath certainly had ample reason to feel satisfied that his work had been worthwhile. In a recent communication to the author, during the preparation of this account, John Strath concluded as follows:

"It was therefore with some regret for a task uncompleted, even after some 15 years of strife, that I completed my service. However, the subsequent success of JINDALEE, exceeding as it does my wildest expectations, has made me realise how fortunate I was to have available the services of such a talented and dedicated team of colleagues—but for these, there would indeed have been no JINDALEE and, for their diverse skills and dedication in transforming this dream to reality, I shall ever be grateful!"

Lester Soden had been involved extensively in planning and technical coordination of JINDALEE since he was promoted to John Strath's position as Senior Principal Research Scientist when John became Superintendent of the Division in 1973. Lester then took over from John Strath as Superintendent of Radar Division in 1981 and, as a result of the retirement of M.S. (Kirk) Kirkpatrick as Chief Superintendent of Electronics Research Laboratory soon after, Henry d'Assumpcao became Lester's boss. These management changes were unsettling factors for the Project, representing a significant loss of corporate memory. Worse was the effect of a protracted delay in filling the position vacated by Lester Soden on his promotion.

By April 1982 another significant project milestone was reached when the final consignment of the so-called "minimum system" was delivered to Alice Springs. Within a month the first aircraft detections using the minimum system Stage B equipment were logged. It was a crude equipment configuration, in some ways little better, at that stage, than the Stage A equipment decommissioned three years earlier. But it logged aircraft detections. That, for the moment, was the important factor. With the project running late, some concrete signs of progress were needed and demonstrated performance, even at a low level, was necessary to satisfy those monitoring the project. The "minimum system" was about half the radar in terms of equipment: it used half the ultimate receive and transmit antennas and employed a subset of the equipment. Over the succeeding months, additional equipment was shipped, installed and checked out, and gradually the radar's operational capabilities built up.

Although the Stage A equipment at Alice Springs had been run by a team from Electronics (Radar) Division the scope of Stage B activities required that a contractor be used. Amalgamated Wireless of Australasia (AWA) was the contractor selected as a result of the tender process. A Radar Division engineer, Peter Oswald was appointed as Station Director and provided with an administrative/technical assistant from the Division. The contractor, charged with "Development, Operation and Maintenance" of the Alice Springs sites, had a staff of around 20. The situation called for some diplomacy on the part of the Station Director as he was totally reliant on contractor staff, under the control of the AWA Senior Engineer, to respond to tasking from the Salisbury-based project management. There was a continuous stream of Salisbury scientific and experimental staff visiting the JINDALEE sites, refining radar performance, and these visitors expected to be supported in their work by on-site contractor personnel. The visitors were keen to work long hours, to get maximum benefit from their week or two on-site, so there were frequent calls for contractor staff to work overtime to support them. This was not always popular and much credit must go to Peter Oswald and AWA Senior Engineers, initially Theo Nysen then Jim Wilcox that harmony generally prevailed.

As well as his role in running the sites and providing oversight of the contractor team Peter Oswald found himself as a public relations man and tour operator. There were always outside visitors—parliamentarians, media, senior defence personnel from Australia and overseas and dignitaries of various categories who found ways of justifying, and having approved, a visit to the JINDALEE sites. Briefings at varying levels of technical content and classification had to be given and frequently hospitality was provided by Peter and his wife Eleanor, at their Alice Springs home. The project always relied on a commitment of its team which went well beyond the strictures of Public Service conditions, whether it be scientists, engineers and support staff working into the small hours in pursuit of system "bugs" or the beyond-the-call-of-duty efforts of the Station Director to ensure that influential visitors to the site left well-satisfied that the project was well-conceived and well managed.

As time passed, other notable milestones were achieved: the detection of ship targets in January 1983, the implementation of automatic aircraft tracking in February 1984. There were results aplenty being accumulated and again it became time for a "convincing demonstration". The Joint Services Evaluation Trials of April 1984 aimed at assessing OTHR performance by trialling JINDALEE against RAAF and RAN targets set up for the trial. For reasons which will be outlined in the next section, further trials were run in the period November 1984 to May 1985 and in July 1986. It may be said in retrospect that JINDALEE had, by mid 1984, substantially achieved its major aim of demonstrating the applicability of OTHR for Australian defence surveillance but there was clear reluctance to embrace OTHR vigorously as a major contributor to long range broad area surveillance.

Bob Greig had retired in July 1983, the second of the Strath-Greig-Mettyear project triumvirate to leave the scene. Bob's role and contribution in areas of planning, costing and facilities were not generally understood—the highly motivated researchers and experimentalists involved in the project had little time or patience with the detail of such matters. Yet his contribution was a vital one and his leaving of the scene created a sizeable hole. Bill Mettyear, having planned early retirement for some time, retired in 1985, completing the passing of the original team which had guided OTHR development in Australia following the early Strath–Edgar work. Bill Mettyear retired as Principal Officer of Jindalee Project Group. His great contribution to the project, unrecognised by further promotion during his JINDALEE career, was recognised by retrospective promotion to Senior Principal Research Scientist; he received back payment and had his retirement pension adjusted accordingly.

DSTO's Project JINDALEE ran until December 1985 but it is appropriate at this point to go back a little to pick up some parallel threads which will tie together the final few years of JINDALEE with what are now agreed plans for the implementation of OTHR in Australia.

11. Towards Operational OTH Radars

It is often said that what DSTO does least well is to ensure that the fruits of its undoubted high quality research and development are taken into production. In the case of OTHR the question of "what happens at the end of JINDALEE" had been considered quite early. The Stage B Task Plan provided for development of a specification for an operational radar late in the task, if the results achieved established the case for operational OTHRs. There was an expectation, though no concrete plans, that, given a specification, some sort of procurement/production would follow if a decision were made to proceed with operational OTHR deployment. The future of the JINDALEE Stage B equipment had also been considered: the Task Plan foreshadowed possible use of the equipment for limited operational and training use.

A more significant effort at defining a way forward in the "life beyond JINDALEE Stage B" was undertaken in response to a September 1979 request from AVM David Evans, then Chief of Air Force Operations. The JINDALEE Monitoring Group, the "Junior" Canberra-based committee overseeing JINDALEE, was asked to indicate likely costs and staffing for an Australian operational OTHR system. The response, prepared after much soul-searching and debate between various Defence agencies, proposed various possible approaches. These included the use of multiple sites and the upgrading of the JINDALEE Stage B radar as a nucleus for future expansion. So was the seed sown that a low-cost, low-risk first step towards operational OTHR deployment would be to somehow "refurbish", "upgrade", "convert"—all three words have been used to convey subtle variations on the theme—the Stage B radar. The result of the process, by whatever name it went, would be a radar which provided at least some degree of operational OTHR capability, as against the deliberately constrained experimental JINDALEE design.

The higher Defence machinery chewed over the options for some time without commitment while Stage B equipment development ground on. By 1982 the notion of a JINDALEE Operational Conversion had gained considerable support and in May and again in November the Force Structure Committee considered a plan for "Refurbishment of Stage B for Operational Use". The Committee was unconvinced, in the absence of significant Stage B data by that time. Whilst supporting the plan, it directed that commitment should be "contained until results from Stage B were sufficient to give confidence that the acquisition of an operational system could be supported". Funds were nevertheless programmed, subject to a decision to proceed when Stage B results were in.

The plan for further OTHR development called for the posting to Radar Division of four service officers to work alongside the project team and plan for what was to become the Conversion of JINDALEE equipment for operational use. During 1982 Squadron Leader Peter Bevan, from the operations side, was first to appear, followed by two officers from the engineering side, Flight Lieutenants Peter Gamgee and Steve Sheedy. The fourth officer never appeared but the three who did were soon in the thick of the Project. (Peter Bevan completed his posting in 1985 and was replaced by Terry Deecke.)

RAAF, under the office of Chief of Air Force Development, had as a priority the preparation of the plan for Conversion of the JINDALEE radar. The plan was a deliberately limited one in which only those changes required to overcome operationally-deficient features of the experimental equipment would be addressed. The design constraints which were accepted as the price of an experimental system would persist. Particular areas which were initially targeted for upgrading included secure communications links, improvements to computing, timing and transmitting systems and augmenting of test equipment holdings.

In time the list grew to include improved and enlarged buildings and provision for housing a significant contingent of service officers in Alice Springs. The aim was to obtain an immediate OTHR capability without extensive further development of the Stage B radar.

To define the detail of the required upgrading in the cases targeted a series of study contracts was issued to a number of firms in 1983. Reports were duly produced and presented to the Salisbury experts. As well as providing answers to questions of detail it was hoped that the studies would stimulate Australian industry to an involvement in OTHR technology which would leave it well placed to respond to tenders for conversion. "Technology transfer" was the aim, but it was not particularly successful. There was little commitment of the companies involved to do more than say, in effect, "give us the money and tell us what you want us to do". Missing was any entrepreneurial flair to foresee the possibility of OTHR becoming big business and warranting a company commitment to embrace the technology, or at least a part of it, and use the opportunity provided to learn from the experience of DSTO.

The studies proceeded through several phases, the later phases being largely a means of keeping some industry involvement going while the Department made up its mind. The Major Equipment Submission for the JINDALEE Conversion, which needed to be approved before the tendering could begin, was submitted to the Department's Force Structure Committee in December 1983. This committee gave approval in principle but insisted on awaiting the outcome of trials before final approval could be given.

There were clearly a number of forces at play, responding to different objectives. The Joint Service Trials in April 1984 were aimed at resolving the Force Structure Committee's reservations. Early trials in the series suffered from equipment unreliability but the latter trials returned results uncoloured by equipment malfunction. Further trials took place, beginning in November 1984, because the Canberra committees remained uncommitted as to whether Conversion was warranted.

Misgivings of a different sort as to the Conversion philosophy had long been held by many of the scientific staff of Radar Division. These staff were familiar with the many compromises inherent in the JINDALEE design, by virtue of its experimental nature, and were critical of any approach which enshrined these compromises in the converted radar. Throughout the industry studies and the departmental wrangling over whether and when the Conversion should go ahead these doubts kept surfacing, sometimes in embarrassing circumstances. The DSTO "party-line" was in support of the Conversion yet there were occasional negative comments made informally by Radar Division staff who saw the much-to-be-preferred way forward a total new design OTHR based on experience with JINDALEE but not constrained by the inbuilt limitations of the present equipment.

It turned out that this thinking was consistent with a new-look approach to OTHR among the senior civilian officers of the Department in Canberra. Starting in mid 1984 the forces questioning whether the Conversion Plan was taking a too conservative line were in the ascendant and led to a high-level review of options for OTHR. As a result of the review, the way ahead for OTHR deployment was changed from the Conversion Plan approach to a plan calling for establishment of a network of new radars, as subsequently announced by the Minister. The upgrade of the JINDALEE radar now assumes an important but secondary role in the plan, providing a testbed for developmental purposes, rather than being a stand-alone defence OTHR of limited capability.

These changes in plans have had their effects on defence planners, potential Service users and the OTHR research community. However, out of this adjustment has come a sense of purpose and direction, with a definite end in view—a network of OTH radars—which was not apparent in the more open-ended Conversion Plan.

As part of the new plan DSTO's Radar Division has split into Microwave Radar and HF Radar Divisions to give effect to a recommendation that a dedicated HF Radar (OTHR) organisation be established to guide the implementation of OTHRs in Australia. Lester Soden retired as Superintendent of the Division in May 1985. Harry Green took up the position, which he currently holds in February 1986. In the intervening period the position had been filled on an acting basis, principally by the author. The author, previously heavily involved in the project as the Senior Principal Research Scientist has now moved to head the Microwave Radar Division and Malcolm Golley is the HF Radar Senior Principal Research Scientist.

There have been a number of other changes in personnel, including recruitments and promotions in recent times in the Division to equip it for its continuing role. The Research Scientist merit promotion scheme, introduced in 1987, recognised the outstanding contribution of a number of Research Scientists in the Division, people who had gone largely unrewarded by promotion despite the spectacular successes of the project to which they had contributed so much. Cyril Carson was promoted to Senior Principal Research Scientist, Fred Earl, Stuart Anderson, Bren Colegrove and Max Lees to Principal Research Scientist.

This paper is a history of OTHR in Australia. The writing of a historical record too close to events is a dangerous enterprise so it is perhaps best to leave the story at this point. Suffice it to say that the present status of OTHR development is well-defined. There is a Canberra-based arm of the Department of Defence, Project Development and Communications Division, seeing to the procurement of the OTHR network over a period of years. The Salisbury-based OTHR research community is required to act as Research and Development authority and to maintain OTHR technology, intended to be used in the new radars, at a current level. Whilst the basic concepts and capabilities have been amply demonstrated in JINDALEE, Stages A and B, there is every reason to expect that the operational OTH radars Australia will deploy in the 1990s will embody new and more highly-developed techniques which will enhance even further the promise to date of OTHR.

12. The 'Cast'

In writing this account it has been impossible not to mention names of many of the players. It also has been impossible to do this in a perfectly even-handed way. There are many people who have made very significant contributions to JINDALEE who have not been mentioned and, conversely, a number who are mentioned in historical context whose contribution may be considered a minor one by comparison.

Whilst it is not the purpose of this account to constitute an "honour roll", nevertheless there are some names which do not appear in the narrative and which ought to appear in some sense because of substantial contributions made.

In addition to those names which appear in the narrative, the following have been significant members of the "cast".

Gordon Brimble played a major role in development of software for both Stages A and B of JINDALEE. Bob Blesing has been with the project since early days, as has Alan Forbes; both have made major contributions. Bruce Ward has been a major force in the frequency management area; Peter Roberts has brought a mature engineering outlook to the major equipment areas he has overseen and Morrie Stevens' long involvement in software development and integration has been of great significance. Others who have escaped mention despite heavy involvement in the project are Doug Priest and Leigh McKenzie, who marshalled major drawing office effort, Gavin Perry (custom computing equipment and software) and the AWA officer in charge of the Stage B transmit site, Geoff Williams. Mal McKinnon, Don Aistrope and Lynn Potter provided essential clerical support over a long period. June Smith has been Secretary and Personal Assistant to successive Superintendents of Electronics and Radar Divisions, beginning with John Strath in 1976.

In reality it is impossible to draw a line which says one person's contribution to the work is significant, another's is less so. Before his retirement as Chief Defence Scientist Tom Fink proposed sending a letter to all JINDALEE people who had had significant involvement, commending them on the success achieved. The list of addressees proved impossible to contain so in the end it became an open letter to all in (then) Radar Division. The same difficulty enters here, compounded by the fact that the "cast" is still growing! JINDALEE has been and continues to be a team effort and to those who have participated in it the sense of having been part of the team is worth infinitely more than passing reference to their names in a record of events.

13. Acknowledgements and a Personal Postscript

I have, in the text and list of references and notes, acknowledged my major sources, formal and informal. In addition, I have greatly appreciated comment provided on various versions of the text by past and present members of the former Radar Division (now High Frequency Radar Division) who have been closely involved in JINDALEE. Malcolm Golley, Fred Earl, Cyril Carson, Lester Soden, Bill Mettyear, Bob Jarrott, Warwick Kemp, Neil Bryans, Peter Drewer and Peter Oswald have assisted in this way.

In putting together this record, I am very much aware not only of my limitations as a researcher of history but also of the fact that a degree of subjectivity is inevitable. Project JINDALEE has been a major slice of my professional career. My experience of it spans a period from a time when I was very aware of the nuts and bolts but little of the policy through a time when I had little contact with the nuts and bolts but a great deal with the technical level policy, to the present when I have close contact with neither policy nor practice. I have had scant personal involvement with the deliberations of Canberra committees and have had to rely largely on written records for details. Inevitably there is likely to be some non-uniformity of treatment on account of my selective experience, despite the information and advice provided by those whose assistance I acknowledge.

It is impossible to write a totally objective account of events past. I have been chastened to find significant differences in matters of emphasis which a number of my sources reveal and have come to conclude that questions as to the "right" interpretation of events are essentially unanswerable. I can only confess that I have tried as best I can to balance conflicting interpretations where I have no personal knowledge, to temper my own interpretations in the light of those whose judgement I respect, yet, where appropriate, to set out my own conclusions despite the fact that I recognise the existence of differing points of view.

The writing of this account has occurred over the space of some months, in the interstices of my time, a few minutes and occasionally hours at a time. It has been written in the knowledge that, given more adequate opportunity and a more adequate chronicler, a more satisfactory result would be achieved. However, of greater importance than the detailed record of events are the lessons to be learned. It would be nice to imagine that lessons from the JINDALEE experience, positive and negative, might provide guidance for future project planning in Defence Science. Nice, but unlikely in general. In defence science, as in most avenues of life, we are generally at one with Henry Ford, "history is more or less bunk", and will do our best to reinvent the wheel and repeat the same mistakes.

About the Author

Donald Hugh (Don) Sinnott is a graduate of Melbourne University (BE in Electrical Engineering, 1966; M Eng Sc, 1967) and Syracuse University, New York, USA (PhD, 1972). He has been active in research in areas of applied electromagnetics, including radio frequency devices and antennas.

His work in the antenna area led to his becoming involved at an early stage in the JINDALEE Project; John Strath sought his involvement in 1972 when the Development Cost Plan for the Project was being drafted and Don contributed to planning and estimating at this stage. As the Project proceeded Don contributed as a consultant on antenna matters, without becoming a member of the designated Project team, until 1974 when he was seconded full-time to the Trade Off Studies Team of the Project to assist in the planning and design of the JINDALEE Stage B configuration.

Promoted to Senior Research Scientist (1975) and Principal Research Scientist heading Radio Group (1979) he became responsible for the design and implementation of the JINDALEE receiving antenna array and beam forming systems, as well as advising on other antenna and radio systems matters.

In 1983 Don was promoted to the position of Senior Principal Research Scientist in Radar Division and became much more involved in policy and planning matters for both the JINDALEE Project and for Research in the field of radar in general. Following the retirement in 1985 of Lester Soden as Radar Division Superintendent and JINDALEE Project Manager Don acted in the position for over six months until the present incumbent, Harry Green, took up the position in February 1986. Since October 1987 Don has been Chief of the newly-formed Microwave Radar Division.

References

1 Press release, October 1986.

2 Swords, S.S., "Technical History of the Beginning of Radar", Peter Perigrinus, 1986.

3 I am indebted to Bob Edgar for a large amount of written recollections and anecdotal material dating from this and subsequent periods.

4 I acknowledge a warm response from John Farrands in providing background from his early involvement in ionospheric sounding between Melbourne and Adelaide and subsequent years as Chief Defence Scientist (1971–77).

5 Headrick, J.M. and Skolnik, M.J., "Over the Horizon Radar in the HF Band". Proc IEEE, Vol 6, No 2, June 1974, pp 664 to 673.

6 John Strath has also been a great source of background information in compiling this history. His response to my requests for detail is acknowledged gratefully.

7 Klass, P.C., "HF Radar Detects Soviet ICBMs". Aviation Week and Space Technology, 6 December 1971 (cites US Congressional testimony relating to 440-L program, "expected to achieve official operational status by fiscal 1973").

8 Jane's Weapon Systems, 1976, p 249

9 Australian Academy of Technological Sciences, "Defence Science and Technology—A National Resource", Proceedings of the Tenth Invitational Symposium, Adelaide, 30 to 31 October 1986, pp 23–30.

10 Edgar, R.S., "Field Analysis and Potential Theory". Defence Science and Technology Organisation, Electronics Research Laboratory, Special Document ERL-0340-SD, June 1985