14

COLD WAR SPACES

Big Science and 'Big Science'

'Big Science' has been a favourite category for historians of twentieth-century science. However, a useful and informative distinction should be made between the phenomenon of Big Science as an emerging style of organization and the labelling of 'Big Science' as something of concern. Although precedents can be found in earlier decades, even centuries, Big Science, qua style of organization, captures aspects of large scientific and technological projects of the Second World War and, especially, Cold War periods. 'Big Science', qua label, was a product of the period of transition of the long 1960s (a period that is the subject of chapter 17). The relationship between 'Big Science' and Big Science is one between text and context.

A basic model of the phenomenon of Big Science as a style of organization is captured by the five 'M's: money, manpower, machines, media and military.[1] The 'M's were often interlinked: the machines were expensive, as were the staffing costs to run them; in the Cold War, military patronage was a major, even dominant, source of this money, and once the scale of expenditure on science became comparable to other projects in the public eye then public justification and image management became essential. So, taking the Manhattan Project as an example, it was a case of Big Science according to this simple model because it cost a lot of money ($2.2 billion), involved tens of thousands of staff, centred around large machines (the calutrons, the reactors, the bomb assemblies), required management of its public representations (both through restricting public knowledge and through coverage of its results, such as John Hershey's *Hiroshima* of 1945), and was a thoroughly military project.

The five 'M' model works particularly well as a description of post-war physical science projects in the United States: the space science sites, such as the Jet Propulsion Laboratory at Caltech, or the particle accelerator laboratories, such as Brookhaven or the Stanford Linear Accelerator (SLAC). It is a less satisfactory checklist as soon as the focus is widened. So, for example, the post-war European nuclear science project of CERN is certainly an entity one would want to label as Big Science: the huge teams of researchers working with large and expensive particle accelerators have received plenty of media coverage, but there is no explicit military interest (apart from the 'standing reserve' argument that it keeps employed physicists with skills of potential military application). Likewise, as we shall see in later chapters, many life science projects of the second half of the twentieth century were big enough to warrant the title Big Science but did not revolve around single, expensive installations of machinery. Historians James Capshew and Karen Rader therefore make the useful distinction between sciences that are big in scale (such as those that are organized around centralized large single instruments) and those that are big in scope (such as scientific exploration, which need not be).[2]

However, the five 'M' model of Big Science is merely a useful checklist and does not tell us much about its distinctive organizational features. There are four. First, Big Science is goal-oriented science. No huge sum of money could be dedicated without a mission, without outcomes that could be articulated and measured. The very success of the Manhattan Project as an organized, mission-oriented project encouraged the view that it was a model for other scientific and technological projects. Second, the expense of Big Science leads to a concentration of resources, resulting in turn in a decreased number of leading research centres based around special facilities. In the nineteenth century, many nations had astronomical observatories that were broadly competitive. By the first half of the twentieth century, the trend towards expensive, wide-aperture reflecting telescopes meant that Mount Wilson (and later Mount Palomar) undoubtedly had the edge. Likewise, in post-war particle physics, the discoveries (and prizes) have generally gone to the teams working with the highest energies. Europe and Japan have struggled to compete with the facilities available in the United States.

As numbers of staff have increased and as the instrumentation has become more complex, so there has been an increased need for specialized expertise and for the work of such experts to be coordinated in an efficient manner. Therefore, third, Big Science was marked by a fine division of labour, hierarchically organized into groups, with group (and higher) managers. There has been a division, within the scientific and technical staff, into specialisms. A particle accelerator laboratory such as Brookhaven or CERN had distinct teams of theoreticians, instrument builders, experimenters, and so on. Getting these groups to work together – even to understand each other's subculture – was one of the greatest problems confronting the leaders and administrators of Big Science projects. Historian Peter Galison argues, for example, that, in order to work together, each subculture had to find ways of translating each other's specialized language at the points (often specific sites) where they met, like traders devising creole languages.[3] The trend towards fine division of labour could also be reinforced by the trend towards militarization, since both favoured the compartmentalization of work and knowledge, albeit for different reasons.

Finally, a high political significance was attached to mission-oriented expensive projects – to national health, military power, industrial potential or national prestige – although the proposed contribution varied. Along with political significance came media management. In the Cold War the political significance was, unsurprisingly, the extent to which the scientific or technological achievement could be presented as a triumph of a form of society. The very fact that the Cold War was not (except by proxy in Korea, Vietnam, Afghanistan, Nicaragua – the list, of course, is a long one) a fighting war but a war of symbols means that state resources were channelled into Big Science above and beyond the level of investment justified by the direct contribution of science to the building of weapons and defences. Space science largely falls under this analysis.

Science education

The political importance of Big Science in the Cold War ensured that there existed funds and the political will to expand scientific and technological education in the post-war years. In countries such as Britain, universities were encouraged to broaden their application pools. New universities were established. In other countries the pattern was similar. In the United States, the GI bill brought many into higher education, often from social and ethnic backgrounds that would have hindered entry before the war. There was, writes historian David Hollinger, an 'ethnoreligious transformation of the academy by Jews', although he considers the Cold War mobilization of talent only partly responsible.[4] The effects reached down to science education at secondary-school level. In the United States, the philosophy of science education inherited from John Dewey was transformed in the 1950s, in the hands of leaders such as Joseph Schwab, into a call for inculcation into the methods and knowledge content specific to disciplines. 'To speak of using scientific methods outside of a disciplinary context was', for Schwab, writes historian John Rudolph, 'to no longer speak of science at all.'[5] The system mass-produced scientists, conversant within a discipline, reluctant to speak outside a discipline; knowledge was compartmentalized at an early age.

Security

The military character of post-war Big Science meant that administrators felt they had to enforce secrecy in the name of national security. Compartmentalization was largely accepted as a wartime measure among the Manhattan Project scientists, although characters such as Richard Feynman delighted in playing jokes that revealed some the absurdities of restricting knowledge.[6] Secrecy in arcane knowledge was certainly not new in the twentieth century.[7] Indeed, in the last century, restricting knowledge, such as that found in double-blind trials or in the anonymization of peer review, was made central to what was regarded as good scientific procedure. Scientists in practice can practise secrecy to protect ongoing research from competitors, hide bad results or trade secrets, or, in common with other creative pursuits, keep a project under wraps until complete.[8] But the negative consequences of secrecy also became a matter of concern and discussion from the middle of the twentieth century. Even someone of the stature and position of Lee DuBridge, president of Caltech, presidential advisor to Eisenhower and Nixon, might warn in 1949 of the consequences of military patronage of Big Science in the Cold War:

> When science is allowed to exist merely from the crumbs that fall from the table of a weapon development program then science is headed into the stifling atmosphere of 'mobilized secrecy' and it is surely doomed – even though the crumbs themselves should provide more than adequate nourishment.[9]

Complicated systems of classification were established to label and manage the secret knowledge generated by Cold War science. The quantities of information are staggering: the closed world of secret documents dwarfs the open world of our great libraries, a picture that remains accurate despite a temporary lifting of the veil at the end of the Cold War.[10] Peter Galison argues that this security blanket ends up stifling science, limiting innovation and wasting money and even leads to weakened rather than strengthened security.

Science and Western values

In this Cold War context it became essential to make explicit the nature and virtues of good science, and to demonstrate that it thrived within certain societies – 'free' or socialist – and not others. We have seen, in chapter 9, the argument that science was congruent with Soviet state philosophy. Symmetrically, we can now examine a liberal democratic variant. The start of this phase can be found in the middle of the Second World War. For example, in 1941 at the Royal Institution in London, between air raids, Richard Gregory, editor of *Nature* and president of the British Association for the Advancement of Science, announced seven Principles of 'scientific fellowship', which made clear that science thrived under conditions of intellectual freedom and independence.[11] Science's values were being made explicit because it was part of the fight against fascism. Before there was a threat, there had not been the need to state explicitly what needed protecting. But the view from 1941 was a transitional view, partly pointing towards the autonomy of a science community and partly looking back at pre-war (and indeed wartime) debates about the necessity to plan science for the 'progressive needs of humanity'.

In the Cold War, the need to make science's values explicit remained, but the form the expression took changed subtly, but crucially, with the times. The best exemplar is the 'norms' of science written out by sociologist of science Robert K. Merton. They are:

> Universalism . . . truth-claims whatever their source, are to be subjected to pre-established impersonal criteria: consonant with observation and with previously confirmed knowledge. The acceptance of rejection of claims . . . is not to depend on the personal or social attributes of their protagonist; his race, nationality, religion, class, and personal qualities are as such irrelevant . . .
>
> Communism . . . The substantive findings of science are a product of social collaboration and are assigned to the community . . .
>
> Disinterestedness . . . [and]
>
> Organized Skepticism . . . Science which asks questions of fact, including potentialities, concerning every aspect of nature and society may

> come into conflict with other attitudes toward these data which may have been crystallized and ritualized by other institutions. The scientific investigator does not preserve the cleavage between the sacred and the profane, between that which requires uncritical respect and that which can be objectively analyzed.[12]

The first version of Merton's norm paper, published in 1942 in a journal article with the title 'Science and technology in a democratic order', was written as a defence of democracy against fascism.[13] In the Cold War, a similar but even more pressing demand was made to present science as an institution that could thrive only in a free Western society (despite the major patron being the state in the form of the defence funding bodies). Merton's Cold War versions of the paper included lengthy footnotes that detailed Soviet breaches of the norms. ('Communism' was sometimes rendered as 'Communalism'.) Merton's 'norms' thus showed how and why science would thrive in free, democratic societies and suffer in totalitarian societies, previously Nazi Germany and now Soviet Russia.

Nevertheless, some ethical expectations of science had changed. A comparison between Richard Gregory's principles of scientific fellowship and Merton's norms reveals a crucial shift: Merton's norms are descriptions of internal values, not external obligations. There was no talk of 'progressive needs'; rather, according to Merton, science would thrive in a liberal state by being allowed its freedom and autonomy and by policing itself. 'As the autonomy of science from external influences and demands was increasingly urged and defended . . . it became all the more important that the moral qualities for which science was ostensibly a vehicle be seen as intrinsic to science', argues David Hollinger, taking the long view of Merton's norms; 'if certain approved imperatives were understood to be endemic to the very enterprise of science, society could rest more comfortably with the expansion of science.'[14]

Many Cold War commentators took up the task of showing that science either fostered democratic societies or thrived within them.[15] The Hungarian émigré chemist Michael Polanyi argued in his paper 'The republic of science' that 'in the free cooperation of independent scientists we shall find a highly simplified model of a free society'.[16] He compared the effectiveness of puzzle-solving of scientists acting independently with that of those being centrally directed and found that 'the pursuit of science by independent self-co-ordinated initiatives assures the most efficient possible organization of scientific progress'. Just as the invisible hand guided markets of independent traders, so science, according to Polanyi, would progress so long as planners (of Soviet or Bernal-style socialist stripe) were kept away: 'Any attempt at guiding scientific research towards a purpose other than its own is an attempt to deflect it from the advancement of science.' The journal that Polanyi's paper appeared in, *Minerva*, was funded by the CIA as part of the cultural Cold War.[17] Other texts, such as Don Price's *The Scientific Estate* (1965) and Harvey Brooks's *The Government of Science* (1968), served up other arguments on the congruence between science and democratic Western society. The decision to make science's values explicit, as well as the form such explicit statements took, were Cold War artefacts. They might be seen as a response to George Kennan's call in his 'Long Telegram': 'We must formulate and put forward for other nations a much more positive and constructive picture of the sort of world we would like to see than we have put forward in past.'

Cold War culture was polarized, not only East and West but outwards and inwards. Presenting science as compatible only with democracy was a projection outwards. But the celebration of the intrinsic virtues of the scientific community also had an inward audience. Indeed, the emphasis on a scientific 'community' itself was new. David Hollinger notes that the term 'scientific community' became widespread only in the 1960s, replacing the more individualist 'the scientist' or 'the scientists'; the switch from representations of science as an individualized pursuit to a communitarian one happened because of the 'revolutionizing of the political economy of physical science' in the wake of the Second World War and sustained by the Cold War.[18] In other words, Western science's dependence on Big Science military patronage raised questions about the autonomy of science which were resolved in part by explicit celebration of the intrinsic virtues of the scientific community. After all, public funds required public audit. And greater funds meant greater scrutiny. But science could resist some of this pressure if it could be accepted as self-policing. Hollinger calls this strategy 'laissez-faire communitarianism': 'Let the community of science alone.'[19]

Others were less sure that science and society could remain unscathed by the Cold War. The most extraordinary denunciation came in fact from the commander in chief, the president of the United States Dwight Eisenhower, in his farewell address to the nation of 17 January 1961. The mobilization necessary to meet 'a hostile ideology global in scope, atheistic in character, ruthless in purpose, and insidious in method' had led to a permanent rearmament that was becoming a deeply rooted, institutionalized power. He warned: 'we must guard against the acquisition of unwarranted influence, whether sought or unsought' by this entity, which he famously named 'the military-industrial complex'. 'Akin to, and largely responsible' for this danger, was 'the technological revolution during recent decades', from which emerged a second threat: the corruption of democracy by technocratic influence. 'In this revolution, research has become central, it also becomes more formalized, complex, and costly', said Eisenhower. 'A steadily increasing share is conducted for, by, or at the direction of, the Federal government.' He continued:

> Today, the solitary inventor, tinkering in his shop, has been overshadowed by task forces of scientists in laboratories and testing fields. In the same fashion, the free university, historically the fountainhead of free ideas and scientific discovery, has experienced a revolution in the conduct of research. Partly because of the huge costs involved, a government contract becomes virtually a substitute for intellectual curiosity. For every old blackboard there are now hundreds of new electronic computers. The prospect of domination of the nation's scholars by Federal employment, project allocations, and the power of money is ever present – and is gravely to be regarded.
>
> Yet, in holding scientific research and discovery in respect, as we should, we must also be alert to the equal and opposite danger that public policy could itself become the captive of a scientific-technological elite.
>
> It is the task of statesmanship to mold, to balance, and to integrate these and other forces, new and old, within the principles of our democratic system – ever aiming toward the supreme goals of our free society.

Eisenhower may, if his science advisor James Killian's evidence is accepted, have later privately retracted his warning.[20] However, the entity he named was real: the close interpenetration of defence industry and government in permanent mobilization, supported closely by a penumbra of dependent and interested parties, including universities and advice consultancies.

Systems thinking

The 'military–industrial–academic complex' (Senator William Fulbright's extended, and more accurate, label of 1967) encouraged a certain style of inquiry, in particular an emphasis on systems. Systems thinking has a long history, with origins in Enlightenment analyses and nineteenth-century technological projects such as railroads, telegraphy, electrical light and power.[21] But a distinctively managerial science of systems emerged during the Second World War.[22] Historian David Mindell has located its origin in fire-control radar projects of MIT's Rad Lab and Bell Labs in the United States;[23] I have made a case for finding systems, especially 'information systems', in British radar of the same period.[24] Agatha and Thomas Hughes distinguish between four forms of mid-twentieth-century systems approaches: operational research, systems engineering, systems analysis, and system dynamics.

Systems analysis, used in comparing, say, the deployment of long-range bombers with intercontinental ballistic missiles, was the specialty managerial science of consultancy think-tanks that worked closely with military patrons. The prime example and prototype was RAND.[25] In 1946, General Hap Arnold, leader of the United States Army Air Force, set up Project RAND in collaboration with Douglas Aircraft and in consultation with Edward Bowles of MIT. Douglas would leave in 1948, but the RAND Corporation, as it became, would continue and deepen its relationship with the new United States Air Force (an independent armed service from 1947). The United States Air Force provided RAND with funds and influence on decision-making. RAND provided the United States Air Force with 'independent objective analysis', helping it build its power within the new Department of Defense on the back of providing the strategic capacity to strike against the Soviet Union with airpower. The United States Air Force was the working world for RAND's science of warfare.

RAND's experts drew on diverse mathematical techniques – linear programming, game theory – and computer power to analyse the air force's work as a system with an aim of optimization. RAND became mathematical innovators too. George Dantzig offered the 'simplex method', while Richard Bellman, who left Stanford for RAND, developed linear programming into dynamic programming, ideal for optimizing the configuration of changing Cold War entities such as the air force and providing generalizable tools such as the minimax method. Game theory was another sharpened tool. Its core text, John von Neumann and Oskar Morgenstern's *Theory of Games and Economic Behavior* (1944), had been published during the war. Now, not least through von Neumann's continued military consultancy, games theory was adopted as a means of thinking about the Cold War. 'The emergence of the Soviet Union as "the enemy" and notions of a possible, single, intense exchange of nuclear weapons between the Soviet Union and the United States', notes historian David Hounshell, 'offered a nearly perfect parallel to the simple building block of game theory – zero-sum, non-iterative, two-person games.'[26]

Early on, RAND's aim was too general and ran into practical opposition. Its first large-scale systems analysis was a project to optimize the United States Air Force's strategic bombing of the Soviet Union. Pilots disliked its conclusions.[27] The next large-scale study, of air defence, also had little effect. However, more restricted systems analysis studies of the siting of bases, including in particular one by Albert Wohlstetter, were immediately persuasive. Likewise, Herman Kahn brought into RAND expertise of modelling scenarios using Monte Carlo sampling methods (which usually required electronic computers to run). Kahn would become a powerful voice on nuclear strategy in the 1950s, contributing to notions of a 'winnable' nuclear war, and, in particular, his 'ladder of escalation', discussed later.[28] RAND provided a channel through which civilian experts would shape Cold War policy and make the atomic devastation of a third world war rational.

RAND was the 'paramount thinktank of the Cold War', which, 'through its development of systems analysis . . . helped to foster the pervasive quantification of the social sciences in the post-war era'.[29] RAND valued its independence of research just as highly as it valued the patronage it received and influence it gained. Indeed, two of the most influential economic analyses arguing that 'basic science' could not be left to the private sector, but must be state-funded yet kept independent of state influence, by Richard Nelson (1959) and Kenneth Arrow (1962), were written from within RAND.[30] Yet, as Paul Forman's arguments might lead us to expect, there was considerable mutual orientation between air force interests and RAND analyses.

Transistors: missiles, markets and miniaturization

Three Second World War technologies were central to the Cold War. One, the electronic computer, will be examined in detail in chapter 16. The other two were the atomic bomb and the rocket. Rockets had several potential uses in the Cold War. First, as small guided weapons, rockets could be used as anti-aircraft weapons or as remote-controlled flying bombs. In common with the demands of military aircraft (and, indeed, naval vehicles), missiles required small, light electronics to make up the guidance systems, essential to turn rockets into guided weapons. This drive for miniaturization created one of the most important trends of the Cold War, resulting in not merely military aircraft packed with sophisticated electronics but also a host of other military and civil spin-offs, from transistors, to integrated circuits, to computer chips.

The crucial scientific innovation – the invention of the transistor – has been presented as a triumph of basic research carried out within industry, at Bell Labs, but its development into the cheap, core component of the post-war semiconductor electronics boom, transforming the second half of the twentieth century, was driven as much by the Cold War as by consumer demand.[31] In 1938, Mervin Kelly, Bell's research director, had set up a team of scientists to conduct 'fundamental research work on the solid state' with a view to replacing the electromechanical switches found in every telephone exchange with something smaller, faster and more reliable.[32] The team of physicists included the Caltech- and MIT-trained William Shockley and Walter Brattain, who had been with Bell since 1929. They were joined by the talented John Bardeen, who many years later would join Marie Curie and Linus Pauling as the only scientists to win two Nobel prizes. The transistor would only be possible through 'multidisciplinary teamwork'.[33]

Shockley proposed an amplifier idea in 1939–40, but it did not work. Investigating the silicon photocell effect of fellow Bell scientist Russell Ohl in 1940, Brattain diagnosed a 'barrier' found between 'commercial' and 'purified' silicon, the first indications of P type and N type semiconductors.[34] Brattain and Bardeen, working with an element similar to silicon, germanium, figured that the effect could be exploited to produce an amplifying device, the point-conduct semiconductor amplifier. Shockley wanted co-credit. Spurned, he remarkably improvised a second way of making a transistor, a sandwich of N–P–N semiconducting material. Therefore in 1947, Bell Labs had a startling new electronic component to show off to the press and the military and to patent. A science fiction writer and Bell employee, John Pierce, named it the 'transistor'.[35] Bell presented the transistor as a triumph of teamwork. An iconic photograph showed the three men working together, even though Bardeen and Brattain were barely speaking to Shockley at the time.

Nevertheless, if it could both be made robust and be mass-produced, the transistor had the potential to replace triode valves as the core component in amplifying and switching circuits. By end of 1940s the 'military supplied about 15% of the Bell Telephone Laboratory's budget'.[36] In the middle of the Korean War, in 1951, the junction transistor nearly became a classified secret.[37] But Bell, concerned about anti-trust accusations, was able to convince the authorities that it was in the national interest to license the manufacturing rights.

The military, however, was the market that drove development. Shockley devised electronic proximity fuses (using transistors) for mortar shells. One of the first uses of transistors was as part of radar control systems, AN/TSQ units, for Mike-Ajax guided missiles.[38] The first fully transistorized electronic computer, TRADIC, was made for the United States Air Force. In the Cold War the military was willing to pay. AT&T, Bell Laboratories' parent company, also offered a captive market for switch applications.

The first transistor radios, using a component whose price had been driven down during military development, appeared at the end of the Korean War. Remarkably, the $25,000 licence to manufacture transistors had also been bought by a small Japanese company owned by Masaru Ibuka and Akio Morita, called Tokyo Tsushin Kogyo. Through experiment, they improved the semiconductor manufacturing process, and in 1954 launched a transistor radio firmly aimed at the commercial market. Ibuka and Morita chose a simple name for the American market: Sony. A Sony employee, Reona 'Leo' Esaki, would discover quantum tunnelling in 1957 and later share the 1973 Nobel Prize, which shows that the working world of Japanese semiconductor manufacture generated its own science.

A burgeoning commercial market began to sustain further investment for military purposes. Shockley decided to set up his own company: 'After all', he told his future wife (while his first wife was dying of cancer), 'it is obvious I am smarter, more energetic and understand people better than most of these other folks.'[39] The Shockley Semiconductor Laboratory was set up near Stanford University, recruiting electronics talent such Robert Noyce and Gordon Moore. But Shockley was a poor manager of people, and morale plummeted. A group of eight left in September 1957 and founded Fairchild Semiconductor. This was the beginning of Silicon Valley, the proliferation of electronics and computing companies as part of the military-industrial-academic complex of the west coast. Fairchild's innovation of the integrated circuit – tiny components etched on a lightweight sliver of semiconductor – was perfect for missiles, aircraft electronics and spy satellites, as well as small computers.

From upper atmosphere to outer space

In 1945, it was obvious that the rocket would be an important military device of the near future, especially in combination with nuclear warheads. A race had developed, already discussed, between the United States and Red armies to capture the Nazi rocket programme. Any concerns about Nazi backgrounds had been waved aside as Wernher von Braun's team had been brought to work under army contracts at White Sands Missile Range in New Mexico, the guided weapon unit at Fort Bliss, Texas, and the Redstone Arsenal in Huntsville, Alabama. The Redstone was a continuation of the V-2. Guided by RAND, the United States Air Force, which saw responsibility for strategic missiles as an extension of its strategic bomber force, set up a competing programme of rocket research.

Larger rockets that travelled into the upper atmosphere at great speeds before falling to earth were strategic weapons against which there was almost no defence. This had been the terror of the German V-2, which had only to travel a few hundred miles. Once rocket technology had improved to the extent that thousands of miles could be flown, the weapons could strike anywhere on the planet – they were intercontinental ballistic missiles (ICBMs). Both the United States (Atlas) and the Soviet Union (R-7 or SS-6) began ICBM projects soon after 1945. The Soviet ICBM programme was boosted in May 1954. The man placed in charge of design was Sergei Pavlovich Korolev, a veteran of amateur rocketry societies of the 1930s who had continued work in the gulag in the 1940s. His rehabilitation was another indicator of the indispensability of technical expertise to Soviet plans. The threat and capability of the ICBM meant that there was a strong military interest in sciences of the upper atmosphere in the early Cold War.

Finally, a missile capable of travelling around the earth was capable of orbiting the earth. Cold War imagineers – organizations such as RAND and individuals such as the science fiction author Arthur C. Clarke – drafted plans for different kinds of artificial satellite after 1945. Among uses imagined were commercial applications (such as communication satellites that would offer a service similar to undersea cables), scientific research (looking up to the heavens, down to earth, or simply exploring the space of low orbits), and military reconnaissance and surveillance. A combination of uses was not uncommon. Each of the three armed services in the United States had plans for satellites and jostled for favour and resources. In the Soviet Union, drawing on the tacit and explicit knowledge of captured German technicians, as well as careful study of facilities now in East Germany, missile development had continued apace. In May 1954, in parallel with the go-ahead for the ICBM, Korolev passed on to the Soviet leaders a *Report on an Artificial Satellite of the Earth*, written by a close colleague, Mikhail Klavdiyevich Tikhonravov.

The most urgent strategic problem facing the United States in the Cold War was knowledge of the state and distribution of Soviet military capabilities. There was an asymmetry here: the United States was more open than the Soviet Union, so the need for surveillance was probably felt less in Moscow than in Washington. Soviet spy networks seem to have been more effective than Western ones, although a sound comparison is almost impossible to make. Nevertheless, good information was the basis of good diplomacy, and for crucial questions – such as, where were Soviet strategic weapons? how many were there? – there was ignorance. From 1952, modified B-47 bombers began long-range surveillance flights over Siberia. From 1956, the specialist U-2 spy planes, complemented by high-altitude balloon flights (Project GENETRIX), provided information. But there were severe problems with these technologies: they violated Soviet airspace, they encouraged the Soviet Union to develop air defence systems as countermeasures, and they risked being shot down. (Indeed, an embarrassing diplomatic incident would occur in 1960: a U-2 was downed over Russia, and its pilot, Gary Powers, was captured.) A diplomatic proposal, 'Open Skies', of transparency over missile sites and freedom for aerial reconnaissance to check, was rejected.[40]

To resolve this issue, Eisenhower's advisors in 1955 came up with a clever plan.[41] The illegality of flying aircraft over sovereign airspace without permission was clear, but the legal status of orbiting satellites was not: after all, a satellite followed a path determined by gravity not, it could be argued, by geopolitics. By launching a scientific satellite, the principle of the 'freedom of space' could be established. Spy satellites, the solution to the problem of Cold War transparency, could follow in this scientific path. Science's image as international and above geopolitical squabbles was essential to the success of this scheme.

A suitable occasion to announce an American scientific satellite was immediately to hand. The International Geophysical Year (IGY), a coordinated set of geophysical research programmes involving 5,000 scientists, focusing mostly on Antarctica and the upper atmosphere, was being organized for the years 1957 and 1958.[42] The IGY provided the ideal backdrop for the presentation of scientific satellites as part of a public show of international scientific cooperation. In July 1955, James Hagerty, Eisenhower's press secretary, announced that the United States would launch a science satellite during the IGY. The announcement generated excitement and plenty of press coverage. In immediate response, a delegation of Soviet scientists, who happened to be at the Sixth International Astronautical Congress in

Copenhagen, announced that the Soviet Union would also launch a satellite during IGY. (Photographs of the event show the scientists and apparatchiks squeezed into what looks like a suburban front room, but was in fact in the Soviet Embassy in the Danish capital.) Their announcement generated almost no coverage at all. Korolev was charged with fulfilling the Soviet plan. The firm expectation, however, was that the United States would be the first nation in space.

The United States government was faced with a decision between the satellite proposals of the three armed services. It set up a committee, chaired by Homer Stewart of Caltech's Jet Propulsion Laboratory, to resolve the issue. The choice was between the army's Project Orbiter, which promised to launch a cheap basic satellite using the Redstone missiles developed by Wernher von Braun, a heavy satellite launched by the air force's Atlas ballistic missile, and the Naval Research Laboratory's scientifically sophisticated satellite, Vanguard, launched from an as-yet-undesigned modified sounding rocket. The Atlas ICBM was politically too important to tamper with, so the air force project was rejected. A combination of Vanguard satellite and the modified Redstone rocket (Jupiter C), which would have represented scientific sophistication with proven launch technology, was rejected because of the complications of inter-service rivalry. The Stewart Committee plumped for the navy's project. American success in space therefore depended on a rocket that existed only on paper. This diffusion of energy and focus was not paralleled in the Soviet Union, where Korolev assured Nikita Khrushchev that satellite launches would not interfere with ICBM development.

On 4 October 1957, in the middle of the International Geophysical Year, the Soviet satellite Sputnik was sent into orbit from a launch site in the Soviet Socialist Republic of Kazakhstan. It was a metallic sphere – 'the first Sputnik must have a simple and expressive form', recalled Korolev, 'close to the shape of natural celestial bodies'.[43] Even more expressive was a radio signal – a regular 'beep' – that was soon picked up by radio hams (as Korolev had designed it to be). The West was deeply shocked. Edward Teller's thought, that the United States had 'lost a battle more important than Pearl Harbor', was a commonplace.[44] The launch into space, only a month later, of a much larger satellite, Sputnik II, carrying the first living creature, Laika the dog, raised the level of alarm further. Sputnik II was the weight and dimensions of a nuclear weapon. Sputnik had announced in the most dramatic way that not only did the Soviet Union possess the ICBM, but it made any Western city defenceless against air-attack with nuclear bombs.

Sputnik suggested that the Soviet Union had overtaken the West in technological progress. Washington worried that Third World leaders would draw conclusions about the relative merits of capitalism and communism. The anxieties were stoked further by the fate of the West's own first attempted satellite launches: the navy's Vanguard exploded on launch-pad in December 1957, and would not be successfully put in orbit until March 1958. By then, a rush job, combining a Jet Propulsion Laboratory satellite, 'Explorer', on top of a Jupiter rocket, had launched from Cape Canaveral in January 1958.

There was a search for credit and scapegoats. Korolev's identity was kept a tightly held secret until after his death, supposedly to keep him safe from Western assassins, but really so that credit would be given to the system rather than the man. In the absence of a story of individual talent, some Western journalists speculated that Peter Kapitsa, the Cambridge-trained physicist held in Russia, must have been behind the triumph. In the United States, derision was heaped on Eisenhower, who was portrayed as out of touch. In fact, historian Rip Bulkeley suggests the previous Truman administration was more to blame, and the consensus now is that Eisenhower was in private content that the important strategic principle of the 'freedom of space' had been secured.[45] In the United Kingdom, the response to Sputnik was a national debate on the supposed failures of secondary education.[46]

Nevertheless, the surprise of Sputnik was a testament to the underestimation of Soviet capability in technical areas of high political value, rather than a result of Cold War secrecy. The Soviet Union had announced the Sputnik programme in public, and had given technical presentations on the satellite at conferences in the months before launch. It was not unknown. Indeed, in July 1957 the Soviets had approached the Naval Research Laboratory with an invitation to install an American 'radio frequency mass spectrometer' on the Soviet satellite; this proposal, made in the cooperative spirit of International Geophysical Year, had been rejected for 'technical' reasons.[47]

Sputnik prompted the establishment in 1958 of two institutions that would drive technological change in the 1960s. The first, in April, was a new government body in the Pentagon, the Advanced Research Projects Agency (ARPA), charged with rationalizing existing research and, more importantly, breaking armed service rivalries by supporting early-stage high-risk research and development that might lead to new multi-service military technologies.[48] ARPA supported a range of projects, including ballistic missile defence, nuclear test detection and materials science, but especially information technologies. The agency had no laboratories of its own, and its funds strengthened the ties between universities such as MIT, Michigan and Stanford and surrounding defence industries. ARPA's Information Processing Techniques Office (IPTO) was particularly important in funding basic computer science, network ideas, command and control 'testbeds' and research into the faster components necessary for new generations of computers.[49] The most famous creation, the ARPANET, will be examined in a later chapter.

The second institution was a great civilian-led agency to compete and contrast with Soviet space successes in the space race. The National Aeronautics and Space Administration (NASA), established in July 1958, may have echoed the name of the National Advisory Committee on Aeronautics (NACA), which it replaced, but it was a different beast. Its first ten-year plan, articulated in 1960, encompassed 260 launches, among them orbital satellites, probes to the moon and the planets, and manned space flights, including some around – but not landing on – the moon.[50] The post-Sputnik boom in space-based planetary astronomy was sometimes viewed with 'hostility by some ground-based astronomers'.[51] Solar system astronomy was already a thriving, interdisciplinary field by the 1950s, an 'interwoven tapestry' of planetary astronomy, meteorology, geochemistry, geology and geophysics, with some large-scale university-based projects.[52] After Sputnik, it had to resolve the tensions between the extraordinary opportunities for investigation represented by NASA's patronage and the competing and expensive demands of human space flight.

The presidential election of 1960 was dominated by space. The Democrat candidate, John F. Kennedy, not initially an enthusiastic supporter of space programmes, chose space as a subject on which his Republican rivals were perceived as weak. The other big issue, civil rights, was muddied by Southern Democrats' intransigence. A decisive phrase in the election was the supposed 'missile gap' that Eisenhower had allowed to open. In fact, as U-2 flights had revealed, the Soviet Union by the end of 1959 had only six vulnerable missile sites, each requiring twenty hours to fuel.[53] Despite the resources pumped into NASA's first major programme, Project Mercury, the first human in space was a Russian, Yuri Gagarin, who orbited the earth on 12 April 1961. Kennedy responded in May 1961 with the announcement of NASA's Apollo mission: 'We choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard.'

Antarctic space

Outer space was becoming defined as a neutral zone of international competition, frozen in place by Cold War rivalry, with activities justified by appeal to the values of international science. Interestingly, a close parallel can be drawn between this definition of outer space and Antarctic space. From the end of the nineteenth century to the 1950s, scientific research in Antarctica had been performed as part of explorations that aimed to ensure national territorial claims. National claims on slices of the Antarctic continent had been made by Britain (1908 and 1917), by France (1924), by Britain on behalf of New Zealand (1925) and Australia (1933), by Germany (1924), by Norway (1939, specifically to counter a German claim), by Argentina (1940) and by Chile (1942), both of which claimed territory in anticipation of a German victory. After the war, a British agency, the Falkland Islands Dependency Survey, a supposedly scientific body, had established Antarctic bases. 'The scientific fieldwork which is carried out in the Dependencies is not research for the benefit of colonial peoples', a civil servant had explained in 1952:

> It is done to maintain a UK interest . . . It is UK, not FIDS policy, that the activity should be maintained at a sufficient level to enable us to compete with our South American rivals, and it is inescapable that the receipt, coordination, working up, and publication of results of fieldwork at the bases must be regarded as integral to these activities.[54]

In this coldest theatre of the Cold War, the United States strategy was to make sure that any redivision of the Antarctic map excluded any sovereign rights granted to the Soviet Union. Freedom of Antarctic space might be best served by international neutrality, justified by science.

The International Geophysical Year provided the opportunity. Antarctica, along with space and the upper atmosphere, was the major location for IGY activity. The twelve IGY nations included seven with claims on Antarctic territory, the others being the United States, the Soviet Union, Belgium, Japan and South Africa. Fifty-five scientific stations were established. The Royal Society of London set up at Halley Bay on the Antarctic coast. The United States placed a station at the South Pole, a symbolic negation of the sector claims that converged at the pole. Not to be outdone, the Soviet Union set up a scientific base at the bleak 'pole of inaccessibility', the furthest spot from Antarctic coasts. Scientists photographed the aurora australis with new all-sky cameras, recorded cosmic ray showers (from which deductions about the upper atmosphere could also be made), drilled snow cores and undertook seismic studies of the depth of the Antarctic ice.

The cooperation of the International Geophysical Year laid the foundations for the Antarctic Treaty, which was signed in 1959 and came into force in 1961.[55] The important provisions of the treaty were Article I (demilitarization of the continent and a ban on dumping nuclear waste), Article II ('Freedom of scientific investigation in Antarctica and cooperation towards that end', requiring that stations would be open to inspection) and Article IV (freezing all sovereignty claims, with implications for biological and mineral resource exploitation), while Article IX.2 stated that the only countries that would be voting members under the treaty were those 'demonstrating [their] interest in Antarctica by conducting scientific research activity there'. In other words, nations could only have a say in Antarctic politics if they pursued science on the continent.

Science and Antarctic politics had become intimately linked for three reasons: science played a key role in defining the regime governing Antarctic decision-making (the Antarctic Treaty), science was used rhetorically to justify actions and cover other, often narrowly interested motives, and science would be essential to the design and implementation of regulations that followed the treaty for resource management and environmental protection. In conclusion, outer space and Antarctic space were both defined in a Cold War context as abstract international spaces, defined by legal treaties (an Outer Space Treaty would be signed in 1967), and the use of which would privilege science.

Global projects and the Cold War

Internationalism, sometimes sustained, sometimes fractured by Cold War polarities, was a feature of the post-war world. The World Health Organization (WHO) of the United Nations undertook a 'war against disease'. A campaign against malaria starting in 1955 was initially quite successful, before the problems of drug and pesticide resistance and a failure to build robust, sustainable, local organizations led to malaria sweeping back into areas whence it had formerly been eradicated.[56] Malaria remained a major agent of death in the twentieth century. However, another WHO campaign, vaccination against smallpox, which began on 1 January 1967, was spectacularly successful. Under the Intensified Smallpox Eradication Campaign, mass vaccination, which had been successful in Japan, Western Europe and North America, was extended to other parts of the globe. Swift responses were needed to combat outbreaks in Nigeria and India. The campaign was a slow process of learning how local populations could be surveyed and recorded and also depended on innovations in freeze-drying and mass-producing vaccine. After 1977, smallpox existed only in high-security laboratories. The resolution made at the World Health Assembly of 1965 to eradicate smallpox on a global scale had been driven not only by the technical opportunity to rid the world of a dread disease, but also by the choice of the United States to divert energies in this direction to project a particularly compelling Cold War message; the expansion of air travel was also a factor, since increased travel had heightened the risk of epidemics.[57] Cold War politics would continue to shape smallpox even after its eradication, determining which handful of laboratories might continue to cultivate the potential bioweapon.

The Cold War encouraged global perspectives. Fallout, the radioactive detritus of atmospheric atomic tests, was perhaps the first recognized global environmental hazard.[58] Data from the atmosphere, oceans and ice cores taken during the Cold War were integral to the recognition of anthropogenic climate change on a global scale.[59] Both will be considered in more detail later. But the Cold War also framed how another global issue was framed and addressed: so-called overpopulation and related threats to food supply. This framing can be seen in the history of developing high-yield crops, especially in the science-based, globe-spanning project known as the Green Revolution.[60]

The Rockefeller Foundation had been active in China before its access was ended by the 1949 victory of the communists over Chiang Kai-shek's nationalist forces in the civil war. The foundation's attention regarding foreign aid turned instead to Mexico. In 1941, a survey team of agricultural science experts reported that significant work on wheat rust and maize was justified. A research team, including the plant pathologist Norman E. Borlaug, was dispatched in 1943 to form the Mexican Agricultural Program, a semi-autonomous unit within the Mexican government funded by the Rockefeller Foundation.[61] It received political support from within Mexico by politicians and scientists who championed industrialization of agriculture over the radical land reform favoured under earlier Mexican regimes. The new moderate president, Ávila Camacho, also had particular hopes of supporting the development of the newly opened Yaqui valley area. This contingency, along with a certain middle-class prejudice, helps explain why wheat became a focus of research rather than the traditional food of working Mexicans, maize and beans: wheat rust was a problem in the Yaqui valley; wheat also offered an export crop.[62] The Mexican Agricultural Program brought in Japanese short-stem wheat varieties, both from Japan and from cultivation in agricultural research stations in the United States. Borlaug and others worked hard to improve varieties, experimenting with crosses, guided by Mendelian genetics. The Rockefeller Foundation in turn learned that it could support large-scale research for agricultural industrialization in foreign countries.

The Rockefeller Foundation was therefore primed to respond to President Truman's call for action in his inaugural address of January 1949. Truman presented four points. Point 3 addressed the need for Western military organization to counter the 'false philosophy' of communism. The result was NATO. Point 4, also framed by the Cold War, addressed food and science:

> More than half the people of the world are living in conditions approaching misery. Their food is inadequate . . . Their poverty is a handicap and threat both to them and to more prosperous areas . . . The United States is pre-eminent among the nations in the development of industrial and scientific techniques . . . Our imponderable resources in technical knowledge are constantly growing and are inexhaustible. I believe that we should make available to peace-loving peoples the benefits of our store of technical knowledge in order to help them realize their aspirations for a better life.[63]

The result was the Rockefeller Foundation redoubling its efforts in Mexico. Warren Weaver, collaborating with Mexican Agricultural Program scientists, summarized the position in a paper, *The World Food Problem*, submitted to the trustees in 1951. In it he echoed Truman's sentiments:

> The problem of food has become one of the world's most acute and pressing problems; and directly or indirectly it is the cause of much of the world's present tension and unrest . . . Agitators from Communist countries are making the most of the situation. The time is now ripe, in places possibly over-ripe, for sharing some of our technical knowledge with these people. Appropriate action now may help them attain by evolution the improvements, including those in agriculture, which otherwise may have to come by revolution.[64]

Historian John Perkins calls this chain of reasoning 'population-national security theory', the Cold War logic that said overpopulation led to the exhaustion of resources, to hunger, to political instability, to communist insurrection, and to dire consequences for the interests of the West.[65] The trustees agreed with Weaver's argument. One of them, Karl T. Compton, president of MIT, wrote: 'I suspect that India may be fertile ground for activity in this field.'[66]

Shortly after India had won independence from Britain in 1947, it was devastated by partition as the Muslim lands broke away to form Pakistan. The first prime minister, Jawaharlal Nehru, at least in his first decade as leader of India, promoted industrialization, but not at the expense of aims for social equality. Intensification of agriculture nevertheless began, supported in part by the Ford Foundation. However, a combination of interconnected factors in the late 1950s – poor harvests, communist success in elections – tipped the balance in favour of the intensification and industrialization of agriculture. When Nehru died in 1964, his successor, Lal Bahadur Shastri, committed the country fully to the Green Revolution: the import of Mexican short-stem wheat varieties, further developed by Indian agricultural scientists such as Benjamin Peary Pal and Monkombu Samasivan Swaminathan, planted widely and fed with fertilizers manufactured by chemical industries. The startling increases in yields fed a burgeoning population and possibly staved off communist insurrection, but certainly promoted the power of elites at the expense of poor farmers.[67]

The limits of containment

So, in a Cold War context, the success of diverse projects across the globe became a freighted question. We will see in the next chapters how the techniques of comprehensive surveillance scrutiny – from exploring the bottom of the ocean to distinguishing between phenomena in the highest parts of the atmosphere – led to distinctive Cold War sciences. Historian Paul Edwards calls this state of global scrutiny, containment and control the 'closed world', a concept to which I will return.[68] Finally, however, the limits of this scrutiny and control need to be noted. The Cuban Missile Crisis of 1962 and the process of nuclear proliferation will illustrate.

In 1962 Nikita Khrushchev had ordered intermediate-range missiles to be deployed on the island of Cuba. It was once thought that this deployment was a bid to regain nuclear leverage after, contradicting the 'missile gap' rhetoric, the relatively meagre reality of Soviet missile forces had been revealed. Khrushchev's bluff had been called (he too had exaggerated the numbers and accuracy of Soviet missiles) and he was raising the stakes. A more recent interpretation, chiming in fact with Khrushchev's contemporary justifications, sees the deployment as an attempt to protect and preserve the revolution in Cuba, the success of which had surprised Moscow as well as Washington.[69] The previous year an attempted invasion of Cuba by the United States had foundered in the Bay of Pigs. The nuclear missiles, some of which were short-range and tactical, were a response. Unknown to the West, some nuclear missiles had been placed under local control. There were, in addition, Soviet submarines in the area, also with missiles under local command.

The missile bases had been revealed by scrutinizing surveillance photographs taken by U-2 aircraft. For fourteen days the significance of the missiles was debated, and responses were discussed. It is now well known that the world came very close to war between East and West. Only recently has it emerged that a fierce argument between the captain and his two senior officers on a Soviet submarine was swung in favour of not launching nuclear weapons only by one vote by one officer (Vasili Arkhipov, to whom the world should be very grateful). The Cuban Missile Crisis was only defused when Kennedy publicly promised that the United States would not invade Cuba, while privately also promising that Turkish intermediate-range missiles would soon be dismantled.[70]

The Cuban Missile Crisis marked a dramatic reversal of nuclear strategy. Eisenhower's strategy had been one dimensional: a promise of massive retaliation if provoked. The Single Integrated Operational Plan, the plan of attack, of 1960 called for 3,200 nuclear weapons used on 1,060 targets in the Soviet Union, China and allied lands, aimed at nuclear bases, military command centres, ports and cities, delivered by the United States Army, Navy and Air Force in a single combined attack.[71] Kennedy, listening to civilian strategic advisors, had moved away from massive retaliation towards favouring the 'rational' escalation ladder approaches exemplified by Herman Kahn's writings. Nuclear confrontation could be rationally managed through 'flexible response'. But rational management requires rational game-players and clear symbols sent, received and understood. The dreadful events of the Cuban Missile Crisis fatally undermined this model. 'What kept war from breaking out', concludes John Gaddis, 'was the irrationality, on both sides, of sheer terror.'[72] Henceforth, in practice there were sharp limits on the technocratic rationality promoted by strategic advisors. Robert McNamara, who perhaps more than anyone else embodied this rationality, was also the architect of the institutionalized irrational strategy: a return to Eisenhower's policy of massive retaliation, now known as Mutually Assured Destruction (MAD).

If the geopolitics of the Cold War were simply two poles, East and West, then containing nuclear proliferation might have been possible. But the reality of geopolitics was the manoeuvres of many interested nation-states within a polarized framework. The United States could not prevent the Soviet Union from developing the atomic bomb and the thermonuclear bomb. Possession of nuclear weapons conveyed status and influence. Neither superpower could prevent other nations eventually joining the atomic club: Britain (first test 1952), France (1960), Israel (probably ready by 1967), India (tested 1974), South Africa (possessed in the 1980s), Pakistan (1998) and North Korea (2006).

Each new nuclear nation has benefited from the transfer of nuclear knowledge, techniques, materials or personnel, despite the containment of the Cold War. Britain had experience of participation in the Manhattan Project, and then in 1954–5 helped the French project by providing crucial information (and samples of plutonium) while keeping the transaction secret from the Americans. Like the British, French politicians wanted the bomb as a signifier of status, following post-colonial humiliation in the battle of Dien Bien Phu (1954) and the effective symbolic demolition of Great Power status (of Britain and France) in the debacle of the Suez Crisis of 1956. The French, facing a rebellion in Algeria, were motivated to help Israel develop a bomb as a deterrent against Soviet-backed Arab nations.[73] This French decision was kept secret from Britain and the United States. Independently, a British civil servant, without informing his minister, sold Israel enough scarce heavy water – for £1 million via a Norwegian front company – to moderate the Israeli secret reactor at Dimona. It suited all nations' interests not to acknowledge the reality of an Israeli nuclear bomb, creating what historian Avner Cohen calls a dangerous state of 'nuclear opacity'.[74] Sometimes merely the resources and knowledge close to but not from active nuclear projects prove sufficient: West German technology exported to South Africa allowed the land of apartheid to build its nuclear weapons.[75]