From Alchemy to Atomic War: Frederick Soddy's "Technology Assessment" of Atomic Energy, 1900-1915

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In 1915, Frederick Soddy, later a winner of the Nobel Prize in Chemistry, warned publicly of the future dangers of atomic war. His foresight depended not only upon scientific knowledge, but also upon emotion, creativity, and many sorts of nonscientific knowledge. The latter, which played a role even in the content of Soddy's scientific discoveries, included such diverse sources as contemporary politics, history, science fiction, religion, and ancient alchemy. Soddy's story may offer important, guiding insights for today's efforts in technology assessment.

As allied and German forces battled on the Continent, an eminent British scientist spoke openly of atomic war. In public lectures addressed to laypersons, he explained that while future energy shortages might be averted by using energy from the atom, the more probable result of the development of atomic power would be mass annihilation by weapons of inconceivable might. The distinguished speaker—handsome, articulate, and obviously worried—was not certain when this would occur.

The British government paid no attention to the seeming breach of national security, for no act of treason or even of indiscretion had been committed: The German troops were those of the Kaiser, and the year was 1915. The speaker, 38-year-old Frederick Soddy, had recently

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completed research for which he would eventually be awarded the Nobel Prize in Chemistry.

We generally imagine that awareness of the potential social implications of atomic energy arose with the discovery of nuclear fission in 1938 and intensified following the atomic destruction of Japanese cities in 1945.[1] How was anyone in 1915 able to forecast the social consequences of a scientific discovery that had not yet been made?

Soddy was able to do so in part because certain essential scientific insights—that there is energy latent within the atom and that it is physically possible for it to be released—had been known since 1903. But it is in general not obvious how to move beyond conceiving a mere scientific possibility to envisioning eventual technological practicability, a range of specific applications, and finally that certain applications are—given social circumstances—more probable than others. After all, many scientists shared Soddy's scientific knowledge, but none became as committed as he to investigating the social implications of that knowledge, much less reached conclusions of comparable power.[2]

To achieve his insights, scientific knowledge and logical argument had, in Soddy's instance, to be supplemented by emotional involvement, intense creativity, and social awareness. In each of these respects, Soddy was unmistakably assisted by sources of knowledge entirely outside the usual domain of science. These ranged from contemporary politics and science fiction to religion, mythology, and ancient alchemy. The mark of such elements indeed appears in the very content of his scientific work.

The story of Frederick Soddy thus provides dramatic evidence for the role of so-called "nonscientific" factors within the content and social organization of science.[3] But it goes further, suggesting that nonscientific knowledge, social context, emotion, and imagination contribute—and in this case fruitfully—not only to the development of scientific knowledge, but also to the interpretation of its social consequences.[4] I conclude by exploring the latter insight's implications for the conduct of contemporary technology assessments.

Alchemy and Atomic Theory

Soddy initially became interested in atomic energy well before 1915, while in the process of making his first important scientific discovery. The circumstances of that discovery were unusual and help explain the subsequent strength and persistence of his interest.

Graduating from Oxford in 1898 with first-class honors in chemistry, Soddy had difficulty finding a suitable job in research or teaching. After two years of somewhat aimless postgraduate research, he ventured to Canada and managed to secure a position as a laboratory demonstrator in the Chemistry Department at McGill University, Montreal. There he encountered a junior professor of physics, 29-year-old Ernest Rutherford, who invited him to join in a collaborative effort to try to make sense of the recently discovered phenomenon of natural radioactivity.[5]

From 1901 to 1903 Rutherford and Soddy undertook chemical and physical investigations that resulted in the theory of atomic disintegration. Their research demonstrated that the radioactive emissions of elements such as radium, thorium, and uranium occurred in conjunction with the spontaneous transmutation (change) of individual atoms of one chemical species into atoms of another.[6] For Rutherford, these discoveries were to mean a Nobel Prize and one step in a long and illustrious career in science.[7] To Soddy they meant more; evidently one reason he and Rutherford were the first to discover natural transmutation was that Soddy had in a sense decided beforehand that he wanted to find it.

Soddy had not been idle during his two years of postgraduate research at Oxford (1898-1890). When not working in the laboratory, he attended chemistry lectures, tutored undergraduates, and began to prepare a number of essays on the history of chemistry. History of science was at the time a relatively neglected subject in England,[8] and thus Soddy's interest was somewhat unusual. We can speculate that specific prior events in his life may have contributed to his interest.

Born in 1877 in Sussex, England, Soddy had suffered trauma during his early years: His mother died when he was 18 months old, while his father was absent half of each week on business in London. Frederick's upbringing was entrusted to a much older half-sister, with whom he frequently fought.

Religion played a large part in the Soddy household. His grandfather had been a missionary, evangelists were routine household guests, and his next elder brother became a minister. But Soddy grew to abhor the stern Calvinist sermons he heard each week in church. Influenced in adolescence by the writings of Thomas Henry Huxley on Darwin and evolution, Soddy rejected the outward trappings of the family religion. What remained was a strong sense of duty and an uncompromising commitment to speak the truth as he conceived it.[9]

Thus perhaps having in 1898 already suffered the triple disruptions of losing his mother, renouncing Calvinism, and leaving home, Soddy unconsciously sought in examining history to ground his sense of identity within an alternative tradition—that of chemistry. In any case, his interest persisted. In May 1900, he was hired at McGill, and the next fall he took the initiative in delivering a series of lectures entitled "The History of Chemistry from Earliest Time."[10]

As understood by chemists in 1900, the atom was by definition the immutable and indivisible fundamental unit of matter. Chemical laws described ways in which atoms combined with one another to form molecules, but individual atoms could by themselves be neither changed nor decomposed. Soddy's lectures, beginning with a description of the origins of chemistry in ancient Egypt, culminated triumphantly in the enunciation of this Daltonian atomic theory.

Two lectures were devoted to the practice of alchemy—the attempt to transmute base metals into gold—which Soddy believed had arisen in the fourth century A.D., long after the origin of chemistry proper. Repudiating "quackery" and the alchemists' "feverish desire" for wealth, he asserted that "the alchemistic period" had nothing to do with "the normal development of chemistry. It is rather the result of a mental aberration. . . ."[11]

Sometime after March 1901 Soddy's views changed radically. During the academic year 1900-1901 he became acquainted with the McGill physicists, including Rutherford. From them Soddy learned of a new theory of matter derived from the identification of the electron in 1897 by the British physicist (and Rutherford's mentor) J. J. Thomson. Thomson had proposed that rather than being the fundamental unit of matter, the atom might be composed of small electrical masses. The idea was shocking to Soddy, for an atom composed of parts could no longer be considered indivisible. Perhaps even more heretical was the hypothesis of British astrophysicist Norman Lockyer, based on spectral analysis of the light from stars, that within the stars heavy and light elements were evolving from one another. To Soddy that was only another way of saying "transmutation"—a notion that smacked of alchemy and deception.[12] But the ideas were also tantalizing and backed partially by experimental evidence, and in the course of the year he was won over.

The concept of an atom composed of parts was inconsistent with Soddy's lectures on the history of chemistry. Rather than overlook the inconsistency, he did some more historical research. The result was

"Alchemy and Chemistry," a short but remarkable unpublished paper in which Soddy reconceived chemical history. Based on evidence discussed in Marcelin Berthelot's *Les Origines de l'Alchimie,* Soddy drove the date for the birth of alchemy back to "an antiquity so remote that its origins appear in the records of mythology rather than in those of history."[13] Thus history was inverted, and alchemy, far from being viewed as an aberrant offspring, became now the parent of chemistry. Soddy continued to dispute fraudulent medieval claims to successful transmutation, but he also argued that there had always been honest alchemists—some of them great chemists, such as Robert Boyle—whose work had been essential to the growth of science.

"Alchemy and Chemistry" differs from Soddy's earlier lectures in one other important respect. "The value of history," he now averred, "lies in the sense of proportion with which the past endows the present in its relation to the future."[14] With that and an allusion to Lockyer's hypothesis, Soddy concluded his paper with the proclamation of a goal—*the* one ultimate goal—for chemistry:

> The existence of an atomic stage of matter is unquestioned, but this in no way relieves the chemist from the necessity of penetrating deeper. The constitution of matter is the province of chemistry, and little indeed can be known of this constitution until transmutation is accomplished. This is today as it has always been the real goal of the chemist before this is a science that will satisfy the mind.[15]

Soddy's idea of trying to transmute the elements was both imaginative and audacious, for it was no small step from accepting the possibility that transmutation might occur under the so-called transcendental conditions present in stars (Lockyer's view), to imagining that somehow the same processes could be made to occur on earth.[16] Moreover, insofar as Soddy had previously identified himself with the chemical tradition, in setting a long-range goal for chemistry, he was presumably setting a goal for himself.

In the meantime he had begun to learn from Rutherford about radioactivity. Since 1899 Rutherford had been studying a mysterious "emanation" given off by thorium. He did not know how to interpret this phenomenon. By Fall 1901 he suspected that the emanation was a gas, but he needed a chemist's help to be certain. The Rutherford-Soddy collaboration began that October. A brief experiment convinced the two researchers that the emanation was probably a gas, but what kind of gas? Soddy found that it would not react with powerful chemical reagents and deduced that it must be a member of the recently (1894-

1898) discovered family of inert gases. Suddenly he believed that he knew what was afoot: The emanation was an inert gas, that is, some element other than thorium. Thorium, Soddy reasoned, must be "transmuting" itself into a different kind of element.[17]

Previous historical accounts have assumed that it was only after this that Soddy composed his "Alchemy and Chemistry" essay. Such a chronology obscures the role of alchemy in Soddy's discovery of natural transmutation, as well as in his later thought and life.

In contrast, I find the available evidence, while not conclusive, to suggest strongly that Soddy had by this time already completed "Alchemy and Chemistry."[18] In other words, influenced by alchemy he proposed transmutation as chemistry's ultimate goal weeks or months *before* discovering thorium transmutation.

The effect of realizing that he had so quickly and unexpectedly taken what seemed a major step toward achieving his goal was transcendent:

> I was overwhelmed with something greater than joy . . . a kind of exaltation, intermingled with a certain feeling of pride that I had been chosen from all chemists of all ages to discover natural transmutation.[19]

Soddy and Rutherford were still a long way from developing their complete theory of radioactive disintegration; for that, another year and a half of inspired research was necessary.[20] Yet to Soddy the import of this one initial insight was "colossal."[21] At the very moment of postulating the natural transmutation of thorium, he was himself transmuted. From a writer of chemical history and a young chemist of ambition and promise but no proven distinction, instantly he felt transformed into a significant historical actor, the lineal descendant of countless past generations of alchemists and scientists.

In "Alchemy and Chemistry" Soddy had, however, expressed the hope of learning to transmute the elements at will. His creative act in discovering natural transmutation was recognizing that thorium was transmuting *itself*. That discovery established that transmutation could indeed occur, and that it could occur on earth absent the transcendental conditions present in stars. Nonetheless, the long-term goal of learning to induce and control transmutation—a goal that Soddy came to term "artificial transmutation"—remained intact.

Thus began Soddy's quest to control the internal forces of the atom. Evidently his interest soared early and endured long precisely because the goal of artificial transmutation held profound personal meaning for him—owing to the manner in which he had set it and, shortly thereafter, made what seemed a significant advance toward its attainment.

Atomic Energy and Practical Applications

Soddy's original (1901) objective in proposing transmutation had been merely to advance pure scientific knowledge or, at most, in some quite vague sense to control "the forces of nature."[22] That such a discovery might have far-reaching technological and social consequences dawned on him only gradually over the course of several years.

Following Marie Curie's discovery of radium in 1898, scientists had been baffled and intrigued by the energy associated with radioactive emissions.[23] By Spring 1903, Soddy and Rutherford had persuaded themselves that the energy manifested during radioactive decay was internal to the atom, and that comparable quantities of energy were probably latent within nonradioactive elements as well.

During this period, Pierre Curie and Albert Laborde obtained an accurate measure of the amount of energy released during atomic disintegration, concluding that it was a million times greater than the energy liberated by an equal weight of any known chemical reactant or explosive. Soddy began to suspect that the goal he had proclaimed in 1901—artificial transmutation of the elements—might, as an inevitable but previously unsuspected *by-product*, release prodigious quantities of energy. With Rutherford he speculated that subatomic processes might even account for the maintenance of solar energy.[24] All of these striking conclusions were based on theory and experimental evidence obtained prior to the development of the nuclear model of the atom and to Einstein's formulation of relativity theory (with its famous $E = mc^2$ equation).

Soddy returned to England in 1903 and soon reported to Rutherford that their own work and that of the French had fired the imagination of the scientific community. The excitement among scientists proved infectious; in 1903 and 1904 popular and semitechnical journals were flooded with articles, not always accurate, describing the various wondrous properties of radioactive matter. Soddy, for his part, embarked on what amounted to a parallel second career as a popularizer and public interpreter of the new science of radioactivity. Beginning in 1903, when he was 25, and continuing to the end of his long life, he wrote articles and books and gave lectures intended for nonscientific audiences.[25]

No doubt Soddy's interest in practical uses of science stemmed in part from his childhood. For example, in adolescence he contrived to illuminate his room for half-hour periods with an electric light powered by a chemical battery. Since then, however, he had to some extent internalized the "pure" scientist's characteristic rhetoric of disdain for applied science.[26] Thus Soddy's first popular discussion of "Possible Future Applications of Radium" (July 1903) was evidently motivated partially by his simple desire to stimulate creation of an English radium industry that would, among other things, supply scientists with greater quantities of that rare and expensive element so vital to their research.[27] Near-term medical and industrial uses of natural radioactivity were stressed, and only the last paragraph alluded to artificial transmutation.

By 1906 Soddy had reordered and clarified his priorities, suggesting to scientists that the most significant practical application of atomic science would be in providing a source of mechanical and electrical power.[28] He popularized these views in 1908 in a series of public lectures and in *The Interpretation of Radium,* a book that was translated into several languages and read widely in Europe and America.[29] Soddy now imagined an atomic-powered humanity able to "transform a desert continent, thaw the frozen poles, and make the whole world one smiling Garden of Eden." To do this it would be necessary to "artificially accelerate or influence the rate of disintegration" of atoms. Success appeared a matter only of time, for

> [l]ooking backwards at the great things science had already accomplished, and at the steady growth in power and fruitfulness of scientific method, it could scarcely be doubted that one day we should come to break down and build up elements in the laboratory as we now break down and build up [chemical] compounds, and the pulses of the world would then throb with a new force.

Soddy's enthusiasm was tempered only by the sobering recognition that at "present we have no hint of how even to begin the quest," and thus fulfillment of man's "aspiration . . . to regulate . . . the primary fountains of energy . . . is, no doubt, far off."[30]

Technological Utopianism and the idea of progress were commonplace in the late nineteenth and early twentieth centuries, and Soddy had probably read science fiction along such lines.[31] But apart from contributing to the realization of Utopia, artificial transmutation would, he came to believe, also become *necessary* as an eventual substitute for the world's limited supplies of fossil fuels: A "turning point is being reached in the upward progress" of civilization, he wrote in 1910. "Thoughts of economy and conservation will inevitably replace those of development and progress. . . ."[32]

The impending exhaustion of Britain's coal mines had been debated since, if not before, the publication of Jevons's *The Coal Question* in 1865.[33] Soddy never cited the book, but the issue was in the air and he alluded to it as early as 1903.[34] A great boost in his interest must have come from George T. Beilby, an important industrial chemist and one of Britain's leading advocates of efficiency in the industrial use of fuel. Beilby was responsible for the creation of a teaching position that Soddy occupied at the University of Glasgow in 1904; four years later Soddy married his daughter.[35]

The year 1908 was also the year Soddy completed the construction of one additional belief that seems afterwards to have played a vital role in shoring up his conviction that artificial transmutation would eventually become possible. Using imagery drawn from religion, mythology, and, once again, alchemy, he was led to speculate that the technology needed to release atomic energy may already have been developed—and then lost and forgotten—in the distant past. He fashioned this idea over a period of several years.

Religious Myth and Rediscovery

In the period 1903-1905 Rutherford and Soddy announced that by taking into account the natural release of energy from within the atom, the physically admissible age of the earth and of the sun could be extended backwards in time an order of magnitude beyond that which physicists had previously allowed.[36] But what of the future? The Second Law of Thermodynamics, formulated during the nineteenth century, implied pessimistically that the entire universe was grinding inexorably toward a dark and chilly death. "Although," wrote Rutherford in 1905,

> consideration . . . [of the internal energy of the atom] may increase our estimate of the probable duration of the sun's heat, science offers no escape from the conclusion of Kelvin and Helmholtz that the sun must ultimately grow cold and this earth must become a dead planet moving through the intense cold of empty space.[37]

Soddy was not so sure. Norman Lockyer's stellar observations were consistent with the hypothesis that within some stars, heavy elements were evolving from light ones. What if atomic *disintegration* occurring (with an accompanying release of energy) in some parts of the universe were offset by a complementary process of atomic *upbuilding* (and energy absorption) occurring elsewhere?[38]

> The universe would then appear as a conservative system, limited with reference neither to the future nor the past, and demanding neither an initial creative act to start it nor a final state of exhaustion as its necessary termination.[39]

> There is at least a dawning probability that . . . the universe may be regarded as . . . [a] system . . . proceeding through continuous cycles of evolution.[40]

Radioactivity itself, prior to the Rutherford-Soddy disintegration theory, had induced some doubt among physicists regarding the universal applicability of the Second Law.[41] Although Soddy was not unduly eager to dispense with so powerful a generalization,[42] it was, as he said in 1904, "an era of speculation . . . and the more the problem [of the origin and end of the universe] is regarded from independent points of view the more likely is the speculation to prove fruitful."[43]

This was not the last of his experiments with speculation. Soddy's *The Interpretation of Radium* (1908) is ungarnished laboratory science until its final chapter, in which suddenly—while still constrained by the bounds of established scientific possibility—imagination is let loose to weave a stunning cosmological tapestry from which emerges, in turn, the single fullest expression of Soddy's Utopian hopes.

Heightened emotions may help account for this imaginative *tour de force,* for recall that 1908 was the year in which Soddy married. We cannot know exactly what was in Soddy's mind, but psychologists and anthropologists do tell us that during episodes of major life transition, people experience a universal need for symbolic immortality, "for imagery of connection predating and extending beyond the individual life span."[44] If so, Soddy—for whom, as a motherless child, marriage may have held unusually acute and complex significance—appears to have succeeded stupendously in establishing the requisite sense of connection with the past and future.

In *The Interpretation of Radium*'s last chapter, Soddy reiterated his earlier ideas regarding the possibility of a greatly extended—if not cyclic and therefore infinite—age and duration of the universe. But now he expressed his views novelly:

> Radioactivity has accustomed us in the laboratory to the matter-of-fact investigation of processes which require for their completion thousands of millions of years. In one sense the existence of such processes may be said largely to have annihilated time.[45]

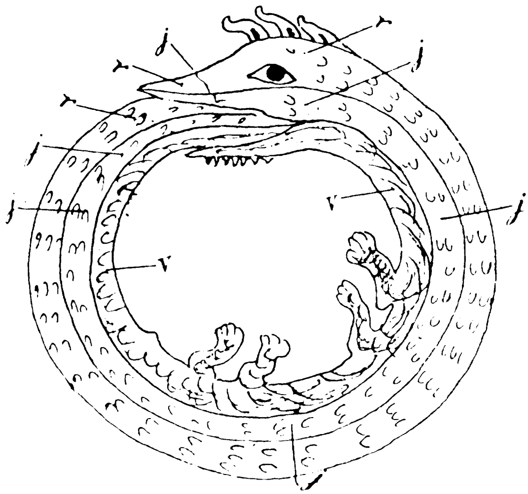

Figure 1. Ouroboros, the Tail-Eating Serpent of the Alchemists
SOURCE: Soddy, 1949, p. 3.

Annihilate time. Throughout this chapter something curious began to happen to Soddy's writing. He appears to have lost control of his verbs, alternating bizarrely from past to present tense. It is almost as though when using the past tense, he was writing a letter to the year 1908 from a vantage point located millions of years in the future—or in the past.[46] Is it possible that Soddy had so distended his conceptions that for a while he became psychologically unhinged in time? My surmise is that Soddy may, in other words, have been in the throes of what Maslow calls a "peak experience."[47] But whatever its precise source, his imaginative energy bloomed magnificently.

Since 1901 Soddy had been alternately captivated and mystified by Ouroboros, a favorite symbol of alchemists throughout the ages, and one associated psychologically with the yearning for transcendence and immortality (see Figure 1). The meanings that Soddy publicly attributed to the serpent varied throughout his later life, presumably adapting to shifting psychological or literary needs.[48] In *The Interpretation of Radium* the symbol seems clearly to have functioned as a source of creative inspiration. If, Soddy wondered,

> the world is no longer slowly dying from exhaustion, . . . what about Man? . . . Here again it is interesting and harmless to indulge in a little

> speculation. . . . Consider, for example, the ancient mystic symbol of matter, known as Ouroboros—"the tail devourer" . . . .[49]

Soddy took an important leap. If one wished to symbolize a cyclic and regenerative cosmological process, "in what better way could it be done than by the ancient tail-devouring serpent?"[50] Was it mere coincidence that this ancient symbol could so tidily encompass the most modern scientific conceptions?

> I prefer to believe it may be an echo from one of many previous epochs in the unrecorded history of the world, of an age of men which have trod before the road we are treading today. . . .[51]

Soddy's long-standing belief in a single progressive ascent of scientific knowledge had crumbled, permitting him to imagine possibilities that would previously have been unthinkable:

> Can we not read into . . . [ancient myths and superstitions] some justification for the belief that some forgotten race of men attained not only to the knowledge we have so recently won, but also to the power that is not yet ours?[52]

His mind moved naturally to consider the Biblical story of the Fall of Man—a tale familiar from childhood and perhaps brought to mind now by intuitive association of the alchemists' serpent with the serpent guarding the tree of knowledge in the Garden of Eden:[53]

> Science has reconstructed the story of the past as one of a continuous Ascent of Man. . . . [T]he traditional view of the Fall of Man from a higher former state has come to be more and more difficult to understand. From our new standpoint the two points of view are by no means so irreconcilable as they appeared. A race which could transmute matter would have little need to earn its bread by the sweat of its brow. . . . [S]uch a race could transform a desert continent, thaw the frozen poles, and make the whole world one smiling Garden of Eden. Possibly they could explore the outer realms of space, emigrating to more favorable worlds . . . .[54]

Thus when Soddy first dreamed what is unquestionably his most sublime Utopian image, he was as much looking backwards as ahead. Only later did he transplant this specific vision firmly and unambiguously into the future.[55]

But if it had all been done before, what had happened in the interim? Perhaps into every atomic Utopia, a little fallout must rain:

> One can see also that such dominance [of men over Nature] may well have been short-lived. By a single mistake, the relative positions of Nature and

> man as servant and master would, as now, become reversed, but with infinitely more disastrous consequences. . . .[56]

That myths survived the ancient holocaust could if necessary be attributed to "latent collective human memory."[57]

In later editions of the book, this chapter has been revised. The section in which time was "annihilated" has itself vanished, misconjugated verbs have been purged, and the Fall of Man results not from a disastrous mistake but "for some unknown reason."[58] Insofar as Soddy introduced his discussion of alchemy and rediscovery as a bit of "interesting and harmless . . . speculation," why begin to suspect that he took it seriously?

Belief in a former atomic age was sufficiently daring that Soddy did in later years seem to waver. Yet the notion that artificial transmutation may have been achieved in an earlier age reappears in his later writing with sufficient frequency and conviction—particularly during the 1914-1919 period—that it is impossible to dismiss it as a one time passing fancy.[59] Moreover, the idea apparently came to serve an important function within the overall pattern of his thought.

Quite independent of any suspicion that he and his contemporaries may have embarked on a scientific voyage of rediscovery, Soddy had found plausible scientific reasons for supposing that humans would in the future probably be able to harness the atom's energy: Natural transmutation occurred on earth, and postulating some sort of accelerated transmutation seemed the most satisfactory way to account for stellar processes. Thus he reasoned in 1906:

> We are starting the twentieth century with the prize in full view, with every factor in the problem accurately and quantitatively known, with the actual process in full operation under our eyes in the laboratory of Nature, and with nothing therefore to be accomplished but the familiar sequence of imitation, improvement, and control.[60]

Nonetheless, while momentous developments in scientific understanding of the atom continued to unfold during the years before the first World War, not one of these harbored an obvious clue as to how, or even whether, it would become possible to control atomic energy. In succession came Einstein's special theory of relativity (1905), the nuclear model of the atom (proposed by Nagaoka in 1904, extended and confirmed experimentally by Rutherford in 1911), Bohr's contributions to the rudiments of quantum theory (1913), and the invention by Soddy and others of the concept of isotopes (chemically identical elements with different atomic weights, 1907-1914). Yet it still proved impossible to induce transmutation artificially or to accelerate the rate of decay of naturally occurring radioactive atoms.

Thus the years following his initial (1903) expression of interest in atomic power afforded Soddy ample opportunity to become frustrated and lose faith in the practicability of artificial transmutation. And it was at precisely those moments, when he seemed to waver in his conviction and wrote most emphatically of the impending risk of depleting the earth's fossil fuel resources, that he failed also to allude to the existence of an ancient atomic civilization.[61] Thus the idea of rediscovery, an outgrowth of Soddy's familiarity with alchemy and religious myth, appears to have been an essential crutch that supported and reaffirmed his belief that means of tapping the atom's energy might not forever elude the human grasp. In short, the notion that artificial transmutation may already have been accomplished in the distant past provided the best possible grounds for supposing that it could probably be done in the future.

Science Fiction and Politics

But was it really certain that artificial transmutation would, if developed, usher in an age of peace and plenty? Essentially a technological determinist and optimist, Soddy had so far implicitly assumed that once the secret was revealed, atomic technology would automatically and unproblematically issue forth. The world would be transformed in accordance with both scientists' benign intentions and ineluctable physical necessity. The course of human events soon helped alter that outlook, impressing upon Soddy the lesson that particulars of a social setting can strongly shape the design, choice, and use of technological systems.

Shortly before World War I, Soddy accepted a full professorship at the University of Aberdeen, Scotland. His plan had been to continue his chemical studies of radioactivity, but the war depleted the university of students. Throughout Britain scientific laboratories were converted into facilities for war production and research. The new professor of chemistry worked night and day assisting in the manufacture of local anesthetics, performing chemical and engineering investigations pertinent to naval propulsion, and supervising the work of others.[62] He thoroughly enjoyed the technical challenges of his war-related research, but "the war dragged on and I felt the futility of it all. The greatness of scientific achievements was being used for destruction. . . ."[63]

Soddy's subsequent turnabout from prognosticator of Utopia to prophet of atomic Armageddon can in the broadest sense be attributed to World War I, but actually more specific influences were at work. Through visits to his father-in-law's household in Glasgow, Soddy had become immersed for the first time in an atmosphere of serious political discussion. He emerged a passionate advocate of women's suffrage and Irish home rule—both burning issues of the day. Moreover, the prewar years were socially turbulent, and Glasgow in particular was a hotbed of radical agitation on the part of industrial labor unions.[64] Thus in a 1913 *New York Times* article—"Science on Road to Revolutionize All Existence"—Soddy reiterated his accustomed Utopian imagery in a manner that now reflected a distinct undercurrent of tension and ambivalence.[65] Yet what seemingly cinched his full change of heart were events, and in particular a genuine dialectical process, only beginning to unfold.

So compelling was *The Interpretation of Radium*'s prophetic vision that during the summer of 1913, while vacationing in Switzerland, H. G. Wells found in it the inspiration to write a novel—science fiction conceived on a grand scale. The dedication of Wells's *The World Set Free* reads:

To
Frederick Soddy's
Interpretation of Radium
this story
which owes long passages
to his eleventh chapter
acknowledges and inscribes itself

Wells's book indeed includes several near-verbatim renditions of Soddy's prose. Beyond what he borrowed, however, Wells brought to his task an awareness of contemporary social history that Soddy still lacked.[66]

The novel's prelude portrays an Edinburgh professor of physics—obviously modeled after Soddy—delivering in 1910 the course of public lectures that Soddy had in fact given in Glasgow in 1908. Peering into the future, Wells then described a solitary scientist's discovery of the means to control atomic energy in 1933, horrendous social and economic dislocations that attend the gradual industrial application of atomic power, atomic industrial accidents, and a civilization-shattering atomic war occurring in the late 1950s. Airplanes drop "atomic bombs"—black metal spheres several feet in diameter containing a heavy artificial element, "carolinum"—destroying over two hundred major cities.[67] The result in each case, while not quite a mushroom cloud, is a "continuously exploding" radioactive volcano that renders the targeted land uninhabitable for decades.

The World Set Free, for all that, remains fundamentally optimistic. The destructive shock awakens people's sanity, and from the rubble arises a Utopian socialist world government. When the real world war broke out in August 1914, Wells considered his prophecy vindicated. He became—although he later regretted it—an unabashed war propagandist, bequeathing to future generations his ironic promise that World War I would be "The War That Will End War."[68]

Soddy read and praised the novel,[69] but evidently gave it quite a different interpretation. Prior to World War I, the conviction had been voiced in some quarters that modern weaponry made possible by science had already rendered warfare unthinkable. In 1900 Soddy met a professor of history who told him flatly that there would never be another war.[70] Wells could be read to provide an alternative hypothesis: People would continue to fight even with the most terrible weapons conceivable. When the actual hostilities erupted, Soddy seemingly witnessed these two competing hypotheses put to the test.

Regrettably, the Wellsian hypothesis was, in more than one respect, confirmed. The Great War became, as Wells had prophesied, a *world* war in which entire nations—masses, factories, and scientific elites included—were mobilized. Chemists played an important role, notably in the development of toxic gases. In one case after another, technological processes that had formerly seemed benign and beneficial were transformed into engines of war. Soddy was shocked particularly to see artificial fixation of atmospheric nitrogen—a process used prior to the war to replace scarce natural fertilizers—applied in the wholesale production of bombs and explosives. Even his beloved radium, added to paint for nighttime illumination of war instruments, found destructive applications.[71]

In an address delivered in November 1915 to the Independent Labour Party in Aberdeen—and published after the war—Soddy asked his audience to

> suppose that it became possible to extract the energy, which now oozes out [slowly] . . . from radioactive materials . . . , in as short a time as we pleased. From a pound weight of such substances one would get about as much energy as would be obtained by burning 150 tons of coal. How splendid! Or a pound weight could be made to do the work of 150 tons of

> dynamite. Ah! there's the rub. Imagine... what the present war would be like if such an explosive had actually been discovered. . . .[72]

Would weapons of total destruction persuade humankind to abandon warfare altogether? Soddy concluded perspicaciously that they would not:

> Some thought science had already made war impossible. As it has not, it may be concluded that no future development of science, however world-shattering, will of itself have that effect. . . . It is our duty, therefore, to spend our lives and brains thinking this thing out for ourselves. It must not be left for our successors to relearn all over again.[73]

In the same year he informed members of the Workers' Educational Association in Aberdeen that

> no one could pretend that in the present stage of human development such a further advance [human control of atomic energy] would be a blessing. The race is not yet fit to be trusted even with the enlarged physical powers which science has already conferred upon it. It has taken these gifts in the spirit handed down from a bygone age, a pop-gun of predatory chieftains, and it has made of them an abomination.
>
> To sum up in brief, the social effect of recent advances in physical science promises to be annihilating, unless, before it is too late, there arises an equal and compensating advance, of which there is at present no sign, in the moral and spiritual forces of society.[74]

Even if prior to reading Wells, Soddy had on his own begun to worry that atomic energy might be used destructively,[75] it seems that the novel was important in providing him with vivid and concrete images of atomic war.[76] Acknowledging the plausibility of *The World Set Free*'s prophecy of atomic war, but tacitly rejecting Wells's Utopian conclusion, Soddy with his strong sense of duty was about to invent a social role—that of the atomic scientist as aspiring world-saver—that would in another three or four decades become almost commonplace.[77]

Postscript and Conclusion

For his contributions to the development of the concept of isotopes and to the radioactive displacement laws (which showed how to assign the atomic products of radioactive decay to their correct positions within the familiar periodic table of the elements), Soddy was awarded the Nobel Prize in Chemistry in 1921.[78] Accepting his prize, Soddy spoke eloquently of "the catastrophe which has recently engulfed the world," and wished

> to acknowledge and accept my own share of responsibility and blame for this. . . . Scientific men can hardly escape the charge of ignorance with regard to the precise effect of the impact of modern science upon the mode of living of the people and their civilization. . . . But, at least, perhaps not all of us are now totally blind to the dangers ahead, or to the need of . . . impersonal but remorseless re-examination of the foundations of society. . . .[79]

These were not idle words. By this time Soddy had become a professor at Oxford and an outspoken social critic who, almost alone among his generation of British scientists, worked tirelessly to try to avert social misuse of atomic energy and of scientific discoveries generally.[80] Soddy understood, among other things, that the moment atomic power became available, it might already be too late to prevent its use for destructive ends.

The impact of Soddy's many efforts at persuasion was less than he would have hoped, and sometimes indirect—but not inconsequential. For example, after World War I, Soddy contributed frequently to the journal *Nature* on political subjects. There other scientists took some note, among other things, of his cautions against conducting science in the service of "big business," or of participating uncritically in war research.[81] While never a socialist, Soddy contributed occasionally to left-wing publications.[82] He gained attention in 1935 for spearheading an unsuccessful effort among dissident members of the Royal Society to democratize that establishment-oriented scientific institution.[83] And, from time to time his warnings concerning atomic energy elicited a prominent public endorsement or rebuttal.[84]

But Soddy's favorite ideas for social reform—a corpus of deeply imaginative but unorthodox economic and monetary theories that he pioneered during the 1920s and 1930s—never earned more than sporadic public attention.[85] As he turned increasingly from scientific research to political and economic concerns, his public credibility suffered.[86]

Meanwhile, and with some historical irony, H. G. Wells's Soddy-inspired novel, *The World Set Free,* was read by—and in various ways influenced—numerous scientists who participated in developing the atomic bomb during World War II.[87] Soddy never knew this. But he did live to witness the realization—in the form of Hiroshima, Nagasaki, and the nuclear arms race—of some of his darkest dreams. The week following Japan's surrender he produced a political analysis of atomic energy, poignantly informing readers that

> during the . . . [first] World War, the writer frequently expressed the fervent hope that this discovery would not be made before the nations had learned to use and honour science for its creative rather than destructive power.
>
> Indeed, that holocaust compelled him as a scientific man to make a critical examination of what passes for "economics," in order to discover why beneficent inventions and discoveries produced nothing but misery, frustration and war.[88]

Frederick Soddy died in relative obscurity in 1956.

* * *

Reviewing Soddy's life, it becomes evident that to appreciate fully the lethal social potentials inherent in atomic science he progressed through a series of intellectual stages—from a purely scientific interest in transmutation to the prophecy, first, of Utopia and, finally, of atomic war. Before and after World War I, other scientists—for example, Rutherford, Henri Becquerel, F. W. Aston, and Sir Arthur Eddington—took halting steps along an analogous path, but none came close to a synthesis of comparable power or vision, nor developed anything approaching Soddy's degree of concern and social commitment.[89]

The difference can largely be attributed to Soddy's deep emotional involvement with his subject, balanced and integrated with his profound imaginative skills, and with both an ability and willingness to draw on such diverse sources of knowledge as modern science, ancient alchemy, the Bible, H. G. Wells, politics, and history. Thus just as Soddy used scientific knowledge to help interpret alchemy and mythology, so in turn he used nonscientific knowledge to help establish a broader context within which his penetrating intuition and logic into the social implications of science could emerge, and be sustained and energized.[90] Soddy ably fulfilled the suggestion of psychologists and philosophers that we strive to balance dispassionate intellectual inquiry with periods of intense creativity and emotional engagement.[91]

* * *

Does Soddy's story have implications for today's attempts to grapple with the social implications of technology and science? I offer several hypotheses.

First, and most obviously, we could benefit from further historical studies of past "technology assessments." If Soddy's history is any indication, these should provide an important basis for developing generalizations concerning promising—and unpromising—approaches for undertaking future technology assessment activities.[92] Such histories might also provide useful role models for today's scientists, engineers, students, and others. (On both counts—as well as for insight into how a far-seeing technology assessment can be used—an adequate treatment of Soddy's post-World War I life would be helpful.)

Second, today's recommended methodologies for technology assessment often focus on fostering logical, deliberate, systematic inquiry.[93] The resulting reports, while sometimes quite insightful, tend nevertheless toward politically cautious, lifeless, mechanical extrapolation. Yet Frederick Soddy, who produced one of the most successful prospective technology assessments on record, did so without ever fully divorcing rigorous logic from passionate involvement, imaginative speculation, sociohistorical awareness, and complementary nonscientific knowledge.

I therefore suggest that we experiment with ways of undertaking technology assessments that may encourage participants not only to demonstrate intellectual skill and breadth, but also to respect and develop their emotional, intuitive, and imaginative faculties. Perhaps likewise, people with demonstrated imaginative gifts—poets, artists, novelists, performers, and so on—should be explicitly invited to participate,[94] as should be those who have intimate knowledge of the social contexts in which a technology promises to be developed or used.[95]

Finally, consider those to whom technology assessments are addressed (a group that potentially includes all citizens). How do we interpret and judge a technology assessment? Ought we to become somewhat less impressed by the mere appearance of scientific authoritativeness, while correspondingly more receptive to evidence that an assessment reflects balanced contributions from its authors' hearts, minds, intuitions, creative powers, and reasoned moral sensibilities? Suppose particularly that there are always likely to be a few Frederick Soddys among us. Can we find the wisdom, both individually and institutionally, to listen sensitively to those who may at first seem under the sway of an overexcited imagination, without thereby forsaking the essential role that our critical and discriminatory faculties can play?

Notes

1. In fact, by the 1920s and 1930s science fiction and scientific speculation had introduced the concept of harnessable atomic energy to a relatively wide audience. See Weart (1988).

2. On Soddy's priority and exceptionalness in evaluating the social significance of atomic energy, see Weart (1985, 1988); Freedman (1979, 259); Trenn (1979, esp. 273 f.); Mumford (1970, 233, 255 f.); Muller (1935, 63).

3. For further examples and supporting argument see, for instance, Fleck ([1935] 1979); Forman (1971); Feyerabend (1975); Dobbs (1975); MacLeod (1977); Bloor (1976); Mulkay (1979); Latour and Woolgar (1979); Knorr-Cetina (1981); Gould (1981); Shapin (1982); Keller (1985).

4. In this respect I differ with Weart (1988, e.g., 430 f.), who tends toward the view that mythical imagery necessarily sways emotion in a way that distorts understanding. The case of Soddy suggests to me the need for considerable qualification on Weart's position. See my succeeding text.

5. Howorth (1958).

6. Trenn (1977).

7. Eve and Chadwick (1938).

8. Cardwell (1972, 190).

9. Howorth (1958); Fleck (1957, 203).

10. Soddy, "Lectures on the History of Chemistry from Earliest Times," TS and MSS, Soddy Collection, Bodleian Library, Oxford, Catalog No. 2 (Hereafter cited as SCB 2).

11. Ibid., Lecture II, 5-8.

12. F. Soddy, "Chemical Evidence of the Indivisibility of the Atom," MS, SCB 101; Lockyer (1900); Trenn (1977, 24-27); Howorth (1958, 79-81); Davis (1974, chap. 2).

13. F. Soddy, "Alchemy and Chemistry," TS, SCB 100, p. 1; Berthelot (1885). For background on Berthelot see, for example, Weart (1979, 3-59).

14. Soddy, "Alchemy and Chemistry," 16.

15. Ibid., 19.

16. Although there is no evidence that Soddy was aware of it, somewhat similar ideas regarding transmutation had been propounded earlier—for example, during the previous decade by British chemist Lyon Playfair. See Crowther (1965, 164 f.); and also Malley (1979, 215, n. 16); Trenn (1974, 54 f.); Badash (1966, 95).

17. Trenn (1977, 36-48); Howorth (1958, 64-91).

18. The chronology I suggest differs, for example, from that implied in previous histories, including Trenn (1977, 42). Trenn—whose work is generally excellent—here assumes tacitly that Soddy wrote "Alchemy and Chemistry" only after discovering natural transmutation.

Soddy must indeed have written "Alchemy and Chemistry" sometime after March 27, 1901, for on that date, in formal public debate with Rutherford, he continued to resist the concept of a transmutable atom. (See Trenn [1977, 24-6]; and Soddy, "Chemical Evidence" [n. 12, above].) Trenn (1977, 42) cites notes that Soddy evidently used in presenting a lecture at McGill after the discovery of natural transmutation (ca. Oct. 1901) as evidence that it was only at this time that Soddy began to take a serious interest in alchemy and practical transmutation. (See Soddy's "Alchemy—A Chapter in the History of Science," TS and accompanying "Notes," SCB 99).

These papers do seem to allude directly to the fact that earthly natural transmutation had by this time been found. For example, "Recent physical work, done nowhere in the world more than in Montreal enables us to detect changes in matter heretofore only appreciable after geological epochs of time" (Soddy, "Alchemy—A Chapter," 3.) There is, however, no such allusion in "Alchemy and Chemistry," in which Soddy discussed transmutation solely within the contexts (a) of Thomson's and Lockyer's hypotheses, and (b) of seeking to effect it on earth through purposive human effort.

Now, especially given his allusions in "Alchemy—A Chapter, " it seems hardly likely that Soddy would have refrained in "Alchemy and Chemistry" from also at least alluding to his own recent "world-shattering" "colossal" discovery of natural transmutation if indeed—as Trenn assumes—that discovery had already occurred. (The quoted words are Soddy's in Howorth [1958, 82].) This internal evidence helps persuade me that in reality Soddy and Rutherford had not yet made their discovery, and thus that Trenn's assumption is unwarranted. As Soddy himself later related:

> I had written in my paper "Alchemy and Chemistry" that transmutation had not yet been found; yet when the time came to investigate the phenomenon [thorium emanation] the whole thing seemed too devastatingly simple.

(Quoted in Howorth [1958, 83]).

Howorth's own chronology is somewhat garbled, but I follow Trenn and others in seeing no reason to assume that her direct quotes of Soddy are unreliable. The startling ease with which Soddy concluded that thorium was "transmuting," as well as the intelligibility and coherence the chronology I propose lends to Soddy's later life, both provide additional, indirect evidence in that chronology's favor. (See my succeeding text, and also note 56, below. The method of reasoning I employ here is discussed in Taylor [1979, 27 f.]. On the patent nonobviousness, at the time, of Soddy's discovery of transmutation see, for example, Malley [1979, 215-220]; and Pais [1977, 124 f.]).

Thus while there is lingering ambiguity, I find the balance of evidence to support this sequence: Insofar as Soddy does not cite it in his earlier lectures on the history of chemistry, it seems to me most probable that he read Berthelot's book after March 1901—perhaps during the summer, which he spent in England—having already been won over at least partially to the physicists' model of the atom. Sometime afterwards he wrote "Alchemy and Chemistry," and shortly after that he and Rutherford discovered natural transmutation.

19. Howorth (1958, 83).

20. Trenn (1977).

21. Howorth (1958, 83).

22. Soddy, "Alchemy and Chemistry" (n. 13, above), 14.

23. See, for example, Crookes (1898, 26 f.); Jauncey (1946, 239); Pais (1977).

24. Soddy (1903a, 719 f.); Soddy (1903c, 226); Rutherford and Soddy (1903); Trenn (1977, 107-123).

25. Trenn (1977, 107, 111); Trenn (1979, 263); Heilbron (1979, 57 f.); Badash (1979, chap. 2).

26. Howorth (1953, 12); Soddy, "History of Chemistry" (n. 10, above, Lecture II).

27. Soddy (1903c, 225 f.); Howorth (1958, 23, 98 f.); 295); Freedman (1979).

28. Soddy (1906b).
29. Soddy (1908); Trenn, ed. (1975, 10).
30. Soddy (1908, 230-233, 244, 250).
31. Segal (1985). Soddy (1903c, 226) alludes to having read science fiction.
32. Soddy (1912a, 246 f.). Soddy wrote the book in 1910.
33. Jevons (1866).
34. Soddy (1903c, 226).
35. Freedman (1979, 259 f.); Beilby (1899); Howorth (1958, 132 f., 167).
36. Rutherford and Soddy (1903, 591); Soddy (1904a, 182-186); Rutherford (1905).
37. Rutherford (1905, 396).
38. Soddy (1903a, 719 f.); Lockyer (1900, esp. 68, 158 f.); Soddy (1903-04, 521, 646, 724 f.); Soddy (1904b, 38-42); Soddy (1906a, 130n.).
39. Soddy (1904a, 189).
40. Soddy (1904b, 42).
41. Pais (1977); Trenn (1977, 116).
42. Soddy (1903d, 239).
43. Soddy (1904b, 41). It was indeed an "era of speculation," particularly regarding the concept of time. See Brush (1979, 161 f.).
44. Lifton (1973, 47).
45. Soddy (1908, 239).
46. Compare Lessing (1979).
47. Maslow (1968). The significance of a peak experience is subject to various interpretations. For example, a Jungian might suggest that Soddy was tapping into material, or wisdom, that is latent in the collective unconscious.
48. See, for example, Soddy's "Alchemy and Chemistry" (note 13, above), 7; "Alchemy—A Chapter" (note 18, above), 1; Soddy (1903b); Soddy (1906a, 123); and Soddy (1949, 2 f.). On the psychological and religious meaning of Ouroboros, and of alchemical symbolism generally, see, for example, von Franz (1980); Eliade (1978).
49. Soddy (1908, 241).
50. Ibid., 242 f.
51. Ibid., 243.
52. Ibid., 243 f.
53. Soddy (1914, 260) mentions the tree of knowledge explicitly.
54. Soddy (1908, 244).
55. Soddy, "The Social Effect of Recent Advances in Physical Science" (1915, TS, SCB 112, 9-12).
56. Soddy (1908, 244). Soddy used essentially the same language about reversing "the respective positions of master and servant" in his "Alchemy and Chemistry" (note 13, above), 13. This suggests the ongoing vitality of that seven-year-old essay in his life.
57. Soddy (1914, 260).
58. See Soddy (1912b, 252); (1920d, 183).
59. Soddy (1914, 259 f.); Soddy, Keith Lecture notes (1913a), TS, SCB 105, Lecture IV; Soddy (1920f, 23, 86 f.); Soddy (1945b). Soddy was also aware of earlier alchemists' claims to have rediscovered their knowledge or learned it from more ancient texts. See, for example, Soddy "History of Chemistry" (note 10, above), Lecture II, 7. It seems likely that as Soddy began to take more seriously alchemical notions of transmutation, he also began to reconsider his earlier rejection of alchemists' claims regarding rediscovery. Soddy was, moreover, certainly not the first important scientist to believe that he might have

embarked on a voyage of rediscovery; see, for instance, Manuel (1968, 165, 391 f.) concerning Isaac Newton.

60. Soddy (1906b, 147).

61. See, for example, Soddy (1909); and, especially, Soddy (1912c). One factor in Soddy's intermittent doubts regarding atomic rediscovery was probably his interest in the geological hypothesis that radioactive heating within the earth might cause cyclical planetary overheating, melting and resolidification. See, for example, Soddy (1909, 57 f.); Soddy (1912a, 235-238); Soddy (1932, 319-322). In that case, past planetary cataclysms could more likely be attributed to natural than to human-induced atomic causes—thus weakening the argument for the prior existence of an atomic civilization.

As in his ideas regarding rediscovery, Soddy's interest in the idea of cyclical planetary destruction and rebirth roughly recapitulates a belief of Newton's. See Manuel (1968, 388). Apart from their shared familiarity with Biblical imagery, another source of this commonality presumably lies in both men's captivation with alchemical symbolism, including its potent unconscious involvement with questions of individual and cosmic death and rebirth. See Eliade (1978) and Weart (1988).

62. Page (1979); Varcoe (1970); Howorth (1958, 200-205); Soddy (1917); Williamson (1956).

63. Soddy quoted in Howorth (1958, 274 f.).

64. Paneth (1957); Howorth (1958, 167-169); Soddy (1913b), TS, SCB, 107; Marwick (1970, 70-72); Daiches (1977, chap. 16).

65. Soddy (1913d). See also Soddy, "Evolution of Matter," Citizen's lecture in the Digbeth Institute, Birmingham, 16 Sept. (1913c) TS, SCB 106; Soddy (1914, 241).

66. Wells (1914); Dickson (1969, 228).

67. I have so far been able to discover in the scientific literature of the day (Soddy's included) not a single speculative mention of the concept of "heavy artificial elements," much less the idea that these might one day prove a usable source of atomic energy. Thus I continue to be deeply perplexed—virtually awed—by Wells's eerie anticipation of the discovery and use of plutonium.

68. Wells (1934, Vol. II, 664-670); MacKenzie and MacKenzie (1973, 297-303); Marwick (1970, 48 f., 214); Church (1928).

69. See Howorth (1958, 194); Soddy (1926, 28).

70. Howorth (1953, 41).

71. Soddy (1909, 53); Soddy (1912a, 233-239); Soddy (1920f, 40, 108); Soddy, (1924, 9 f.); Page (1979, 132); Marwick (1970, 159-190); Kevles (1978, 102-138); Whittemore (1975); Badash (1979, 146-149); Weart (1979, 11 f.).

72. Soddy (1920f, 36).

73. Ibid., 38.

74. Soddy (1915, 13).

75. Soddy, Keith Lecture notes (note 59, above), Lecture IV (delivered on 10 March 1913), 45 f.:

> Yet, as might now happen any day, if one of the [scientific] workers tomorrow were to discover the means of liberating this [latent atomic] energy . . . the one sure and immediate use to which it would be put would be for war. . . . Last year . . . the maintenance of a modern war service . . . absorbed one-third of the available revenue of the country.

76. Soddy continued to make favorable references to the novel even after World War II. See, for example, Soddy, "Is the Deterioration of the Climate Due to the Radioactive Pollution of the Atmosphere?" (1954), TS, SCB 126, 2.

77. On atomic scientists' later attempts to "save the world" see, for example, Smith (1970).

78. Soddy (1923a); Söderbaum (1923); Kauffman, ed. (1986, esp. chaps. 1, 3-5).

79. Soddy (1923b, 107).

80. On Soddy's political exceptionalness among his British scientific generation see, for example, Werskey (1978, esp. 35, 37); Trenn (1979, 273); Marwick (1970, 238); MacLeod and MacLeod (1979, esp. 15 f.). Among his age-cohort of prominent, contemporary British scientists, Soddy's only peer in political consciousness appears to have been mathematician and philosopher Bertrand Russell.

It is possible that Soddy's active concern with the social impact of science reflected, among other things, his knowledge of the ethics of certain alchemists. For example, in "Alchemy and Chemistry" (note 13, above), p. 14, Soddy acknowledged the tradition through which an alchemist "sought by all means in his power to prevent the special knowledge he was possessed of falling into the hands of unworthy successors."

Soddy's life after World War I has not yet received adequate historical treatment. The best attempt to date is Trenn (1979). Cruickshank (1979) is informative on some points, but misleading and far too quick to pass judgment on others.

81. See, for example, Anonymous (1920); Soddy (1920a); and letters responding to Soddy by Boycott (1920), McKenzie (1920), and Campbell (1920).

82. See, for example, three articles by Soddy (1920e and 1920b and 1928).

83. Cruickshank (1979, 283 f.). For other instances of Soddy's criticism of the political conservatism or elitism of scientific societies, see two of his letters in *Nature* (1920c and 1938).

84. Fosdick (1929, 13); Millikan (1930).

85. See Trenn (1979); Daly (1980). Soddy's focus on the physical basis of economic processes—particularly on the role of energy and the laws of thermodynamics—anticipated by decades some of the thinking of economists such as Daly and Nicholas Georgescu-Roegen.

I believe that Soddy's interest in alchemical attempts to transmute base metals into gold exerted a role in his becoming concerned with the social effects of monetary policy. See, for example, Soddy, "Alchemy and Chemistry" (note 13, above, 5); Soddy (1906c, esp. 59 ff.); Soddy (1926, e.g., 144, 301); Soddy (1950, 3, 5). In this respect Soddy again parallels Sir Isaac Newton, whose interest in alchemy contributed to a serious preoccupation—as Master of the English Mint—with establishing the gold standard and preventing counterfeiting. See Manuel (1968, e.g., 63, 161-172, 231).

86. Russell (1961); Fleck (1957, 210-213); Paneth (1957, 1086 f.); Trenn (1979, 274, 276); Cruickshank (1979).

87. See, for example, Weart (1979) and Weart (1988).

88. Soddy (1945a, 9).

89. See, for example, Crookes (1910, xxiii); Eve (1939, 102); Eddington (1920, 46); Aston (1923, 14). Rutherford's best known comment on the subject was: "Anyone who says that with the means at present at our disposal . . . we can utilize atomic energy is talking moonshine" (quoted in Kaempffert, 1933).

90. On the role of nonscientific knowledge in sustaining scientific inquiry, compare Habermas (1971, e.g., 68 f., 304-306); Polanyi (1969, Parts 3 and 4); Bernstein (1983).

91. See Maslow (1968); Keller (1985); Beiner (1983); Dreyfus and Dreyfus (1984); Deikman (1982, esp. chap. 5 [on intuition]); Worster (1979, esp. chap. 4 [on Henry Thoreau's attempt to establish a science grounded in subjective, empathic, personal involvement]); Salk (1985).

That Soddy continued to rely importantly on his capacity for logic and dispassion is made evident by contrasting his behavior with that of his onetime mentor and collaborator, Sir William Ramsay. Beginning in 1903, Ramsay began a decade-long quest to achieve transmutation, in the course of which he repeatedly deluded himself into believing that he had a succeeded. "So firm was his own conviction in transmutation that he saw it wherever he looked" (Trenn 1974, 57). Soddy rarely, if ever, succumbed to this (not uncommon) sort of scientific self-deception.

92. For historial studies of less prescient technology assessments, see Corn, ed. (1986).

93. See, for example, Jones (1971); Porter et al. (1980); Armstrong (1980).

94. See also Sclove (1982). H. G. Wells's imaginative reworking of Soddy's thought—and the subsequent influence of Wells's novel upon readers—lend direct support to this recommendation.

95. See, for example, Henderson (1978, chap. 19); Berger (1977); U.S. Congress, Office of Technology Assessment (1976, 255-279); Barber (1985).

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