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SIR SAMURAI T. D. LUCKEY, PHD

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EARLY LIFE

I, Thomas Donnell Luckey, was born on May 15, 1919, in the Natrona County Hospital in Casper, Wyoming. It was a new hospital, and my father, Dr. Frank Seymour Luckey, physician, surgeon and rancher, was a founding director. Dad was taciturn, very knowledgeable, and the strongest man I ever knew. During my birth, my mother, Lily Waggener Luckey, had a near-death experience. She was ill for several months following my birth and my Aunt Floti Waggener took care of me during this time. Although we always had enough to eat, mother worked and acted as if we lived in poverty. I was the youngest of five with three sisters and one brother. We lived at 415 So. Beech St. My B average shattered my siblings' haloes of academic achievement through high school. I played basketball, clarinet (poorly), sang in choirs and musical productions, and, in 1933–34, was president of my 300 member freshman class at Natrona County High School. Summers were spent on our ranch.

Our ranch was about 60 miles north of Casper, about halfway between two famous spots in Wyoming: Kay Cee of the famous Johnson County range war in 1892, and the Hole-In-The-Wall, the only breech in a 30 mile red cliff through which "outlaws" escaped from the more settled country onto our range. The ranch consisted of about ten family/friends' homesteads of 640 acres each which controlled about 20 square miles of range on both sides of Murphy Creek. We eventually had about 500 cattle (5–8 were milked), about 150 horses (about 20 were used for work and riding), and 1–2000 sheep. The ranch provided a practical education in biology. I worked hard (half-days from 7 years old and full time from 11), mostly in hay fields, and became a good rider. I was not a cowboy, never had chaps, boots or spurs. Without radio, electricity, telephone, TV, or books, a boy had to do something. My hobby was snakes. I knew every part of Ditmar's (1931) encyclopedic volume on snakes. When I was about 11, "milking" rattlesnakes and collecting dried venom was a preamble to becoming a biochemist.

When the ranch went bankrupt in the summer of 1935, I became foreman with one hired hand, a cook and a few remaining animals. I graduated early from high school and had to study for the fourth year of English (literature) in order to complete the requirements. That summer, 1936, I was the only person within a 10 mile radius. I would go for

weeks at a time without seeing a single person. Dad brought supplies once every two weeks; if I were riding the range, he would leave groceries on the kitchen table and pick up my list.

In the fall of 1936, I started college as a pre-vet and vet student at Colorado A&M, Ft. Collins, CO. When I realized I didn't want to be called out of bed in the middle of the night to deliver Farmer Jones' pigs, I became a chemistry major at the University of Wyoming at Laramie, WY. At summer camp (1939) in Ft. George Wright near Spokane WA, I earned my 2nd lieutenant commission in R.O.T.C. I graduated from Colorado State University with a B.S. in chemistry in 1941. Next was one year at Texas A&M doing graduate research in organic chemistry. In 1942, I went to the University of Wisconsin and received a M.S. degree in 1944 and a Ph.D. in biochemistry/nutrition in 1946. I had a record of 23 publications from my four years at Wisconsin University. Most are included in the first few pages of my 280 publications.

In 1942, my reserve commission from the university of Wyoming (infantry) was not welcome at Texas A&M (artillery). My poor eyesight kept me from being commissioned in the air force. I became exempt from the draft because my Ph.D. thesis was "essential war research" within a consortium of universities contracted to evaluate the U.S. Army field rations.

MID-LIFE

In 1943, I married Pauline Miller (1921–2000), a Home Economics student from Portage, WI. Each year, I lectured at various meetings and we visited her family at Portage (Fig. 1). From 1946 to 1954 I was assistant/associate research professor at the Laboratory of Bacteriology at the University of Notre Dame (LOBUND). Our three daughters were born in South Bend, IN: Jane, July, 1947; Mary, December, 1948; and Donna, June, 1950. We vacationed at Rosita, our condo at Winter Park, CO. In 1954, I became professor and chair of the Department of Biochemistry and member of the Executive Faculty at the new four-year Medical School of the University of Missouri at Columbia, MO. I quit the chair after 14 years and, in 1984, retired after 30 years of teaching and research at UMC.

RETIREMENT

After traveling in Europe the last three months of 1984, we moved to a home on the east shore of Silver Lake (1009 Sitka St, Loveland, CO); this helped Pauline's asthma. I continued studying, writing and lecturing, while developing the interest in dolls that Pauline and I had started during our several trips to Europe. During visits to antique shops and doll fairs, I would often comment,"I had this toy when I was a boy." This became my salute to the love of a Dad who talked so little. Pauline pub-

FIGURE 1. Don visits the Miller farm near Portage, WI, 1950.

lished about 20 articles in doll magazines. My job was photographer and "Doll Doctor" as needed; Pauline did the dressing and writing. With Pauline's help, I authored an article, Doll Hunting in Germany (Luckey and Luckey 1980), and wrote *A Vignette of 29th Century America: Horsman Dolls* (Luckey and Luckey, 2003);this had 246 pages including many dolls in 34 pages of color.

Late in 2001, I moved to Lawrence, KS, where my youngest daughter, Donna Luckey, was chair of the Architecture Program in the School of Architecture at Kansas University. She and her husband, John Heider, made my life very comfortable. My writing has been productive only with her frequent computer help.

The above background introduces the major drive of my life, research. It is obvious that I am a writer who can't quit. I continue to write and publish articles on radiation hormesis into the 21st century. In the mill are books on *Radiation in Evolution* and *A History of the Balance.* Then will come new concepts regarding Earth climate. And then…

B VITAMINS

My PhD thesis involved the exploration of unidentified B vitamins before the isolation of folic acid and Vitamin B-12. I worked autonomously with a group of 2–3 graduate students among Dr. C.A. Elvehjem's 50–60 students (E. B. Hart was my co-director). Animals (chicks for our group) died when fed a purified diet having all the known vitamins. They grew well when the diets were supplemented with liver powder. Feeding products from the chemical fractionation of liver powders revealed the pres-

ence and characteristics of essential, but unidentified, B vitamins. In 1943–4 our group identified vitamins B-10 and B-11. Our evidence for a hematopoietic factor was good; we would have named this third vitamin, vitamin B-12. "Dialysis separated the hematopoietic activity from folic acid, thus giving evidence for another unknown factor necessary for normal hemoglobin levels in the chick." (Luckey, 1947). However, we felt we should finish our work on vitamins B-10 and B-11 before formally proposing vitamin B-12.

Since intestinal bacteria were known to produce some B vitamins, there was a good possibility that our unknown vitamins were produced by "intestinal synthesis." Thus, a better deficiency of unidentified B vitamins should result if intestinal bacteria were eliminated. I cleaned out an old storage room in the attic of the Biochemistry building, sterilized (1) a small plastic enclosure with chloroform, (2) eggs in $HgCl_2$, (3) gallon jars with lids modified for sterile air, feed, and water in the autoclave, and raised germfree chicks. Drs. E. McCoy and P. Wilson, Department of Bacteriology, helped to monitor my germ-free chicks (Luckey, 1969). They became so interested, they asked me to teach my methods to their student, Barbara Lakey, for her master's thesis. That work went so slowly that I decided to feed antibiotics to reduce the synthesis of B vitamins by intestinal bacteria.

ANTIBIOTICS

In order to evaluate the role of bacteria in the production of unknown vitamins, I should feed antibiotics; theoretically, these would sterilize the intestine and produce a better deficiency of our unknown vitamins. In 1945, I wrote to Dr. J. M. McGuire of Eli Lilly and Company (Terre Haut, IN) for a sample of antibiotics which had recently been released for non-military uses. He sent streptomycin and streptothrycin. Surprise! When added to the diet, no deficiency developed; dietary antibiotics increased animal growth. The data (Table 1) gave convincing evidence that dietary antibiotics increased growth rates. Since writing this paper involved collaboration with members of the Bacteriology Department, I asked Peter Moore to write it (Moore *et al.* 1946). The effect was soon confirmed in other laboratories with several antibiotics and, as leader of our group, I became a celebrity in nutrition circles.

Drug companies (Ely Lilly, Merck, Lederle, and Sharp and Dohme) sponsored a deluxe tour for a dozen nutritionists, most were European, to show what we were finding with dietary antibiotics. "To Don Luckey who started all this, from Tom Jukes" (1955), this is the dedication written by Dr. Jukes (1955). In 1955, I proposed the term "hormoligosis" (from the Greek, *hormo,* I excite, and *oligo,* small amounts) for the stimulation by low doses of toxicants (Luckey, 1956). This paper presented evidence that dietary antibiotics increased the growth rate of germfree

TABLE 1. Growth of chicks fed antibiotics

Supplement	Amount*	Weight**
none	—	155
liver fraction "L"	2 g	220
folic acid	0.5 mg	220
folic acid + sulfasuxidine	1 g	280
folic acid + streptomycin	10 mg	280
folic acid + streptomycin	50 mg	300
folic acid + streptomycin and sulfasuxadine	10 mg 1 g	240

*Per 100 gm diet (starch, casein, gelatin, soy bean oil, salts and known vitamins).
**Average weight of six chicks at four weeks.

chicks and turkeys. And on p.161 was a new term: "A hormoligant is a compound which will excite or stimulate in small quantities." Because it cost less than good management, dietary antibiotics quickly became utilized throughout the world for chickens, pigs, and cattle. For two decades I enjoyed VIP visits to European countries to lecture about antibiotics in animal feeds. Soon, the tons of antibiotics used for feed and human medicine became about equal, as they are today.

LOBUND

In 1946, I became assistant research professor at the Laboratory of Bacteriology of the University of Notre Dame (LOBUND) at South Bend, IN. In order to raise Caesarian born, germfree rats in the absence of their mothers, my staff elucidated the chemical composition of rat and mouse milk. I claimed title to "world champion rat milker." I began a course in biochemistry and graduated one MS student, R. Meeks. Dr. Burton, Professor of Physics, and I worked on the X ray sterilization of milk; it was not sucessful due to oxidation of the fats.

Following my side interest of comparative nutrition, I developed a "universal diet." This was tested across the phylogenetic spectrum from microorganisms to mammals (Luckey, 1954). I became consultant, chief mixer, and part of the administration for Mr. W. Happ who manufactured a dog food, Mygrodol. I also consulted for the White Pharmaceutical Co. of Mishawaka, IN.

Notable accomplishments of our group at LOBUND (M. Wagner in bacteriology, Dr. H. A. Gordon in pathology and myself in biochemistry/nutrition) with staff included: (1) providing sterile diets for germfree animals, (2) reproduction of germfree chickens, turkeys, mice and rats, (3) creation of colonies of germfree and gnotophoric (animals bearing only known species of bacteria) rats, hamsters, and mice, (4) vitamin metabolism in germfree chicks and rats, (5) the role of specific

species of bacteria in tooth decay, and (6) the growth rate increase of germfree chicks fed antibiotics. I was promoted to associate research professor in 1952. When I left LOBUND in 1954, I was in charge of the first gnotophoric animal room, a small building housing rats and mice with only known species of bacteria. After publishing several papers, I resigned "in order to grow professionally."

UNIVERSITY OF MISSOURI (UMC)

In 1954, I became the chairman of the Department of Biochemistry in the new four year Medical School at the University of Missouri, Columbia, MO. During that summer, I redesigned the space allocated to biochemistry. We moved into the new building in1956. My first focus was to build the new department, starting with a staff of three; this increased to thirty by the time I left in 1984. During this time, I became a member of various scientific societies. We, the staff of three, developed a biochemistry curriculum, as well as a laboratory manual, second edition (Luckey *et al.*, 1957a, 1959), and Cram Cards in Biochemistry (Luckey *et al.*, 1958). We also produced educational movies: The Use and Care of the Analytical Balance (Luckey *et al.*, 1957b), Germfree Room with Lambs (Luckey,1960a), and The Determination of Total Nitrogen (Luckey *et al.*, 1964).

From UMC, I helped inaugurate several organizations in order to expand educational opportunities. (1) Nutritional Emphasis Week involved inviting nationally celebrated speakers to the campus for three days for a series of discussions and lectures. One of the speakers was Dr. Hans Selye of Montreal. We had discussions comparing his methodology with short term stress with my relatively long term experiments with dietary antibiotics. (2) The West Central States Biochemistry Conference was established with Russell Mills of Kansas University to provide important speakers in Biochemistry to regional meetings in the states of Missouri, Kansas, Nebraska, South Dakota, Iowa, and Oklahoma. I was elected chairman at the first meeting and received a National Institutes of Health grant to be the director for 10 years. This series continued for about 20 years. (3) With Dean Herb Goldberg and members of the Bacteriology Department (particularly Dr. D. Hentges), I established a series of international symposia on the topic of intestinal microecology.

I continued my work in germ-free research with chickens and lambs at UMC. I also supervised numerous student theses. Herman Miller developed the concept of folic acid production in gnotobiotic animals. Pat Neville continued the comparative nutrition studies with alligators and insects. His work with crickets showed that there was a nutritional vitamin in clover leaves, a rutin related compound. We called it "Vitamin P" (Neville *et al.*, 1961). Dr. P. C. Stone, Professor of Entomology, collaborated by providing crickets and discussions.

I accepted several international invitations during my years at UMC. For one month in 1963, I was Guest Scientist in Romania. In 1983 I evaluated Qatar University where they were building a multimillion University in the desert about 10 miles from Doha.

Some bitter came with the sweet. When I returned to UMC after two leaves of absence (1976–77 and 1978–79, see below) with only one semester of teaching in between, I was forbidden use of biochemistry laboratories by the new chair because I was not bringing in research monies. I had an office about a half-mile from the Medical School. One staff member allowed me to use the floor under a sink in one room to incubate my "control cultures." As my bibliography shows, this did not stop me. Friends were most gracious. I used the facilities of Dr. Olin Brown at the UMC Nuclear Reactor in the Dalton Research Center and Dr. Bill Noteboom in the Surgery department. The staff of the UMC Nuclear Reactor were always helpful. My research showed that ionizing radiation promoted photosynthesis in total darkness (Luckey, 1980a). Vicki Spate helped raise and lower the Co-60 gamma ray source anytime day or night. Demonstration of radiogenic photosynthesis was my most significant research.

Although the first International Conference on Radiation Hormesis (Oakland, CA, 1985) was based upon by my paper, Physiologic Benefits from Low Levels of Ionizing Radiation, the two papers I presented at the Conference were rejected for publication by the guest editors of that special issue of *Health Physics*. I was not invited to the second International Conference in Frankfurt, Germany, in 1987. Nor was I one of the 400 participants of the International Conference on Low Dose Irradiation and Biological Defense Mechanisms, Kyoto, 1992. I attended as a speaker at an adjunct meeting held in Kyoto during that week.

THYMIC HORMONES

Several of my UMC students isolated proteins which were thymic hormones: T. Hand, Isolation of a Thymic Hormone, M.S., 1966; W. G. Robey, Antibody Stimulating Factor from Thymus, Ph.D., 1972; S. U. Wang, A New Assay for Lymphocyte Stimulating Proteins, M.S., 1975; and M. D. Pierschbacher, Biologic Activity of a Lymphocyte Stimulating Factor (LSH), Ph.D., 1979. From this base, I was a frequent speaker on thymic hormones and edited a book, *Thymic Hormones* (Luckey, 1973a). Representatives of Elsevier Press invited me to edit a new journal, *Thymus*. Since this was a student project more than my own research, I declined and became a member of the international editorial board of *Thymus*.

My invitation to spend the 1976–77 sabbatical year at the Medical School with Professor V. Diehl, Department of Medicine, University of Hannover, Germany, became invalidated by an election with a change in City government which put strict budget limits on the University. With

$1000 from Symbioflore, I sent a graduate student, Mike Pierschbacher, as a guest researcher in their Biochemistry Department. He did all his research there for a doctor's degree on thymic hormones. Pauline and I used his large apartment as headquarters for a month while we hunted dolls in Germany. Pauline and I then retreated to Rosita where I wrote the first draft of *Hormesis with Ionizing Radiation* (Luckey,1980b).

I received an Alexander von Humboldt Senior Scientist award for study of new thymic hormones with Dr. M. Zeppezauer at the Biochemistry Department of Saarbrucken University and Dr. J. Comsa at the Medical School in Homburg am Saar, Germany. Since I must lecture at UMC in the fall, my research time was December, 1978 to September 1979.

INTESTINAL MICROECOLOGY

In 1968, I lectured to the sixth group of NASA astronauts on the subject of intestinal microecology. As a result, I became a nutrition consultant with NASA for Apollo 11 through 17 missions. For a brief time I consulted for the Boeing Co., St. Louis, MO, about the sterilization of the outer surface of Moon rockets following launch (since "we" were not to contaminate the moon, everything was to be sterile). During a sabbatical leave, 1968–69, I was visiting scientist at the GE Manned Space Center in Valley Forge, PA. With Dr. M. Bengson of the GE Manned Space Center and M. Smith of NASA, I worked on the evaluation of sterile astronaut diets using germfree and gnotophoric mice (Luckey, 1973b).

Work with germfree animals and my book *Germfree Life and Gnotobiology*, (Luckey, 1963a) raised questions of which bacteria were in the intestine and what species should be added for gnotophoric animals. These led to a series of biannual International Symposia on Intestinal Microecology (Flock *et al.*, 1970; Luckey and Flock, 1972; Luckey and Hentges, 1976,and 1979; and Luckey *et al.* 1982). The symposia were published in the *American Journal of Clinical Nutrition* and reprinted as separate volumes. The last was held at Boston and is in *Progress in Food and Nutrition Science*. The symposia were a tribute to the vision of Dr. H. Goldberg, Assistant Dean of the UMC Medical School.

From this base came new associations and journals. In 1971–75, I was a member of the Board of Directors for the Association for Gnotobiotics which was started by P. C. Trexler before he left LOBUND. In 1981 the International Association for Gnotobiology started biannual meetings. Some proceedings were published in the renovated *Journal of Microecology and Therapy*, edited by Dr. Volker Rusch (published in Herborn, Germany) with me as co-editor. Later, Dr. Rusch began a yearly advanced seminar on the broad topic of intestinal microecology. In 1982, I helped initiate the Society for Intestinal Microecology and Disease (SIMED). Another group started the Society of Microbial Ecology and Disease

(SOMED). Some of these symposia were published in a new journal started by that group, *Journal of Microbial Ecology in Health and Disease* (published by Academic Press, New York). My book, *Germfree Life and Gnotobiology,* made strong waves!

My work helped to provide a scientific base for the yogurt, lactobacillus milk, and lactobacillus capsule industries. It is valued today as shown by the 2006 Experimental Biology Annual Conference titled: Probiotics and the Hygiene Hypothesis in San Francisco, April 3, 2006. The term "probiotics" includes living organisms. It was sponsored by Harvard Medical School Division of Nutrition, the American Society of Nutrition, and the American Association of Immunologists.

A strong alliance was formed with Dr. Volker Rusch of Herborn, Germany. With the help of Dr. R. Hyde, one of my students, Terry Hand, injected the German-made "therapeutic bacterial products" into mice, which then showed increased resistance to injections of a lethal bacteria. This demonstration was vital to the survival of the Symbioflore Co. which produced the vaccine. Subsequently, I became Secretary-Treasurer if Symbiomed, Inc., 1980–83, Board of Directors, 1981–84, and a consultant for Symbiomed. Dr. Rusch and I gave numerous lectures on intestinal ecology in Japan and many European countries.

My international leadership in intestinal microecology was honored in 1984 when I was made Honorary Professor of the Free University of Herborn at their 400th anniversary, and knighted, *Ritter von Greifenstein*; I was the only non-German, non–beer drinker of 13 knights.

HORMESIS

The stimulation of growth rates by dietary antibiotics inaugurated a decades long review of the literature on stimulatory compounds. The key was Nageli's (1893) concept of the oligodynamic action of heavy metals: dilute concentrations of heavy metals are toxic to bacteria. Richet (1906) wanted to know at what concentrations were they effective. He found that when toxic metals were diluted in tenfold increments, every one of them was stimulatory. His paper suggested to me the general nature of physiologic stimulation by low doses of any toxicant. For any given physiologic parameter, large doses are harmful and low doses stimulate. This biphasic effect of most agents presents a threshold equivalent with the control value. Any dose below this threshold is considered to be a low dose.

The Paracelsus paradigm, "the dose is everything," is ageless (Table 2). This many-splendored view of the history of hormology highlights my contributions. The more succinct statement of Dr. R. Arndt of the Psychology Department of the University of Greifswald is paraphrased: "unusually low doses of a toxicant should be beneficial" (Schulz, 1918). The concept that small doses of poisons are stimulatory was verified experimentally by Dr. H. Schulz (1888) (Pharmacology Department, University of Greifswald)

TABLE 2. Hormology in history

Year	Discipline	Author	Concept
1500 BC	Medicine	Hatshepset	Poisons stimulate
1000 BC	Immunology	Chou	Smallpox vaccination
700 BC	Medicine	Sargon II	"Dual" belladonna
400 BC	Therapy.	Hippocrates	Give no fatal dose
1540	Pharmacy	Paracelsus	The dose is everything
1780	Medicine	Withering	Potential toxicants
1878	Botany	Bernard	Stress builds strength
1897	Botany	Townsend	Trauma increases plant growth
1888	Fermentation	Schults	The Arndt-Schultz law
1906	Bacteriology	Richet	Oligodynamic offect of metals
1908	Psychology	Yerkes	The inverted U-curve
1919	Radiation	Davey	Homeostatic doses
1922	Medicine	Hahnemann	Minute doses heal
1930	Toxicology	Maximov	Toxicants increase plant growth
1930	Therapy	Merck	Therapeutic index
1936	Radiation	Gager	Radiation increases plant growth
1936	Physiology	Selye	General adaptive syndrome
1943	Entomology	Southam	Hormesis
1946	Nutrition	PM/Luckey	Antibiotics stimulate growth
1950	Radiation	Lorenz	Pseudo growth effect
1950	Nutrition	Briggs	Dietary promotant
1951	Immunology	Taliaferro	Radiation enhances immunity
1959	Toxicology	Luckey	Hormoligosis
1960	Pharmacology	JT/Luckey	The beta curve
1961	Bacteriology	Jacob	Adaptive enzyme induction
1974	Nutrition	Parker	Probiotics
1974	Agronomy	Zelles	Biopositive effects
1976	Radiation	Acher	Paradoxic reversal
1976	Radiation	Friedberg	Peculiar curve
1979	Immunity	Hellstrom	T-cell activation
1980	Radiation	Luckey	Radiogenic metabolism
1980	Radiation	Luckey	Bi-phasic action of radiation
1985	Cancer	Hickey	The J-or Hockey Stick-Curve
1988	Metabolism	Heiby	The reverse effect
1990	Neurotoxicity	Davis	The U-shaped functions
1996	Cell culture	Salone	Adaptive survival response (ASR)
1997	Cancer	Bogen	Cytodynamic 2-stage (CD2)
1997	Chemistry	Calabrese	The dose is everything

Adapted from Luckey, (1999).

with mercury, chromium, arsenic and iodine in yeast cultures. This established the Arndt-Shultz law, generalized and paraphrased: *sufficiently diluted toxicants should have a beneficial effect on the organism.* In Sept. 1979, I visited the campus and was keynote lecturer at the II Symposium of Gastrointestinale Mikroflora des Menchen, Greifswald, DDR.

In 1955, I proposed the terms *hormoligosis* (from the Greek, *hormo* meaning I excite, and *oligo*, meaning small amount) and *hormoligant* (an agent which will excite or stimulate in small amounts) to the First International Conference on Antibiotics in Agriculture (Luckey, 1956).

My chapter titled Antibiotics in Nutrition (Luckey, 1959) explored all aspects of dietary antibiotics. I used the word *hormology* to describe a general field of study (Luckey, 1975). In 1959, I came across the term *hormesis*. It was so concise that I used it to include stimulation by low doses of any agent. *Hormesis* was coined by C. M. Southam and J. Erlich (1943) to describe the stimulation of fungi (from redwood trees) by low doses of cedar heartwood; larger doses were toxic. I wrote to each and talked on the telephone to Dr. Erlich who was delighted to have this concept resurrected and broadened.

I verified the general nature of the hormesis thesis with a variety of studies. (1) The discovery that dietary antibiotics stimulated animal growth (Moore *et al.*,1946). (2) A general review of antibiotics (Luckey, 1959). (3) The biphasic action of low doses of the essential element, sodium (Luckey,1960b). (4) A survey of hormesis in drugs (Townsend and Luckey, 1960). (5) Growth promotion of dietary fiber (Luckey, 1962). This paper was instrumental in changing commercial feeds for livestock. (6) Research showing dietary antibiotics stimulate the growth (reproduction rate) of vinegar eels (Luckey,1963b). This was performed during a sabbatical leave (supported by a Commonwealth Fellowship, 1961–62) in the Biochemistry Department of Dr. Marcel Florkin, University of Liege, Belgium. (7) Dietary insecticides increase growth rates in insects (Luckey, 1968). This was my most popular paper; several hundred reprints were requested. (8) Ionizing radiation (gamma rays from cesium 137) increase the growth (replication) rate in paramecia (see below). (9) Internal (radioactive) potassium cures a deficiency of radioactivity in paramecia (Luckey, 1986). The predicted results in a wide variety of species and conditions indicated the hormesis thesis was valid.

Occasionally, I addressed the relationship of hormesis with homeopathy. In the summer of 1976, I gave a lecture, Hormology *vs* Homeopathy (unpublished), at the 3rd International Symposium in Biology and Medicine in Lausanne, Switzerland. In October, 1976, I lectured (unpublished) to the annual meeting of the American Institute of Homeopathy at Kansas City, MO. Another lecture, 1993, was at the VII International Research Group on Very Low Dose Effects at the University of Montpellier, France (Luckey, 1997a). Needless to say, there is little in common between hormesis and homeopathy.

RADIATION HORMESIS

I continued studying the literature and, during a sabbatical leave in 1969–70, I began writing a book on hormesis as a general phenomenon. An interesting thing happened. As I looked at the evidence showing the stimulation of low doses of physical, chemical and biological agents, I was overwhelmed by the tremendous literature about stimulation by ionizing radiation. After commenting that I could not encompass all the radiation

literature in this book, Pauline suggested that I write a book limited to radiation hormesis. I did.

That book, *Hormesis with Ionizing Radiation* (Luckey, 1980b), had 222 pages and 1269 references. It was written during my 1976–77 sabbatical leave at Winter Park, CO. Every two weeks, we would drive over the continental divide (11,300 feet) for shopping and to visit one or more of four libraries: Colorado State University at Ft. Collins for biology, Colorado School of Mines at Golden for earth sciences, Colorado University at Boulder for science, and Colorado School of Medicine at Denver for medical items. This gave me real appreciation for the combined libraries of the University of Missouri. We often stayed overnight with my sister, Doris, and her husband, Les Nelsen, in Arvada. Pauline was my gofer and her asthma suffered while retrieving many large, dusty volumes from the lower levels of the stacks. The trips down the mountain were fun (I would coast about 20 miles without brakes from the end of the switch-backs to Empire, CO). This book showed radiation hormesis applied throughout the phylogenetic spectrum of life, including humans. This led to increased interest in this topic in many different countries and another whirlwind of lecture tours.

In August, 1983, I consulted for the defense in the Ra-Rn suit for the Monsanto Co. in the *Canonsburg* case.

My second book, *Radiation Hormesis* (Luckey, 1991) reviewed stimulation in mammals and humans by low doses of ionizing radiation. The main criteria were was less disease (especially cancer), longer life spans, and improved (more abundant and more healthy) reproduction. Both books were a base for Dr. E. Calabrese to produce his *BELLE Newsletter* and *Nonlinearity* journal. Both books undoubtedly contributed to my invitation to become a charter member of the International Hormesis Society in 2004. In his book, *Underexposed: What if Radiation Is Actually Good for You?*, Ed Hiserodt (2005) wrote (p. 3): "The one figure whose research in this area has been pivotal is Professor T. D. Luckey…"

Between 1991 and 1993, both books on radiation hormesis were published in Japan, by Soft Science, Inc. I am grateful to the tremendous work done by Dr. Takeshi Yamada and his staff for the Japanese translations. Following a lecture in Seoul, Korea, in October, 2003, I was invited to a Symposium held in honor of T. D. Luckey at Tokyo. Here I became an honorary Samurai (Fig. 2). Two months later, two of the organizers of the symposium came to Lawrence to present a magnificent sword and authentic Samurai uniform.

IONIZING RADIATION AS AN ESSENTIAL AGENT

A *leitmotif* runs throughout the 20th century literature on the biologic effects of low dose irradiation; it promises to become a major issue. Ionizing radiation may be essential for life.

Evidence for a radiation deficiency in six invertebrate species has been summarized (Luckey, 2003). More pertinent are data showing decreased growth rates in rats and mice which were reared in sub-ambient radiation laboratories (Kuzin *et al.* 1994).

My search for an underground laboratory (needed to reduce cosmic radiation) led me to the Argonne Institute in Chicago, IL. In 1982–83 and in the summer of 1984, I was Visiting Scientist at Argonne National Laboratory. Without stipend, living expenses, or travel funds, I had available the power and expertise of this National Laboratory.

FIGURE 2. Sir Samurai T. D. Luckey, PhD, a writer at his home in Kansas, 20055

Within their underground laboratory was a room made with 21 cm of steel and a four ton door. I made two studies showing that a deficiency of ionizing radiation was corrected by the addition of either gamma or beta rays. The medium was very low in ionizing radiation; natural (radioactive) potassium was replaced with K-39, the non-radioactive potassium. The K-39 Cl at Argonne was recycled and had a toxicant in it (Luckey, 1983). For $28,000 I bought one gram of Russian made potassium-39 chloride from an English firm. The results from two large experiments with subambient radiation typify those for an essential agent such as a vitamin or oxygen.

When cultured in subambient levels of ionizing radiation, the growth rate of a pure culture of the protozoan, *Tetrahymena pyriformis*, was statistically less than that at ambient radiation levels. When exposed to gamma rays from Cs-137, the increased growth rate was directly proportional to the log of added radiation. These results show that radiation is an essential agent for this organism (Luckey, 1986).

A second experiment utilized primarily beta radiation from internal, radioactive potassium (K-40). When radioactive potassium (K-40) was omitted from the medium which had ample non-radioactive K-39, the protozoa became deficient (using growth rates as the criteria). When radioactive K-40 was substituted for K-39, the protozoa grew at rates equivalent with the controls. The results showed protozoa could utilize internal radioactive potassium, either natural or K-40, for their radiation requirement (Luckey, 1991).

As Vice President and Director of Research at the Central Research Institute of the Electric Power Industries (CRIEPI) in Tokyo, Dr. S. Hattori (1994) stated "If T. D. Luckey's claim (1980–1982) was true, our daily activities in radiation management have been extremely erroneous" and "Radiation is essential for life. Dr. Luckey's assertion seems to be right." CRIEPI organized a Hormesis Research Steering Committee which sponsored 15 research projects in Japanese Universities; these were published in the scientific literature.

Many results can be interpreted as supplementation of an essential agent to subjects which live in a partial deficiency. My book, *Radiation Hormesis,* reviews benefits from increased levels of ionizing radiation: fertility, early physical development, immune competence, radiation resistance, mental acuity, and mean lifespan. Supplementation with low dose irradiation provides decreased heart disease, sterility, infections, lung diseases, cancer deaths, and premature deaths. These benefits would accumulate if we lived with 20 times more ambient radiation than we have now. The optimum appears to be many times our present background, about 60 mGy/y (Luckey, 1997b). Such evidence indicates additional irradiation would provide a new plateau of health for most people. This is my challenge.

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