

The Impact of Nuclear Science on Life Science

Introduction

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The development of life science was always strongly interconnected with physical sciences. This interaction occurred on various ways as by the exchange of people, ideas, machines and techniques. For instance the migration of new techniques and apparatuses in biology and medicine that originate from physical science like the use of microscopes, X-ray machines, centrifuges, computer homographs, etc. becomes visible rather dramatically if a power failure cuts off all the high- and low-tech facilities in a biology institute or in a hospital. But the linkage between life science and physical science was more than just a simple exchange of sophisticated machines. It was also a vivid exchange of ideas and knowledge that connected both areas of sciences. One of the most outstanding and successful examples was the application of the knowledge and methodology of quantum physics to biology by Erwin Schroedinger in his book “What is life?”, where he analyses radiobiology experiments in terms of quantum physics [1]. Schroedinger was the first to postulate the existence of the genes as biochemical entities and was able to estimate their size from the radiation response within reasonable physical uncertainties. It was the influence of his ideas that led James Watson and his colleague Francis Crick to the study of genetics and to the discovery of the molecular structures of DNA.

Vice versa, a stimulation of physics by a broad interest of medicine was prompted by the application of X-rays by W.C. Roentgen. There, the primary article on the “new kind of radiation”, published in some proceedings of the Wuerzburg Medical-Physical Society, would not have been noticed worldwide within a few weeks, without the parallel publication of the medical application i.e. the X-ray photography of the hand of Roentgen’s wife in many newspapers [2]. Although the physical nature of the new radiation was not known then - Roentgen named them X-rays according to the X used in mathematical equations for the unknown – X-rays were applied all over the world within a few days after publication for medical diagnosis and later on also for therapy. With this application physical research was stimulated in its effort to understand the nature and the action of the “unknown” X-rays.

However, more frequent than the common interest of different people in the same subject was the opposite i.e. the broad interest in different fields by the one and the same person. In this sense, it is quite remarkable that the first radiobiological experiments were performed by Pièrre Curie. He tested whether the inflammation and ulceration found by H. Becquerel at his skin under a pocket with the newly discovered radioactive material was caused by radioactivity. P. Curie confirmed Becquerel's findings and extended his biological experiments with radioactivity. At the beginning of the last century, he reported to the French Academy of Science anomalies in tadpole embryos that had been exposed to Radium emanation i.e. to Radon. This was the very first experiment on the influence of ionizing radiation on the embryonic development and became important much later, after the bombing of Hiroshima and Nagasaki.

A very powerful tool for biology can be attributed to G. de Hevesey, who was the first to use natural and later on artificial radioactive elements as tracers in order to study the pathway of stable elements in biological systems. It is frequently reported that Hevesey invented the tracer principle when he added some radioactivity to the leftovers of a dinner and tested his goulash soup with a Geiger counter in the same restaurant the next day [3]. Although it is impossible to find a reliable confirmation of this anecdote in Hevesey's publications it very well illustrates the tracer principle. An amount of radioactive elements – much less than detectable by chemical analysis – can easily be followed in a biological system such as the human body or in plants.

In the biology of today, the analysis of the DNA uses large quantities of radioactive isotopes for sequencing. With radioactive isotopes, the bio molecules are labelled and their decay is detected with a photographic film after the separation of complex DNA fragments on a gel. Radioactively labelled molecules have also been used for the elucidation of the photosynthesis of plants or for diagnostic purposes in nuclear medicine.

In nuclear medicine, a large variety of labelled compounds have been developed specifically for almost each individual organ in the human body. Measuring uptake and secretion, it is possible to determine the organs' functions. Because it is also possible to label tumors with specific drugs the location of tumors can be determined by Single Photon Emission Computed Tomography (SPECT) as well as by Positron Emission Tomography (PET) where positron

emitting isotopes are used for instance that attach preferably to active brain areas. SPECT and PET are standard in tumor diagnostics as well as in function studies of the normal healthy brain.

Today, more and more of these measurements of organ function and of diagnostics can be performed with Nuclear Magnetic Resonance Imaging (MRI). MRI has the big advantage that no radioactivity has to be used and the magnetic field applied to the patient does not produce any damage in the tissue. Thus, these measurements can be extended and frequently repeated if necessary.

Another example for the use of stable isotopes instead of radioactive material is the accelerator mass spectroscopy (AMS). Because of their high sensitivity to the isotopic distribution accelerators can be used to detect tiniest amounts of exotic but stable isotopes. This technique can be employed to follow biological pathways in the body without any risk for the patient.

From the radioactive elements, Iodine plays an exceptional role in medicine because it attaches to thyroid tissue with an extreme affinity and selectivity. Therefore, it can be used in low doses for diagnostic purposes as well as for tissue reduction where a thyroid cancer can be destroyed by ionizing radiation emitted from radioactive iodine exclusively attached to the thyroid tissue. Iodine also attaches to metastases of thyroid cancer that are dispersed throughout the body and kills the metastases all over the body.

This exceptional affinity of an element or molecule to a malignant cell represents an optimum model for tumor therapy because these “cell seeking” drugs obviously conform the dose to the tumor volume in a perfect way. This is not the case for other deep-seated and inoperable tumors that have to be treated with external radioactive sources or other ionizing radiation . Using electromagnetic radiation like the most advanced Roentgen-Bremsstrahlung from high-energy electron linacs a reasonable amount of dose is always deposited in front and behind the target volume in the healthy tissue. That is, the tumor dose is mostly limited by the tolerance of the normal tissue around.

An essential improvement in external radiation therapy can be achieved using heavy-particle beams like protons or carbon ions of high energy. Ion beams exhibit an inversed depth-dose profile with an increase of dose with penetration depth up to a maximum at the end of the particle range. In addition, for ions heavier than protons, like carbon, the radiobiological efficiency increases towards the end of the particle range. Thus, ion beam therapy allows to deposit a higher and more effective dose in the tumor than any other type of external therapy. Up to now, more than 30,000 patients have been treated with protons worldwide and more than 1,000 patients with heavy ions. Together, they reach an outstanding tumor control rate. As a result, numerous initiatives for the promotion of ion beam therapy emerged in many countries in the last years.

Table 1: History

1895	W.C. Roentgen	X-Rays
1896	H. Becquerel	Natural Radioactivity
1898	M. + P. Curie	Radium
		First Radiobiological Experiments, Application of Radium in Therapy.
1923	G.de Hevesey	Tracer Principle
1927	Blumgart/Weiss	Blood Circulation Studies (Ra)
1931	E.O. Lawrence	Cyclotron
1934	E. Fermi	128-Iodine
1937	R. Stone	Neutron Therapy
1938	Hertz, Roberts, Evans	Thyroid Studies with Iodine
1939	J. Lawrence	Artificial Radioisotopes for Therapy
1942	Hertz + Roberts	Treatment of Thyroid Hyperfunction
1946	R. Wilson	Proposed Proton and Carbon Therapy
1951	Wrenn/Brownell,Sweet	Positron Emission Tomography – PET
1954	J. Lawrence	Proton Therapy
1958	H. Anger	Scintillation Camera
1970s	G. Hounsfield/ A. Cormack	Computer Tomography
1972	Damadian	Patent of NMR
1974	C.A. Tobias/J. Lawrence	Heavy Ion Therapy
1997	GSI/PSI	Beam Scanning and Tumor-Conform Ion Treatment

Tab. 1 outlines a brief history of the application of nuclear techniques in life science. It is remarkable to see how many techniques in nuclear medicine as well as the ion beam therapy originate from Berkeley. Ernest O. Lawrence, the inventor of the cyclotron and founder of the Berkeley laboratories had a brother, John Lawrence, who was a physician. Therefore, the medical and biological applications of isotopes and beams were pushed from both sides - nuclear physics and medicine. In addition, the Lawrence brothers' success is a remarkable example that close personal relations of two outstanding scientists are much more effective than any administrative regulation.

This also shows that science is driven by individuals and justifies the connection between people and projects as given in Tab. 1. Of course, not all projects in this table can be treated here in detail. It is the purpose of this booklet to give some examples for the positive impact of nuclear science on life science. The selection of the topics for this chapter is somewhat arbitrary and surely influenced by personal affinities. We tried to give a stimulating overview and to demonstrate the benefits of nuclear science but also the problems regarding the application of ionizing radiation.

The risk of the application of nuclear methods using ionizing radiation is summarized in the last part. Most of the available data originate from the Nagasaki and Hiroshima victims and from patients treated too extensively with diagnostic procedures using ionizing radiation. Moreover, the results from the Chernobyl accident were analyzed. A low incidence of genetic mutations and of cancer induction is reported. That is why these data have large error bars. However, the confidence limits are narrow enough to calculate solid values for the risks connected to the application of nuclear techniques. This is very important because the benefit of a procedure has always to be weighed up against its potential disadvantage as it also has to be done for other techniques being used in everyday life.

References

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- [3] Tobias C.I., People and Particles, San Francisco Press, San Francisco 1997 and private communications