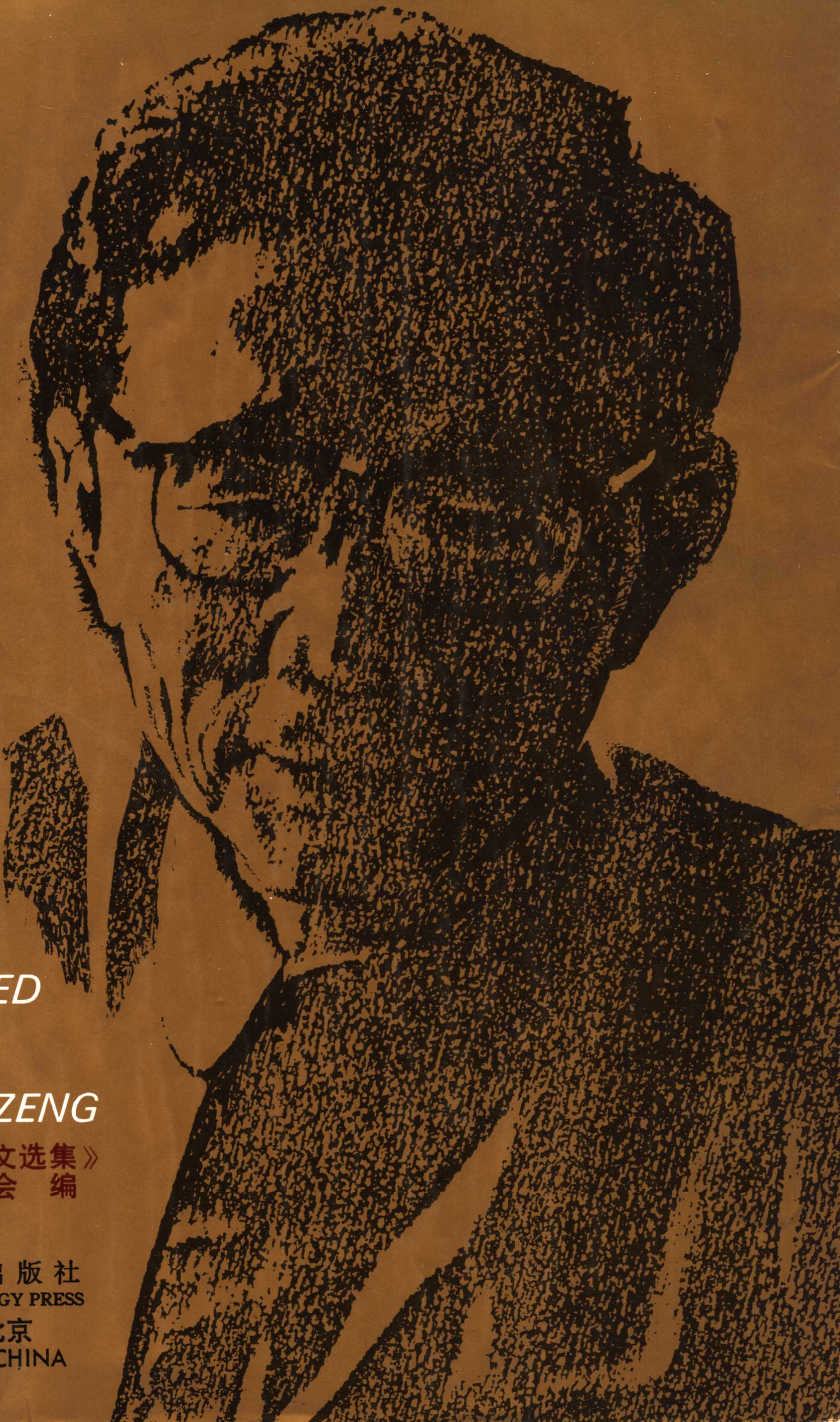
戴传曾论文选集

SELECTED WORKS OF DAI CHUANZENG



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内容简介

本文集收集了我国著名实验核物理学家、反应堆物理学家、反应堆工程和核安全专家、中国科学院院士戴传曾教授在 1949 年至 1990 年间公开或未公开发表的部分文章,重点涉及核探测技术、核反应、中子物理、反应堆物理和反应堆工程技术以及核电安全研究等领域,反映了戴传曾教授毕生的科研活动和学术贡献。

本文集可供广大科技工作者和大专院校师生阅读。

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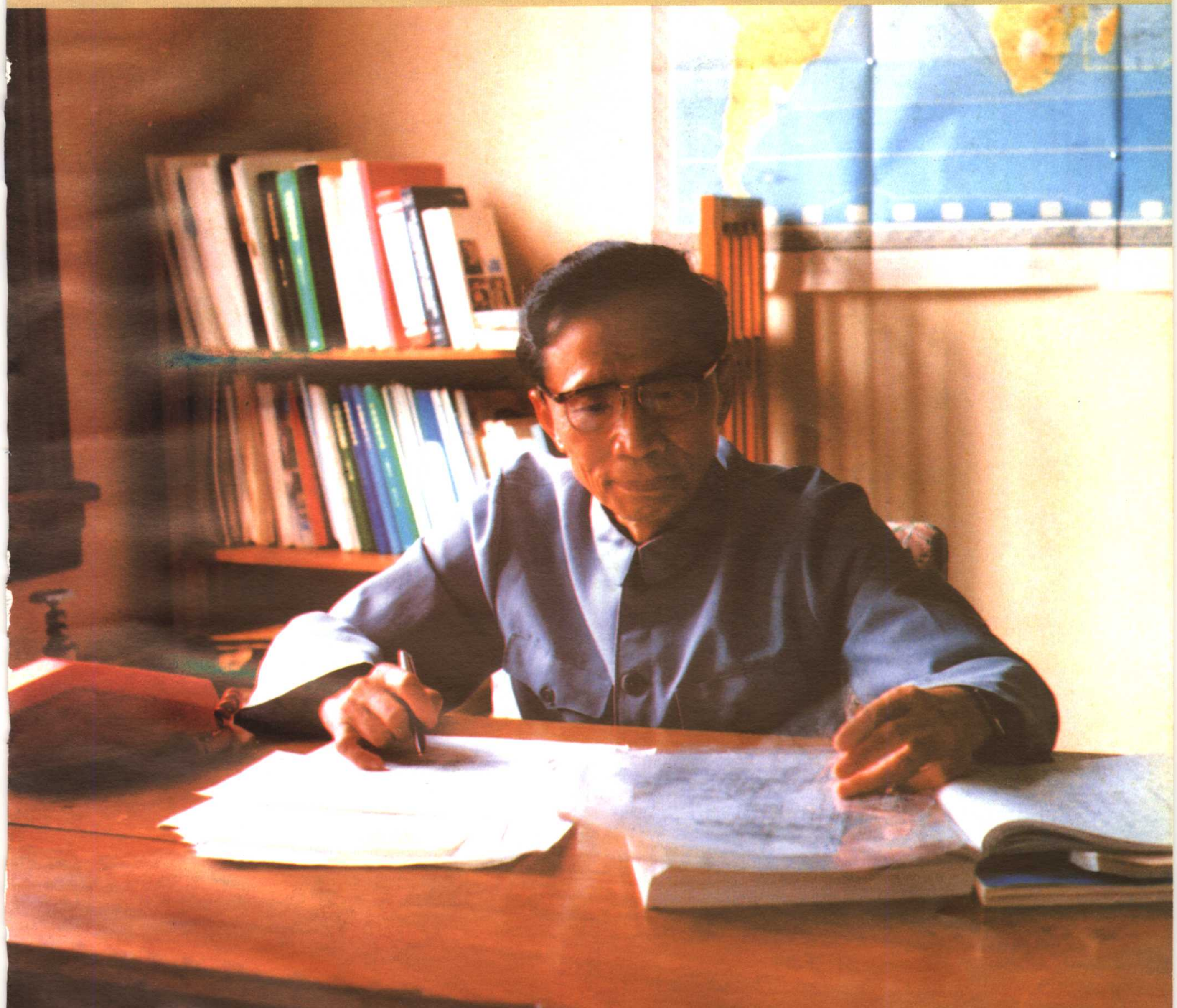

1985年于中国原子能科学研究院

朱凤云 顾明远 摄

《戴传曾论文选集》编辑委员会

THE EDITORIAL COMMITTEE OF SELECTED WORKS OF DAI CHUANZENG

序　言

戴传曾教授是我国著名的核物理学家、反应堆物理学家、反应堆工程和核安全专家，中国科学院院士。

他1921年12月21日生于浙江宁波的一个知识分子家庭。1942年以优异成绩毕业于西南联合大学物理系后，留校担任助教。1947年以物理专业全国第一名的成绩考取了公费留学，到英国利物浦大学攻读核物理，那里有回旋加速器和良好的核物理实验研究条件，他得到查德威克教授的帮助，开展了氖、氧的(d,p)和硼、氧、碳、铍的(d,n)反应出射粒子的角分布研究，导出了有关原子核能级的自旋和宇称。这些工作是国际上研究削裂反应的首批成果之一。在英国期间，他还研究了核乳胶的收缩因子及射程修正。1951年，获哲学博士学位。同年底，他谢绝了英国一些研究机构的挽留，毅然返回祖国，投身到新中国原子能科学的艰苦创业中来。这充分表现了他强烈的爱国主义精神。

回国后，在中国原子能科学研究院的前身中国科学院近代物理所工作。早期他领导一个气体探测器组进行开创性的研究工作。当时实验室条件很差，他带领大家艰苦创业，制成了我国的卤素盖革计数管。在抗美援朝期间，为应付美国使用核武器的可能，他受我的委托，还试制成功了强流管，并制成手提式的辐射检测仪表。由于“卤素计数管与强流管的制备和它们放电机构的研究”填补了我国核探测技术领域的空白，达到了当时的国际先进水平，并在放电机构研究上有所创新，1956年获中国科学院自然科学三等奖。为了发展我国的中子探测技术，他把从英国带回的铍粉装入玻璃管，再充入从协和医院的500毫克镭源中提取的氡气，做成氡铍中子源，一方面用来测试三氟化硼中子计数管的性能，另一方面开展初步的中子物理研究。以上研制成的几种计数管，很快都推广到工厂批量生产，为地质勘探、教学工作、武装我国防化兵以及一些中子物理实验和原子弹爆炸试验提供了有力的测量手段。

在他指导下，还开展了“空气等效电离室”，“硼膜及裂变电离室”，“栅网电离室”，“用于绝对测量的β-γ符合技术”，“中子源绝对测量”等大量开创性工作，培养了一批年轻的科技人员。

为在我国实验性重水反应堆上开展慢中子谱学和固体物理的研究，戴传曾教授从1956年至1960年期间曾主持研制成我国第一台中子晶体谱仪和第一台中子衍射仪。这两台谱仪均达到当时的国际先进水平。在它们上面先后开展了堆中子能谱、中子全截面和裂变截面及中子衍射的实验研究。这两台谱仪连续可靠地

使用 20 多年，在我国核物理和固体物理研究中发挥了重要的作用。

1958 年，他组建并领导了辐射屏蔽物理组，在重水反应堆的热柱上建立了先进的大面积裂变中子谱屏蔽实验装置，进行铁、水及铁、铅、水等不同屏蔽组合系统的裂变快中子衰减性能研究和动力堆活性区的屏蔽模拟。他指导制定了 γ 射线在水中绕屏蔽体散射的实验方案和初期的实验工作，为核动力堆的屏蔽设计提供了可靠的实验数据。

60 年代初，他受命担任稳定同位素分离研究室主任，成功地领导并组织了大型电磁分离器的关键部件——离子源和同位素接收器的研制工作，同时指导氘、锂同位素丰度分析，为核武器装料提供了可靠数据。

1961 年，二机部领导任命他兼任生产堆设计的科学顾问，使他在反应堆工程研究领域有机会显示卓越的才能，走上成为我国著名的堆工专家的道路。1965 年他担任 194 所副所长，对生产堆、动力堆、高通量堆及重水动力堆等反应堆工程的各项重点科研任务，以及游泳池式研究堆和几座零功率堆的安全运行，进行了有力的组织领导和技术指导。

他亲自参与了对生产堆工艺资料的消化吸收和选定材料技术参数的工作。组织并指导了高通量堆的各项科研开发工作，包括水力模拟、控制棒工艺试验、燃料组件性能、材料、腐蚀等。他还组织完成了动力堆元件的辐照考验研究任务。组织并领导了我国第一个辐照后材料检验热室的设计及建造。70 年代，他组织了快中子堆、空间堆电源系统和脉冲堆等的研究、设计工作。亲自指导建成了我国第一座快中子零功率堆，为我国快堆起步作出了贡献。在从事这些科技活动中，他十分注意培养年轻科技人员，造就人才。

1978 年，我邀请他回原子能所工作。他先后担任了副所长、所长的职务，1985 年后任原子能院名誉院长。他非常重视核能和核技术的开发应用。1979 年他访美归来，立即提出并指导开发了单晶硅中子嬗变掺杂技术，亲自组织和制定研制方案，具体指导改造游泳池式研究堆，扩大活性区，用铍代替石墨反射层，提高中子照射通量；亲自组织攻关，解决控制辐照注量、辐照温度、辐照均匀、退火等一系列工艺技术问题，成功地制备出我国第一批中子嬗变掺磷的单晶硅。他组织并指导完成了微型反应堆的设计、研制及应用工作。亲自指导了微堆物理方案的确定，审定了堆的初步设计和施工设计。在微堆建造过程中，他亲临现场，具体指导，倾注了大量心血，使之能在不长的时间内建成了我国第一座微堆。中子嬗变掺杂单晶硅和微型反应堆这两项成果已成为原子能院转民工作的支柱性技术，后者还获得了国家科技进步一等奖，为我国核技术出口作出了贡献，取得了良好的经济效益和社会效益。

他从国民经济发展的要求和能源结构分析出发，积极主张和推动发展核电，并在我国开创和组织了核电安全研究。早在 70 年代末，他亲自领导原子能院在国

内首先开展核电安全研究，这个技术方向的决策是十分正确的。同时，他为开辟核电安全国际合作渠道和培养人才作了很大努力。他受聘担任国家核安全专家委员会副主任。受国际原子能机构邀请，担任国际核安全顾问委员会的委员，参与了前苏联切尔诺贝利核电厂事故分析，以及核电厂基本安全原则的制订。与此同时，他还亲自开展了反应堆严重事故的分析研究，亲自指导多名博士和硕士研究生，围绕我国第一座核电厂——秦山核电厂的安全，开展事故分析研究工作，对秦山核电厂设计、运行、事故预防和处置，提出了有意义的建议。为适应核电发展的需要，他还领导成立了我国核电软件中心。

他十分关注我国快堆的发展，经常过问快堆研究设计工作的进展，并提出重要意见。特别是对快堆研究中心能在原子能院建立起来，他由衷地感到欣慰。

他曾任我国第六、七届全国政协委员，国务院学位委员会委员，中国核学会第一、二届常务理事，核能动力学会常务副理事长，中国计量学会名誉理事。他长期担任《核科学与工程》杂志的常务副主编，为促进与发展国际、国内学术交流，作出了重要贡献。

在与他多年的交往中，我们深深感到，他在实验核物理、反应堆物理、反应堆工程和核电安全等宽广的专业领域内，知识渊博，造诣很深；他爱国热情高，事业心强，哪里需要他就到哪里，对工作认真负责，兢兢业业；他学术思想活跃，治学态度严谨，为人光明磊落，坦诚直爽，坚持真理，无私无畏；他生活艰苦朴素，廉洁奉公，善于团结同志，热心培养人才。

出版这本科学论文集既寄托了我们对把毕生精力献给了国家核科学事业、并作出了重要贡献的戴传曾教授的深深怀念，也将使我们从中受到启迪，从一个侧面了解我国核科学事业发展的艰辛历程。这是很有意义的。

戴传曾教授为我国核事业发展无私奉献的精神和严谨的治学态度将永远铭记在我们核科技战线广大同志们的心中。

王淦昌

1995 年 5 月 5 日

PREFACE

Professor Dai Chuanzeng (Chuan-Tsen Tai) was a famous Chinese nuclear physicist, reactor physicist, expert in reactor engineering and nuclear safety, and a member of the Chinese Academy of Sciences.

Prof. Dai was born in an intellectual family in Ningbo, Zhejiang province, on December 21, 1921. He graduated with excellent marks from the Southwest Associated University in 1942 and became a teaching assistant there. He took the first place in the field of physics in the national examination for studying abroad at public expense in 1947 and was then sent to the University of Liverpool in United Kingdom for his PhD study of nuclear physics. The Nuclear Physics Laboratory of the University of Liverpool was equipped with a cyclotron and other advanced facilities for nuclear physics research. There he carried out the studies of the angular distribution of the ejectiles for the Ne and O(d,p) and B,O,C and Be(d,n) reactions and determined the spins and parities of the nuclear states involved. These experimental studies were the early exploration of nuclear stripping reactions. He also investigated the shrinkage factor and range correction of nuclear emulsions. During his dissertation work in the University of Liverpool he benefited considerably from the Nobel Prize Laureate Prof. J. Chadwick who discovered the neutrons. He received his PhD degree in 1951. At the end of the same year he politely declined the invitations to work in United Kingdom and resolutely returned to China. From then on he devoted himself to the pioneering work with great hardships in new China's atomic energy science. His deeds fully revealed his profound patriotism.

After returning to China, Prof. Dai worked in the Institute of Modern Physics, Chinese Academy of Sciences, the predecessor of the present China Institute of Atomic Energy. He led a pioneering work on the gas detectors in the early days of China's atomic energy science. Though the laboratory conditions were very poor, he and his crew endured great difficulties and developed the China's first halogen-quenched Geiger-Muller counter. During the period of the War to Resist U. S. Aggression and Aid Korea I entrusted him to prepare some nuclear detectors to meet the urgent demands. He thereby manufactured the high current Geiger-Muller counters and portable radiation monitoring instruments. His research on the halogen-quenched Geiger-Muller counters and the high current Geiger-Muller counters and their discharging mechanism filled the gaps in the field of nuclear detection techniques in China and caught up to the world advanced level of that time, for which Prof. Dai and his crew won the third-class Natural Science Prize of the Chinese Academy of Sciences in 1956. In order to develop neutron detection techniques in China he prepared a radon-beryllium neutron source by putting the beryllium powder brought back from United Kingdom into a glass tube which was then filled with the radon gas extracted from a 500 mg radium source in Peking Union Medical College Hospital. This neutron source was successfully used for neutron physics research and for testing boron fluoride neutron counters. These different kinds of counters mentioned above were put soon into mass production, and provided a fundamental and powerful tool for geological exploration, education and training, neutron physics experiments as well as nuclear radiation monitoring materiel for the army of chemical defence and nuclear explosion tests in China.

Under his guidance a number of pioneering researches on the air-equivalent ionization chamber, the boron foil ionization chamber and fission ionization chamber, the grid ionization chamber, the beta-gamma coincidence technique for absolute counting and the absolute measurement of neutron source strengths were performed and many young scientists were trained.

To conduct the research of slow neutron spectroscopy and solid state physics on the heavy water research reactor the first neutron single crystal spectrometer and the first neutron diffractometer in China were designed and manufactured in his charge from 1956 to 1960, which reached the world advanced level at that time and worked successfully for more than 20 years. The reactor neutron spectra, total neutron cross sections and fission cross sections were measured and the neutron diffraction studies were carried out by making use of them. These two facilities have made great contributions to the research of nuclear physics and solid state physics in China.

Prof. Dai organized and led a research group of radiation shielding physics in 1958. An advanced large area fission neutron source shielded by the water tanks for measuring macroscopic neutron cross sections was established at the heavy water research reactor, with which the attenuation of fast fission neutrons passing through different combinations of iron, lead and water and the shielding simulation of the active area of nuclear power reactor were investigated. He led the early experiments and the experimental project for investigating the gamma ray shadow shielding effect in water. These experiments generated the reliable data for the shielding design of nuclear power reactors.

Prof. Dai was assigned to be the head of the Stable Isotope Separation Laboratory in early 1960's. The ion source and isotope collector, which are the two key parts of a large-scale electromagnetic isotope separator, were successfully developed under his leadership. He supervised the determination of the abundance of deuterium and lithium isotopes, which yielded the important and reliable data for nuclear weapons.

Nominated by the Second Ministry of Machine Building in 1961, Prof. Dai held a concurrent post of the scientific advisor on the production reactor design, which offered him an opportunity to show his brilliant talent in the field of reactor engineering and paved his way to a well-known reactor expert in China. He took a post of Vice Director of Beijing Institute of Reactor Engineering in 1965. He vigorously organized scientific staffs and workers to fulfil various tasks of reactor engineering for production reactors, nuclear power reactors, high flux reactors and heavy water power reactors, and he supervised safe operation of the swimming pool reactor and several zero-energy reactors in the Institute.

Prof. Dai personally studied the production reactor technology and took part in determining technological parameters of the selected materials. He organized and directed the research and development of the high flux reactor, including hydraulic simulation, technological testing of controlling rods, fuel element performances, materials and corrosion problems. He arranged and conducted the in-pile proving test of the fuel elements of the nuclear power reactor. He led the design and construction of the China's first hot laboratory for the post-irradiation examination of materials. He made preparations for the investigating and designing of the fast reactor, TRIGA reactor and space nuclear reactor power system in 1970's. He guided the construction of the China's first zero-energy fast reactor, which has played an important role in the beginning of China's fast reactor development. He also attached great importance to the training of young scientists and competent persons in his scientific and technological activities.

I invited him to work in China Institute of Atomic Energy in 1978. He served as Vice-President and President of the Institute, and from 1985 he became the Honorary President of the Institute. He paid great attention to the development and applications of nuclear energy and nuclear techniques. He put forward a proposal to develop neutron transmutation doping of single crystal silicon in 1979 after his visit to the United States of America. He worked out a detailed program for the neutron transmutation doping in the Institute and directed the reconstruction of the swimming pool research reactor to increase neutron flux for it, which enlarged the reactor active core and replaced the graphite reflector by the beryllium one. He arranged to tackle the key problems such as the irradiation neutron fluence, temperature and homogeneity and the post-annealing. Under his leadership the first batch of neutron-transmutation-doped single crystal silicon was produced in China. Moreover, he then directed the design and construction of the miniature neutron source reactor and its applications. He decided its physical plan as well as checked and approved the preliminary design and the construction design. He came to the site and gave his instructions during the construction. He did a lot for the miniature neutron source reactor, which made it possible for the China's first miniature neutron source reactor to be established in a short time. The neutron transmutation doping of single crystal silicon and the miniature neutron source reactor have been two of the pillars of the Institute in civilian applications. The latter was awarded the first-class prize of National Science and Technology Progress and has made an important contribution to the export. Both social and economic benefits have been gained from these two items.

After analyzing the national economy development and the energy structure, Prof. Dai actively advocated and gave impetus to the development of nuclear power in China. He initiated the nuclear power safety study in China in late 1970's. Facts of the China's nuclear power development have proved that this is a correct decision. Meanwhile, he did his best to open up the way of international co-operation in nuclear power safety studies and to train qualified scientists and technicians. The China National Nuclear Safety Expert Committee got Prof. Dai to act as Vice-Chairman. The International Atomic Energy Agency invited him to be a member of the International Nuclear Safety Advisory Committee. He took part in investigating the Chernobyl accident of the former Soviet Union and formulating the basic safety principles of nuclear power plants. In the meantime, he carried out the study of severe accident analysis of reactors. In close connection with the safety of the China's first nuclear power plant——Qinshan Nuclear Power Plant he conducted the investigation of accident analysis and put forward a lot of important proposals for the design, operation, and accident prevention and disposal of Qinshan Nuclear Power Plant. He trained a number of MA and PhD graduate students in this field. As proposed by him, the China's Nuclear Power Software Center was set up in the Institute to meet the needs in China's nuclear power development.

Prof. Dai followed with great interest the development of fast reactor in China. He concerned himself with the progress of the fast reactor design and made important suggestions. He was very gratified with the establishment of the China's Fast Reactor Research Center in the Institute.

Prof. Dai was a member of the 6th and 7th Chinese People's Political Consultative Conference and served as a member of the Commission on Academic Degree of the State Council. He was elected a member of the 1st and 2nd Standing Council of Chinese Nuclear Society and Vice-President of Nuclear Power Society. He took a post of the co-editor in chief of the Journal of Nuclear Science and Engineering for a long time. He was also an honorary member of the Council of Chinese Metrology Society. He made great contributions to the promotion and development of domestic and international academic exchanges at his posts.

My long-time contacts with him made me deeply feel his comprehensive knowledge and great scientific attainments in experimental nuclear physics, reactor physics, reactor engineering and nuclear power safety, his patriotism and enthusiasm, his lofty dedication to his work and the state needs, his fine qualities of being active in science, rigorous in scientific approach and ardent in training competent persons and easy to work along with people, being open and aboveboard, honest and straightforward and selfless and fearless, firmly holding to the truth, performing his office duties honestly and leading a plain living.

As a token of our deep grief, we now publish the selection of his scientific treatises to commemorate Prof. Dai Chuanzeng who devoted all his life and made tremendous contributions to China's nuclear science and also to enlighten people on hardships encountered in developing nuclear science in China.

His utter devotion to China's nuclear science, selfless spirit and rigorous scholarship live for ever.

Wang Ganchang

May 5, 1995

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Shrinkage of Photographic Emulsions for Nuclear Research

J. Rotblat and C. T. Tai

The photographic emulsions used for the recording of ionizing particles contain a very high ratio of silver halide to gelatin. This results in a considerable shrinkage of the emulsion at processing, due to the washing out of the silver halide. In order to be able to interpret correctly events occurring in the emulsion, or to measure accurately the lengths of tracks which have a large angle of dip, it is important to know the exact relationship between the orientation of the track in the processed emulsion and the path of the particle while passing through the plate. This relationship is usually given by the so-called shrinkage factor S, which is the ratio of the thickness of the emulsion at exposure to that after processing; it can be determined either directly, by measuring the thicknesses of processed and unprocessed strips of emulsion, or by observations on tracks of known angle of dip[1] or known length[2]. The usual way to correct for shrinkage is to multiply the vertical projection of the track-length by the shrinkage factor. This is based on the assumption that the shrinkage affects all tracks in a uniform manner; but this is not immediately obvious, owing to the complicated phenomena which occur at processing. Taking into account that the photographic emulsion technique is becoming a method of high precision, it was thought worth while to study the shrinkage problem in greater detail.

First we determined the shrinkage factor, by direct measurement of thicknesses, in various types of emulsions with different loadings, concentrations of gelatin, thicknesses, and under different conditions of development, fixing and washing. Our results show that the shrinkage factor roughly follows, although is always smaller than, the ratio of the total volume of the emulsion to that of the gelatin. For emulsions of normal composition we found that Ilford *C*. 2, *E*. 1, *G*. 5 and Kodak *NT*-1*a*, *NT*-2*a* and *NT*-4 emulsions give nearly the same shrinkage factor, namely, $S = 2.7 \pm 0.2$, the limits being extreme values and including measurements on emulsions from different batches. For lithium-loaded emulsions S may go up to 3.2, due to the washing out of the lithium sulphate. We have also found that increasing the strength of the developer, or the time of fixation or washing, increases the shrinkage factor; but the changes in S are less than 10 per cent even for wide variations of processing conditions.

Our main aim was to determine whether the shrinkage is uniform throughout the depth of the emulsion, and whether the same correction can be applied to all angles of dip. For this purpose we used mainly lithium-loaded emulsions (Ilford *C*. 2 and *E*. 1), which we exposed to a flux of thermal neutrons. In the unprocessed emulsion the $H^2 + \alpha$ tracks, resulting form the disintegration of lithium, should all have the same total lengths and be orientated at random. The effect of shrinkage can then be determined in two ways: by observing the angular distribution of the tracks in the emulsion, and by measuring the horizontal and vertical projections of the individual tracks.

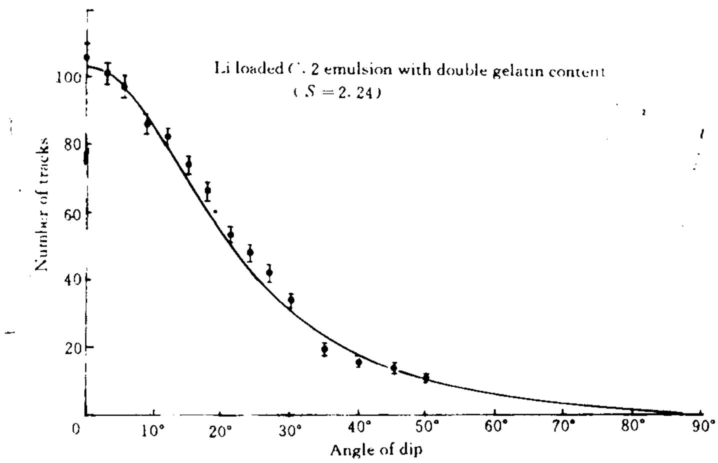

Fig. 1

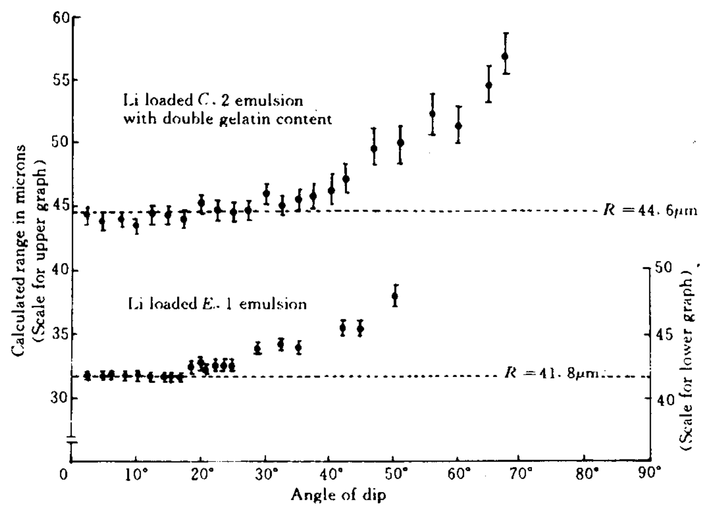

Fig. 2

In Fig. 1, which shows the result of one series of observations, the number of tracks of a given angle of dip is plotted against that angle. The full curve is that calculated for a random distribution, modified by taking into account the directly measured shrinkage factor. The agreement is seen to be very good, although the observations at large angles are not very reli-