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THE ATOMIC NUCLEUS: JANUSIAN ASPECTS AND HUMAN EXISTENCE.

by

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Professor of Physics

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INTRODUCTION:

An inaugural lecture can take various forms depending on the speaker, his interests, and his disposition to problems in his field. Some of the several forms it can take are as follows:

- an exposition of the past and / or ongoing scholastic efforts of the Professor,
- an exposition of what one would like to be, a future direction of research and development in one's area of work internationally or within one's nation.
- an exposition of past, present works and / or future projections in areas related to, or that could be beneficial to one's specialty.
- an exposition of special or specific problems facing one's specialty with a view to ameliorating them and thus leading to maximum benefit sbeing derived from efforts in one's field, and
- a general historical and philosophical overview of one's specialty for the sole purpose of enlightening the public and perhaps helping to make meaningful future projections in one's field.

Before we go into the actual form adopted for this discourse, it would be useful to pass some remarks which could help this august audience in seeing the need for the choice made herein.

This speaker became a Professor of Nuclear Physics more than fifteen years ago. He could thus be tagged an 'old' Professor as opposed to a 'recent' or 'eaglet' Professor on campus. Given this length of one's tenure as a Professor, it is perhaps not totally inappropriate if anyone has a tendency to regard this lecture as belonging to the valedictory genre as opposed to its being an inaugural one. This is, however, an inaugural lecture even though a form suited to a valedictory lecture is adopted here. The obvious advantage of this approach is that one is able to focus better on the peculiarity, and problems in one's field based on one's experience world - wide and in this our Third World setting.

With regard to the actual structural form adopted out of all the ones enumerated above, it should be clear as we proceed that a synthesis of most of the forms is presented here *albeit* with more emphasis on some aspects than others. The presentation here takes due recognition that the first form above is more suited to a newly appointed professor who would normally want to justify his new appointment by showing his contribution to knowledge. An old professor on the other hand needs to concentrate on some of the problems, peculiarities, and challenges in his field at least for the sake of posterity.

JANUS THE FORGOTTEN GOD:

I sincerely believe that several people in this audience can guess at the thrust of this lecture from the topic. However, for the benefit of those who might not be able to do so, I would like to crave the indulgence of the Vice Chancellor to make a short digression about an ancient god. The one in question was a Roman god. He was called JANUS. He was regarded as guardian of ***gates*** and ***doors***, and of ***beginnings*** and ***ends***. He was usually represented with two faces, probably symbolizing the faces of a door - one in front and the other at the back of the head. Appropriately, the month of January was named after him. That month as we all know, can be said, literally, to have two faces - one overlooking the old year and the other opened widely on the new year.

What then, it may be asked, is the relevance of this ancient and almost forgotten god to us, to the atomic nucleus or Nuclear Science or human existence ?

Janus and the universal philosophy of existence.

Everything under the sun, or indeed in the universe, has a ***beginning*** and will almost surely have an end. The time spans involved in these beginnings and ends vary very widely. In the cosmic domain the spans are 'measurable' in billions (10^9) or even trillions (10^{12}) of years or simply referred to as eons of time if the time being referred to would, in years, have several zeros after the number 10. In the normal or everyday or terrestrial domain time spans could be measured in seconds, minutes, hours, years, or tens or hundreds of years. In the nuclear domain however, time spans are measurable in extremely widely divergent scales ranging from extremely tiny fractions of a second (pico second - 10^{-12} , nano second - 10^{-9}, micro second - 10^{-6} etc.) to time scales used in the cosmic domains.

Our life - giving sun was born 5 billion years ago and is likely to die in about 5 billion years from now. Thus, the ultimate quenching of the sun need not border us or our great grand children since our own lifespans fall in the normal or ordinary domain.

Besides the beginning and end aspects of Janusism indicated above, there are other antithetical aspects as well. The existence of 'beginning' and 'end' imply progression in a sort of way just as they imply past, present and future in the cosmic realm.

Progression has the forward and backward aspects; and it also implies progress and retrogression. I believe that we could all also imagine the creation and destruction aspects of Janus.

We, individuals, nations and humanity at large, all worship at the altar of Janus in our everyday lives without realizing it. With a little imagination, we can recognize the omni - presence of Janus' hand in virtually every aspect of human activities. On a daily basis, we begin (or enter gates or doors of) new things [relationships included] or end (or close gates or doors to) things. We take or adopt both progressive and retrogressive actions on the same issue or matter at different times; and we create new things and destroy some things. Very importantly also, we recognize that there are positive and negative aspects to almost all things.

One of the sayings in Yorubaland is **"Meji n' ilèkun ; ti o ba si sile, a si s'ita"** . This means simply that a door either opens inward or outward. The 'inward' or 'outward' aspects of a door (or indeed of the almost forgotten Janus himself) also mean 'forward' and 'backward' respectively or vice versa if we consider the intrinsic nature of a door or the dynamic aspect of going through a door.

Yorubas are not, throughout their history, or as reflected in all of their folklore and fables, known as devotees of Janusism even though the saying above is Janusian in its meaning in more than one way. Sayings with the same or similar meanings are likely to occur in some other languages as well. Thus *Janus to the ancient Romans, and perhaps to the modern man, could be taken to be the expression and recognition of the antithetical nature of man, or of existence, or of the nucleus, or of human institutions and creations.*

Before we proceed to look at these and some of the Janusian aspects of the nucleus I would once again like to create your indulgence for us to look at some simplified fundamental aspects of the nucleus.

THE ENTITY CALLED THE NUCLEUS

The nucleus can be described loosely as one of the smallest forms of matter. The understanding of what a nucleus is may be helped by the following diagram:

Compounds → Element

Matter →   Element

Elements → Molecules → Atoms   Protons

                                  Nuclei   →

                                                    Neutrons

Matter is anything that has mass, and volume. It may also be viewed as that of which any physical object is composed. It may exist in solid, liquid, or gas forms from the point of view of a layman's consideration. Matter itself is made up of compounds or elements. While a **compound** can be resolved into simpler substances (or elements) by ordinary *chemical methods*, an element cannot. An **element** is a substance that cannot be decomposed into more simple substances.

Compounds or elements are made up of some smaller but unique units called molecules and atoms. While a **molecule** is the smallest portion of an element or compound that retains chemical identity with the substance in mass, an **atom** is the smallest particle of an element.

The atom is made up of an ***extremely tiny*** but relatively massive, *positively* charged, central core called the **nucleus** that is surrounded by *negatively* charged particles called **electrons** revolving round it. The electron is one of the fundamental particles of nature; and it is very light. The ratio of the mass of ***all*** the electrons in an atom to its nuclear mass ranges from ~ 1: 2000 (for hydrogen), ~ 1: 4000 (Oxygen), ~ 1 : 4233 (^{91}Tc) to ~ 1 : 5000 (for both ^{238}U and ^{260}Lr). Thus, *greater than 99.5 % of the mass of any atom resides in its nucleus*.

The nucleus, for the sake of this lecture, is made up of some fundamental particles called **protons** and **neutrons**. They are both collectively called **nucleons**. The proton has the same magnitude of charge as the electron even though it is positively charged; while the neutron has no charge. Approximately, the proton and the neutron can be taken to have the same mass which is about 2000 times the electronic mass.

The atom as a whole is electrically neutral since it contains the same number (equal to the atomic number, **Z,** of the atom) of protons and electrons. For a nucleus with mass number **A**, the number of neutrons in its nucleus is **(A - Z)**.

(a). Properties of Nuclei

The nucleus is imbued with several properties. Basically, these fall into two categories which may sometimes overlap, viz.: time independent (TIP), and time dependent (TDP) properties.

Some of the common TIP that the layman can readily relate to or grasp are : size, mass and charge. These as well as the nuclear spin or intrinsic angular momentum, isotopic spin, binding energy, energy level scheme, parity and symmetry of its state function are dictated by the basic properties of its constituent nucleons.

The shape of a nucleus is also one of its definitive TIP. Being a conglomerate of nucleons, a nucleus can have different shapes even for the *same number* of nucleons in *different nuclides*. It can be spherical or it can be deformed. Associated with each type of shape are electric and magnetic multipole (dipole, quadrupole, octupole etc.) moments which determine how the nucleus interacts with applied electromagnetic fields.

Among the time dependent properties (TDP) of a nucleus are the type of radioactive decay (, , , internal conversion, or fission), and artificial transmutations (nuclear reactions) that it is capable of undergoing as well as the transitions between its different energy levels. It is to be noted that while the separations between adjacent energy levels in an atom are of the order of an electronvolt (ev) those between adjacent levels in nuclei are about 10^4 ev to 10^6 ev (or 1 Mev).

The distinctive difference between a decay or spontaneous process and a reaction process depends on whether the total energy of the final system (E_f) is less (decay) or greater (nuclear reaction) than that of the initial system (E_i). The greater the energy difference ($E_f - E_i$) , the greater the transition rate in each case. While no energy is required for a decay to take place, some energy needs to be furnished for a nuclear reaction to take place.

From all the preceding , it should be quite clear that the problem of the nucleus is a **<u>many - body - problem</u>** (MBP) . It is by no means a simple one even when we are considering static properties. For example, obtaining a simple property like the mass of a nucleus from those of its components (nucleons) is not such a straightforward exercise as the case of , say, obtaining the total mass of fifty four oranges and twenty grapefruits. The mass of ^{20}O for example , is not just the sum of the masses of 8 protons and those of 12 neutrons.

In deriving **nuclear properties from those of its components**, various parameters such as the interactions, laws, principles, and sometimes quantum numbers have to be taken into consideration. Several of each of these parameters may have to be invoked simultaneously - thus leading to the type of complexity that is not to be found in other areas of study *including* Atomic Physics. For example, in addition to the normal complement of four quantum numbers involved in almost all atomic physics problems throughout the periodic table myriad of *other* quantum numbers are needed in handling some many body problems in Nuclear Particle Physics (High Energy Physics) and Nuclear Physics (Intermediate Energy Physics). Some of these are : isospin, helicity, parity, G - parity, baryon, lepton, hypercharge, strangeness, seniority etc. quantum numbers.

(b). Size of the Nucleus

In order to appreciate the size of the nucleus and the ingenuity involved in its study, it is useful to consider the sizes of some common everyday objects along with those of atoms and nuclei.

Oduduwa Hall here can be assumed to have a dimension of about 120' x 120' x 50' (on the average) while a fairly sized 'standard' orange has a diameter of ~ 3 inches. Thus about 88 million oranges will be required to fill it up. An extremely intrepid, indefatigable, indigent student (IIIS) who is 'working his way through the University' counting oranges at the rate of one orange per second will require about 2.8 years to count the oranges filling this hall without pausing to eat or sleep or ease himself !

Copper is a medium sized atom with a radius of about 2×10^{-10} m while its nucleus has a radius of ~ 4.8×10^{-15} m. An average sized *coccus* (a round bacterium) has a diameter of ~ 1.0 . Counting the number of copper ***atoms*** that will fill a **coccus** will take 50,000 years while it would require **7.2 million years** by IIIS to count the number of ***Cu nuclei*** that will fill a ***Cu atom*** counting at the rate of one nucleus per second under the condition indicated earlier. Similar operations for the numbers of **copper nuclei** that will fill the volume of an **average sized coccus,** or that of our **standard orange** will require, respectively, and 1.13×10^{19} years and 1.27×10^{32} years ! Assuming IIIS were present at creation (i.e. beginning of the Universe) and he started his 'aeonic' *magnum opus* then he would <u>not</u> yet have finished counting the number of nuclei of copper that could occupy the volume of an orange at this Janusian point between the 2nd and 3rd millennia.

Before we proceed to deal with the main thrust of this lecture we would like to deal briefly with the subjects of technology transfer and the neglect of

theoretical science studies in many Third World Countries (TWC). *The misconception about technology, and this neglect is at the bottom of most of the woes with which TWC have been, and continue to be. afflicted with within the last several decades.*

IT IS HARDER FOR THE HORSE TO FOLLOW THE CART

The truism of the above is obvious. However, for inexplicable reasons, <u>underdeveloped</u> countries (UDC), who are sometimes erroneously or mischievously called developing countries (Rodney, 1972) believe or are made to believe in the falsity of the statement. If this were not so one would be completely at a loss to explain why they (African, Asian and Latin American countries) do some of the things they do or are made to do.

Elusive Grail of Technology Transfer

A case in point of the above is the ever constant yearning ***for technology transfer*** when they should be pursuing <u>science transfer.</u> This fruitless pursuit apparently arises out of ignorance or perhaps from an 'induced cutting-corner syndrome' (ICCS). A close look at the following definitions of the word technology will expose the folly in the pursuit.

Technology :

1. ***Application of scientific knowledge*** for practical purposes **in a particular field**
2. ***Application of scientific knowledge*** by man to improve the quality of human life and / or control his environment; or in a modern sense,
3. **<u>Applied science.</u>**

From the above, it is obvious that **<u>science is the precursor of technology</u>**. Thus **it is** meaningless and wasteful to talk of, or pre-occupy oneself or country, with the technology of **any field** without a preceding or proper or sound foundation in the science of that field. Besides, UDC fail to realize that the technology of carrying out a process can (and does) change (sometimes rapidly) while the science behind the process generally remains immutable.

In general, <u>**use**</u> of products of technology made elsewhere is confused to mean <u>transfer</u> or <u>creation</u> of technology. For example, we <u>use</u> or <u>assemble</u> or <u>repair</u> automobiles in Nigeria but the technology of making one has <u>not</u>

numbers have to be taken into consideration. Several of each of these parameters may have to be invoked simultaneously - thus leading to the type of complexity that is not to be found in other areas of study *including* Atomic Physics. For example, in addition to the normal complement of four quantum numbers involved in almost all atomic physics problems throughout the periodic table myriad of *other* quantum numbers are needed in handling some many body problems in Nuclear Particle Physics (High Energy Physics) and Nuclear Physics (Intermediate Energy Physics). Some of these are : isospin, helicity, parity, G - parity, baryon, lepton, hypercharge, strangeness, seniority etc. quantum numbers.

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yet been transferred here in spite of the fact that we have been using vehicles for close to ninety years here. The basic science and technology of making engine blocks has never been, and probably will never be, transferred since the makers are not yet tired of getting their '*gari*' from us.

Most UDC readily go for technological assistance and projects. In time, and in several of these countries the assistance, especially in projects involving medium level and high level technologies, do not have lasting effects or the projects soon come to grief due to a myriad of reasons including lack of local expertise, lack of spare parts, lack of commitment by the foreign partners, escalating costs, and rapid obsolescence of installed machinery (Amusa, 1997).

The fact that technological advances depend more and more on results of basic research that are getting less and less published in open literature in advanced countries points to the need for developing countries to get off their hanker for living off the scientific results obtained by others.

Given the modern meaning of technology, it is very intriguing how third world countries hope to apply with *lasting effect* **knowledge they do not possess!**

It is thus clear why preoccupation or concentration with the technology of any field without a preceding (or at the worst concurrent) *strong* concentration in the relevant science, both *theoretical* and *experimental*, will lead to "erewhon" (apologies to S. Butler).

Bricks are better and stronger when made with straw

One of the costly, common major mistakes being made by third world countries, including Nigeria, is that they pay very little or no attention whatsoever to theoretical studies or research especially in the sciences. They often fund technology programs without the prior (most important) or concomitant funding of both theoretical and experimental scientific programmes in the erroneous believe that they would master the technology and make progress.

For meaningful progress, each country must aspire to create a good percentage of the technology it needs. In addition, *and preferably well before the commencement of the project, it must be well provisioned with the requisite experts and activity in the scientific field of the proposed technology project.*

To *illustrate the exceedingly great impact of promoting theoretical physics studies on mankind, we shall consider some of several theoretical*

physics discoveries that have been responsible for the modern world or human civilization as we know it today.

The theoretical formulation of the Maxwell's Equations in electromagnetism by James Clerk Maxwell in 1864 helped to explain the **nature of light and the inter - relationship between electricity and magnetism.** The equations predicted mathematically the existence of radio waves which were later confirmed experimentally by Heinrich Hertz in 1889. Without them, our several fields encompassing electromagnetic wave propagation, Radio communication, TV, Radar (widely used in military and in aviation industry), even telephony, Information Technology (IT) and other communication systems would not have been possible. We should for a second imagine our individual or national life without these communication systems.

Bardeen was until his death in 1991, a Theoretical Physicist and a Professor in my former Physics Department, as well as a Professor of Electrical Engineering in the same University of Illinois at Urbana, Illinois, USA. He was the only man in human history to have received two Nobel Prizes in the same field.

Bardeen **ushered in** both the **Computer Age** and the **Space Age** when he invented the transistor theoretically in 1947. He later shared a Physics Nobel Prize in 1956 with Walter Brattain and William Schockley who fabricated the first device. Without the invention, <u>silicon chips</u>, <u>integrated circuits</u>, <u>modern computers</u>, various <u>electronic gadgets</u> like wrist watches, <u>robots</u> used for dangerous operations in industry, miniature <u>hearing aids</u>, <u>pacemakers</u> for human hearts and others., and would not have been possible. <u>Fax</u>, <u>E-mail</u>, <u>IT</u> etc. facilities that have helped to make the world into a global village would not have been possible without this theoretical invention also. Prior to the invention, a computer capable of doing what an ordinary secondary school student's calculator can do would be the size of this Oduduwa Hall since it would contain very bulky therminionic vacuum tubes.

BCS theory on the microscopic aspect of **superconductivity** also fetched Bardeen and two of his post doctoral students, L. N. Cooper and J. R. Schrieffer, another Nobel Prize in Physics in 1972. This deals with the vanishing electrical resistance of some metals at very low temperatures or conduction of electricity at zero resistance. It has opened up a whole wide future for land transportation with the possibility of bullet trains that can move at the speeds of jet planes. Japan and France are presently testing models of these super fast trains. The power distribution industry, construction of huge powerful electromagnets such as might be needed in generation of electricity through Fusion (the virtually safe process for inexhaustible supply of energy in future) are also going to be revolutionized through the application of results emanating from the use of BCS theory.

Another landmark theoretical contribution was by Enrico Fermi, a Nobel Laureate, who theorized on the possibility of Nuclear Fission in 1934. Eight years later in 1942 he built and tested the world's first self - sustaining nuclear chain reactor or simply **the world's first nuclear reactor** at the University of Chicago in the US.

It is obvious from the preceding that several things that define the modern world as we know it, or define the level of present world civilization, or define our level of material comfort, or that even define our modes of business transactions, or define how we relate to our families, friends and relations originated from results of the Theoretical Physics discoveries of J. C. Maxwell, John Bardeen, and Enrico Fermi. It is thus clear that investment in Theoretical Physics studies and research can be very rewarding and even open up entirely new industries and businesses in any country. While it is recognised that not all Theoretical Physics research results and activities have land shaking consequences as those considered above, it is obvious, especially in very serious countries (both developed and developing) that Theoretical Physics helps to do some or all of the following and thus contribute significantly to national security and national development:

- improve the quality of physics being imparted at all levels in the country,
- improve the quality and quantity of experimental research work being done in the country. Interpretation of experimental results become easier and new experiments are more readily suggested.
- easily keep abreast of development in physics in other parts of the world. It is to be noted in passing that there are several areas of physics where the literacy levels are zero or dangerously low in Nigeria owing to the long time neglect of this area of activity, and
- possibly open up new fields of economic activity, or lead to new inventions in a country. The invention of the " plasma torchlight " in Brazil that resulted from theoretical plasma physics studies there is a case in point.

NUCLEAR SCIENCE STUDIES

Nuclear Physics is one of the most fertile grounds for the display of human ingenuity. Some of the smallest known objects in the universe, as indicated above, are routinely studied both theoretically and experimentally in the field; and vast arrays of results that have led to the re-definition and understanding of our world have been obtained.

Our knowledge of the cosmos - in terms of the age, composition, history and lifetimes of the planets, stars, and galaxies etc. - got tremendous boost from the study of Nuclear Physics. For instance, Hans Bethe, a Nobel Laureate in Physics, discovered that our life - giving sun and indeed all the stars are driven by nuclear processes and reactions.

On the terrestrial plane, nuclear study has (among several other results) led to:

- understanding of the radioactive nature of our world,
- unleashing of some of the greatest sources of energy known to man that could, with proper management, help to improve the quality of human life and possibly help to prolong the existence of man on this planet.
- the applications of nuclear energy and radiation in several fields such as agriculture, hydrology, medicine etc.

A brief look at both the experimental and theoretical aspects of nuclear science studies is as follows.

1. Nuclear Experimentation

Experimental nuclear studies involve looking at nuclear particles at enormous energies. The energies involved in low energy nuclear studies are several million times those encountered in atomic processes or experimentation. Some of the primary devices for achieving these enormous energies in different areas of nuclear studies are reactors, accelerators, and some super - colliders. The latter have been used to provide particles with energies comparable to those found in stars (our sun is a small main sequence star !) and in cosmic rays or some extra terrestrial sources.

Without accelerators, several nuclear experiments requiring high energies would not be possible. A typical nuclear experiment could be regarded as a scattering process of the form:

$$P_1 + N_1 \rightarrow N_2 + P_2 + Q$$

where P_i ($i = 1$ = projectile, and $i = 2$ = ejectile) and N_j ($j = 1$ = target nucleus, and $j = 2$ = daughter or residual nucleus) and Q is the energy released or absorbed in the reaction process. In order to carry out an experiment such as is indicated above, one typically needs: an accelerator, beam transport system, and a detector.

2. Theoretical Nuclear Physics

Nuclear theory is one of the veritable and very fertile playgrounds for Quantum Mechanics (QM) which is a very powerful theoretical tool for Modern Physics. Indeed no other area of Modern Physics has such diverse and ramifying use of QM as nuclear physics.

Nuclear problems are in general MANY BODY problems and are therefore extremely large and very complicated. These aspects arise because a nucleus has many particles or nucleons, each of which has several degrees of freedom or parameters, quantum numbers etc. (or several properties, using a layman's language) i.e. the properties of a nucleus arises from the 'interactions' of all these parameters of the constituent nucleons. Given this, theoretical nuclear problems are some of the largest problems known to man.

A problem aimed at eliciting some of the properties of a new isotope, of say a light (or small) nucleus such as O^{20}, for example, using shell model theory (SMT) and using no further approximations will take 15 to 20 years to complete by a very hardworking, knowledgeable, and ***infallible*** (HKI) young Ph.D (TNP) **working by hand** (i.e. no computer) day and night with no sleep and no time taken out for food, and other conveniences ! Such are the sizes and concomitant complexities of problems encountered in TNP that they would have been insoluble or intractable but for the use of extremely huge and superfast computers coupled with the use of very insightful theories. The history of the development, size, and speed of computers cannot be divorced from the ever escalating needs of TNP to solve some class of many - body problems. In addition to this, several softwares that are now routinely used in diverse areas of research originated from TNP studies.

BRIEF NOTE ON MY SOJOURN AS A NUCLEAR PHYSICIST

I received my Ph.D. in **experimental nuclear physics** (ENP) in 1971 at the University of Illinois, Urbana, USA after my B.S. (Engineering) and M.A. (Physics) degrees at Columbia University, New York, USA. I intended to continue with ENP on my arrival in Nigeria in 1972 but I had to re-train myself and switch to **theoretical nuclear physics** (TNP) on being informed at Ahmadu Bello University, Zaria that there was no way I could get the type of money I needed for research in ENP. Professor Abdus Salam, the 1979 Nobel Laureate in Physics facilitated my efforts in this direction by inviting me to the **International Center for Theoretical Physics** (ICTP), Trieste, Italy in September 1973.

My plan was to continue theoretical work, help to build an active group in this area, then commence simple, cost effective experimental work as money became available, and hopefully, active and full blown ENP groups can result from these efforts. This projection also happens to dovetail with the usual steps in the development of nuclear science or plasma physics in any country aiming at serious efforts in these fields. Countries like the US, Canada, India, and Brazil followed this pattern of development in these and other areas. Unfortunately, owing to the unusual politicization of nuclear science matters on our campuses and elsewhere this pattern of development never came to pass in nuclear research in Nigeria.

I visited ICTP on International Atomic Energy Agency (IAEA) fellowships several times since my first contact there. I was made an **Associate** from 1984 to 1993. I also visited Argonne National Laboratory (ANL), a high powered US government research center in 1980 when I was on sabbatical leave. There I worked on some nuclear structure problems. I was subsequently made a Visiting Research Associate from 1981 to 1991

I published my first theoretical nuclear physics paper in 1975 in **Nuclear Physics** journal. Since 1973 I had published several theoretical nuclear physics Technical Reports at both the International Center for Theoretical Physics in Italy and at Argonne National Laboratories in the US. The areas in which I had published journal articles since I started TNP research are:

- **nuclear reactions** - I worked mostly on *absolute* normalization of single nucleon transfer reaction (

SNTR), two nucleon transfer reaction (TNTR) and three nucleon transfer reaction (3NTR) cross-sections using Distorted Wave Born Approximation (DWBA) theory and different nuclear interactions. The results obtained resolved some difficulties in the theoretical fitting of experimental data. Some of my publications in this area are: Amusa (1975), and Amusa (1980 a).

- **Quasi-degenerate Hamiltonians and some s-d and 2p-1f nuclei** - the low - lying collective states of some nuclei in these shells were studied with a new *modified* Hartree - Fock approximation approach that my colleague, Prof. S. K. Sharma, and I introduced for enlarged model spaces. Improved results were obtained in the cases considered: Amusa and Sharma (1976) and Amusa and Sharma (1980 b).
- **Studies of some light and medium heavy nuclei** - The nuclear shell model theory was used to study the high spin states of some medium heavy and neutron deficient nuclei like ^{89}Nb, ^{90}Zr, ^{91}Tc, ^{94}Ru, ^{95}Rh, and ^{97}Rh. Also the effects of intruder or core -excited 4p-2h and 6p-2h states in some oxygen isotopes were considered. Some of the publications on these are: Amusa and Lawson (1982); Amusa and Lawson (1983a); Amusa (1985a); Amusa (1985b); Segel, Amusa et al (1989); and Amusa (1993).

I would like to comment briefly on some developments in the course of my research as a theoretical nuclear physicist.

Our work on ^{91}Tc produced the first known spectrum on the nucleus. Dr. Lawson and I in the US, worked concurrently with the experimenters, Paolo Blasi and E. Nolte and others of the Munich - Florence group who were working in Europe. Our results helped them to identify the experimental levels and hunt for the electromagnetic transitions in the nucleus. Their results agreed with our predictions except for a few transitions. They informed us on this; we checked our theory and informed them some weeks later that they would find the transitions. They still could not find them; we checked our work again, confirmed the existence of the transitions and requested them to carefully check their work. They did and confirmed all our predictions except

the E2 transition from the 41/2 $^-$ to the 37/2 $^-$ state which is a very weak transition. The two papers were both published in Vol. **314** of **Zeitschrift für Physik A - Atoms and Nuclei.**

Another highlight in my career as a theoretical nuclear physicist was the research on the quenching of magnetic transition strengths in inelastic scattering to some states in ^{28}Si which culminated in a publication in **Physics Review Letters** which is the physics journal noted for publishing pointers to new developments in Physics worldwide [Amusa and Lawson (1983 b)]. The paper dispelled the requirement for the inclusion of non-nucleonic degrees of freedom to explain these transitions in some nuclei. Our work was a major highlight in the nuclear physics community in the US in the summer of 1982. Several papers, all referring to our work and based on our theory have since been written and published in international journals since 1983.

NUCLEAR SCIENCE AND MANKIND

Nuclear science as a discipline started in 1911 with the correct theoretical interpretation of the Geiger - Marsden - scattering experiment by Rutherford. This was the *first* nuclear theory of the atom and it also gave a quantitative value for the relative sizes of a nucleus and its atom. This was followed in 1913 by the discovery of isotopes by J. J. Thomson.

Other landmarks in the development of nuclear science were:

- **1919** Demonstration of induced nuclear transmutation by Rutherford
- **1932** Discovery of the neutron by Chadwick
- **1932** The n - p (neutron - proton) hypothesis by Heisenberg
- **1934** Enrico Fermi's theory on the possibility of **nuclear fission**
- **1939** Otto Hahn and Fritz Strassman, two Austrian physicists, demonstrated the fissionability of Uranium nucleus by neutrons
- **1942** Enrico Fermi started **THE NUCLEAR AGE** when he built and tested the **first Nuclear Reactor** in a converted Squash Court at University of Chicago

- **1945** The explosion of the **first Nuclear Fission Bomb** at Alamogodo, New Mexico, USA on July 16th. 1945
- **1945** Nuclear Fission bomb detonated over Hiroshima on 6th. August 1945. (The bomb was equivalent to 20,000 tons of TNT - 66,000 killed and 69,000 injured with about 67 % of the city destroyed). A second bomb was detonated over Nagasaki on 9th. August 1945 (39,000 killed and 25,000 injured).
- The theory of non - conservation of parity in - decay by Lee and Yang - two of Enrico Fermi's Ph.D. students - who got the 1957 Nobel Prize in Physics etc.

In so as the ı ıyman is concerned, the most important aspects of nuclear science are conci rned with its applications especially in the generation of energy, as in Nuclear Fission Reactors, and in several other fields - some of which shall consider shortly

The double - facedness or Janusness - the useful and destructive or the salutary and the bad aspects - of nuclear science are usually demonstrated by focusing on the applications. While it is generally recognized that nuclear science applications could constitute a very great boon to mankind, it is also recognized with great trepidity that it could also constitute one of the greatest menace to the existence of man.

In the light of the preceding, several questions come to mind, viz.:

- Is each of these diametrically opposite views justified?
- Do the bad aspects far outweigh its useful aspects?
  - If so, should man continue to invest in the study of this branch of science and its applications?
  - Also, is it possible to ameliorate or eradicate its bad aspects and thus effectively use the science in the service of man ?
- Do the good aspects far outweigh the bad aspects?
  - If so can we afford to live with the few bad aspects no matter the preponderance of the good over the bad aspects ?

- Similarly, is it possible to ameliorate or eradicate its few bad aspects and thus effectively use the science in the service of man ?

These and several other questions arise in a supposedly detached consideration of nuclear science applications.

In addition to the above are the following very important questions:

- Are the above questions just arising for the first time in a field of human activity or invention ?
  - If the answer is in the negative, how did man respond in those preceding cases ?
  - If the answer is in the affirmative, must man abandon this field of science or its applications especially on account of the perceived danger of some of the latter ? Would such an abandonment be in line with spirit of man as demonstrated through the ages in his unceasing efforts to tame and dominate his environment ?

Needless to say, it is not easy to give simple answers to each of these questions most especially as applications of nuclear science require very complex considerations bordering on technical, political, sociological and economic or financial matters.

In spite of this however, we shall attempt to proffer some information in the course of this lecture that could help us to look for answers to some of these questions.

A. NEGATIVE JANUSIAN FACE OF NUCLEAR SCIENCE APPLICATIONS:

In considering the seamy side of nuclear science applications (NSA) some of the areas that are readily focused upon are :

- the problem of man - made or artificial radiation,
- nuclear accidents,
- problem of storage and / or disposal of nuclear wastes,

- decommissioning of nuclear reactors after their useful life - spans, and
- the problem of the bomb - both nuclear and thermonuclear.

A brief consideration of each of these is as follows:

1. Man-made Radiation Problem

The spontaneous emission of energy by a body is what is called radiation. The energy emission could be in form of some rays (visible or invisible) or some particles. Radiation sources fall into two categories, viz.: natural, and man-made or artificial sources. Most of the radiation from the application of nuclear energy are of the second kind at least with respect to the location of the application. (We shall have cause to consider natural radioactivity later in this lecture).

Several useful nuclear processes such as those that take place in nuclear reactors, accelerators and in some nuclear reactions lead to the release of various forms of radiation. The fact that nuclear radiations are not visible, coupled with the fact that some of them (- rays, and - rays) are so penetrating and / or destructive to living matter accounts for the justified awe and revulsion with which the average person views anything emitting or involving radiation. The fact that a myriad of diseases such as cancer, leukemia etc., and genetic mutations are known to be capable of being caused by high and perhaps low levels of radiation also contribute to these fears.

In the process of generating energy in existing reactors the fission processes involve the release of copious amounts of radiation in addition to the creation of several radioactive isotopes some of which have very long half - lives running into thousands of years. The containment of the radiation and the radioactive wastes released have received serious attention in nuclear energy generation. Radioactivity produced by radon gas in mines or produced by uranium tailings in or near old uranium mines also add to man - made radioactivity in the environment

2. Problem of Nuclear Accidents

Nuclear accidents can be of various forms depending on the processes involved. It could be, as in the case of a reactor, it could be due to the failure of any of the different parts in the reactor system - including the control rods,

or the pipe system for the coolants or cracks in the containment vessel or the reactor building. Other forms of nuclear accident could be due to development of cracks in or loss of sealed radioactive sources used in various salutary nuclear application processes or the malfunctioning of some radiation - producing device such as x - ray machines.

The end results of such accidents in a reactor or elsewhere could be the release of radioactivity into the environment - the air, the soil, rivers and lakes near, and sometimes hundreds of kilometers from the reactor or nuclear application device. In some cases, both short - lived and long - lived radioisotopes could be released into the surrounding ecosystem.

3. Nuclear Wastes Problem

Simply, nuclear waste is the end product of the use of some nuclear material in some (nuclear) application process. In general, most of these waste products are radioactive and invariably remain so for several years or even millions of years in some cases. In many cases these bye-products have no known uses and hence need to be disposed of. Even in cases where these by-products could be useful, the technology of extracting them is either unknown or prohibitively expensive or commercially unaffordable.

Unfortunately for the Nuclear Industry and perhaps the world, Nuclear Waste Disposal (NWD) was not given much attention or the attention that it deserved right from the inception of the Nuclear Age. This major omission or negligence is responsible for the accumulation of several high - level and low - level nuclear waste products in several countries of the world. Some of these wastes are currently being stored in temporary sites either near the reactor or in some remote areas.

4. The Bomb and other problems

The problems of nuclear science as perceived by the layman could be said to have its source in the fact that the first applications were for military use or for very destructive purposes as represented by the Atomic Bomb and then the Hydrogen Bomb. The peaceful applications which far outnumber the destructive ones in the present day world came much later.

In line with the latter viewpoint, it is feared , correctly or incorrectly , that the explosion of a few super nuclear (fission or thermonuclear) bombs in a major nuclear world war or some series of unusual major nuclear accidents could lead to the extinction of man and perhaps other living things on this planet. Some of the other problems associated with nuclear power generation as well as with the decommissioning of a nuclear power plant after its useful lifetime include the huge costs of money involved in both aspects.

B. POSITIVE JANUSIAN FACE OF NUCLEAR SCIENCEAPPLICATIONS:

Hardly any aspect of life in any advanced country, and increasingly in many developing countries, is not touched by the diverse fields of applied nuclear science. The most commonly known application is for generation of electricity. Other diverse fields of application include industry, medicine, agriculture, teaching and research, hydrology, criminology, photogrammetry, archeology etc. A brief consideration of some of these fields would seem to be appropriate at this point.

1. Applications in Power Generation

World - wide the percentage of electricity generated in 1991 by nuclear fission reactors was 17 % and the figure is increasing in spite of the unceasing crusade against nuclear energy.

The single largest source of energy in Europe is Nuclear Energy. It accounted for 32 % of total energy supplied in 1990. As at December 1994, France, Lithuania, United Kingdom, Belgium, Spain and Argentina generate, respectively, 75.29 %, 76.37 %, 25.79 %, 55.77 %, 34.97 % and 13.77 %. The corresponding figures for the United States, Russia, and South Africa are 21.98 %, 11.39 %, and 5.69 %, respectively.

It is to be noted that even with the fears of dangers of radiation and of wastes disposal, the excellent safety records of nuclear facilities, the containment of its wastes so far, and the fact that no greenhouse gases (carbon dioxide, methane, and chlorofluorocarbons [CFCs]) get released into the atmosphere are some of the weighty points considered in favour of nuclear energy in several countries.

2. Industrial Applications

The applications of NST in industry are so diverse that one can just mention a few in a lecture like this. A few of these applications are as follows:

- Machinery such as jet planes, high speed trains or cars are routinely tested for strength and reliability by radiographs made by high energy gamma rays from some nuclear sources.
- Gamma rays and X - rays from radioactive sources are used to detect the smallest defects in turbine blades, high pressure steam boilers and other potentially dangerous machinery. These have guaranteed reduction in mechanical failure of these devices and thus contribute to reduction of accidents.
- Nuclear radiation has also been used to sterilize packaged food items to ensure long shelve lives.
- Qualities of such industrial products as steel, rubber, petrochemicals, fertilizers etc. are enhanced by using nucleonic controls.
- Radiation techniques are also used in synthesizing chemicals and in detecting composition of wines, rivers (for pollution tests) etc
- Use in well-logging, and in leak detection in pipelines in the oil industry

3. Medical Applications

One of the most distinctive features of Modern Medicine as compared to medical practice of about 60 years ago is the diverse application of nuclear science in the field. Consequent upon this Nuclear Medicine is now an important specialty in most modern Medical Schools abroad. Some of the uses of Nuclear Science in medicine are as follows:

- Radiation is used in Cobalt therapy to treat about one-half of all cancer patients. Also, cancer cells have been detected in patients in a diagnostic procedure involving the use of ^{99m} Tc which has affinity for cancer cells and is unstable and soon decays within the patient.
- Radioisotopes have also been used to determine the amount of body protein in an individual with the aim of diagnosing such ailments as cancer, AIDS, malnutrition diseases and trauma caused by surgery
- Radioisotopes are used in research to investigate

metabolic pathways of elements normally found in the body as well as in the study of hemodynamics and cardiac shunt studies.

- Radiation and radioactive pharmaceuticals have become prominent diagnostic tools in medicine in several advanced countries. Before the utilization of radioactive materials in Nuclear medicine, doctors often relied on exploratory surgery or educated guesses to diagnose patients. Nowadays, it is routine for doctors to inject minute quantities of radioactive chemicals into patients to examine the health of organs, locate tumors, detect malfunctions of the tyroid glands, and determine the chemical balances in the body.
- Penetrating radiation is a much more effective sterilizing agent for medical supplies than traditional agents such as heat or disinfectants. Besides, the use of radiation is also more reliable and ensures health safety for the patients.
- Use of several radionuclides such as ^{123}I, ^{201}Tl, ^{11}C, ^{111}In, ^{67}Ga, ^{81m}Kr, ^{15}O, ^{13}N, and ^{18}F (with various lifetimes for medical studies.

4. Applications in Agriculture

The use of nuclear science applications in agriculture is very great and has led to a tremendous boost in world food supply. Radiation techniques have been used to improve the health of farm animals and crops and thus to keep down food prices in some advanced countries. Also specific problems in irrigation, soil fertility, genetics, plant breeding, animal breeding, insect and pest control, food preservation, agrochemicals and pesticide residues can now be solved using nuclear techniques. There is no doubt that some developing countries that experience periodic food shortages due to floods or draughts can benefit from the applications of these and several other nuclear techniques.

5. Other Diverse Applications

Nuclear science applications and techniques are now routinely used in several other fields especially in advanced countries. It is now used in

criminology because it allows for the possibility of solving cases that might not otherwise have been solvable. Also, radioactive isotopes and nuclear techniques have been used in hydrology to investigate both surface and ground water supplies with great dividends. The age and origin of groundwater water lying deep beneath the land surface in arid areas could be established when these investigations are coupled with studies in environmental isotopes. Isotope techniques could also be used to investigate difficult problems such as finding salt-free groundwater supplies for cities near coastlines like Lagos, Epe, Port-Harcourt or on islands. Also nuclear science applications have found very wide usage in assessing the environment.

6. Spin-offs from Nuclear Technology

Thousands of spin - offs have been made and continue to be made from nuclear science and technology in various non - nuclear fields. A few examples are

- the development of a porous ceramic piece used in cardiac pacemakers from the technology used in the nuclear industry in developing SYNROC - a man - made material that is to be used in storage of radioactive wastes from the nuclear industry.
- The discipline of risk and reliability analysis which grew from developments in nuclear science applications
- Based on extensive knowledge in handling environmental and health implications of uranium mining a high level of expertise has been developed to analyze the stability of dams, tailings, movement of heavy metals in the environment and the optimization of other non - nuclear mining operations.
- Various equipment like multichannel analyzers used in diverse fields had their origins from experimental nuclear physics

NEED FOR A BALANCED VIEW ON NUCLEAR APPLICATIONS

There is no doubt whatsoever about the seriousness and genuineness of some of the misgivings and fears expressed about some aspects of nuclear science applications. However, we need to ask at this junction whether the world would be taking greater or unusual risks in the pursuit of scientifically, sound, and *steps - tested* and well - supervised nuclear science applications?

It is useful to note some very important facts about human existence at this point :

> ***hardly any human activity does not involve some* risks.**
>
> at the **commencement** and close to the historical beginning of any human activity the risks always usually appear enormous to the extent that any sensible and reasonable human at that historical juncture would be averse to further development of the new activity.

Existence is all about Risks

The preceding statements may appear rather sweeping and perhaps exaggerated. Or, are they ? Let us quickly look at a few human and / or biological activities to see the truth or otherwise of these statements.

Ubiquity of Natural Radiation

We all fear radiation; yet we cannot live without some forms of radiation. Heat and light are forms of radiation without which our very existence on this planet will be quite doubtful. No doubt our fear of radiation seems justified moreso as there are other forms of radiation to which our senses are not sensitive. These types of radiation (alpha, beta, or gamma) which are usually what the layman refers to, or calls radiation emanate from radioactive substances as well as from cosmic rays.

Nuclear radiation is ubiquitous. It is everywhere at every time on earth and indeed in the universe. It is in the air we breathe, the water we drink, in the soil , in our houses and offices, in our bones and muscles, and it in our food and in everything we use.

Each of us is bombarded by about 15,000 gamma particles per second from cosmic rays and from radioactive minerals in the earth's crust assuming natural radioactvity exposure is 0.1 rem / year.

The materials with which we build our houses - bricks, sandcrete blocks,

stones, sand, cement etc. - *are* all radioactive to some extent ! Radioactive radon gas (formed as the metal radium [Ra^{226}] decays in a normal brick house (not to talk of a stone house) could expose its occupant to an annual dosage of 150 - 300 millirems or approximately 22,500 to 45,000 gamma particles per second !

In order to protect ourselves from these constant and unceasing bombardments whether from the inside or outside of our homes, if we like, and we do not mind the consequential clumsiness and the attendant heat, *we can wear metal - lined clothing or even metal clothing (Ti a ba fe, a le wo ewu irin, bòbàta irin, ki a si tun de fila irin pelu)* ! This will not, however, save us totally from natural radioactivity no matter the cost of our clothe and the ingenuity of our ' metal - clothe - designer '

Everyone of us is intrinsically radioactive just as every other animal or plant is. Each of us has radioactive potassium (K^{40}) and radioactive carbon in our muscles just as we each have radioactive radium and polonium in our bones. Equally, we all have radioactive noble gases and tritium in our lungs. The radioactivity of each of us can be detected by very sensitive radiation meter.

We cannot do anything about our intrinsic radioactivity moreso as each one of us, on the average, ingests about 0.1 Ci (microcurie) of K^{40} daily in our food beside some other naturally occurring radionuclides in our drinks. Thus each of us is bombarded from inside by 3,000 to 5,000 beta and gamma particles per second.

2. Risks in Living in Houses

Living in our snug or cosy, well - provisioned, modern or old house, is also a risky business if we care to look more closely than we are used to. The chances of accidents from electric shocks, fire, pollution from cooking gas or kerosene stoves, household chemicals etc. are quite high to the extent that most people might want to live in the open air if they were to be well - informed about the statistical figures about how living in their homes affect their health and possibly life-spans. Needless to say, living in the open air is equally a risky business. An eight - year old child could educate anyone on the risks (hypothermia, heatstroke, exposure to rain and storms, snake or insect bite, attack by wild animals etc.) that could be involve[illegible] total open air living.

3. Nutrition Risks

Eating or nutrition, recognized everywhere as a desirable activity for most living things, involves some risks. The risk of not getting proper or adequate or the right 'food' exists for all living things. A seed may fall in the wrong type of soil and thus fail to germinate properly just as some other living things may be unlucky to find themselves in the wrong environment.

The process of discovering and adopting new items of food for humans, as I believe that we could all imagine, involved some risks. Equally, eating established food items could also be risky since they can contain stray chemicals that could pose health hazards.

There is also risk involved in the actual human eating process. A morsel could get in the windpipe instead of into the gullet in the case of a man; or a herbivore could eat the wrong plant or wind up in the stomach of a carnivore while foraging for food; or a voracious carnivore with an inordinate hunger and deranged sense of judgement could receive a mortal gore or a crushing blow from a big herbivore or an elephant all in a bid to eat. In order to lessen the risk of choking in the case of man, one is advised not to take big mouthfuls or big morsels, or not to talk while eating, or not to wolf down ones food no matter how delicious the food or how hurried one might be to eat.

4. Risks in Transportation

Moving from one place to the other involves some risks - the seriousness of the risks depends on the mode of transportation under consideration. For normal road transportation in an advanced country like the US the chances of being involved in an automobile accident in a 50 kilometer journey is about 1 in 100. The corresponding figure for Nigeria with all the bad roads, old rickety vehicles, rusty *tokunbo* vehicles, fake auto parts, undisciplined drivers and other road users, unlicensed or fake - licensed drivers, drivers with undocumented or untreated impairment that do not allow for safe driving would make one shudder. It could be anywhere between 1 : 50 optimistically, or 1 : 20 realistically.

Traveling by train is equally risky what with collisions, derailments, jumping off tracks etc. that occur so regularly that they no longer always make the national or international news headlines. Whole country – sides have been devastated by dangerous chemicals, gases and substances from train derailments. **The Bhopal, India train derailment of a few years ago led to over ten thousand deaths and several hundreds of other casualties**

as result of the deadly chemicals carried on it.

Travel by air is also risky even though it is not as bad as that of road and train transportation if the risks are considered in terms of events per million - man - kilometers. The danger of exposure to radiation in air travel is also there - even though this is not known to the layman. A single plane journey from Lagos to London could expose each passenger to about 7 millirems (of radiation) which could be considered in terms of its danger level to about 10 millirem exposure for a chest x - ray.

5. Risks in Conventional Power Generation

Electricity generated from ***coal and other fossil fuels*** causes emission of noxious gases which cause air pollution, acid rain, and depletion of the ozone besides contributing to the greenhouse effect. Coal power plants also emit radioactivity into the environment from the radioactive minerals usually found with coal as impurities.

Hydroelectricity as a source of power has its drawbacks in the restriction of its plant location, its requirement of large area of land and the damage / alterations of local ecology usually for the worse, and the very grave risk involved in failures of dams.

Intrepidity of Man and his Inventions

A close look at most human inventions and new activities at their commencements shows that they all have some common features that reveal the true spirit and nature of man. He is irrepressible, and constantly disposed to taming , improving and conquering his environment and facilitating his efficiency and chances of survival on this planet. A few examples, drawn for convenience from the transportation sector at this point will suffice:

1. Harnessing Horses for Travel

The first efforts to harness horses for transportation cannot be said to be easy and smooth sailing. Thousands, or perhaps millions, of human bones (including neck bones) were broken, several kicks were received from rear or front hoofs, even some biting were received before our ancestors mastered the horse for transportation . Man never gave up; he learnt from his mistakes, made necessary adjustments and (perhaps) atonement (to the horses so that they became calmer and more disposed to him) until he could, some thousands of years ago, almost uneventfully ride horses. It is now possible to count horse riding as a (petrol - free) mode of transportation besides it being a sport or a form of recreation.

2. Air Travel

The intrepid nature of man is best demonstrated by his obsession to fly. His first attempt was to copy the bird by building himself wings - at first simple and later intricate. Flying with such a contraption from a level ground was very problematic for him especially given the weakness relative to his body weight of the muscles of his arms and chest. He then shifted to hills for his starting points - often times with very disastrous and terminal results - as gorges moved up to him or other smaller hills moved in direct opposite to him.

When the age of machines arrived (after the industrial revolution) man decided to bypass or ameliorate his muscular shortcoming by building flying machines - at first powered by his arm and / or leg muscles. When liquid petroleum fuel became available he built gasoline powered flying machines. Most of the attempts in the first ten years of machine flights ended in disaster - what with the machines capsizing, or falling apart, or exploding, smashing into trees or other objects - almost all with very grievous consequences to the intending aviator. After achieving reasonable flight or getting air - borne for brief moments, the frequency of accidents increased just as they became more fatal. It was not unusual for his contraption to nose - dive into the earth or smash into hills or other structures, or even explode mid - air. Needless to say, man did not give up in spite of these.

As a result of his intrepidity, patience and irrepressible spirit in this connection man is now able to fly over both short and long distances. Helicopters are routinely used for transportation, civil defense and rescue operations and for security duties. Jet planes routinely criss - cross the skies all over the world at very high speeds linking countries and continents that are thousands of kilometers apart. Of course, we are all aware that man in the US and Russia routinely moves around the earth and stays in orbits, sometimes for months, at speeds of about 28,000 kilometers per hour at a height of about 200 km above the earth surface. We all know that man as far back as 1968 has succeeded in landing on the moon. Equally, he has landed instruments on Mars - and interplanetary travels are now being considered as being possible.

Along with the convenience, routine and popularity of covering

enormous distances by flight in short time intervals by planes and satellites, it is to be noted that more serious accidents still happen. However, man, realizing the risky nature of his existence, never for once contemplated scrapping air and space travels. Instead he is continually making efforts to make them safer. As usual, he learnt from his mistakes, made corrections or amendments in his design and fabrication of planes, rockets, and satellites. He also 'atoned his machine more' by using better materials and creating special fields of study such as aerodynamics and fluid mechanics in other to reduce his ignorance about flying objects.

3. Automobile Transportation

A series of tragi-comic events would be related if we are to communicate with some of the first (rich) riders or owners of automobiles about 80 to 100 years ago. The then machines were every inch patently and definitely unsafe. Besides thousands of broken bones (including necks, hips and spinal cord bones), being dumped into deep ravines and gorges, being smashed against trees and walls that seemed to have suddenly become mobile and were thus in the path of the rider, or collision with people or cows who were hundred of yards from the path of the rider - all of which in some cases led to some terminal events. One would also be informed of fine dresses that were ruined after being splattered with mud or water or dust; one would also be told of butterflies and insects developing much interest in nesting on human eyes or mouths or other parts of the face. Other gory details will also be presented in such a time - gap communication.

The present safety records of road transportation is known to be bad as indicated earlier but the statistic at the time under reference was very atrocious: it could have been anywhere from 1 in 10 to 1 in 2 for a 10 - kilometer automobile journey. Not only that, almost all automobiles were usually involved in accidents in the first one or two decades of their introduction.

In spite of all the above and more, man never gave up travelling by car. He learnt from his mistakes, made amendments or corrections or adjustments in the design and fabrication of the car ; he also made atonement against bone jarring rides by using pneumatic tyres and macadamised roads.

Call for Realism and Fairness in Viewing Nuclear Matters

A closer look at the contents of Sections A and B above cannot but, we believe, inform us of the need to adopt a realistic utilitarian outlook on the pursuit of nuclear science applications with an open mind and with less emotion and paranoia as had been the case for some years now.

The following pertinent question arises from considering Section A: ***Do we advocate for fear of pneumonia, cancer, accidents, collapse of dams, acid rains and greenhouse gases, exposure to natural radioactivity outside or the intrinsic radioactivity in our bones and muscles that we should, respectively, never breathe again, nor eat, nor travel by train or road or by air, nor generate electricity by hydroelectric plants or by coal or fossil fueled plants, nor walk in the open air, nor live in houses, or that we should get rid of all the bones and muscles in our bodies ?*** Of course, we would never do such things. We routinely or normally accept the risk involved in each human activity or process in the full recognition of our earlier statement that life or existence is a series of risks

In order to have a fair and perhaps balanced view of nuclear science applications, it is also useful to consider the attitude of man towards most epochal developments (such as those in Section B above) in his march through time. It is useful to note that the point that could be made for continued pursuit of nuclear science applications (for energy purposes, especially, since applications in other fields are somewhat more acceptable by man) is obvious from the three immediately preceding examples in that sub - section.

The above is not to be misunderstood as advocating that it is all right to recklessly overburden the environment with artificially generated or man - made radiation and radioisotopes all in the name of reaping the benefits of applied nuclear science . Far from it. All we are advocating is that we must not focus on one danger while ignoring others nor must we be ***qualitative*** in considering ***danger*** from ***some sources*** while being ***quantitative*** about ***danger from one particular source***. What is good for the goose is good for the gander. We should use the ' same scale' based on cold statistical facts, the usefulness and the records of the antecedents of each human activity or invention or human-motivated process or even natural process right from its inception in judging its further pursuit and / or scrapping or avoidance.

NUCLEAR ENERGY AND THE FUTURE OF MAN

Human existence on planet earth, apparently, cannot be guaranteed without an assured energy supply to cover man's multivarious activities or needs. While most other animals and plants can survive in their local

environments by depending solely on the cycle of energy supplied in various forms by the sun (primary channel of energy on earth), man in most of the locations where he lives needs additional forms of energy or man - rechannelled energy to survive.

These rechannelled forms come from directly burning of wood, coal, gas and other organic materials, from some chemicals, or mechanically as in water from water falls used in turning wheels, as well as from electricity which could be generated in various ways. Coal, oil, wood, gas and chemicals have been used in generating electricity. Equally, hydroelectric dams, solar energy, tidal waves, geothermal heat, and nuclear reactors have been used for the same purpose.

Apart from solar energy and nuclear fusion energy , all other sources of additional or man - made or man - generated or man - rechannelled energy are limited, quantitatively, in their availability; or are limited and also location - dependent. A look at the accompanying fig. 1 *(McMullan et. al.)* shows the consumption and projected availability of reserves for some energy sources.

Given the fact that man or one of his very close ancestors had been in existence for about a million years and assuming (very optimistically and to drive home a point) that he would be around for another one million years, most of the other natural sources (oil, coal, gas etc.) of energy would have been exhausted at the present rate of use as indicated in the figure referred to above. Conceivably, the hydroelectric, geothermal, tidal, and wind energy sources will be inadequate for man's use just as they are inadequate now unless the world population were to be radically reduced.

One could envisage a situation where all of the energy needs of man will be supplied through solar energy were all the sources mentioned above to dry up. This would either entail covering a huge percentage of the earth surface with super efficient solar collectors or photovoltaic cells such as are still to be invented or it would entail diverting a great percentage of the sun's energy to the earth (at a great risk - as flora and fauna may dry up)

World energy consumption has been escalating at astronomical or far greater rate than the world population growth rate. For instance, while the world population has increased fourfold since 1850 the corresponding energy consumption has grown twenty fold (**IAEA publication Ref. No. 14**) Thus a projection of energy supply at the current level of consumption in about four hundred years (not to mention one million years) from now is obviously not realistic.

Several nuclear scientists and engineers believe that nuclear energy

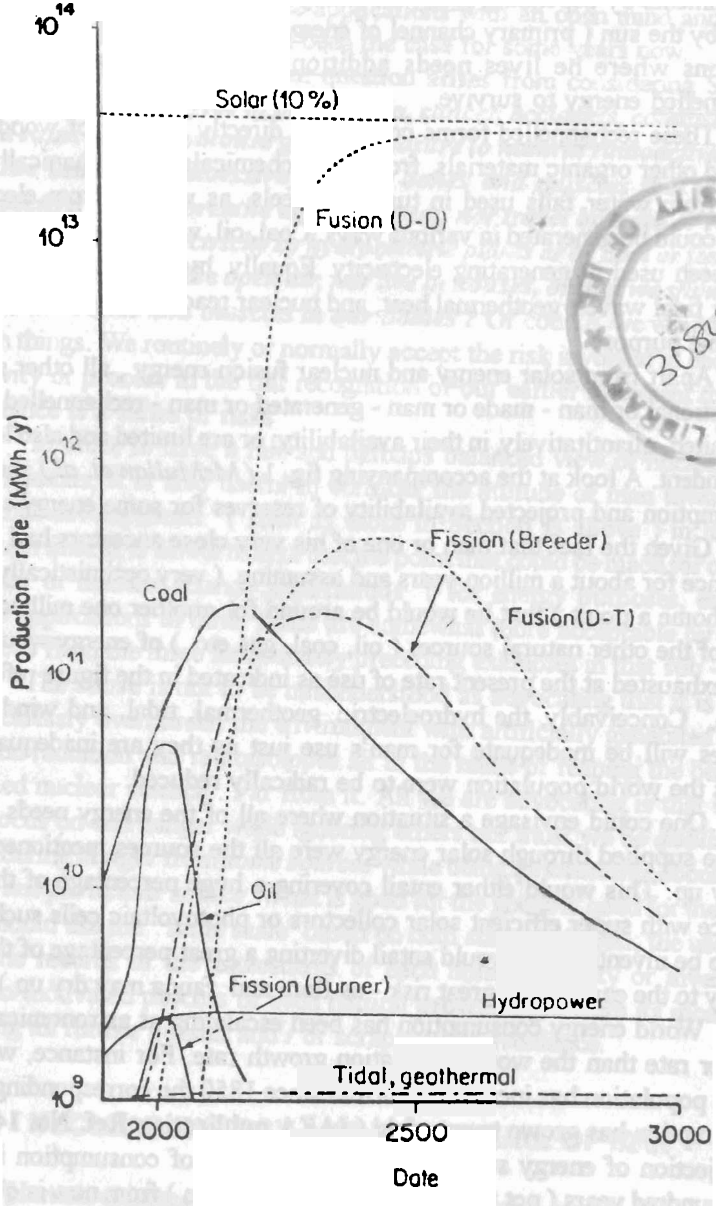

Figure 1.3. Possible fuel consumption levels and projected availability of reserves

has to supply a large percentage of the world energy needs for human survival. Fission reactors are presently supplying more than 17 % of the total world electricity needs and are capable of doing more.

The development of **fast breeder reactors** in which the fissile fuel plutonium - 239 (Pu^{239a}) is manufactured in the reactor from U^{238} (99.3 % natural occurrence) as opposed to the use of uranium - 235 (U^{235} - which comprises 0.7 % of naturally occurring uranium) in regular fission reactors is also a major plus for the use of nuclear energy. Plutonium can be sourced from the existing world reserve in Uranium for the next 100,000 years.

An even more attractive development is the existence **of FUSION REACTORS** even though these are still to be made commercially viable as energy supply sources. The inexhaustible occurrence of the needed fuels and the fact that they are free from man-made radioactivity unlike fission reactors makes them part of the **'heavenly-sent'** solution to the world energy supply problems. The IAEA is encouraging international co-operation in fusion research; and the largest international collaboration on it is the International Thermonuclear Experimental Reactor (**ITER**) Project. It was formed in 1987 and it involves the European Community, the Russian Federation, Japan and the United States.

Once fusion reactors are commercially viable (around the middle of the next millenium) in terms of energy supply on a large scale, we would actually be ***"tapping energy for our needs as it is done in the heavens."*** Our sun and most of the stars are vastly efficient fusion reactors that have been supplying energy for billions of years , and are in most cases, still capable of supplying energy for more billions of years. The seemingly inexhaustible supply of energy of about 10^{26} joules per second obtainable from our sun is nuclear in origin. A primary source of the energy is the proton - proton cycle which is a fusion process involving H ions to form helium. The enormous energy burst above is equivalent to converting ten billion kilograms of uranium completely into energy per second or of burning approximately three million billion (3.03×10^{15}) tons of coal per second. Assuming the ***entire earth*** (mass = 5.93×10^{24} kg) were made of coal, it would take, about **22 days** ***to burn it to produce the amount of energy generated in the sun in one second*** !

A religio - philosophical pun of a question could be asked at this point with due apology to our religious authorities as no blasphemy is intended. 'Assuming that we, as humans, find it easy to operate at the level of goodness found only in heaven, must we on account of prejudice or fear of faulty attempts or beginnings, or known misconceptions refuse to do so ? From a religious point of view, and this is to be found in almost all religions, "**man with all his shortcomings is capable of winning acceptance into heaven provided he learns from his moral or religious transgressions or mistakes, makes needed amendments and carries out needed atonement where required.**"

In order to have an assured future in energy matters, almost all countries should aim at acquiring both the science and technology of nuclear energy generation - of both (what we can call) 'mundane' (fission), and 'heavenly-like' (fusion) type of nuclear energy generation.

Needless to say, and for obvious reasons as pointed out already in the course of this lecture, it is extremely dangerous to pursue a programme in nuclear science applications, most especially, nuclear energy generation without a proper scientific foundation or with a haphazard approach as we are noted for doing most things in this our vastly endowed but yet pedestrian country. Haphazard approach in nuclear matters is a sure prescription for some future nuclear disaster the magnitude of which (given the Nigerian way of doing things) would make Chernobyl (1986) and Three Mile Island (TMI) (1979), Goainia, Brazil (1987) disasters look like little storms in a tea cup !

The present speaker sincerely believes that we can have a scientifically based, purposeful, successful (and not - disaster - prone) nuclear science and technology program in this country provided we follow some time - tested and scientifically - sound procedure in the pursuit of our nuclear programme. However, before we present the required steps and the needed modifications in the present approach to nuclear energy matters in Nigeria, it would be quite useful to take brief looks at the disposition of the international community to nuclear research and the situation of nuclear research in Nigeria.

INTERNATIONAL RECOGNITION OF THE NEED FOR PURSUIT OF NUCLEAR RESEARCH

All the applications discussed earlier as well as several other uses of Nuclear Science and Technology are recognized by experts and the well-informed as making it necessary for virtually every country of the world to pursue Nuclear Studies. The socio-economic benefits as well as the potential of Nuclear Science as a potent tool for rapid development in any country of

the world pursuing it is responsible for the establishment of such a pre-eminent international body as the International Atomic Energy Agency (IAEA). Essentially, IAEA is for the SPREAD of nuclear knowledge WORLD-WIDE . This statement may sound surprising to the average man. However, this need not be so when it is realized that virtually all United Nations members (super powers, medium powers, and 'weak' powers) belong to it.

IAEA provides training, organizes seminars and conferences, donates equipment and radioisotopes, provides specific technical (nuclear science) information for member countries. It also ensures the utilization of nuclear safety regulations, inspects nuclear facilities for safety and non-application for weapons research in member countries world-wide. Other international bodies that complement the work of the IAEA are ICRP (International Commission on Radiological Protection), UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation), INFCE (International Nuclear uel Cycle Evaluation committee), LNSG (London Nuclear Supplier Group) etc.

Generally, the notion is rife in Nigeria that Nuclear Research must be conducted in **secrecy** as if there are international organizations ready to pounce on any country pursuing ***any*** nuclear research. This self-serving notion was propagated and is still being propagated by 'non-nuclear' nuclear experts (NNNE). The absurdity of the notion is best realized if one considers that virtually all the nuclear experts in the country were trained abroad, and that ALL the nuclear research equipment that are in use or dis-use in Nigeria were purchased abroad.

The mischievous notion arises partly from aversion of the international community to the pursuit of NUCLEAR WEAPONS RESEARCH, and partly (and most importantly) from the need of these non-experts to hide their ignorance on nuclear matters especially from experts and other knowledgeable members of the public.

Nuclear weapons research is a very tiny part of nuclear research. Its pursuit is dictated by several political, socio-economic, industrial, and military considerations. We sincerely believe that its pursuit cannot, and should not arise in Nigeria especially given the level of our technological development and the fact that we have signed the Nuclear Non-Proliferation Treaty (NPT).

NUCLEAR RESEARCH EFFORTS IN NIGERIA

Meaningful level of funding for Nuclear Research (NR) became available in Nigeria over two decades ago. Given the length of time that has elapsed, Nigeria should be in a position where it is able to train and graduate several Ph.D and M.Sc. candidates per annum in several areas of NR if she had followed *an ordered and time-tested scheme of development* in the discipline as had happened in several (advanced and developing) countries with meaningful nuclear programmes. As one of the protagonists or initiators of Nuclear Research and Education in Nigeria (NREN), it is with great regret that I now submit that nuclear research in Nigeria is characterized by the following unfortunate and unseemly developments:

- Unusual control of nuclear research by non-experts or 'non-nuclear' nuclear experts (NNNE). This is coupled with bare-faced ***exclusion*** of several bonafide nuclear experts from taking part meaningfully in experimental nuclear research efforts.
- Pre-occupation with operation of **second stage** or **Developed Nuclear Research Stage**(DNRS) instead of with the **first stage** or **Initial Developmental Nuclear Research Stage** (IDNRS) of nuclear research.
- Pre-mature declaration of centers of excellence in nuclear research when virtually no experimental nuclear physics research was going on anywhere else in Nigeria then.
- Pre-occupation with purchase of very big and very costly Nuclear Research Equipment (NRE) instead of reasonably-sized, easily-installed, and easily-managed equipment that are usually involved at the commencement (IDNRS) of nuclear research programmes world-wide.
- The unusual practice of buying NRE *before* the experimental research programmes they are to be used for are planned or even proposed. This questionable practice has led to the availability of several unused NRE costing millions of dollars (in scarce foreign exchange) in some of our nuclear research centers. These equipment, may become obsolete or unserviceable due to non-use or non-installation even several years after purchase.
- Aversion to the establishment of Theoretical Nuclear Research Efforts (TNRE) in our 'Nuclear Establishments' as if these do not constitute parts, *albeit* very important parts, of nuclear research.

- Undue emphasis (for several years after inception) on overseas training of prospective nuclear experts. This is also usually coupled with their training on equipment that are not available or are not likely to be available locally for a very long time.

There are other problems associated with NRN but time will not allow us to go into these in this expose. Meanwhile, we shall now expatiate on some of the problems listed above in order to enhance our understanding of the issues involved.

Nuclear Research is one of the few areas of research (anywhere in the world) that requires huge sums of money (running into millions of dollars) in its operations especially after passing its INITIAL DEVELOPMENTAL STAGE (IDS). Non - experts are not aware of the IMPORTANCE of this IDS and are so easily attracted by the huge sums connected with the later stages of nuclear research.

World-wide, the second stage in the development of nuclear research involves big research equipment. This is in contrast to the initial developmental stage (IDS) of nuclear research which usually does not involve the purchase of big equipment. Because of preoccupation with purchase of big nuclear research equipment goals that could have been achieved in the nuclear research programme within a few years are becoming increasingly unachievable even in time spans seven to ten times the normal times for them.

In order to curtail this kind of waste in future it is useful and pertinent at this juncture to examine the problems faced in equipment *acquisition*, *installation* and *utilization* especially in a Third World or underdeveloped country setting or situation. It is believed that this brief analysis will show us why the wrong choice of equipment or undue emphasis on big equipment especially by non-experts can condemn a research effort, especially a nuclear research effort, to a sterile or moribund or comatose state.

It is easy to recognize and perhaps accept the following about the use of equipment, generally, in a third world setting:

- It takes between six months to two years (from placing an order to the arrival of the order) to acquire a new equipment or get a replacement part. The time involved usually varies directly with the size, complication and cost of the equipment or spare part.

Between placing an order and its arrival, the model has probably changed and spare parts for the old model may no longer be available. Added to this problem is the sharp practice by some equipment vendors or companies in advanced countries whereby they dump second hand equipment, usually outdated models, in third world countries. The bigger the equipment the more the number of spare parts that can create headaches due to their non-availability to a third world client.

Generally, and most especially in a developing country, the bigger the equipment, or the more complicated the equipment, the more difficult and problematic are the *installation, utilization,* and *servicing* of such an equipment. This more than any reason is responsible for *starting* the initiation of research in any new area in any part of the world with *small, easily-assembled, easily-used,* and *easily-serviced equipment*. A Brazilian example on the prosecution of a similar program in Plasma Physics at the same time Nigeria embarked on her Nuclear programme in 1975 attests to the validity of this age-old wisdom **[ICTP publication (1975)]**. The Ghanaian example on the acquisition of nuclear reactors also confirms this. Ghana acquired a big high flux nuclear reactor from the Soviet Union about forty years ago and has not succeeded in getting it to work till now owing to a host of problems. She however acquired a 30 kW capacity Chinese mini reactor a few years ago that reactor was commissioned in March 1995 and several research projects have *already* been, and are being, carried out on it. **[IAEA publication (1995)]** It is unfortunate for Nigeria that this age-old and time-tested approach was lost and continues to be lost to those who have taken us into the morass of buying big

equipment.

A little reflection on the above will show us clearly why the Nigerian Nuclear Research effort is faced with problems because of its premature exposure to the purchase of big and expensive equipment and the exclusion of most nuclear physicists.

Starting with big expensive equipment creates a myriad of installation and servicing problems for the researchers and their students. It also robs the country doing this of the golden opportunity of attempting local repairs or fabrication of spare parts for small and medium sized equipment. Above all, it virtually excludes the country from being able to fabricate the sort of big or expensive equipment ordered from abroad even several years after commencing, *if at all*, the research effort concerned.

The entire future orientation and performance or non-performance in any field of research, and most especially in Nuclear Research, depends on the kind of training programme envisaged or planned or practiced by the 'researchers' in the field. For several years, the training programme embarked upon by nuclear research establishments in Nigeria has been ineffective, wasteful and unrealistic to say the least. For the most parts, the emphasis was on overseas training instead of a training program built around available local experts. The premature involvement of the country with the second, as opposed to the first (and primary) stage of nuclear research is partly responsible for this unfortunate emphasis.

One of the hallmarks of this emphasis is the following: the training of prospective nuclear researchers on the use of equipment that are *not* available locally or on equipment that would not be available locally for several years after their training. This has contributed immensely to low activity at nuclear research centers nation-wide. The glaring or virtual exclusion of most experienced or seasoned nuclear experts for several years from these nuclear centers contribute in no small measure to all the problems indicated above.

The overall danger of this emphasis on overseas training is that it robs the country of the vital opportunity of local researchers, and young Ph.D's and graduates from nuclear establishments abroad to build upon recently acquired knowledge (by these young Ph.D's) in the immediate or even distant future *in* Nigeria. Besides, when young scholars go abroad for higher degrees or Ph.D's, they, for the most part wind up helping to solve problems of their host countries as opposed to solving those of their own (or parent) country. In the nuclear research programme several of our prospective brilliant nuclear research candidates sent abroad have not returned home in many cases several years after the completion of their training programmes overseas.

One strongly hopes that Nigeria would shift the emphasis of the training of her nuclear experts from its overseas orientation to a local orientation before it is too late. This is all the more imperative since it is through properly conceived and well directed local research and local training of next-generation researchers that countries make meaningful and assured progress in any research field or endeavor. No amount of money or efforts expended in making this change will be too much. In fact the money to be involved is meager compared with what is to be lost if the present arrangement persists.

USUAL STAGES FOR DEVELOPING VIABLE NUCLEAR RESEARCH PROGRAMMES

Most areas of complex specialized activities require progression through some given sequential stages for their proper, meaningful and productive developments. Virtually no area of human activity requires strict adherence to this sequential development than nuclear research. This fact is well known to nuclear experts and may not be known to non-experts. Some of the reasons that dictate strict adherence to some time tested sequence which we shall soon indicate has to do with the complexity of **real** nuclear research *and* the extreme danger that could be posed to a community that encourages or fails to check haphazard development of the field. Some of the hazards that could be encountered from its faulty pursuit or sheer accident are already indicated above. It can be said categorically that no country can develop a meaningful or successful nuclear programme if it does not follow this sequence of development.

In terms of nuclear research activities, all countries of the world can be classified into four distinct stages, viz.:-

- Backward nuclear research stage (BNRS)
- Initial developmental nuclear research stage (IDNRS)
- Developed nuclear research stage (DNRS)
- Advanced nuclear research stage (ANRS)

DNRS and ANRS are in countries with VIABLE nuclear programmes. IDNRS are in those countries in the process of developing viable nuclear programs while BNRS are in countries that are still to commence meaningful **rudimentary experimental nuclear research**

Nigeria as of now belongs among BNRS even though she should rightly belong among IDNRS. This unfortunate development is directly as a result of control of nuclear research by non-experts for almost two decades.

The time-tested or time-honored progression for developing nuclear research is for a country to go through the stages listed above in that order. There is no known case of a country in stage 4 which has not gone through stages 1 to 3 in that order nor of any stage 3 country that had skipped any preceding stage or altered the order of pursuit of these preceding stages. It is important to note that all bonafide Nuclear Physicists recognize the necessity of this ordered progression just as all bonafide Plasma Physicists recognize the same sequence of development for Plasma Physics research whose stages of development in ANY country with viable programme bear a one to one correlation to the stages of viable nuclear research development indicated above.

INITIAL DEVELOPMENTAL STAGE OF NUCLEAR PHYSICS RESEARCH

As implied in the title as well as in the preceding section, this is the beginning stage of meaningful Nuclear Research in any country. It is marked by the conduct of simple experimental nuclear physics research on *simple and inexpensive* equipment as well as the pursuit of *theoretical nuclear physics* research. The duration of this stage could be between ten to twenty years for a country where genuine and serious nuclear physicists are engaged at this level.

The science and principles of nuclear research are LEARNT *and* at the same time DISPERSED as widely as possible within the country during this stage. Experimental Nuclear Physics researches are carried out with inexpensive equipment *and* **the results are published in INTERNATIONAL** (not local) **Nuclear Physics Journals** in order to show the seriousness, acceptability, and high academic merit of the research efforts. Several M.Sc. and Ph.D graduates are produced and at the same time the number of nuclear physics research centers **in Universities** within the country are gradually increased during this stage.

The increase in nuclear physics research centers is imperative and very vital in order to guarantee cross fertilization of ideas and efforts, and absence of inbreeding with its obvious and concomitant retrogressive effects

As a matter of **strict** and **deliberate** policy **expensive** and **huge** nuclear research equipment are **avoided** during this stage also. This is so because involvement with them is known to be counterproductive and misleading..

The principles and technology of construction and servicing of small equipment and possibly those of their huge cousins are thus easily learnt at this stage by the researchers, their graduate students and technicians. This is a very crucial knowledge to be acquired in any EXPERIMENTAL NUCLEAR or PLASMA PHYSICS research efforts that are aimed to culminate in the use of complicated , huge and expensive equipment at the ANRS or equivalent stage. The final stage of IDNRS is marked by **local construction or fabrication** of basic Nuclear Physics research equipment. The same thing happens with the final stage of IDS of Plasma Physics Research (IDSPPR) in any country that aims at a viable research effort in Plasma Physics (**ICTP Publication, 1975).**

Skipping IDNRS for DNRS from BNRS status is like teaching a five-month-old baby to **run** without first teaching it to **crawl, stand and walk** in that order first ! While it is not totally impossible for the child to learn running that way it is obvious that serious problems and danger would be encountered in such an attempt.

PRESCRIPTIONS FOR VIABLE NUCLEAR PROGRAMME IN NIGERIA

There is no doubt whatsoever that the present approach to nuclear research in Nigeria can be improved upon. This is more incumbent on us for several reasons, some of which are:

- The future gains from nuclear science applications are too great for any country to miss. Having a viable and rigorous nuclear program will help to guarantee making maximum gains very safely.
- There is need, in nuclear matters, for us to develop constant aversion to the type of unfortunate development that we have with our ***petroleum refineries*** especially if we are to ultimately 'acquire' Nuclear Power Plants and some other complicated nuclear devices. Such acquisitions are possible especially since our 'better placed' technocrats like to purchase big equipment. The consequence of such purchases will be more dangerous than what we have with the refineries where almost every repair has to be carried out by foreign personnel. The seriousness of possible nuclear accidents is so great that the risk must <u>not</u> be taken with the type of our present approach .
- It is getting more expensive financially and '<u>consequentially</u>' to buy technology or to have technology transferred. In particular, nuclear technology transfer will get more prohibitively expensive in future - hence the need for heavy investment in science and especially nuclear science to forestall or reduce these..

Given all these, the present speaker believes that we should take the following steps in order in order for Nigeria to be poised for hitch-free, viable, scientifically sound, and well - ordered nuclear science program and nuclear science applications program:

1. Efforts should be made to ***mobilize* all** Nuclear Scientists for whatever Nuclear Science or Nuclear Technology program being pursued or being proposed in the country The present <u>exclusion</u> of some nuclear scientists in some research centers should stop. Ethnicity, tribalism, quota, cronyism etc. should cease to find their ways into nuclear matters as these would not augur well for the country.
2. Generous provisions should be made to enable each scholar in the nuclear science area to attend at least one International Seminar or conference in his discipline per year. Also, very generous scholarships, fellowships etc. should be provided, especially for all students in the nuclear science area.
3. For a few years to come, <u>medium</u> and <u>high</u> technology nuclear projects should be avoided for some of the reasons advanced in this lecture moreso as the required <u>local scientific</u> personnel to support such projects are not yet available in the required number.

4. Efforts should be concentrated to produce more personnel with Ph.D. and M.Sc. in the nuclear sciences **locally.** Besides the needed focus on some problems locally, knowledge in the field would be dispersed in the country in a few years. Nuclear science studies and research should be pursued in as many Universities as possible in the next few years and beyond.
5. Emphasis should be shifted to running subject-specific research laboratories (SSRL) in all disciplines in the sciences (especially in Nuclear Science) instead of the present set-up of running global research laboratories (GRL) where all kinds of non-experts can hold sway. This subject specific approach is used effectively in many countries, and in many Universities, Research Centers and Institutes in many parts of the world. Subject-Specific Research Laboratories should be called their appropriate technical names. By so doing, non-experts can easily be kept off. For\instance the Pakistani national nuclear research center in Rawalpindi is called "Pakistani Institute of Nuclear Science and Technology." Calling Nuclear Research Centers by other names is bogus propaganda especially as the need for Nuclear Studies and research is recognized world-wide. As indicated earlier, no one pounces on anyone for carrying out nuclear studies for academic or peaceful or national development purposes.
6. Each Laboratory - especially in the Nuclear Sciences should have a THEORY DIVISION with its own budget in the overall Laboratory budget. One of its duties is to develop theoretical tools and provide insights into experiments being performed or proposed in the laboratory. Theory Divisions are inseparable parts of most Laboratories abroad.
7. Purchasing big equipment for Nuclear Science or Nuclear Technology projects in the country should be avoided for the next several years for obvious reasons.
8. Early over-emphasis on Nuclear Technology should be

avoided in the absence of meaningful Nuclear Science being done nation-wide. Technology for it to last or achieve its end follows logically from sound scientific knowledge *within* a country. The Brazilian example in Plasma Physics demonstrates this. Undeveloped or Third World Countries need ***science* not *technology transfer*** for progress.
9. There is need, for quite some time to come, to avoid centralization of nuclear research in some national center for some reasons:
    - the available manpower in the country is too small and not that developed, and
    - scientists, like other academics, cannot commute easily to some central location on account of poor remuneration by government as well as poor transportation network and petrol scarcity.
10. There should be Visitation to each Research Laboratory by experts and related experts every three years to ensure that the laboratory is carrying out the project it is saddled with effectively. This is a normal practice world wide except in Nigeria.

CONCLUSION:

It is recognized that great benefits are derivable from nuclear science applications just as it is equally recognized that great danger can be posed by poor pursuit of nuclear research and nuclear science applications. It is also recognized that nuclear energy is one of the major assured sources of energy for the future when all the oil and coal reserves would have been depleted.

Given these a country like Nigeria must put her 'nuclear house' in order for her to avoid nuclear disasters from faulty approach and practices and in order to reap maximum benefits from this great field of science . The present speaker believes that following some of the prescriptions contained in this speech could go a long way in helping to guarantee this.

On the global scale there is a need for realism and fairness in considering nuclear matters. There is need for us to adopt a realistic utilitarian outlook on the pursuit of nuclear science applications with an open mind and with less emotion and paranoia as had been the case for some years now.

We believe that man should continue to work hard and carry out further research on how to improve the present excellent safety records of power generation by nuclear fission reactors as well as on how to make sources of artificial radiation and other nuclear systems safer for himself and his environment. The objective, along with that of efficiency, is to further reduce the tiny contribution of man - made radiation contributed to the environment and solve more satisfactorily the waste disposal and other problems encountered in some nuclear systems.

Man should also concentrate on **nuclear fusion** research so that he would ultimately be able ***to generate energy 'as it is done in the heavens'*** or as in the sun and the stars. While saying this, we are not implying that nuclear energy should be the only means of power generation by man. We believe that it should be one of the prominent items or the most prominent item in the 'mixed bag equation' or 'the rich cocktail' of different energy sources that would be available to man in the foreseeable thousands of years. Achieving this would free some of the present sources such as oil for other uses as in food (protein source) or in producing pharmaceuticals and other useful chemicals.

Thank you

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