

Nuclear Waste & Energy Sustainability: Are They Compatible?

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As the six billion inhabitants of planet earth cross the boundary into the 3rd millennium, it is clear that very serious global planning must be undertaken if the energy required to serve this rapidly growing population is to be sustained over the next century. Of at least equal importance to the energy supply itself is the compatibility of the sources of the supply with maintaining an environment worthy of passing on to subsequent generations.

Nuclear energy appears unique in its promise of having the capacity to provide the prodigious amounts of energy that will be required, consistent with the environmental challenge posed. However, there is currently wide-spread concern regarding the appropriate disposition of nuclear waste and, in particular, the ability of the nuclear power industry to minimize the possibility of nuclear proliferation—given the vast amounts of plutonium that are envisioned to be associated with this huge enterprise.

We begin this paper with a look at the sobering amounts of energy that our planet will require over the next millennium and, in particular, the demands that will very likely be placed upon nuclear energy. Given this expected burden, we then examine the amount of

nuclear waste that might be associated with this huge commitment. Whereas some would declare nuclear energy to be inappropriate because of this "waste issue," it is important to compare these wastes with the wastes from alternate energy sources. As any prudent planner knows, there is nothing on the face of the earth that is able to deliver useful energy without leaving some type of waste product behind. Hence, it is essential to provide perspective. Indeed, nuclear energy, unlike many other energy forms, offers the potential for beneficial utilization of many of its byproducts currently considered "waste." Given the very long planning horizon time lines before us, it is important to explore how future technological advances may be able to directly benefit from nuclear "waste" materials that we now consider objectionable.

Finally, we offer an approach that the international community may wish to consider as a responsible way to deal with nuclear waste management. It is recognized to be ambitious—very ambitious. It would also likely evoke considerable controversy, since any realistic global solution is likely to raise some national sovereignty issues. On the other hand, it is abundantly clear that some compromises will have to be made in this regard if nuclear energy is to achieve the high deployment rates that a growing population is likely to place upon it. We suggest that the IAEA is in a unique position to provide the leadership necessary to allow nuclear energy to become the humanitarian servant so desperately needed in the coming millennium.

1) Energy Needs for Sustainable Development

We begin our discussion of global energy needs by examining the actual history of energy and population growth in the world over the past 150 years. VG #3 clearly indicates that global energy consumption is rising faster than global population. There is nothing in the historical record that suggests the demands for energy will decrease. Indeed, energy per capita has been on a continual rise for several generations.

As shown in VG #4, the same trend is seen in the United States over the same 150 year time period. There are more fluctuations in the energy use (as evidenced by the dip during the Second World War, and the cyclic behavior during the economic recession of the 1980s), but even in this highly energy consumptive country that has been challenged to become

more energy conservation conscious, energy per capita continues to rise.

As the U.S. came out of World War II and the economy began to blossom, economic planners started noticing the strong correlation between total energy use and the Gross National Product (GNP), as depicted in VG #5. However, the oil crisis of 1973 (in which the oil cartel nations forced dramatic increases in world oil prices), caused U.S. citizens to become very energy conscious. National leaders began to campaign for energy conservation (smaller cars, more building insulation, etc.) and, indeed, the subsequent two decades witnessed a breaking of the strong correlation of total energy use and GNP. On the other hand, the correlation between electrical energy use and GNP remained as tight as ever (note VG #6). The message became very clear. Electricity is becoming the energy form of choice! This is particularly true in the developed countries, where electricity is a central component of driving motors, heating & air conditioning systems, lighting, and is absolutely essential to the explosion of the information age. It is only a matter of time before the same dependence will be seen in the developing countries, where the population gains are expected to be most dominant in the coming decades.

2) How Much Nuclear Energy is Needed?

The big question is how much energy will be needed to support this growing population in the next millennium and, in particular, how much of this will need to be supplied by nuclear energy. Several studies have been conducted over the past decade in an attempt to bound the projected energy needs. For our present purposes, the work of the International Nuclear Societies Council (INSC) will be used⁽¹⁾. Using energy experts from around the world, a careful review was done to provide high and low (ecologically driven) forecasts for energy needs for the next 50 to 100 years. VG #8 illustrates their results, as appended to the historical data over the past 150 years (taken from VG #3).

As summarized in VG #9, the INSC provided a reference case (best estimate) that indicated total energy needs by the year 2050 would increase by a factor of about 2.5, relative to current energy consumption. This would be needed to serve a population of 10 billion inhabitants (relative to the 6 billion today). Whereas an increase in total energy consumption from the current value of 400 EJ to 1000 EJ may seem high to some observers, it should be recognized that this would still represent only 1/3 the energy consumption per capita as *currently* enjoyed in the United States. Given the massive advances in transportation and communication systems, inhabitants of almost any corner of

the earth now know the type of life styles that high energy use provides to those who live in the developed nations. The demands to become a part of this life style should not be underestimated.

The real challenge is how to provide such prodigious amounts of energy. Where will it come from? VG #10 may be instructive in this regard. The bar on the left side illustrates how the current level of 400 EJ of total energy is produced. Note that about three-quarters comes from fossil fuels (coal, oil, and natural gas). About 4% is from hydropower, 7% from nuclear, and the remainder from biomass. The amount coming from biomass may be surprising to some, but there are still many countries of the world where wood and animal dung are in high use for such basic uses as cooking and heating.

The next three bar charts contain mix options to meet the year 2050 demands for 1000 EJ of total energy. The bar labeled "straight scale-up" simply suggests that our grandchildren will derive their energy from precisely the same sources that we get it today, i.e. the mix will not change. However, there are at least two fundamental problems with such an expectation. First, this would require well over twice the amount of electricity to be generated from hydroelectric dams, and that may be impossible. The world has already captured approximately half of all the hydroelectric energy that is theoretically possible, given the scarcity of additional sites where there is sufficient water flow and head to make such new sites feasible. But of far more importance, the second bar implies we will be burning well over twice as much fossil fuel by the year 2050 as we currently consume. The issues here are sobering. For starters, this represents a depletable resource (almost certainly a major issue for oil and natural gas over the next millennium). Perhaps of even greater importance, all fossil fuels are known to release prodigious contaminants into the atmosphere.

Given the rising concerns regarding potential global climate changes, world opinion may be a strong force in driving the mix to something resembling the bar at the far right, labeled "hold fossil levels." But for this extreme, the pressures on the remaining potential sources of energy are likely impossible to meet. Only the most ardent solar zealots would suggest that solar energy could even begin to provide energy in the quantities needed for such a scenario. The demand indicated for nuclear, though theoretically possible, is likewise judged to fail the test of credibility.

Hence, the INSC concluded that the bar located third from the left (labeled "INSC") is the most likely outcome. In this case, fossil fuel consumption is pragmatically acknowledged to

approximately double (despite pleas for *reductions* from the environmental community). The staggering result of this analysis, however, is revealed by VG # 11. This chart reveals the number of new 1000 MWe nuclear power plants that would have to be built over the next century to match the demands for nuclear power projected by the INSC studies. This indicates that an average of 8 new nuclear plants would have to be built each year for the next three decades (their study was referenced to the year 1990), and that by the year 2020 an average of **75 new plants** of 1000 MWe size would have to be built **every year** for the next three decades! This number would rise to approximately 140 plants per year by the middle of the century (accounting for replacement plants).

Is this possible? Technically, yes. The infrastructure could be put in place. But what about the nuclear waste (including the vast amounts of plutonium buildup) associated with such a massive commitment to nuclear energy?

3) How About Nuclear Waste?

VG #12 provides the historical data for installed electrical generating capacity of commercial nuclear power in the 20th century. By far the bulk of this capacity has been installed in OECD countries to date, but it is in the non-OECD countries where the rapid growth rate for nuclear power is anticipated in the next century.

The buildup of spent nuclear fuel (SNF) is directly related to the amount of thermal energy generated by nuclear reactors. VG #13 contains this historical record up to the year 2000. Note that over 200,000 MT of SNF was generated during the first half-century of commercial nuclear energy, and it is currently being accumulated at a rate of about 10,000 MT/year. Plutonium is, of course, generated in the uranium-fueled cores and, in fact, approximately one-third of the total energy delivered is derived from the subsequent fissioning of the plutonium that is created from neutron capture in U-238. However, some of this plutonium remains unfissioned in the SNF. Although hard to see in VG #13 (since it is well under 1% of the total material content of the SNF, with uranium being by far the largest constituent), VG #14 clearly reveals that approximately 1400 MT of Pu has been generated in SNF to date. Of this, approximately 200 MT has been separated out via reprocessing as fuel grade Pu.

VG #15 illustrates the global reprocessing capability that has been developed for commercial use within the 20th century. France and the U.K. were the first countries to construct reprocessing plants, and they have remained as the leaders in the field. France and

the U.K. constitute approximately 80% of the world's reprocessing capability, with Russia a somewhat distant third. The U.S., Belgium, Germany, Japan and India have all had, or still have, commercial reprocessing capability. However, of these, only Japan and India appear at the moment to be interested in expanding their capability. Note that even if the entire world's commercial reprocessing capability were operating at 100% capacity, the approximately 5000 MT/year total capability would be only half that required to keep in step with the 10,000 MT of SNF being currently generated every year. Hence, SNF stockpiles will continue to grow at several places around the world.

The *big* question is how much nuclear waste should we expect to be generated over the next century?

VG #16 was generated by using the historical data of VG # 13 and then deducing the approximate amount of SNF that would be generated for the three nuclear energy scenarios of VG # 8 (note that VG #8 projects total energy, whereas VG #11 contains an approximate building rate of nuclear plants necessary to provide the nuclear share of electricity). The three curves of projected SNF in VG #16 correspond to the high, low, and reference cases conducted in the INSC study. The message is clear. The amount of SNF anticipated to be generated over the next century by commercial nuclear plants completely dwarfs the quantities that have been generated to date.

VG #17 contains approximations to the associated mass of plutonium that would reside within the SNF projected in VG #16. Those who fear that a large-scale commitment to nuclear energy may generate a plutonium economy have some basis for their concerns. On the other hand, VG #16 shows only the Pu generated. In a mature nuclear enterprise, it would be expected that most of this Pu would be utilized for fuel, such that a high percentage of it would be residing and protected inside reactors as recycled fuel.

Civilian and military nuclear power sectors have, for the most part, operated as separate entities in the past. This has been done largely to protect national defense interests. Further, it was thought for quite some time that there may be less proliferation concern about plutonium coming out of the civilian sector because it was "fuel grade," not "weapons grade." The distinction is that plutonium produced in commercial power reactors contains relatively large amounts of Pu-240 (due to the long fuel residence time), and this material spontaneously emits neutrons (a highly undesirable feature for weapons design). However, weapons technology has proceeded to the point where weapons designers are careful to point out that useable weapons can be made out of essentially any grade of

plutonium. Fuel grade Pu is far less desirable (due to the enhanced sophistication required in the design of a workable weapon, the delivery system, etc.) but it can be done. Hence the line between the civilian and the military sector has become somewhat blurred. Accordingly, most scientific bodies and nuclear nonproliferation experts have warned that commercial reactor generated plutonium be treated with the same degree of security as that deliberately generated for weapons use.

Hence, in our efforts to suggest an integrated system for dealing with commercial nuclear waste (outlined in Section 6 of this paper), it may be helpful to recognize that the current amount of separated Pu from the civilian and military sectors is comparable. As noted from VG #18, the approximately 200 MT of separated Pu from the commercial sector is about 2/3 of that residing in the global military sector. However, both the U.S. and Russia have each declared 50 MT of weapons grade Pu to be excess. Both nations are giving strong consideration to utilizing the bulk of this 100 MT of weapons grade Pu in commercial reactors as MOX fuel. This would shift the balance of separated Pu to the commercial sector, and commercial separated Pu would then continue to grow, relative to separated military Pu.

4. Wastes & Environmental Impacts from Other Energy Sources

If we were to stop at this point, the uninitiated reader might conclude that the waste products associated with nuclear energy were so vast and undesirable as to render this energy source unsuitable to serve the future populace. However, it is essential that we consider the wastes from alternative energy sources and place the whole question of energy delivery systems into perspective.

VG #19 provides a qualitative comparison of the wastes and environmental challenges posed by the principal alternatives to nuclear energy. Most knowledgeable energy planners are aware of the prodigious quantities of objectionable gases emitted into the atmosphere by the burning of fossil fuels. Coal is likely the worst, but the quantities of such gases are very significant for both oil and natural gas (except that natural gas does not release the sulfur oxides that are thought by many to be a principal ingredient in acid rain). Biomass and geothermal energy sources are likewise of doubtful environmental compatibility in this regard.

Whereas the solar sources do not directly pollute the atmosphere, they have a substantial environmental impact due to the huge landmass required to deliver meaningful amounts of

energy. Solar energy is intrinsically a very diffuse energy source. Substantial toxins and carcinogens are also associated with solar energy because of the large quantities of such substances generated during the manufacturing of the vast amounts of glass, copper, etc. required for the solar power plants. Also, all direct solar sources require a backup system to account for the day/night cycle plus intermittent weather conditions.

The amount of solid and gaseous pollution from fossil fuel and biomass sources is staggering, compared to nuclear. This is graphically illustrated in VG # 20, where the waste in producing one GW-yr of electricity is shown (in millions of metric tons) for various energy production means. In order to even see the comparable waste from nuclear power plants, it is necessary to employ an 8-cycle log scale (as shown in VG #21). Numerically, the mass of SNF is about 100,000 times *less* than that of coal, oil, natural gas and wood. The corresponding mass of high level waste and plutonium is even much smaller. This huge difference in the mass (or volume) of wastes when comparing alternate energy sources *must* be taken into consideration for any serious long-term energy planning.

Although not shown on any of these graphics, if the concern about nuclear wastes is that of radioactivity, it should be noted that substantially more radiation is discharged into the atmosphere from coal, natural gas, biomass and geothermal plants than from comparably sized nuclear plants. That is because of the trace amounts of U-238 in coal, radon in natural gas and geothermal systems, and the natural radioactivity in biomass. The other factor that needs to be appreciated is the great attention that is given to concentrate and control nuclear wastes, whereas the wastes from competing energy sources is diluted and discharged directly into the atmosphere, generally in an uncontrolled fashion.

5. Beneficial Uses of Nuclear Waste

Perhaps of at least equal importance to the exceptionally small mass of nuclear waste per unit of energy delivered, substantial amounts of what we now call nuclear "waste" may eventually become recognized and utilized as valuable material. Certainly the most obvious use of Pu, which is deemed by many as an undesirable waste product, is that of producing vast amounts of electricity. VG #22 was created assuming that the Pu produced from the reference case of VG #17 was utilized as MOX fuel in a single recycle operation. Assuming a price of 5 cents/kW-hr, this translates into over **\$20 trillion** US over the next century! If this same Pu were to be incorporated into a breeder reactor cycle, the potential revenue would be many times more. To ignore this potential in a world of rapid growth, especially

when realizing that fossil fuels are being depleted at an astonishing rate, is to pose some profound ethical questions.

It may be worth mentioning that many of those opposed to the use of plutonium believe that it should all be buried within the matrix of the SNF in which it was created. They argue that SNF should not be reprocessed. Rather, it should be buried to "rid the world of proliferation concerns." This is one of the most tragically misunderstood elements to responsible management of nuclear materials. As graphically illustrated in VG #23, the radiation barrier provided by the fission products residing in freshly discharged SNF decays away very rapidly. Within a time of only about 100 years, this radiation barrier has diminished to only a few percent of its original strength, thus leaving the plutonium essentially unprotected. Some have even referred to such a strategy as being paramount to creating Pu mines.

VG #24 provides a broad sketch of the possible uses that future technology could possibly exploit from several of the other radionuclides produced in SNF. Examples of Sr-90 and Cs-137 use are shown in VGs #25 and #26. Sr-90 is currently being "milked" for Y-90, a beta emitter that is enjoying remarkable success in fighting several forms of cancer. Sr-90 is also a power source that may find substantial applications in industrial applications (such as powering underwater fiber optics cables). Cs-137 is currently considered by many to be a major nuisance in SNF, but its gamma rays could well be exploited in the future to transform municipal sewage into useable fertilizer or, perhaps of even greater importance, to markedly enhance the safety of food via irradiation. Food irradiation could well become one of the largest growth areas of nuclear technology in the next century.

6. An Approach for Responsible Nuclear Waste Management

Given the incentives previously identified for the wide-scale utilization of nuclear energy, we now focus specifically on the question of responsible nuclear waste management. Our first recommendation is that this issue be addressed in an integrated, international manner.

The move toward internationalization in almost every field of endeavor is unmistakable. Dramatic advances in communication and travel have driven the world of nations into a highly interdependent mode, and this linkage is almost assuredly irreversible. The evolution of the European common market and the North Atlantic Free Trade Agreement are but two examples of a world becoming inescapably interlinked.

And so it is with the nuclear power industry. Whether it be an issue of safety, nonproliferation, economics or waste, it is becoming abundantly clear that an international perspective is essential to the formulation and implementation of meaningful solutions. Hence, we suggest that it would be prudent to study evolution of the international approaches in dealing with nuclear safety, non-proliferation, and economics considerations, and then evaluate the lessons learned from such endeavors to be applied to developing a responsible international approach to nuclear waste management.

A) Nuclear Safety

In the realm of nuclear safety, we recall that the Three Mile Island Accident in the United States spurred the U.S. utility industry into forming the Institute of Nuclear Power Operations (INPO). This voluntary sharing of relevant safety information is widely viewed as having contributed a markedly positive effect on the safety of operations in U.S. plants. Accordingly, it was not surprising that the World Association for Nuclear Operations (WANO) was created shortly after the Chernobyl accident as a response by the global utility community to significantly upgrade the safety of nuclear power operations worldwide.

Since that time, a further step to improve safety has been taken at the instigation of the IAEA. This effort, which focused on the development of international safety standards, resulted in the International Safety Convention—adopted in 1995. Whereas absolute safety can never be guaranteed, any informed assessment would rate the safety of currently operating commercial nuclear power plants well above that existing two or three decades ago. The recognition of the need to establish and follow international safety standards has been a key factor in this achievement.

Only one major step remains to complete the task; namely, to require that *all* licensed operations in the nuclear fuel cycle be carried out under international authority. Whereas some nations may object to this being yet another erosion of national sovereignty, the lessons of INPO and WANO strongly suggest that international experience should be directly folded into the daily operating practices of every nuclear plant and its associated fuel cycle throughout the globe. For nuclear power to take its rightful place as a major power source for the next millennium there must be no compromise regarding the safety of operations.

B) Nuclear Proliferation

Considerable experience has been gained over the past three decades in formulating a workable international approach to nonproliferation issues. Although not perfect, the NPT has achieved far greater success in limiting nuclear proliferation than thought possible at the time of its original adoption in the late 1960s. One key aspect of this effort has been to bring an impressive fraction of the world plutonium streams under IAEA safeguards.

This pursuit should be expanded to the point that *all* plutonium is brought under IAEA safeguards. If a nation is truly interested in only the peaceful applications of nuclear energy, there is no legitimate reason for objecting to placing all of its plutonium under the strict accountability of the IAEA safeguards system.

Whereas there are well recognized sensitivities associated with plutonium that is still considered vital for military interests in a few nations, there is no valid reason to deny IAEA safeguards accountability for all commercial plutonium and plutonium declared excess to weapons use. Further, given the major strides toward nuclear disarmament within just the past half decade, it would seem both plausible and highly desirable for even the plutonium designated for defense purposes to be given international accountability. Knowing the quantity and quality of all plutonium should not constitute a detriment to any national defense system, and it would contribute greatly to assuring the international citizenry that clandestine activities can be minimized.

In fact, aside from some possible transportation issues, there is no intrinsic reason that all commercial plutonium could not be transferred into an international stockpile (or series of stockpiles) where integrity could be more readily assured. The international monetary system might serve as a model to establishing the necessary accounting procedures.

Lest new nations fear the consequences of such an implementation, it should be pointed out that even as far back as 1973 the IAEA was applying safeguards at more than 800 facilities and sites in 60 countries.⁽²⁾ This included thousands of tons of nuclear material (over 450 tons of plutonium, of which 37 tons were in separated form). Since that time, IAEA coverage has expanded considerably, providing additional assurance that even more coverage could be successfully accomplished.

C) Economic Considerations

As we consider economic implications, we must first recognize that despite nuclear proliferation concerns that we may have regarding certain situations, any nation desiring access to nuclear energy has a right to do so. In fact, the Non Proliferation Treaty (NPT) itself guarantees such rights. Specifically, Article IV of the NPT grants "...the inalienable right of all the parties to the treaty to develop research, production and use of nuclear energy [*sic*] for peaceful purpose without discrimination..." and "...the fullest possible exchange of equipment, materials, and scientific and technological information..."⁽³⁾ Any successful approach to managing the nuclear waste issue must recognize this reality.

Given this situation, we must further recognize that all nations desiring the benefits of nuclear energy will simply not be able to bear the burden of developing the full nuclear fuel cycle completely on their own. To expect developing nations to do this as the "price of entry" into commercial nuclear power is surely to be argued as discriminatory. Further, forcing such a situation upon emerging nations would likely be counterproductive from the standpoint of key aspects such as safe operations. Such nations simply don't have the resources available to fully develop the technological infrastructure necessary for success in this complex enterprise.

With specific regard to the nuclear waste issue, even if all nations were to make the investments necessary to fully integrate their nuclear fuel cycle, that would mean that nuclear waste and sensitive nuclear materials would be processed and stored at literally hundreds of places around the globe. Those truly concerned about nonproliferation and nuclear waste safety issues would immediately recognize the implications of such a plethora of locations.

D) Basic Ingredients for Success

It is recognized that some national sovereignty must be yielded when control is elevated to the international level. But the above observations provide considerable weight to the imperative of seeking a global solution to the nuclear waste issue.

Further, there is strong incentive to move ahead with such a pursuit rapidly. The degree of struggle among nations on how to establish and implement a new international paradigm will only get worse with time. Failure to focus prompt and deliberate attention on this

challenge further solidifies the inoperable national infrastructures now in place. An accepted international structure is also sorely needed to provide a framework for responsibly allowing additional nations to enter the "nuclear power club."

A carefully designed international approach should accomplish at least the following desirable attributes:

- Assure the implementation of international safety standards.
- Minimize the risk of nuclear proliferation.
- Reduce the cost of establishing required fuel cycle facilities.
- License and operate temporary locations for storage of SNF.
- License and operate permanent locations for disposal of HLW.

We further suggest that in order for any long-term success to be attained, it will be essential to provide incentives for heavy participation from the private sector. Modern history clearly reveals this to be an important ingredient for large-scale and sustained success.

E) Suggested New International Approach for the Management of Nuclear Waste

We come now to the crux of our issue; namely, the ingredients for an international approach to the solution of nuclear waste disposition. Based on the international progress made to date in both nuclear safety and nuclear nonproliferation (plus the prospects for even greater strides as outlined above), there is good reason to be confident that a successful global approach to nuclear waste can be accomplished.

Several options have been previously proposed, but they usually focus^{on} only certain parts of the overall nuclear waste issue. Hence, with a healthy dose of trepidation, we suggest the creation of a new, fully integrated international entity, which for present convenience we simply entitle the International Nuclear Waste Authority (INWA). This entity would be comprised of and directed by representatives selected from all nuclear power nations. It would **establish** nuclear waste disposition standards, **enforce** all nuclear waste disposition standards, and **execute** all financial and contractual arrangements for full-scale global implementation.

The customers, facilities, and contractors of INWA are outlined below:

1) Customers (Users)

- **Existing Nations** (nations employing nuclear power at the time of INWA enactment)
 - Adhere to INWA standards in any fuel cycle activity.
 - Retain choice of maintaining current national nuclear infrastructure or being serviced by the INWA.
 - Handle all nationally generated low-level waste (LLW) internally.
- **New Nations** (nations that acquire nuclear power after INWA enactment)
 - Adhere to INWA standards in any fuel cycle activity.
 - Join INWA system services.
 - Demonstrate the ability to independently meet all INWA standards before being allowed to develop and implement national nuclear infrastructure.
 - Handle all nationally generated LLW internally.

The fundamental idea here is to establish the INWA as a fully integrated international authority for handling *all* aspects of the back end of the fuel cycle. For those nations already fully functional, they could retain their current infrastructure—so long as they adhere to all INWA standards. New nuclear power nations would be required to adhere to the INWA system upon entry. They would be allowed to develop their own national fuel cycle structure only after they could demonstrate the capability to operate independently.

Clearly there must be a mechanism to raise the revenue necessary for the back end of the fuel cycle services to be performed. Whereas there are likely several methods that could be made to work, the current system in the United States of collecting approximately 1 mil/KW-hr to go into such a pool may be adequate. There certainly has been sufficient funding generated by this mechanism in the U.S. to perform the needed services if a rational system for collecting the funds, setting the standards, and implementing the work were to have existed.

2) Facilities

- Regional interim monitored retrievable storage sites.
- Regional geological repositories.
- Regional reprocessing plants.
- Regional IACS-type centers.
- Transportation casks (all internationally licensed).

3) Contractors

- Acquire long-term contracts to perform all operations.
- Be guaranteed long-term stability and sufficient financial incentive to provide private capital and commitment.
- Derive authority from INWA (not national governments)
- Hold title to all materials within its specified domain
(unless otherwise negotiated for separate contract work approved by the INWA)

F) IAEA Leadership Role

Given the near stranglehold that the lack of effective nuclear waste disposition programs is placing on the advancement of commercial nuclear power, it is paramount that new leadership emerges. The IAEA may or may not be the appropriate entity to provide the role suggested in the previous section as the "International Nuclear Waste Authority" (INWA). But the reality is that there is no other international agency currently in existence with both the constituency and credibility necessary to develop the needed structure. Furthermore, the IAEA is clearly the appropriate agency to take the further steps suggested in ultimately placing *all* plutonium under safeguards accountability. Plutonium commerce is very closely tied to the overall issue of nuclear waste disposition.

It is well recognized that putting together a structure along the lines suggested above will not be easy. Considerable debate is both a necessary and desirable activity if a meaningful international approach to the dilemma is to be enacted. Here again, the IAEA is ideally situated to assume the leadership role.

The framework outlined earlier indicated standard setting would be the job of the INWA. However, it is recognized that the creation of such a system will take considerable time. In the meantime, the international fuel waste disposal entity already operating within the auspices of the IAEA could take the initial standards-setting role and hand off to the new agency when appropriate.

In actuality, should something like the INWA be developed, it is entirely possible that it would become a branch of the existing IAEA. If so, preliminary work by the existing international fuel waste disposal entity would be doubly effective.

The nuclear waste issue has now become perhaps the biggest stumbling block to nuclear progress in many nations. In the United States, for example, the current political stalemate has resulted in the need for nuclear utilities to continue storing SNF on site—despite the fact that they have collected approximately *ten billion* dollars for the U.S. government to provide an appropriate disposal solution. Even in France and the United Kingdom, where the fuel cycle has been closed for years, a combination of public opinion and political discord has prevented even the siting of a possible geologic repository.

Consequently, the most important action is to develop the international machinery to at least construct one or more interim storage sites for SNF. As pointed out by W. Hafele⁽⁴⁾, we must buy time.

W. Sutcliff has pointed out another reason for treating this problem with a sense of urgency⁽³⁾. The risk of nuclear proliferation (a central issue regarding current arguments on the open vs. closed fuel cycle in many nations) will likely fade after the next few decades. This is because advanced technology will likely drive the development of other types of weapons. Consequently, the challenge is to deal with plutonium and SNF as rapidly as possible, during the time the risks are highest.

A necessary first step in implementing the suggestions offered herein would be to obtain a consensus among the current IAEA leadership that this is a problem worthy of urgent attention. Assuming affirmative support, the immediate corollary would be to initiate working sessions, symposia, conferences, etc. with appropriate IAEA member state leadership to develop a proposal to the IAEA General Assembly. Launching a new international approach of the magnitude suggested would almost certainly require support from the highest levels of the Agency.

Once launched by the IAEA as a major new initiative, in-depth dialogue with leaders of the member nations would be necessary. This would entail the development of a substantial new educational program, such that leaders without a strong technical background could grasp the essence of the issues and be motivated to exercise their leadership role as statesmen truly concerned about sustainable development on a global scale.

Once the framework is in place, including the logistics of the leadership structure and the methodology for internal operation, the first major output from the new organization would be a set of international standards for all fuel cycle operations. The next step would be to develop work packages for carrying out those standards at new or existing facilities. In all

of this, considerable financial incentives should be established to lure the private sector into forming the appropriate international consortia for bidding on the defined packages and implementing the work.

If there is a silver lining to the current global slowdown in the building of nuclear power plants, perhaps it is that this hiatus may allow clever nuclear professionals to develop advanced fuel cycles, where the implications of the entire fuel cycle are properly optimized. During the first "nuclear era," much of the planning was done in a disjointed fashion. Fuels were chosen largely on the basis of expediency and reactor systems were developed to achieve a certain set of performance objectives that had very little to do with the question of nuclear waste disposition.

An opportunity now exists to take advantage of the lessons learned from the first half-century of nuclear technology and blend features to achieve overall optimal performance. As an example of such thinking, Mourougov⁽⁵⁾ has suggested a fast reactor fuel cycle employing plutonium fuel and thorium blankets. Properly configured, this has the potential to enhance reactor safety characteristics and provide U-233 fuel for thermal reactors that would enable exceptionally long run times. Such a system could fit well into the framework that we propose, since the resulting thermal reactor may provide an ideal "nuclear battery" for nations taking advantage of the fuel services of the INWA. The fast reactor providing the fuel could be a part of the Integrated Actinide Conversion System (IACS) proposed by Wagner⁽⁶⁾, which would be operated by the private contractor organization.

These represent only examples of numerous possibilities worthy of exploration. IAEA support of such concepts could prove exceptionally rewarding.

Needless to say, the entire process of setting up an INWA-type system could take many years and it is very likely to entail a good bit of frustration. But parts of it could be implemented relatively soon (e.g. interim storage sites), so long as there was general agreement that a long-lasting effort of the nature suggested was forthcoming.

Conclusions

Nuclear power represents an enormous source of energy to help undergird global sustained development. Upon reflection, the discovery of ways to peacefully harness nuclear might even be considered providential, given the extraordinary demands for plentiful electricity that have arisen within the past half century—and the expectations for even much higher electricity demands over the coming millennium.

Further, nuclear energy is unique among alternate sources for supplying huge quantities of needed electricity in that it has the potential to be pollution free (except for the thermodynamic thermal pollution that is associated with all large-volume energy delivery systems). It is only the small amount of pollution associated with the construction of nuclear power plants (manufacturing the materials necessary for building the plants) that is intrinsic to the nuclear energy enterprise. Indeed, there is always the potential for accidents, whereby pollutants could be dispersed either within a nuclear waste repository or into the atmosphere, but such events are avoidable (or at least can be greatly mitigated by proper design). For the competing large-scale energy delivery systems, huge amounts of pollutants are routinely discharged directly into the atmosphere. Even the solid nuclear waste, which many currently believe represents an “insurmountable problem,” may turn out to have enormous commercial value. Because of the potential for processing and recycling the nuclear “waste,” there are strong reasons to contemplate a rich and highly beneficial future market for a concentration of such well-defined materials.

However, there is currently widespread concern for the enormous buildup in the quantities of SNF and the corresponding plutonium that are associated with the demands likely to be placed upon nuclear power. Whereas we believe a proper system can be established to manage such materials, it is essential that this system be done on an integrated, global basis. The days when individual countries could consider handling the entire fuel cycle completely independently are likely over (if they ever truly existed). Establishing an effective international system such as the INWA to manage the disposition of both SNF and the associated fissile components will not be easy. But in order to realize the enormous contributions that nuclear energy can make to humanity over the next millennium, it is a task that must be undertaken. The IAEA is in a unique leadership position to lead the way. It is a responsibility that must not be forsaken.

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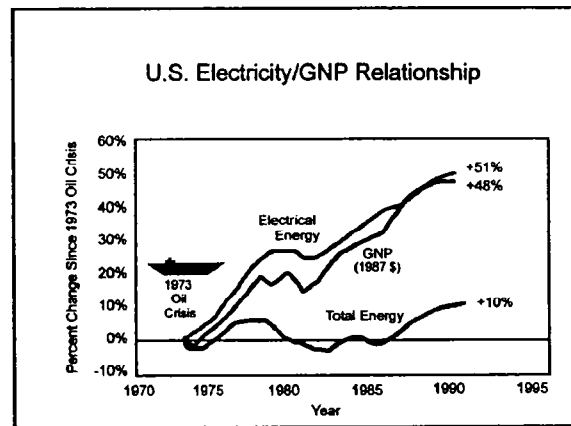
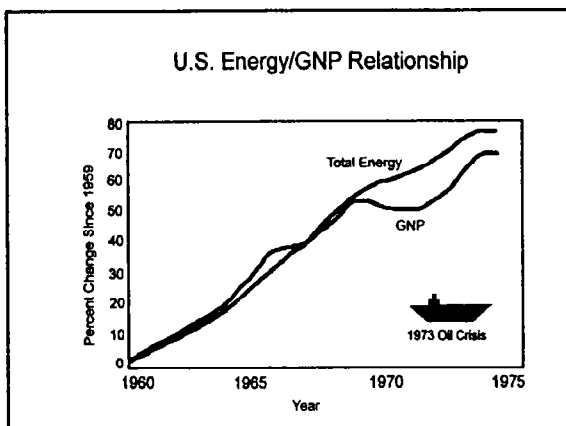
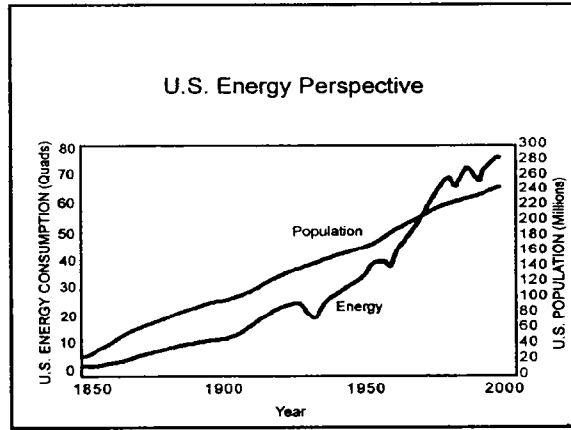
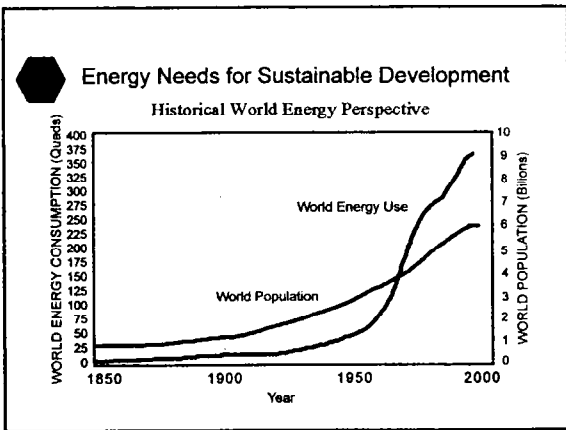
NUCLEAR WASTE & ENERGY SUSTAINABILITY: Are They Compatible?

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IAEA Scientific Conference
Sustainable Development: Is There a Role for Nuclear Power?
September 28, 1999
Vienna, Austria

OUTLINE

- 1) Energy Needs for Sustainable Development
- 2) How Much Nuclear Energy Needed?
- 3) How About Nuclear Waste?
- 4) Wastes & Environmental Impacts from Other Energy Sources
- 5) Beneficial Uses of Nuclear "Waste"
- 6) An Approach for Responsible Nuclear Waste Management

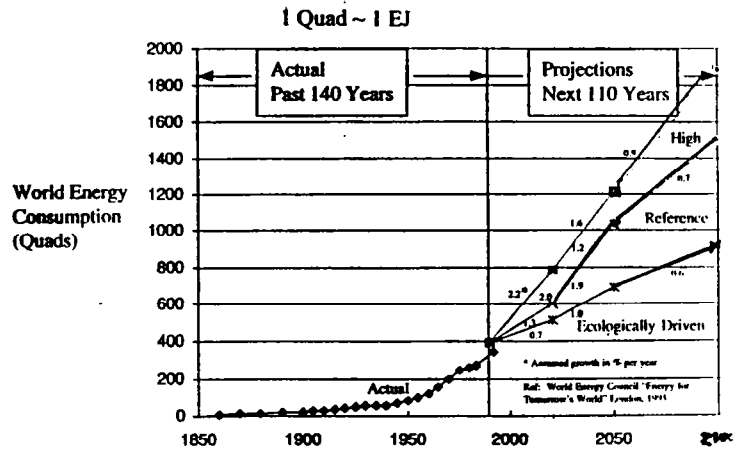


How Much Nuclear Energy is Needed? World Energy Consumption

The Message is Clear---

Electricity is Becoming the Energy Form of Choice

- Motors
- Heating & Air Conditioning
- Lighting
- Information Systems
- ...

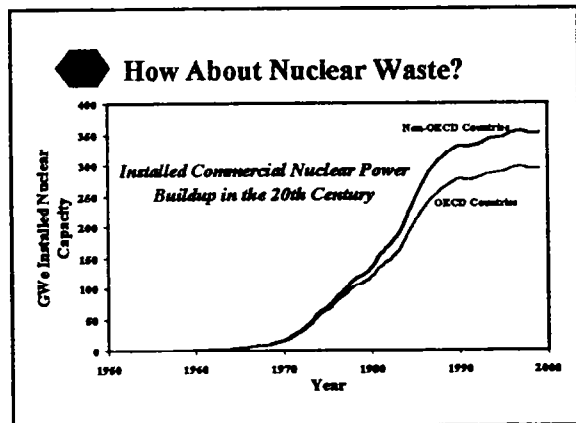
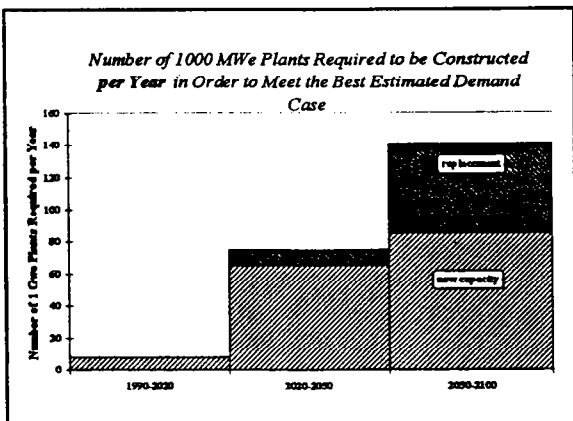
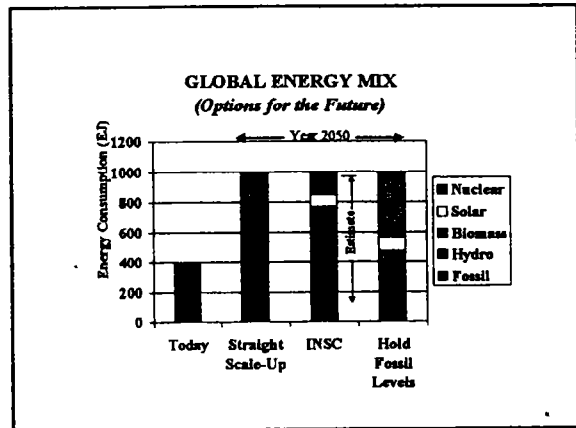


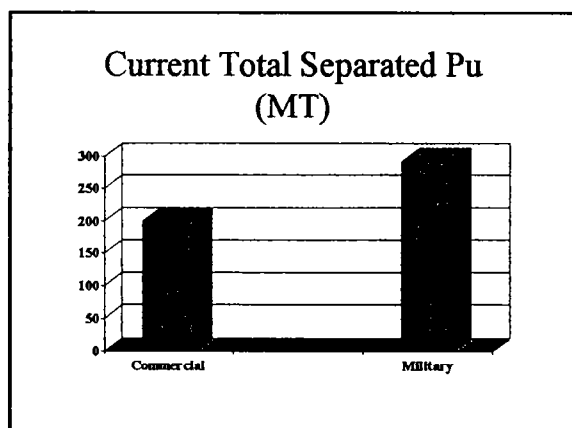
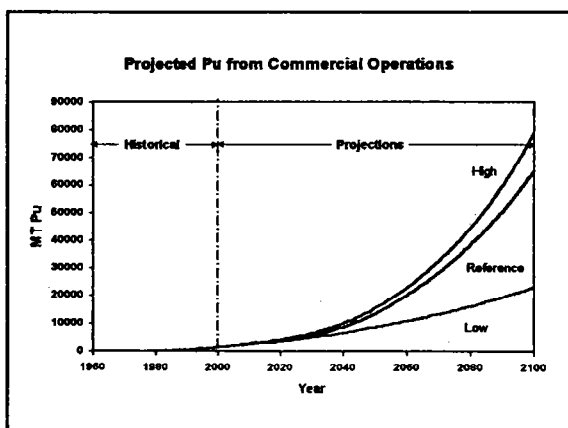
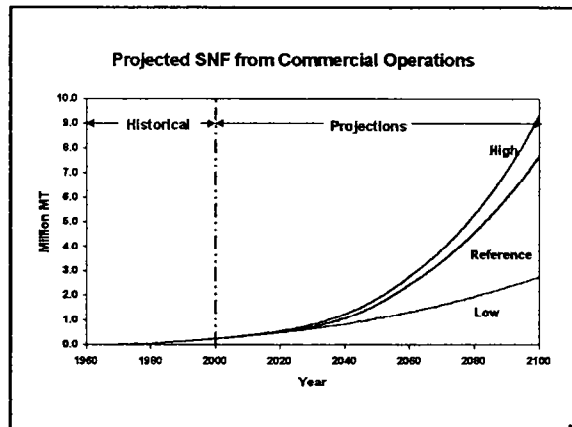
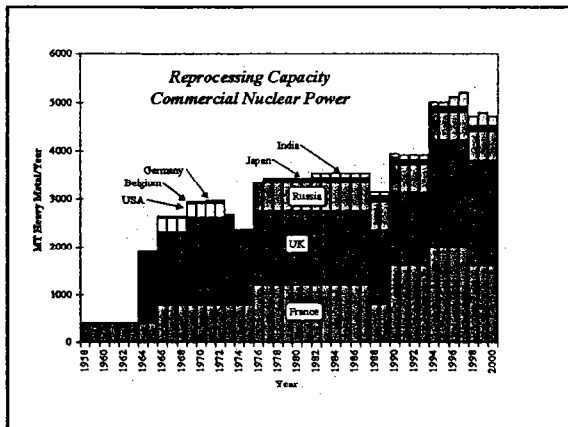
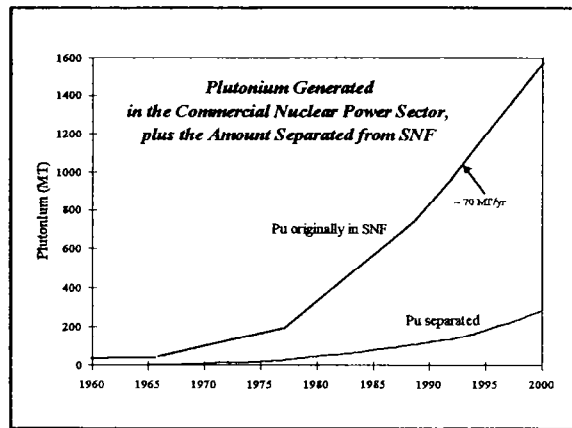
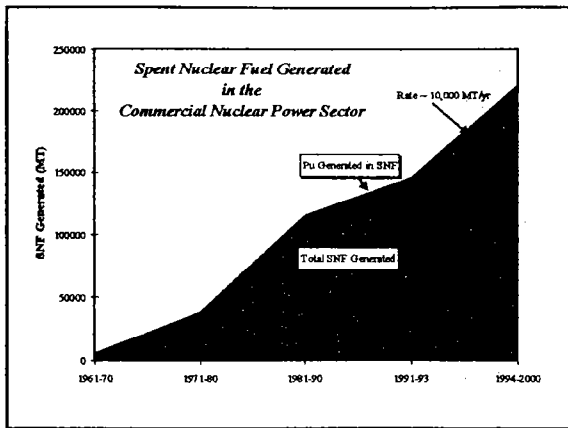
World Energy Perspective

Projected growth over the next half century
(International Nuclear Society Council)

Year	Population (Billions)	GJ/Person	Total Energy (EJ)
2000	6	67	400
2050	10	100*	1000

* NOTE: U.S. Today ~ 300 GJ/Person
 100 GJ/Person represents 3 times increase for poor nations

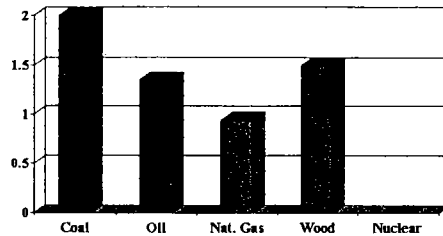




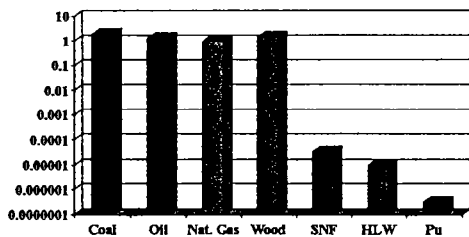
④ Wastes & Environmental Impacts from Other Energy Sources

Source	CO ₂	SO _x	NO _x	Toxins/ Carcin.	Land Mass	Other
Coal	High	High	High	High	Low	} Needed for huge commerce
Oil	High	High	Med	Low	Low	
Nat. Gas	Med	---	Med	Low	Low	
Solar	---	---	---	Med	High	Backup Req'd
Hydro	---	---	---	Low	High	Backup Req'd
Wind	---	---	---	Low	High	Backup Req'd
Biomass	High	Low	Med	High	High	Denuding
Geotherm.	---	High	Med	Low	Med	Remote

Environmental Pollution from Various Energy Sources
(Million MT waste per GW-yr electricity generated)

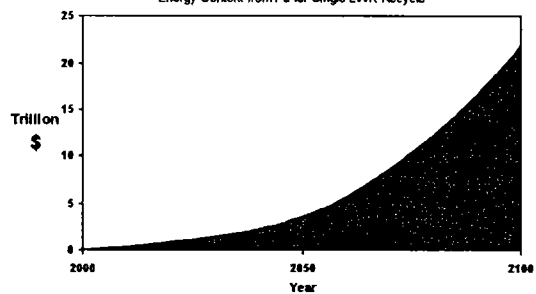


Environmental Pollution from Various Energy Sources
(Million MT waste per GW-yr electricity generated)



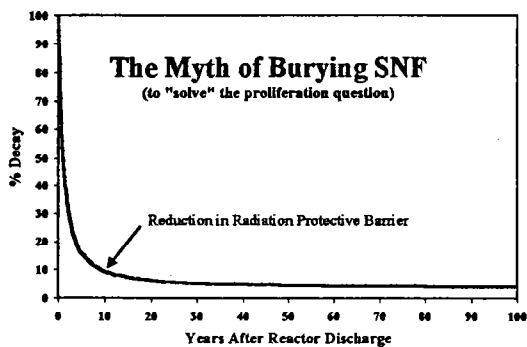
Beneficial Uses of Nuclear "Waste"

Energy Content from Pu for Single LWR Recycle



The Myth of Burying SNF

(to "solve" the proliferation question)



Other Uses of Nuclear "Waste"

Power Source	Medicine	Food Irrad.	Sewage Irrad.	Agriculture	Targets
Fiss. Prod.					
Sr-90	X				
Cs-137	X	X	X	X	
Mo-99*	X				
I-131*	X				
Actinides					
U					
Pu					
Am					
Np-237					Pu-238
Cm-244					Cf-252
Activat. Prod.					
C-14	X				
Co-60	X	X	X	X	

* Must be separated immediately after formation.

Sr-90 (β)

1 year of reactor operation, 1000 MWe PWR, 10 year cool down
 Mass = 13 kg
 Activity = 2 million Curies

MEDICAL

$^{90}_{38}\text{Sr} \rightarrow ^{90}_{39}\text{Y} + ^0_{-1}\beta$ \Leftarrow Hodgekin's Lymphoma
 Rheumatoid Arthritis

POWER SOURCE

One 10 watt RTG requires \approx 0.1 million Curies
 Example: Trans Atlantic Fiber Optic Cable Requires \approx 300 such batteries
 \Rightarrow 30 million Curies
 (i.e., 15 reactor years of "waste")

Cs-137 (γ)

1 year of reactor operation, 1000 MWe PWR, 10 year cool down
 Mass = 30 kg
 Activity = 2.7 million Curies

FOOD IRRADIATION

One Commercial Food Irradiator Requires = 3 million Curies
 (i.e., one reactor year per irradiator)

\therefore 200 food Irradiators require \Rightarrow (twice the current U.S. yearly produced nuclear "waste" capacity)

6 An Approach for Responsible Nuclear Waste Management

MUST BE GLOBAL APPROACH

Leverage from experience gained in areas of:

- * Safety
- * Non Proliferation
- * Economics

Safety

- TMI \longrightarrow INPO (Institute of Nuclear Power Operations)
 - Chernobyl \longrightarrow WANO (World Association for Nuclear Operations)
- \downarrow
IAEA : International Safety Convention

Next Step (?) -- All licensed operations in the nuclear fuel cycle be carried out under international authority

Issue: Erosion of national sovereignty
 (Is it worth it ?)

Non Proliferation

- NPT: Adopted 1960s
 - Far greater success than thought possible at time of adoption
 - Substantial fraction of world plutonium stream now under IAEA safeguards

Next Step (?) -- Bring all plutonium under IAEA safeguards

- * All commercial Pu into international stockpile (use International Monetary System as model for accountability)
- * Include declared excess weapons Pu
- * Include undeclared excess weapons Pu

Economics

- All nations have a right of access to nuclear energy (guaranteed by Article IV of the NPT)
- To expect all nations to bear full costs of nuclear fuel cycle is impractical (and likely considered as discriminatory)
- Certainly developing nations do not possess the resources or technical infrastructure necessary for success in this complex enterprise

Key Ingredients for Successful International Fuel Cycle

- Implement international safety standards
- Minimize risk of nuclear proliferation
- Reduce number and cost of required fuel cycle facilities
- License and operate
 - temporary facilities for SNF storage
 - permanent facilities for disposal of HLW

Provide incentives for heavy private sector participation

Suggested New International Approach

Establish new International Nuclear Waste Authority (INWA)

[Composed of representatives of nuclear power nations]

- **Establish** nuclear waste disposition standards
- **Enforce** all nuclear waste disposition standards
- **Execute** all financial and contractual arrangements

Customers of INWA

- **Existing Nations** (Nations employing nuclear power at the time of INWA enactment)
 - Adhere to INWA standards in any fuel cycle activity
 - Retain choice of maintaining current national nuclear infrastructure or being serviced by the INWA
 - Handle all nationally generated LLW internally
- **New Nations** (Nations that acquire nuclear power after INWA enactment)
 - Adhere to INWA standards in any fuel cycle activity
 - Join INWA system services
 - Demonstrate the ability to independently meet all INWA standards before being allowed to develop and implement national nuclear infrastructure
 - Handle all nationally generated LLW internally

All pay ~ 1 cent/KW-h for back-end fuel cycle services

Facilities of INWA

- **Regional Facilities**
 - Interim monitored retrievable storage sites
 - Reprocessing plants
 - Geological repositories
- **Transportation Casks**
 - All internationally licensed

Contractors of INWA

- Acquire **long-term contracts** to perform all operations
- Be guaranteed **long-term stability** and sufficient financial incentives to provide private capital and commitment
- Derive **authority from INWA** (not national governments)
- Hold **title to all materials** within its specified domain (unless otherwise negotiated for separate contract work approved by INWA)

IAEA Leadership Role

- IAEA logical entity to develop system and put into place
 - Only agency currently existing with sufficient constituency and credibility
 - Only agency that could put *all* Pu under safeguards accountability
 - Pu accountability closely tied to overall issue of nuclear waste disposition
 - IAEA itself might play the role of INWA

Urgent Need to Proceed

- **Must buy time** (Hafele)
 - SNF and separated Pu continues to build (spread out)
- **Risk of nuclear proliferation may be highest in the near-term**
 - Could reduce in the future as new weapons systems evolve (Sutcliffe)

Steps to Success (with IAEA Leadership)

- 1) Initiate working sessions, symposia, conferences, etc. to develop proposal for IAEA General Assembly approval
- 2) Launch major initiative to gain acceptance of member nations for approval of INWA
 - Leaders/constituents must be convinced of cooperation necessary to gain full benefits of nuclear power

Steps to Success (with IAEA Leadership)

- 3) Initial INWA steps:
 - Confirm membership/leadership structure
 - Develop logistics for internal operation
 - Establish standards for fuel cycle operation
 - Develop work packages
 - Develop financial incentives to attract private sector in forming appropriate international consortia to bid on defined packages

Conclusions

- Nuclear power, properly harnessed, represents an enormous source of energy to undergird global sustained development
- It has the potential to provide needed energy in a manner completely compatible with environmental sensitivity
 - pollution free
 - use of recycled materials } far superior to any other energy source

But...

- Nuclear proliferation & long-term waste disposition problems must be solved
- This must be done on an integrated, global level
- An INWA approach may provide an acceptable way to proceed