A. INTRODUCTION

A. 1. STATEMENT OF CONCEPT AND GOAL

The objective of the Status Report on Accelerator Driven Systems (ADS) is to present the state of the art of this technology by reviewing the current status and progress of national and international programmes in this field. The report aims at helping to identify and possibly stimulate important directions of national and international efforts in this area.

The experts working on this report noted the increasing interest among some Member States and international research groups in exploring possible accelerator impact on the nuclear fuel cycle and consequently on the future of nuclear energy.

This report is divided into several sections. The basic physical phenomena and physical aspects of ADS are described in the first parts (**Section A**) followed by a review of existing national/international projects. The most important research and development issues are also reviewed. Nonproliferation aspects, the impact of ADS on the future of nuclear power and the experts recommendations on the international cooperation are presented in the final part of the report.

The chapters written by invited experts are signed by their names, the parts in which names are not indicated are written or/and compiled by the editor, Mr. W. Gudowski of Sweden.

Section B - Physical Features of ADS describes the most important parts of these systems: target, blanket, fuel cycle, associated fuel cycle technologies and general accelerator issues. Special attention is focused on the neutron economy for different concepts of ADS.

Section C is dedicated to some research and development problems : radiation damage and computer code development necessary for the progress of ADS.

Section D - Performance of the ADS Systems - the most important national/international projects are presented by the respective project leaders. Some smaller efforts in ADS are also described. Contributions to this section were written by the managers/leading scientists of the selected national/international projects. Many issues from sections B and C are also extensively described in the context of the particular projects. Planned demonstration/integral experiments are also reviewed in this section.

Section E with two appendices address some selected safety problems connected to ADS projects proposed by CERN-group.

Section F - formulates briefly the expert recommendations.

A.2. HISTORY AND CURRENT STATUS

In a fission chain reaction the excess of neutrons - if available - may be used for converting non-fissile materials into nuclear fuel as well as for transmutation of some long-lived radioactive isotopes into short-lived or even nonradioactive ones. This excess of neutrons can also be used to facilitate incineration of long-lived waste components, for fissile material breeding or for extended burnup. One way to obtain excess neutrons is to use a hybrid subcritical reactor-accelerator system called just Accelerator-Driven System. In such a system the accelerator bombards a target with high energy protons to produce a very intense neutron source (a process called spallation), these neutrons can consequently be multiplied in a subcritical reactor (often called a blanket) which surrounds the spallation target.

The basic process of accelerator-driven nuclear systems is nuclear transmutation. This process was first demonstrated by Rutherford in 1919, who transmuted ^{14}N to ^{17}O using energetic α-particles. I. Curie and F. Joliot produced the first artificial radioactivity in 1933 using α-particles from naturally radioactive isotopes to transmute Boron and Aluminum into radioactive Nitrogen and Oxygen. It was not possible to extend this type of transmutation to heavier elements as long as the only available charged particles were the α-particles from natural radioactivity, since the Coulomb barriers surrounding heavy nuclei are too great to permit the entry of such particles into atomic nuclei. The invention of the cyclotron by E.O. Lawrence [1] removed this barrier and opened quite new possibilities [2]. When coupled with the spallation process, high power accelerators can be used to produce large numbers of neutrons, thus providing an alternative method to the use of nuclear reactors for this purpose. Spallation offers exciting new possibilities for generating intense neutron fluxes for a variety of purposes.

The first practical attempts to promote accelerators to generate potential neutron sources were made in the late 1940's by E.O. Lawrence in the United States, and W.N. Semenov in the USSR. The first such application for the production of fissile material was the MTA [3] project at the Lawrence Livermore Radiation Laboratory. This project was abandoned in 1952 when high grade Uranium ores were discovered in the United States. The Canadian team at Chalk River [4] has always been a strong proponent of such a producer of fissile material which could be used in conjunction with a conversion-efficient CANDU reactor.

When the United States administration decided to slow down the development the fast breeder to promote non-proliferation goals, Brookhaven National Laboratory presented several proposals for accelerator breeders such as the Na-cooled fast reactor target, the Molten Salt target, the He-gas-cooled target, as well as the LWR fuel regenerator.

This concept of the accelerator breeder has also been studied by Russian scientists. Under the guidance of V.I. Goldanski, R.G. Vassylkov [5] made a neutron yield experiment in depleted Uranium blocks using the accelerator at Dubna.

The original idea of exploiting the spallation process to transmute actinide and fission products directly was soon abandoned. The proton beam currents required were much larger than the most optimistic theoretical designs that an accelerator could achieve, which are around 300 mA. Indeed, it was shown that the yearly transmutation rate of a 300 mA proton accelerator would correspond only to a fraction of the waste generated annually by a LWR of 1 GWe.

To use only the spallation neutrons generated in a proton target, the fission products would be placed around the target. For the highest efficiency, depending on the material to be transmuted, either the fast neutrons would be used as they are emitted from the target or they would be slowed down by moderators to energy bands with higher transmutation cross-sections, for example, the resonance or the thermal region.

In the last few years hybrid systems were proposed for different purposes. ADS on fast neutrons for the incineration of higher actinides was proposed at Brookhaven National Laboratory (PHOENIX-project) and is now carried out in Japan as a part of OMEGA-programme. Los Alamos National Laboratory has developed several ideas to use the hybrid system on thermal neutrons with a linear accelerator for incineration of Plutonium and higher actinides, for transmutation of some fission products in order to effectively reduce longterm radioactivity of nuclear waste as well as for producing energy based on the Thorium fuel cycle. In 1993 Carlo Rubbia and his European group at CERN proposed a cyclotron based hybrid system to produce nuclear energy with Thorium-based fuel. This is an attractive option reducing the concerns about higher actinides in the spent fuel and giving the possibility of utilizing cheap and quite abundant Thorium. First experiments have already been performed by the CERN-group.

Many countries are considering to permanently store long-lived highly radioactive material in stable geologic formations, e.g. such as the Yucca Mountain in Death Valley. However, there is concern that the waste remains dangerous for many tens of thousands of years. The concern that such repositories can become mines for Plutonium has become of even greater concern as the U. S. has made it known that nuclear weapons can be made from Plutonium generated in commercial power reactors [6]. Therefore, it is worthwhile studying an alternative approach that would separate the long-lived nuclei from the high-level waste by transmuting such nuclei into short-lived or non-radioactive wastes.

ADS operates in non self-sustained chain-reaction mode and therefore minimizes the power excursion concern. ADS is operated in a subcritical mode and stays subcritical, regardless of the accelerator being on or off. The accelerator provides a convenient control mechanism for subcritical systems than that provided by control rods in critical reactors, and subcriticality itself adds an extra level of operational safety concerning criticality accidents. As described later, a subcritical system driven with an accelerator decouples the neutron source (spallation neutrons) from the fissile fuel (fission neutrons). Accelerator driven systems can in principle work without safe-shutdown mechanisms (like control rods) and can accept fuels that would not be acceptable in critical systems.

The technology of accelerating a charged particle to high energy has been well demonstrated in recent years, as has the technology of the target. However, extension of this capability to high-current beam-acceleration is required.