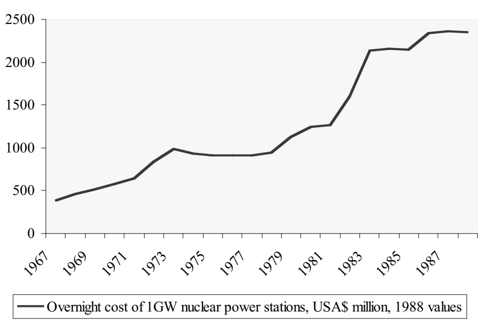
WHY THE UK NEEDS NUCLEAR POWER

Malcolm Grimston
Associate Fellow, Chatham House

The change in the profile of nuclear power in many countries, notably the UK, during the first decade of the new century has been one of the most startling aspects of the rise of energy up political agendas. In 2003 the Government Energy White Paper said: "Nuclear power's current economics make it an unattractive option for new, carbon-free generating capacity and there are also important issues of nuclear waste to be resolved. This White Paper does not contain specific proposals for building new nuclear power stations." Just five years later, the 2008 Nuclear Energy White Paper, by contrast, stated: "The Government has concluded that nuclear should have a role to play in the generation of electricity. Nuclear power is a tried and tested technology. It has provided the UK with secure supplies of safe, low-carbon electricity for half a century. More than ever before, nuclear power has a key role to play as part of the UK's energy mix."

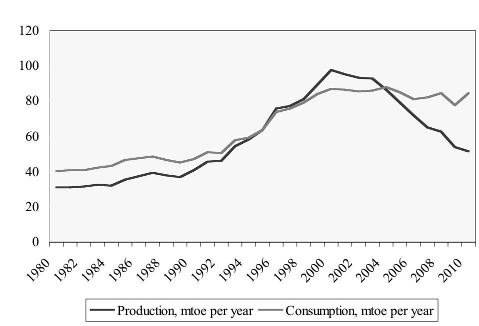
This turnaround followed an equally dramatic fall in the global and national fortunes of nuclear power between the late 1970s and the middle years of the 2000s. The key question is whether the global 'nuclear renaissance' that appears to be under way, albeit modestly so far, should gain momentum, or peter out like the last major wave of investment in the 1960s and 1970s.

We need four things from our electricity supplies – security and reliability; economic competitiveness; environmental sensitivity; and social and political acceptability. After its initial flourish, nuclear power hit problems on all these fronts. In the 1960s and, especially, 1970s, the security of supplies of alternative fuels to nuclear power had looked shaky, but the collapse of OPEC, the decline in power of the coal mining unions and the discovery of significant quantities of gas (including reserves in the North Sea) pushed such fears into the background. As oil, gas and coal prices fell the costs of nuclear power were growing, largely (though not solely) because of the effects of the Three Mile Island accident in 1979. This accident happened in a brand new Pressurised Water Reactor at a time when many such plants were under construction. Huge costs were incurred redesigning these partially built reactors (a much more expensive undertaking than redesigning a plant before construction has begun), servicing the capital which had been invested but was not earning an income, designing new evacuation procedures and responding to more vigorous regulatory requirements.



Environmental concerns about radiation grew (although from the early 1990s there was also international attention on climate change), and the social and political attraciveness of nuclear energy took a very severe blow after the Chernobyl accident in 1986. In the UK the 'dash for gas' in the 1990s ticked all the boxes – there was plenty of gas in the North Sea (indeed we became a net exporter of gas), the new Combined Cycle Gas Turbine (CCGT) technology was cheap and reliable, shifting from coal to gas for power production resulted in reductions in greenhouse gas emissions and gas did not provoke major public protests. The main task for governments of both political colours in the 1990s and early 2000s seemed to be to complete the liberalisation of the market commenced in the late 1980s. Since nuclear power is very heavily capital-intensive it was further disadvantaged by this change, being inherently more risky in economic terms when compared to sources of electricity production which are cheaper and quicker to build (though more expensive to run), notably gas.

Things began to look very different halfway through last decade. The UK became a net gas importer as reserves became depleted, while the failure to build any new electricity capacity for much of the decade raised fears about the ability of the system to cover peak demand.

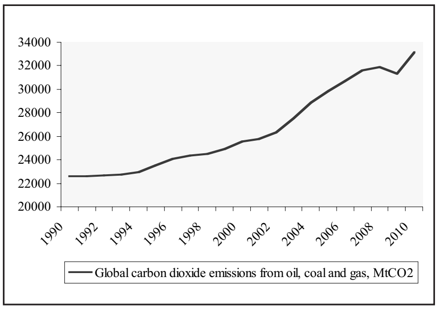


UK gas production and consumption 1980-2010

The geopolitics of oil and gas, especially unrest and military conflict in the Middle East and Russia interrupting oil and gas supplies to

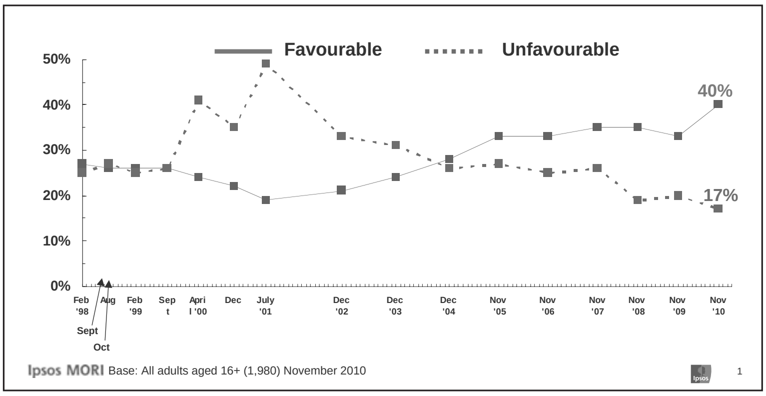
Ukraine and Belarus in 2005 and 2006, revived fears of the dangers of becoming overdependent on imports from that region. Further, as older power stations neared the end of their lifetimes, there was a growing need to install very large amounts of new generating capacity of some description in the UK – government estimates suggest around 35,000 MW over the next 15-20 years.

Concerns over climate change grew as global emissions of carbon dioxide rose inexorably.



Public confidence in nuclear power grew considerably after nearly 25 years without a major accident, and several prominent green campaigners who had been opponents of nuclear power publicly revised their stance.

Q How favourable or unfavourable are your overall opinions or impressions of the nuclear industry/nuclear energy?



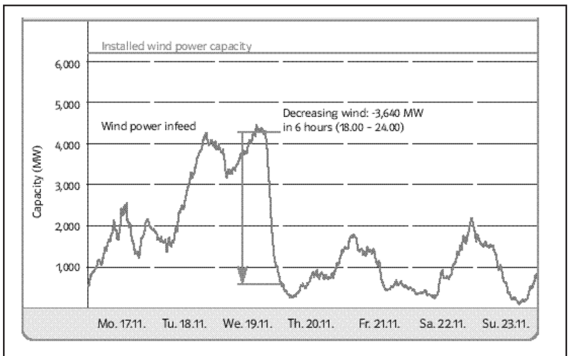
In the UK the Coalition Government elected in 2010 essentially maintained the pro-nuclear stance of its predecessor, on the assumption that nuclear power did not receive specific subsidies that were not available to other fuels (insurance against major accident being the exception).

The accident at Fukushima certainly led to a pause for thought, but no apparent major change in policy in the UK, or indeed in the USA, Russia, China, South Korea and many other countries (though Germany, Italy and Switzerland stood as counterexamples). Public confidence proved remarkably robust – a poll in The Times in early July 2011 showed the percentage of people in favour of replacing the UK's current nuclear fleet with new reactors falling from 52% to 47% (those opposed growing from 24% to 28%), around the level it had been as recently as 2008. Unlike Three Mile Island or Chernobyl, Fukushima involved old plants (using 1960s technology), which had suffered a huge external challenge from the earthquake and tsunami – remarkably, of the 14 reactors in the affected zone in Japan the 10 newest were in stable 'cold shutdown' within a week. Any redesign lessons can be applied before construction begins, but newer reactor designs such as the Toshiba-Westinghouse AP1000 make much more use of 'passive safety' as opposed to 'engineered safety'. To take an example, the main problem with the reactors at Fukushima occurred because the tsunami flooded the back-up generators which power the pumps which send water into the core of the reactors to remove waste heat. The loss of these pumps resulted in the fuel melting (it now seems) and ultimately in releases of radioactive materials and hydrogen, which caused the explosions we saw. In an AP1000 there is a huge reservoir of water above the reactor containment itself. If all power is lost to the plant, pressure inside the containment would increase, and this would open valves which would allow water to flow under gravity from the reservoir into the containment. This process does not require any power and so would have been effective even during the tsunami.

Climate change is a much bigger policy driver now than it was in the 1980s while in many countries there is an urgent need to build large amounts of new generating capacity of some description (again unlike the 1980s when globally the problem was overcapacity as a result of the recession caused by the oil price hikes of 1973 and 1979).

The nuclear industry, if it is to fulfil its potential in providing very low carbon electricity and reducing the UK's dependence on imported gas, will need to demonstrate that it can build plants to time and cost (even more vital within competitive electricity markets where cost overruns cannot be passed on to captive customers). It will also need to maintain and extend its much more open approach to communication and debate with people about the pros and cons of nuclear technology – the industry's previous secrecy and sometimes arrogance have contributed to a degree of public mistrust.

But the growing need for reliable new capacity, for alternatives to imported fossil fuels, for low carbon sources and for economic competitiveness leaves few attractive options. Many renewable technologies (notably wind, tidal and solar) are inherently intermittent, which makes them poorly suited to providing 'baseload' power, the electricity demand that must be met at the time it arises to keep our water flowing, mass transportation operating and so on.



Fluctuations in wind power feed in E.On Netz control area, Germany, November 2003

In effect, then, each nuclear plant that is not built will represent a coal or gas plant which is, locking us into greenhouse gas emissions and increasing our dependence on imported fossil fuels. With most of our current nuclear plants coming to the end of their lives over the next decade or so, a rapid start to a new programme is now vital.

NUCLEAR SCIENCE AND ENGINEERING – WHY ARE THEY IMPORTANT TO THE UK ECONOMY?

Robin Grimes
Director, Centre for Nuclear Engineering, Imperial College

Nuclear energy is tempting. It provides a low carbon secure energy resource. Nevertheless, without consistent underpinning science and engineering it would not be possible, or wise, to proceed with this option. This is because nuclear energy generation demands a very high degree of engineering capability to build, control, monitor, maintain and decommission plant. The spent fuel also requires careful handling and its final disposal has not been fully resolved. It is probable that within the reactor pressure vessel, the combination of high radiation fields, temperatures, pressures and corrosion, make this the most extreme of engineering environments. Consequently, it is not sufficient to understand only the pre-irradiation properties and behaviour of nuclear plant. Rather, to optimise performance, reliability and guarantee safety, it is necessary to understand how plant behaviour evolves during operation – particularly how components age and the properties of constituent materials change under irradiation. This demands the application of science and engineering at the highest levels.

Irrespective of the challenges, nuclear energy provides by far the most compact energy source. A single nuclear reaction releases a hundred million times more energy than a chemical reaction. Put another way, one cubic centimetre of conventional nuclear fuel will release as much energy as 500 litres of fuel oil. This makes the nuclear option very attractive, particularly for intensive energy users such as chemical and manufacturing industries, where both fluctuations in cost and reliability of supply are crucial issues.

To address the challenges, science and engineering must provide the understanding and deliver developments and improvements that ensure the continuing safety, security and reliability of all aspects of the industry. In the UK, safety is the responsibility of everyone in the industry and the regulator. The generator must advance arguments based on engineering experience to develop a safety case and the regulator must test and scrutinise the case to ensure that it is robust against both normal and possible accident scenarios. Scientific developments allow new processes to be considered, with the aim to proceed towards even safer and more efficient generation. However, existing reactors are getting older and those extreme conditions are causing parts of the plant to slowly degrade and evolve in ways that cannot always be anticipated from previous experience. Thus, scientific research is crucial to enable possible problems to be anticipated and their effects minimised.

The regulator is currently undergoing significant evolution as it prepares for a new build programme. This is evidenced by it changing from being the 'Nuclear Installations Inspectorate' to the 'Office for Nuclear Regulation'. Having been a nation that pioneered nuclear energy, we have a diverse fleet of reactors. This has demanded a continuous regulatory focused R&D programme so consequently the Regulator is well exercised and able to address a new build programme while progressing life extension of the existing fleet. Post Fukushima there will be a greater international emphasis on safety and reliability. UK companies are at the forefront of developing and applying the required advanced engineering processes and methods to offer enhanced safety and security for plant world wide.

The existing UK fleet are mostly Advanced Gas Cooled reactors (AGR), an almost unique UK design. Near term reactors, for the new build programme, will be Pressurised Water Reactors (PWR), a variant of light water reactors. These are used by the majority of other nations, including France and the US. The UK has one PWR reactor, Sizewell B. Commissioned in 1988 it is our most recent reactor and right now the most recently commissioned power reactor in Europe. We are presently considering different PWR designs for new build. Importantly for UK industry, reactor build is no longer the domain of a single company – build is an international multi-company venture and as such, UK companies will play a considerable role in the new build supply chain, irrespective of the name on the front of the building.

A major factor in why we have changed over to PWR design is the remarkable increases, over the past 20 years, in the capacity factors of PWR plant. Continuous incremental improvements in plant design and operation have resulted in the proportion of time during which the reactors are available to generate electricity (their capacity factor) increasing from around 70% to over 90%.

A second factor in the success of the PWR reactor is the increase in burn-up of their uranium dioxide nuclear fuel. In a nuclear reactor, uranium atoms undergo fission due to neutron irradiation – that is, atoms are split into two non-identical smaller atoms (fission products). This is accompanied by a significant release of energy and additional neutrons that maintain the (chain) reaction. Conventional fuel relies upon only one isotope of uranium (U-235) to sustain the fission reaction while another isotope (U-238), is slowly transmuted into plutonium (Pu-239), which then also undergoes fission. Eventually the initial U-235 is mostly used up and the fuel becomes inefficient and must be removed from the reactor – it is spent. Increasing the time over which the fuel is usefully generating energy provides an important economic incentive and burn-ups in light water reactors have been increasing steadily from 20 GWd/t in 1970 to over 50 GWd/t at present (10 GWd/t corresponds to approximately 1% of the uranium atoms being used up). While engineering solutions will increase burn-up further (helping to maintain nuclear as an economically attractive energy generation option) this will still mean that only a few per cent of the available uranium is being used. Dramatic increases are possible but require significant scientific advances.

One option that would consume over 70% of the uranium fuel atoms is to use fast reactor technology. In this case, the neutrons interact with the uranium and plutonium atoms with greater energy but the technology only works if the energy density within the core is even greater than in a PWR – about 4 times greater. This is an enormous challenge and an entirely different cooling technology is required (for example liquid sodium). In the UK we did build working fast reactors in the 1970s but the technical problems were too great to make this option economically competitive at that time. A further issue with this technology is that it requires the fuel to be recycled multiple times. That is, useful uranium and plutonium must be separated from the fission products. Such reprocessing technologies were still in their infancy at the time and the waste arising, due to the difficult chemical processes, caused major problems of their own. At the present time India is embarking on a major power generating fast reactor programme and Russia continues to operate fast reactors.

An alternative approach to fast reactors, which also utilises reprocessing, is to use the uranium and plutonium to fabricate new mixed-oxide (MOX) fuel that can be used in conventional PWR reactors. While a much less challenging technology, this would only improve the efficiency of uranium use by a few per cent. Again, the UK has reprocessed not only UK fuel but fuel from overseas reactors to produce MOX and exported it back to the country of origin (eg to Switzerland and Japan). It is not clear at this point if we will continue to offer this service but it has generated substantial revenue.

A final option is to employ the thorium fuel cycle. In this case the thorium isotope Th-232 undergoes transmutation to produce a lower isotope of uranium, U-233, which is able to undergo fission. There are a number of attractive points to this technology, including a greater abundance of thorium compared to uranium and the smaller inventory of very long-lived elements in the spent fuel. However, it does still produce as many fission products and a detailed understanding of how the fuel performs is lacking. Nevertheless, it is a technology that will undergo significant scientific investigation over the next decade and the UK could play an important part, with work presently being carried out, for example, at the National Nuclear Laboratory.

Returning to the diversity of UK nuclear plant, this means we are having to overcome some unique challenges in decommissioning resulting from our being a pioneer nuclear nation. Consequently the UK is already a world leader in decommissioning technologies with companies such as AMEC and SERCO now finding expanding international markets in which to apply their UK engineering experience. They are developing innovative solutions to problems that are arising first here in the UK but will certainly arise later in other countries.

Finally, UK universities are enjoying their own nuclear renaissance with Research Councils UK having increased funding of fission research to ~£50M. There can be no doubt that what attracts academics to nuclear energy research is the challenge of understanding those extreme radiation environments! Furthermore, as John Roberts describes in his article, UK universities are working hard to supply the graduates to fuel industry-based nuclear science and engineering. Much of this involves blurring the boundaries between academia and industry. For example, in collaboration with more than a dozen industries such as Rolls-Royce and Westinghouse, Manchester and Sheffield Universities are developing a Nuclear Advanced Manufacturing Research Centre. This aims to fast forward academic innovation into civil nuclear manufacturing.

In conclusion, the UK is in a good position to capitalise on its historic excellence and pioneering experience in nuclear science and engineering. We have a diverse set of legacy activities that require our companies to innovate and they are integral to the supply chain delivering new highly efficient reactors. Our regulator is internationally respected and we have a rapidly expanding university sector. Nuclear energy has been part of the UK science and engineering identity for nearly 60 years. It is entering an exciting new phase that offers numerous national and international opportunities for industry and academia alike.

NUCLEAR EDUCATION IN THE UK: IS IT RESPONDING TO THE HUMAN RESOURCE REQUIREMENTS?

Dr John Roberts
Dalton Nuclear Institute, The University of Manchester

As of July 1st 2011, following the closure of one of the two reactors at Oldbury, the UK has 18 nuclear reactors at 10 sites producing electricity to the grid. To support the operations at these sites the UK also has fuel enrichment and fabrication facilities along with reprocessing capability at the Sellafield site. Decommissioning is also taking place at 10 sites. Taking account of all these activities the nuclear industry in the UK currently employs around 44,000 people[1].

The government target[2] for maintaining nuclear energy on the grid is to have at least 25 GW of new supply by 2025. This entails at least one reactor being built on land near each of eight existing reactor sites:

Hinkley Point, Sizewell, Heysham, Hartlepool and Bradwell - owned by EDF Energy

Yr Wylfa and Oldbury – owned by Horizon Nuclear Power a consortium of EoN and RWE

Sellafield – owned by NuGeneration, a consortium of Iberdrola, GDF Suez and Scottish and Southern Electricity.

The Committee on Radioactive Waste Management recommendations for the final disposal of the UK's civilian higher levels of radioactive waste were accepted by the Government in 2006. This will entail the construction of an underground geological disposal facility (GDF) with site investigations due to commence in five years, if a volunteer host community can be identified, followed in twenty years by the construction of the GDF.

Together the three areas of decommissioning, new build and geological disposal will require a new generation of nuclear engineers and scientists. The UK nuclear workforce also has an older average age than the UK workforce as well as a greater percentage retiring over the next 15 years[1]. To meet these demands the UK universities with nuclear expertise have developed new undergraduate, postgraduate taught and postgraduate research programmes. Ten years ago the situation was not as healthy, a report commissioned by the Health and Safety Executive[3] stated "if nuclear education were a patient in a hospital it would be in intensive care". It suggested that "immediate action is needed; otherwise nuclear education will slowly disappear" and recommended that "the focus of nuclear education should be on postgraduate courses".

Some nuclear postgraduate courses, such as those at the Universities of Birmingham, Surrey and Liverpool had survived the downturn in student numbers which followed the "dash for gas" in the 1990s but the majority of nuclear expertise had declined to just individuals at the Universities rather than major research groups[3]. To deliver nuclear postgraduate education in the 21st century a consortium approach was required, and so the Nuclear Technology Education Consortium (NTEC) was formed in 2004. NTEC originally consisted of 11 Higher Education Institutes and organisations:

- University of Manchester
- University of Sheffield
- Imperial College London
- University of Liverpool
- University of Leeds
- University of Birmingham
- City University
- Lancaster University
- University of Highlands and Islands Millennium Institute
- Westlakes Research Institute
- Defence Academy, College of Management and Technology

with the University of Central Lancashire joining in 2009. The consortium brought together the nuclear experts to provide 21 different possible Master level modules in one programme. Another significant advantage of the NTEC programme was due to it being a totally new programme it could be designed to accommodate full-time or part-time students. Through discussions with industry partners, who still meet twice yearly as an External Advisory Board, NTEC is delivered in a "short-fat" format rather than day release as this was the preferred model for industry. The modules are all delivered in Monday-Friday blocks rather than day-release. This allows students to have the level of interaction with the programme that is appropriate for their needs, from Continual Professional Development (CPD), postgraduate certificate or diploma or a full MSc in Nuclear Science and Technology, see figure 1. The full MSc can be taken as a full-time programme over one year or part-time over three years.

Bringing together so many universities allows NTEC to provide a unique breadth to the course content with 22 modules now being offered with successful completion of 8 modules being required for a full MSc. This allows the students to tailor the content specifically to their personal needs, whether it is more focused on nuclear technology for the new build programme,

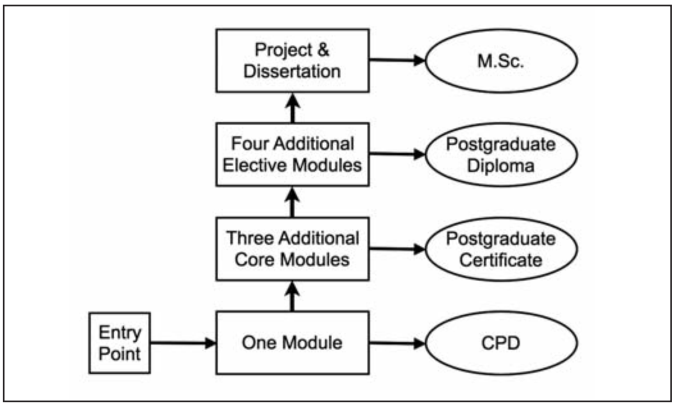


Figure 1. NTEC Programme Structure

or on decommissioning, rather than a one fit for all approach. Consistent with the integration of the programme with industry the MSc students are encouraged to undertake their Masters project within industry, which has led to an excellent track record of the project students being employed by the sponsoring company on completion of their project. In 2011 NTEC is now a mature programme with student numbers increasing year on year. A key feature of the programme, which has enabled the student numbers to grow, is that the most popular modules have been converted for Distance Learning. This has allowed students from outside the UK to access the course, providing they have the required security clearance, as well as increasing the number of part-time students that are already part of the nuclear industry, or want to re-train to become part of the nuclear industry.

The success of NTEC has shown the renewed student interest in university nuclear courses and this has enabled universities to develop more traditional undergraduate and postgraduate courses. Lancaster University was the first in 2006 with an undergraduate MEng programme in Nuclear Engineering. Imperial College London and the Universities of Manchester and Leeds have developed "and/with Nuclear Engineering" undergraduate courses which allow Mechanical and Chemical Engineers and Material Scientists to have 25% nuclear content in their courses, which can ideally prepare them to be Mechanical or Chemical Engineers or Material Scientists in the nuclear industry. The Physics departments at the Universities of Liverpool, the West of Scotland and Nottingham Trent have developed Physics with Nuclear Technology undergraduate degrees. Full-time one year nuclear masters have been developed by Imperial College London and the University of Cambridge, a testament to the demand now being seen for nuclear courses.

Despite the Engineering and Physical Sciences Research Council (EPSRC) decision to stop the funding of any Masters programmes they are increasing their support for nuclear research and in particular their support for PhD students. Two PhD programmes led by The University of Manchester are training over 20 students every year. The Fission Doctoral Training Centre (DTC) has a traditional approach to the research content but provides additional support to the students by adopting a cohort approach to recruitment and training. A cohort of at least ten students is recruited annually to start at the same time. In the first year they have comprehensive postgraduate training and the opportunity to experience different research topics before deciding on their PhD for the final three years. This allows the PhD to establish the same level of networking and support normally only available for taught undergraduate or postgraduate courses.

The Nuclear Industrial Doctoral Centre (led by the University in Manchester in partnership with Imperial College London) has a radically different approach to PhD level training with the "research engineers" carrying out their research primarily in industry with a project of direct relevance to the sponsoring company. This, again, is an excellent example of how nuclear universities and the nuclear industry are working together, not in isolation, in response to the human resource requirements as new nuclear developments take place in the UK.

To maintain the student numbers it is vital that schools, schoolchildren and teachers are engaged. Some examples of this at The University of Manchester include:

- The EPSRC is funding the development of supporting material for the nuclear content of the school curriculum. This is enabling university material to be converted for schools to use in the classroom.
- The Smallpeice Trust, Urenco and the National Nuclear Laboratory are supporting an annual residential course at The University of Manchester for 50 14-16 year olds who are interested in a career in the nuclear industry.
- Supported by the Nuclear Institute the Universities of Manchester, Liverpool and York provide an annual training day on nuclear technologies for schoolteachers.

New web-based developments to support the nuclear universities programme include Nuclear Liaison (www.nuclearliaison.com) and NLTV (www.nltv.co.uk). Nuclear Liaison has been set up to list all the nuclear courses at UK universities along with a Directory of all the nuclear experts at UK universities. This allows prospective students, or universities and industry that are interested in collaboration, to find out all the information on UK nuclear universities in one place. It also provides industry contacts for students that are looking for summer placements or graduate training schemes within the nuclear industry. NLTV has taken this one step further with the introduction of recorded lectures that can be viewed online. This allows a greater dissemination of the information as well as providing a record of the event for knowledge management purposes.

The nuclear universities and nuclear education has come a long way in the last ten years and is now a thriving part of university education in 2011. A key aspect of the continuation of this success is that many of the newly qualified students have already registered as STEM Ambassadors. They are visiting schools to encourage the next generation of school children that the nuclear industry in the UK will provide them with a challenging, stimulating and long lasting career.

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