A Joint Report by the Nuclear Energy Agency and the International Atomic Energy Agency

Measuring Employment Generated by the Nuclear Power Sector

60th anniversary NEA NUCLEAR ENERGY AGENCY

IAEA International Atomic Energy Agency

A Joint Report by the OECD Nuclear Energy Agency
and the International Atomic Energy Agency

Measuring Employment Generated by the Nuclear Power Sector

NEA No. 7204

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

The OECD is a unique forum where the governments of 36 democracies work together to address the economic, social and environmental challenges of globalisation. The OECD is also at the forefront of efforts to understand and to help governments respond to new developments and concerns, such as corporate governance, the information economy and the challenges of an ageing population. The Organisation provides a setting where governments can compare policy experiences, seek answers to common problems, identify good practice and work to co-ordinate domestic and international policies.

The OECD member countries are: Australia, Austria, Belgium, Canada, Chile, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Luxembourg, Mexico, the Netherlands, New Zealand, Norway, Poland, Portugal, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission takes part in the work of the OECD.

OECD Publishing disseminates widely the results of the Organisation's statistics gathering and research on economic, social and environmental issues, as well as the conventions, guidelines and standards agreed by its members.

NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1 February 1958. Current NEA membership consists of 33 countries: Argentina, Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Korea, Luxembourg, Mexico, the Netherlands, Norway, Poland, Portugal, Romania, Russia, the Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The European Commission and the International Atomic Energy Agency also take part in the work of the Agency.

The mission of the NEA is:

– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes;
– to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD analyses in areas such as energy and the sustainable development of low-carbon economies.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

Cover photos: Unit 1 of the Novovoronezh nuclear power plant II (Hullernuc); Leningrad nuclear power plant (RIA Novosti); Dismantling of the turbine at the Jose Cabrera nuclear power plant (Enresa).

Foreword

The contributions of the nuclear power sector in relation to employment have been studied for many years by both the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA). The present publication has grown out of the activities undertaken by these agencies. The NEA Division of Nuclear Technology Development and Economics' (NTE) 2013-2014 Programme of Work, for example, included work on the social and economic impacts of nuclear power. The NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC) agreed that the NTE would focus on the employment implications of nuclear new build, which had not been examined in recent years although a related report, *Nuclear Education and Training: From Concern to Capability*, was published in 2012 (NEA, 2012a).

In addition, from 2004 to 2009, the IAEA, in co-operation with Korean Hydro and Nuclear Power (KHNP) and a team of experts from five Korean institutes, including the Korean Atomic Energy Research Institute (KAERI), organised a series of studies to quantify the benefits of nuclear technology for the Korean economy. This collaboration led to the IAEA publication, *Nuclear Technology and Economic Development in the Republic of Korea* (IAEA, 2009a). The IAEA continued work on social and economic impacts in two consultancy meetings entitled "Roadmap for Development of PESS Tools* and Methods for Economic Impact Assessment of an NPP Programme" (17-19 December 2012) and "Macroeconomic Impacts of a Nuclear Power Programme in Southeast Asia" (2-6 December 2013) respectively. Following an increasing number of requests from member states in this regard, the IAEA launched a co-ordinated research project "Assessing the National and Regional Economic and Social Effects of Nuclear Programmes" (2014-2017). This latter activity is intended to provide useful guidance to participating member countries on how to develop and to apply quantitative tools for assessing economy-wide impacts of nuclear programmes. The IAEA Milestones Approach – which was developed to assist countries that are considering or planning their first nuclear power plant – suggests that macroeconomic analyses should be conducted in addition to energy demand and energy alternatives studies. An evaluation of the impacts of nuclear power on the national economy, in particular on gross domestic product and employment, is explicitly recommended in *Milestones in the Development of a National Infrastructure for Nuclear Power* (IAEA, 2015).

To complete this task, economists from the NEA, the IAEA, the Nuclear Energy Institute (NEI), KAERI, the Energy Policy Institute (Boise State University) and the Institute of Energy Economics and the Rational Use of Energy (IER) prepared this report to aid member countries in determining the employment impacts of the nuclear power sector in their respective countries.

* PESS is the Planning and Economics Studies Section of the Department of Nuclear Energy at the IAEA.

Acknowledgements

The Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA) gratefully acknowledge the co-operation of the following organisations and individuals for contributing to this report.

Victoria Alexeeva[*+]	IAEA, Vienna, Austria
Robert Beestermöller[*+]	University of Stuttgart, Germany
Geoffrey Black[*+]	Boise State University, Idaho, United States
David Bradish[*+]	Nuclear Energy Institute (NEI), United States
Ron Cameron[+]	NEA, Boulogne-Billancourt, France (to July 2014)
Irmak Colakoglu	Ministry of Energy and Natural Resources, Turkey
Jannet Emeric[+]	AREVA, France
Man-ki Lee[*]	Korean Atomic Energy Research Institute, Korea
Fedor Karmanov	Rosatom Central Institute, Russia
Jan Horst Keppler[+]	NEA, Boulogne-Billancourt, France
Jeanne Lubek[+]	PricewaterhouseCoopers Strategy Group (to December 2013) NERA Economic Consulting, Paris, France (from January 2014)
Brian Molloy[+]	IAEA, Vienna, Austria
Steven Peterson[+]	University of Idaho, United States
Geoffrey Rothwell[*+]	NEA, Boulogne-Billancourt, France
Maria Elena Urso	NEA, Boulogne-Billancourt, France (to November 2014)

[*] contributors; [+] presenters.

Table of contents

List of annexes

List of figures

List of tables

List of abbreviations and acronyms

AP1000	Westinghouse Advanced Passive PWR of approximately 1 100 MWe (net)
CES	Constant elasticity of substitution
CGE	Computable general equilibrium (models)
COA	Code of Accounts
CRS	Constant returns to scale
EMWG	Economic Modeling Working Group (GIF)
FTE	Full-time equivalent (annual)
GIF	Generation IV International Forum
GM	General manager
HVAC	Heating, ventilation and air conditioning
IAEA	International Atomic Energy Agency
I&C	Instrumentation and controls
IMPLAN	Impact Analysis for Planning (model)
I/O	Input/output
ISIC	International Standard Industrial Classification
M+E	Mechanical and electrical
MWe	Megawatts, electric
MWh	Megawatt-hours
MTHM	Metric tonnes of heavy metal
NAICS	North American Industrial Classification System
NEA	Nuclear Energy Agency
NEI	Nuclear Energy Institute
NEWAGE	National European Worldwide Applied General Equilibrium (model)
NPP	Nuclear power plant
NSSS	Nuclear steam supply system

OECD	Organisation for Economic Co-operation and Development
PACE	Policy Analysis based on Computable Equilibrium (model)
PESS	IAEA Planning and Economic Studies Section
PWR	Pressurised water reactor
QA	Quality assurance
REMI	Regional Economic Models, Inc.
SAM	Social accounting matrix
SNF	Spent (or used) nuclear fuel
T&D	Transmission and distribution
TVA	Tennessee Valley Authority
TMI	Three Mile Island
US NRC	US Nuclear Regulatory Commission

Executive summary

The nuclear energy sector employs a considerable workforce around the world, and with nuclear power projected to grow in countries with increasing electricity demand, corresponding jobs in the nuclear power sector will also grow (NEA/IAEA, 2016). The Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA) have been collaborating on activities in relation to employment implications in the nuclear power sector for many years, and the present publication has grown out of such activities.

The NEA Committee for Technical and Economic Studies on Nuclear Energy Development and the Fuel Cycle (NDC), for example, agreed that the NEA Division of Nuclear Technology Development and Economics (NTE) should focus on employment implications of nuclear new build, a subject that had not been examined extensively in recent years. From 2004 to 2009, the IAEA, in co-operation with the Korean Hydro and Nuclear Power (KHNP) and with a team of experts from five Korean institutes, including the Korean Atomic Energy Research Institute (KAERI), organised a series of studies to quantify the benefits of nuclear technology for the Korean economy. This collaboration led to the publication of *Nuclear Technology and Economic Development in the Republic of Korea* (IAEA, 2009a). The IAEA continued its work on the social and economic impacts of nuclear power, and following an increasing number of requests from member states, it launched a co-ordinated research project "Assessing the National and Regional Economic and Social Effects of Nuclear Programmes" (2014-2017). The latter activity is intended to provide useful guidance to participating member states on how to develop and apply quantitative tools for assessing the economy-wide impacts of nuclear programmes. The IAEA Milestones Approach – which was developed to assist countries that are considering or planning their first nuclear power plant – suggests conducting a macroeconomic analysis in addition to energy demand and energy alternatives studies. An evaluation of the impacts of nuclear power on a national economy, in particular on gross domestic product and employment, is explicitly recommended in *Milestones in the Development of a National Infrastructure for Nuclear Power* (IAEA, 2015).

This report generalises and simplifies the modelling efforts of the OECD member countries (where macroeconomic models are generally available) to make them more applicable to other economies, in particular, those of IAEA member states (where macroeconomic models might be less developed). It reviews and compares macroeconomic models that can be used to quantify employment effects generated by the nuclear sector (Chapter 1). The discussion is largely based on publicly available quantitative country studies. Though this report aims to provide an international view, the existing literature exhibits bias in terms of country coverage (for example, many of the studies are from the United States). After a detailed literature review, the report focuses on how to collect, compile and prepare data needed for a macroeconomic analysis of employment generated by the nuclear power sector (Chapter 2). Finally, it reviews and discusses case studies that have been based on the application of the methodology (Chapter 3) recommended in Chapter 4.

While it is hoped that this methodology can be used in modelling employment in other forms of electricity generation, it does nonetheless focus on modelling employment in the nuclear power sector where *direct* employment is defined as employment at nuclear power plants under construction, or in the operation, decommissioning and waste management phases; *indirect* employment is employment supplying products and services to these activities at nuclear power plants; and *induced* employment in an economy associated with *direct* and *indirect* plant and labour expenditures. *Indirect* and *induced* employment must be calculated with a macroeconomic model of a particular region or country. For policy analysis, total *gross* employment can then be compared to the total *gross* employment of the "next best" alternative for generating electricity. The difference yields the total *net* employment of investing in nuclear power capacity.

Given the deterministic nature of the parameters in most macroeconomic models, error bands surrounding employment estimates do exist. Given that most *direct* employment estimates are done with surveys, the error bands around *direct* employment estimates are quite tight, for example, about ±10%. Because *indirect* employment is based on the *direct* employment estimation, the error bands are necessarily larger, for example about ±20%. Because *induced* employment is based on *direct* and *indirect* employment estimates (or the associated parameters used to calculate these values), the error bands related to *induced* employment are necessarily larger, for example about ±30%. Finally, because most investments in electricity generation could be used for competing technologies, *net* employment calculations (the difference between *total direct* plus *indirect* plus *induced* employment for two electricity generating technologies) could have error bands as high as ±50%. Decision makers should thus keep these error bands in mind when evaluating employment estimates using macroeconomic models.

Several macroeconomic models are available. However, the most universally available one has been the input/output (I/O) model based on I/O tables, as described by the OECD Statistics Directorate. I/O models capture input (demand) and output (supply) interrelationships between economic sectors in a geographic region. They also capture the consumption of goods and services for final demand by these sectors and by the household sector. The basic geographic region is a country, but model results can be developed at regional levels. These results are particularly useful in examining the total effects of an economic activity or of a change in the level of that activity. Typical applications of these models, discussed in Chapter 3 for the United States, Korea and France, include facility openings and closings and other public infrastructure investments.

Because of these linkages, the influence of an economic activity in any sector or geographic area on other sectors and areas can be modelled. These influences can extend well beyond the sector and area in which the original economic activity is located. They include not only the *direct*, or initial, effects of the economic activity, but also the secondary, or "ripple" effects that flow from this activity. These ripple effects can be categorised as first-order impacts (those effects on the immediate supply chain), second-order impacts (those effects on the supply chains to the primary supply chain), etc. The sum of the ripple effects beyond the first-order effects are referred to as "N^{th}-order" impacts. Direct effects are analogous to the initial "impact" made by the economic activity, and ripple effects are analogous to the subsequent "waves" of economic activity (new employment, income, production and spending). A full accounting of the impact should include all ripple effects. The sum of the *direct* and ripple (*indirect* and *induced*) effects is called the total effect. Multipliers can be developed for any of the model outputs, such as earned income, employment, industry output and total income.

Multipliers can also be developed for any industrial sector or geographic area included in the model. Multipliers for a locality are smaller than for a larger area, such as the region in which the locality is located, because some spending associated with an economic activity flows from the smaller area into the larger area. At the local level, multipliers are larger if the local area tends to produce the types of goods and services that the nuclear power industry requires. Secondary effects include *indirect* and *induced* effects, modelled separately within I/O models. *Indirect* effects are those influencing the supply chain that feeds into the sector in which the economic activity is located. Induced effects arise from purchases generated by revenues outside the supply chains, for example in the housing sector.

While the purpose of this report is to help member country experts determine the levels of inputs (particularly labour) flowing into the nuclear power sector, these inputs depend on the state of development of the nuclear power sector in a particular economy. This report recommends as a compromise between completeness and simplicity that the life of a nuclear power plant be divided into four periods: i) construction, ii) operation, iii) decommissioning, and iv) waste and spent nuclear fuel management. Direct employment follows the logic of the levelised cost methodology. Because an I/O model assumes static relationships between inputs and outputs, these relationships should be updated at least every five years. *I/O models should not be used for projections beyond the short term*.

During construction, although flows to other industries in an economy change each month and different types of labour with different levels of training change throughout the construction period, expenditures are discounted to the end of construction (assumed to be simultaneous with the start of operation and the output flow of electricity). These expenditures are spread uniformly over the construction period, considered for simplicity reasons to involve five years of site preparation and advanced procurement, and five years from the pouring of base-mat concrete to commercial operation, meaning that expenditures, (for example on labour, equal to hours times salaries or wages plus benefits) are discounted and divided by ten years.

Further, while there are periods of refuelling and periods of refurbishment during operation, expenditures on labour, maintenance supplies, equipment replacement, insurance, taxes and capital are discounted to the start of operation and spread uniformly over the operating life of the nuclear power plant, assumed to be 50 years (again for simplicity reasons, even though this might involve the replacement of major pieces of equipment for the plant to operate for a duration of 50 years).

In addition, after retirement of the nuclear power plant, there is a period of five years of decommissioning planning and preparation, and five years of active decontamination, dismantling and site restoration. There could also be 40 years of active waste management starting with the retirement of the plant. At the end of this period, all remaining long-lived radioactive waste is placed in geological repositories. However, because repositories are so geologically site specific, they are not modelled here.

The first step in the modelling process is to map the expenditure data from a nuclear power plant to the applicable codes used in the selected I/O model. This involves converting expenditures, labour, profits and taxes into the applicable codes. For regional analysis, the total spending in each category and the percentage of that spending in each region are required. Different I/O tables have various definitions of industrial sectors. The OECD tables use the International Standard Industrial Classification (ISIC) codes, available from the United Nations (see Annex A). An alternative to the ISIC is the North American Industrial Classification System, NAICS, following the implementation of the North American Free Trade Agreement (NAFTA; see Annex B). In I/O tables based on ISIC or NAICS, nuclear power generation is combined with all other forms of electricity generation, transmission and distribution. This implies that the relevant I/O coefficients describe the monetary amounts of all other industries that are expended in the entire electricity sector, and the coefficient describes how much output of every other industry is consumed as intermediate inputs in the production and consumption of electricity.

To analyse the flows between the nuclear power industry and all other industries, this report recommends: i) that the nuclear power sector be separated as a distinct industry; ii) that the nuclear power sector consist only of constructing, operating and decommissioning nuclear power plants and the management of all waste forms, *this does not include supply chain industries*; iii) that the homogeneous output (electricity) of the nuclear power sector (other outputs, such as heat or medical radioisotopes are not considered here) be sold as intermediate inputs either to the electricity or utility sector, which transmits and distributes electricity to the remaining sectors or to all other sectors in proportion to the amount of electricity consumed annually by each sector.

Total construction cost is equal to total overnight construction cost plus contingency and financing costs. To measure these consistently, a set of standard definitions of construction accounts, structures, equipment and personnel is presented in a Code of Accounts (COA) system. This is an industry-standard cost-accounting framework for allocating the direct and indirect costs of nuclear power plants, as well as for comparisons of costs of these plants with fossil fuel plants. (In most COAs "indirect costs" refer to costs that cannot be attributed to a specific direct cost category; these are not the same as "indirect" costs in I/O models.) The cost estimates provided in the COA system detail expenditures on materials and services for virtually all aspects of nuclear power plant construction. As such, they can enter input-output models by assigning the appropriate industry codes in the I/O model used. Annex C discusses the Generation IV International Forum (GIF) Economic Modelling Working Group's 2007 COA from the *Cost Estimating Guidelines for Generation IV Nuclear Energy Systems*. Annex D provides an example of the GIF-COA estimates for a four-loop pressurised water reactor (similar to TVA's Watts Bar units) allocated to NAICS industries. The analysis finds approximately the same number of full-time equivalent jobs for this power reactor as reported for the Westinghouse AP1000.

The results in Chapter 2 demonstrate that *direct* employment during site preparation and construction of a single 1 000 MWe (net) advanced light water unit use about 12 000 labour-years during construction. For 50 years of operation, annually there are approximately 600 administrative, operation and maintenance, and permanently contracted staff, or about 30 000 *direct* labour-years during operation. For 10 years during decommissioning, there are approximately 500 employees annually, or about 5 000 *direct* labour-years. Finally, for 40 years, there are about 80 employees managing nuclear waste, or about 3 000 *direct* labour-years; hence, about 50 000 *direct* labour-years. This does not include labour expenditures in the supply chain. Direct expenditures on equipment from the supply chain generate approximately the same number of *indirect* employment, or about 50 000 *indirect* labour-years. *Direct* and *indirect* expenditures generate approximately the same number of *induced* employment, or about 100 000 labour-years. *Total* lifetime employment is about 200 000 labour-years, or about 400 million labour-hours (assuming 2 000 hours per employee per year).

Modelling total numbers of *direct*, *indirect* and *induced* employment for the United States is discussed in Chapter 2, and in Chapter 3 for Korea and France. For example, in Korea, the number of full-time equivalent jobs *directly* created by the nuclear industry was estimated to be around 29 400 persons in 2009, which is divided between i) 9 000 for the construction of four nuclear power units and ii) 20 400 for the operation of 20 units. *Indirect* employment (created through linkages) is about 36 700, equal to 9 400 attributable to the construction of nuclear power units and 27 300 attributable to the operation of nuclear power plants. The number of jobs created through the *induced* effects was estimated to be around 27 400, including 9 000 attributable to the nuclear power plant construction supply chain and 18 400 attributable to nuclear power plant operations. The (*indirect*/*direct*) multiplier was 1.25, yielding 36 700 *indirect* employees. The ([*direct* + *indirect*]/*induced*) multiplier was 0.41, yielding 27 400 *indirect* employees. Taking into account these values, the total employment associated with the nuclear industry as a whole was about 93 500 persons in 2009.

In comparison, in France *direct* employment has been estimated at 125 000 employees. In 2009, there were 58 units in operation and 4 under construction (1 in France, 1 in Finland and 2 in China). *Indirect* and *induced* employment was estimated by using multipliers calculated (in February 2011) by the National Institute of Statistics and Economic Studies (INSEE) using an I/O model. The (*indirect*/*direct*) multiplier was 0.912, yielding 114 000 *indirect* employees. The [(*direct*)/*induced*] multiplier was 1.368, yielding 171 000 *induced* employees. The total number of employees generated by the nuclear sector was estimated to be 410 000 persons.

Recommendations for measuring employment generated by the nuclear power sector in specific countries are as follows:

- When attempting to estimate the employment impacts of existing or anticipated nuclear power plants (in the construction, operation, decommissioning and waste management sectors), identify the most transparent input/output model of the country and work to adapt the model by creating a separate nuclear power sector, as described in this report. One should be aware of the potential limitations of tools and methods used in modelling. Consider to what extent, for example, the impacts of stable electricity prices are included and evaluated. The results should be interpreted in the context of model features and assumptions. Whenever possible, estimate nuclear industry impacts at both national and regional (local) levels.

- *Direct* employment in the operation of commercial nuclear power plants consists of those employees working at nuclear power plants, including permanent subcontractors, such as security personnel and full-time equivalent outage personnel. *Indirect* employment includes full-time equivalent personnel in the nuclear supply chain (*first-order indirect* employees) and industries supplying products and services to this supply chain (*N^{th}-order indirect* employees). *Induced* employment is composed of all employment in the relevant economy generated by *direct* and *indirect* expenditures.

- While *direct* employees can be determined through surveys of existing nuclear power plants, estimates of (total) *indirect* and *induced* employees require the specification of a macroeconomic model. Further, for policy analysis, total *gross* employment should be compared to the total *gross* employment of the "next best" alternative for generating electricity. The difference yields the total net employment of investing in nuclear power. The "next best" alternative varies and will usually be determined through the application of a multi-attribute analysis, taking into account economics, energy security issues, and employment and environmental impacts.

- When attempting to estimate the employment generated by the nuclear power sector, one should pay particular attention to the consistency of the data used for the modelling exercise. Generally, modelling requires the use of data from different sources. Potential sources of inconsistency between I/O tables and nuclear programme data should be eliminated, if possible; for example, by using only annual data. Depending on data availability, uniform or actual distributions of costs can be used. A uniform distribution provides an estimate of the average impact over time; an actual distribution allows an assessment of differences in economic impacts over time. The model should be tested by varying key parameters to determine the sensitivity of the results with respect to changes in assumed values. At the end of the exercise, modelling participants should suggest additional techniques and data for future modelling efforts.

- Consistency should be verified across assumptions, for example, the consistency between the financing structure and the level of local content. External financing from the vendor or the vendor's government will most likely be restricted to financing imports from the vendor; the local content will more likely be financed with funds from local sources. It is also probable that the greater the anticipated local content, the lower the external financing available.

Chapter 1. Introduction to macroeconomic assessments of the nuclear power sector

The investments in a country's energy system depend on macroeconomic aggregates, such as real economic activity and costs of capital. Further, in small economies, in terms of gross domestic product, nuclear investment and fuel costs can be large when compared to macroeconomic aggregates. At the same time, energy investments tend to trickle down into other sectors in the economy such as construction, manufacturing and services, thus generating economic growth and creating new employment. Labour market effects are known to be at the core of the impetus for local and regional economic growth. These effects work primarily through the inter-sectoral linkages associated with construction, operation and maintenance of power plants, and typically differ among technologies. In this respect, it might be worth considering to what extent potential impacts from energy policy strategies and investments on a country's overall goals for macroeconomic development, including employment creation, might support or discourage the adoption of a particular technology.

The Nuclear Energy Agency (NEA) has been assisting its member countries, and the International Atomic Energy Agency (IAEA) has been assisting its member states in evaluating alternative strategies for the development of the electricity sector and the role that nuclear power might potentially play in meeting future electricity demand. Quantitative methods can assist policy makers in analysing those impacts and in making informed decisions in the choice of the most appropriate electricity technologies. For this purpose, the IAEA and NEA have developed a set of models and guidelines to provide systematic frameworks for analysing various issues in the context of the electricity capacity expansion decision-making process, for example IAEA (2009b) and NEA (2012b).

The existing IAEA modelling tools belong to the class of partial equilibrium models that are characterised by a detailed representation of the energy (electricity) sector. Partial equilibrium modelling is a widely used tool to provide an assessment of alternative paths for the development of the electricity sector to meet the future demand in a given country. As a common practice, however, interrelationships with other sectors in the economy are disregarded in partial equilibrium models. Potentially important benefits or detriments are not captured in models when comparing costs only. To fill this gap, the current document provides an overview of methods for assessing the employment creation potential of a nuclear power plant (NPP) programme in the national economy beyond the electricity sector.

The current report reviews and compares macroeconomic models that can be used to quantify employment effects generated by the nuclear sector (Chapter 1). This discussion is largely based on publicly available quantitative country studies. Though the report aims to provide an international view, the existing literature exhibits bias in terms of country-coverage (for example, many of the studies are from the United States). After a detailed literature review, the report focuses on how to collect, compile and prepare data needed for a macroeconomic analysis of employment generated by the nuclear power sector (Chapter 2). Finally, the report reviews and discusses case studies that have been based on the application of the methodology (Chapter 3) recommended in Chapter 4.

1.1. Macroeconomic modelling

The model archetypes analysed in this section encompass traditional input/output (I/O) models, computable general equilibrium (CGE) models, and integrated econometric I/O – see NEI (2014b) that used the Regional Economic Models, Inc. Policy Insight Plus, and Section 3.1. The main virtue of these quantitative tools is to simulate consistently the linkages within an economy and the ability to measure the impacts of policy options and investment decisions.

The outcome of the literature review from publicly available sources is summarised in Tables 1.1 and 1.2. (For a literature review of employment generation in renewables and energy efficiency, see UKERC, 2014). This section focuses explicitly on the application of different models related to the assessment of economic activities and sub-activities in the nuclear sector such as NPP construction, operation, decommissioning and waste management. In this narrow context, three model types have been identified: I/O models, CGE models and integrated econometric I/O models. However, the CGE models mainly focus on nuclear phase-out, whereas I/O models deal with all economic activities and sub-activities except the nuclear phase-out. Integrated econometric I/O models appear to be less common, an outcome that might be partly explained by the large amount of data required for such a model.

The great popularity of I/O models is reflected in many papers dealing with an economic impact assessment in the nuclear sector. This section focuses explicitly on application of the I/O models related to the assessment of economic activities and sub-activities in the nuclear sector such as uranium mining and milling, construction, operation and others. The literature review summarised in Table 1.1 gives a non-exhaustive list of examples for I/O model application in this context rather than defining its limits. Major observations from the literature review can be summarised as such:

- Most of the reviewed studies provide an *ex-post* analysis of introducing NPPs (IAEA, 2009a; NEI, 2003, 2004a, 2014a). Only a small fraction deals with an *ex-ante* analysis (future introduction of economic activities in a nuclear sector). For example, Anindita (2007) and WorleyParsons (2011) undertake an *ex-ante* assessment of an NPP for Indonesia and Jordan, respectively.
- In terms of coverage of economic activities within the nuclear power sector, the common practice is to calculate sectorial and aggregate output, value added and employment effects from plant construction, operation, or from both phases. Other related economic activities are typically not included. Timilsina et al. (2008) is an exception. It focuses on four sub-activities: i) uranium mining and milling, ii) construction, iii) operation and maintenance, and iv) exports of uranium. ERA (2014) considers uranium mining only.
- In most studies, households are assumed endogenous components of the economy, with an I/O matrix being extended to include a household sector. Such model extensions allow accounting not only for *direct* and *indirect* changes in industry production levels as a result of an initial stimulus to final demand, but also for the related income changes (IAEA, 2009a; Timilsina et al., 2008; Solan et al., 2010).
- In some cases, a sequence of I/O tables is employed to study both local and economy-wide impacts, with local implications being approximated by additional calculations. A few studies build upon the regionally disaggregated data that allows for the analysis of both local and economy-wide impacts within a consistent framework (NEI, 2004b, 2006a, 2006b, 2013).

Table 1.1. Studies with an explicit assessment of a nuclear sector based on an I/O framework (non-exhaustive)

Study (year)	Economic activities and related sub-activities						Model*	Region (sorted by)
	Uranium mining	Construction	Recycling and enrichment plants	Operation and maintenance	Exports of nuclear technology	Exports of uranium		
Anindita (2007)		x					Not identified	Indonesia
Applied Economics (2010)		x		x			IMPLAN	United States
ERA (2014)	x						Not identified	Australia
IAEA (2009a)		x		x			Not identified	Korea
Lesser (2011)				x			IMPLAN	United States
Mayeda and Riener (2013)				x			IMPLAN	United States
NEI (2003)				x			IMPLAN	United States
NEI (2004a)				x			IMPLAN	United States
NEI (2004b)				x			IMPLAN	United States
NEI (2006a)				x			IMPLAN	United States
NEI (2006b)				x			IMPLAN	United States
NEI (2014a)				x			IMPLAN	United States
Oxford Economics (2008)		x	x	x			Not identified	United States
Oxford Economics (2013)		x					Not identified	United Kingdom
PWC (2011)**		x		x			Not identified	France
PWC (2012)**				x			Not identified	Belgium
Solan et al. (2010)		x		x			IMPLAN	United States
Timilsina et al. (2008)	x	x		x	x	x	Not identified	Canada
WorleyParsons (2011)		x		x			Not identified	Jordan

* IMPLAN = Impact Analysis for Planning.

** Both studies consider additional sectors not covered here (e.g. medical, industrial applications).

Table 1.2. CGE studies with an explicit assessment of the energy sector with nuclear power (non-exhaustive)

Study (year)	Topic of a study	Model	Regions
Aydın (2011)	Nuclear and hydro	Not identified	Turkey
Biesl, Ellerdorfer and Fahl (2006)	Nuclear breakthrough (decrease specific investment costs) and nuclear phase-out	NEWAGE-W	Global
Böhringer, Wickart and Mueller (2003)	Nuclear phase-out	Not Identified	Switzerland
Bretschger, Ramer and Zhang (2012)	Nuclear phase-out	CITE	Switzerland
Galinis and van Leeuwen (2000)	Nuclear investments and phase-out	Not Identified	Lithuania
Itakura (2011)	Nuclear phase-out	GTAP	Japan
Kobayashi, Ochiai and Tachi (2011)	Nuclear phase-out	JCER	Japan
Konovalchuk (2006)	Chernobyl accident	Not identified	Ukraine
Magné, Chateau and Dellink (2014)	Nuclear phase-out	ENVLinkages	OECD, China and Russia
Mukaida, Shiotani, Ono, and Namba (2013)	Fast reactor and related fuel cycle system	STAP-E, DN21	Japan
Okuno, Fujii and Komiyama (2012)	Nuclear phase-out	GTAP	Japan
Yamazaki and Takeda (2013)	Nuclear phase-out	Not identified	Japan

Models: ENVLinkages – an OECD dynamic CGE model with environmental linkages; GTAP – Global Trade Analysis Project; GTAP-E – an energy-environmental version of the GTAP; DNE21 – Dynamic New Earth 21; JCER – Japan Center for Economic Research; LEAN-TCM – a CGE model of Germany and much of the rest of the EU, from German; NEWAGE-W – National European Worldwide Applied General Equilibrium with a dynamic multi-regional, multi-sectoral world; PACE – Policy Analysis based on Computable Equilibrium, CITE – Computable Induced Technical Change and Energy.

1.2. "Input/output" and "computable general equilibrium" models

From 2004 to 2009, the IAEA co-operated with a Korean team of experts from five Korean institutes: the Korean Atomic Energy Research Institute, the Korea Institute of Nuclear Safety, Kyungbuk National University, Korean Energy Economics Institute and Daegu-Gyeongbuk Development Institute. This collaboration led to the publication of *Nuclear Technology and Economic Development in the Republic of Korea* (IAEA, 2009a).

This document generalises and simplifies this modelling effort to make it more applicable to other economies, in particular, those of the OECD member countries (where macroeconomic models are generally available) and IAEA member states (where macroeconomic models might be less developed). While it is hoped that this methodology can be used in modelling employment in other forms of electricity generation, it nonetheless focuses on modelling the nuclear power sector where *direct* employment is defined as employment at NPPs in construction, operation, decommissioning and waste management; *indirect* employment is employment supplying products and services to these activities at NPPs; and *induced* employment in an economy associated with *direct* and *indirect* plant and labour expenditures. *Indirect* and *induced* employment must be calculated with a macroeconomic model of a particular region or country. For policy analysis, total gross employment can then be compared to the total gross employment of the "next best" alternative for generating electricity. The difference yields the total net employment of investing in nuclear power capacity. On definitions of *direct*, *indirect* and *induced* employment in the literature, see IAEA (2009a).

Given the deterministic nature of the parameters in most macroeconomic models, there are error bands surrounding employment estimates. Given that most *direct* employment estimates are done with surveys, the error bands around *direct* employment estimates are quite tight, for example, about ±10%. Because *indirect* employment, as estimated by the model, is based on the *direct* employment estimation, the error bands are necessarily larger, for example about ±20%. Because *induced* employment, as estimated by the model, is based on *direct* and *indirect* employment estimates (or the associated parameters used to calculate these values), the error bands on *induced* employment are necessarily larger, for example about ±30%. Finally, because most investments in electricity generation could be used for competing technologies, *net* employment calculations (the difference between total *direct* plus *indirect* plus *induced* employment for two electricity generating technologies) could have error bands as high as ±50%. Decision makers should keep these error bands in mind when evaluating employment estimates using macroeconomic models. (On these error bands, see Cameron and van der Zwaan, 2015.)

There are several available macroeconomic models (including computable general equilibrium, CGE, models). However, the most universally available one has been the I/O model based on I/O tables, as described by the Statistics Directorate of the OECD (www.oecd.org/trade/input-outputtables.htm) – see Figure 1.1. Although various currencies could be used in I/O models, this document uses (real) 2013 US dollars (USD_{2013}). Note for more information on I/O models and solving them, see Annex I in IAEA (2009a).

I/O models capture input (demand) and output (supply) interrelationships between economic sectors in a geographic region. They also capture the consumption of goods and services for final demand by these sectors and by the household sector. The basic geographic region is a country, but model results can be developed at regional levels. These results are particularly useful in examining the total effects of an economic activity or of a change in the level of that activity. I/O models are typically used to answer the following questions: i) How much spending does an economic activity (such as at an electricity generating plant) bring to a local, regional or national area? ii) How much income is generated for businesses and households? iii) How many jobs does this activity support? iv) How much tax revenue is generated by this activity? These models also are useful in addressing related questions, such as the geographic and industry distribution of economic and fiscal impacts. Typical applications of these models include facility openings and closings, and transport or other public infrastructure investments.

Because of these linkages, the influence of an economic activity in any sector or geographic area on other sectors and areas can be modelled. These influences can extend well beyond the sector and area in which the original economic activity is located. They include not only the *direct*, or initial, effects of the economic activity, but also the secondary, or "ripple" effects that flow from this activity. These ripple effects can be categorised as first-order impacts (those effects on the immediate supply chain), second-order impacts (those effects on the supply chains to the primary supply chain), etc. The sum of the ripple effects beyond the first-order effects are referred to as "N^{th}-order" impacts. Direct effects are analogous to the initial "impact" made by the economic activity, and ripple effects are analogous to the subsequent "waves" of economic activity (new employment, income, production and spending). A full accounting of the impact should include all the ripple effects. The sum of the *direct* and ripple (*indirect* and *induced*) effects is called the total effect. Multipliers can be developed for any of the model outputs, such as earned income, employment, industry output and total income.

Multipliers can also be developed for any industrial sector or geographic area included in the model. Multipliers for a locality are smaller than for a larger area, such as the region in which the locality is located, because some spending associated with an economic activity flows from the smaller area into the larger area. At the local level, multipliers are larger if the local area tends to produce the types of goods and services that the nuclear power industry requires. Secondary effects include *indirect* and *induced* effects, modelled separately within I/O models. *Indirect* effects are those influencing the supply chain that feeds into the sector in which the economic activity is located. Induced effects arise from purchases generated by revenues outside the supply chains, for example in the housing sector.

I/O tables (see, for example, the X_{ij} matrix in the third column and third row of Figure 1.1) describe the sale and purchase relationships between producers and consumers within an economy. They can be produced by illustrating flows between the sales and (final and intermediate) purchases of industry outputs, as reflected in the OECD I/O database. This approach reflects the collection mechanisms for many other data sources such as employment statistics, which are primarily collected by employers. The latest set of OECD I/O tables includes matrices of inter-industrial flows of transactions of goods and services (domestically produced and imported) in current prices, for all OECD countries (except Iceland) and 15 non-member countries, covering the years 1995, 2000, 2005 and later years for some countries. Using a standard industry list based on the International Standard Industrial Classification (ISIC), comparisons can be made across countries, see Annex A. Further information for each country and the estimation methodology is available in Yamano and Ahmad (2006). In many cases, national statistical offices compile national I/O tables. Other sources of recent I/O tables can be found in the World Input-Output Database (WIOD), a database covering 27 EU member states and 13 other major countries for 1995 to 2011 (www.wiod.org/database/wiots13).

In the I/O table each row placed in the transactions among producers represents an industry from which inputs are sold to industries listed in each column. This creates a matrix in which each cell defines the monetary amount of each industry's input that is consumed by the industry itself and all other industries. I/O models assume there is a fixed relation between intermediate inputs and gross output (=gross input), say, $a_{ij} = X_{ij}/X_j$. In Figure 1.1, the I/O table is represented by the matrix of X_{ij} (=a_{ij} X_j) where the index *i* in a_{ij} represents the intermediate input produced by industry *i* to produce *one unit* of commodity *j*. For example, if industry μ is the uranium sector and if industry η is the nuclear power generating industry, then $a_{\mu,\eta}$ is the dollar amount of uranium required to produce a dollar of electricity by an NPP, and $a_{\eta,\mu}$ is the dollar amount of electricity (from the nuclear power sector, although it could be from the power sector more generally) to produce a dollar of uranium. In Figure 1.1, sum of the X_{ij} over *j* is equal to W_i, which is consumed by other industries. The remaining gross output of industry *i*, which is not consumed by industries, is consumed in final demand, F_i, including the household sector, C_i, the investment sector I_i, the export sector, E_i. As imported commodities, M_i, are included in W_i and F_i, an equation is hold as follows: $W_i + F_i - M_i = X_i$. At the same time, the sum of the X_{ij} over *i* is equal to U_j, that is, total intermediate inputs to industry *j*, to which the value added sectors of employees, R_j, businesses including capital, S_j, depreciation, D_j, and indirect taxes, T_j are added finally arriving at an equation as follows: $U_j + V_j = X_j$.

Further, because this document is associated with measuring employment in the nuclear power sector, if the I/O table does not include a "household" sector, this sector must be added. For example, in the regional study in IAEA (2009a) to calculate the economic and social impacts of Ulchin NPP (see www.nti.org/facilities/6) in the surrounding region a household sector was added; see Annex III, "Calculation of Location Coefficients," in IAEA (2009a). This yields a closed model: "Closing the model with respect to households moves the household sector from the final demand column and places it inside the technically interrelated table of productive sectors" (IAEA, 2009a: 111). In particular, Annex II explains:

> The household employment effect translates the impacts of final demand spending changes into changes in employment in physical terms. Although this study does not address or calculate this *induced* household employment effect for an NPP, it may be of interest subsequently or to others and so is explained here. This effect can be calculated by converting the output effects into the number of employees hired, by using physical labour input coefficients (IAEA, 2009a: 118)

There is an implicit assumption that households will consume each commodity in a fixed proportion to the labour services they supply. As discussed in IAEA (2009a: 129), "The last adjustment that needs to be made to these coefficients before applying them to our analysis, is for the household sector. The above derivation of the closed regional input coefficient matrix must be adjusted to exclude household savings before being applied to the household sector … based on the exclusion of household savings from household income…" This effectively transfers what is not consumed by the household sector into final demand.

Figure 1.1. An input/output model

		Producers		Final Demand		Import	Gross Output
		$1 \cdots j \cdots n$	Sum	C I E	Sum		
Producers	1	$X_{11} \cdots X_{1j} \cdots X_{1n}$	W_1	$C_1 \cdots I_1 \cdots E_1$	F_1	M_1	X_1
	$\vdots$	$\vdots \quad \vdots \quad \vdots$	$\vdots$	$\vdots \quad \vdots \quad \vdots$	$\vdots$	$\vdots$	$\vdots$
	i	$X_{i1} \cdots X_{ij} \cdots X_{in}$	W_i	$C_i \cdots I_i \cdots E_i$	F_i	M_i	X_i
	$\vdots$	$\vdots \quad \vdots \quad \vdots$	$\vdots$	$\vdots \quad \vdots \quad \vdots$	$\vdots$	$\vdots$	$\vdots$
	n	$X_{n1} \cdots X_{nj} \cdots X_{nn}$	W_n	$C_n \cdots I_n \cdots E_n$	F_n	M_n	X_n
	Sum	$U_1 \cdots U_j \cdots U_n$					
Value Added	Employees	$R_1 \cdots R_j \cdots R_n$					
	Business owners and Capital	$S_1 \cdots S_j \cdots S_n$					
	Depreciation	$D_1 \cdots D_j \cdots D_n$					
	Indirect taxes	$T_1 \cdots T_j \cdots T_n$					
	Sum	$V_1 \cdots V_j \cdots V_n$					
Gross Input		$X_1 \cdots X_j \cdots X_n$					

Source: Lee (2014).

In addition, according to Kratena (2015), the I/O model developed through the IAEA's co-ordinated research project "Assessing the National and Regional Economic and Social Effects of Nuclear Programmes," follows the traditional impact analysis with input-output analysis, where a new industry is introduced (see Miller and Blair, 2009: ch. 13). There are two different methodologies to deal with a new activity (new plant or new industry) in impact analysis (according to Miller and Blair, 2009), namely i) the final demand approach, and ii) the full inclusion in the input-output matrix. The differences between the two methodologies are minor and the final demand approach is much more straightforward to implement and slightly less data demanding (the delivery structure of the new activity does not need to be known). Given that the focus in this co-ordinated research project is on deepening the macroeconomic feedback mechanisms of an input-output model by introducing additional model features, the decision for the simpler basic model framework (a final demand approach) was taken. IAEA (2009a) presents this in detail: how technical and commercial data from NPPs can be used to inform a simple static input-output model for impact analysis.

In addition to the suggested I/O modelling approach, it is worthwhile to describe CGE modelling as an alternative approach for assessing socio-economic impacts and highlight major differences to I/O models. A useful introduction to applied CGE modelling can be found in Böhringer, Rutherford, and Wiegard (2003). A CGE model, like NEWAGE, is a mathematical representation of the circular flow of income of an economy in a period (for example, one year) based on neo-classical economics. Such an economy consists of two types of markets: factor markets and goods markets, and four types of actors: households, firms, government and foreign traders. Production and consumption possibilities are determined by an exogenously given endowment of production factors (capital, labour and resources) to the households, who receive income by selling these endowments to firms. Under the assumption of perfect competition, firms transform inputs into market products and services assuming cost minimisation, subject to possible technology constraints; and households spend their income on buying these goods assuming welfare maximisation, subject to preferences and a budget constraint. This implies that all market participants act as "price takers" and no excess profits are possible. In equilibrium, prices adjust such that all markets clear, so supply equals demand. The equilibrium conditions involve market clearance, zero excess profit and income balance on all markets for all actors of the economy simultaneously. After an external shock, for example the construction of a new NPP, the system returns to equilibrium, which is characterised by an adjusted set of prices, quantities and income levels. A sequence of equilibria reveals dynamic insights into market developments.

In an economy, prices have important functions: they show scarcity and guide markets to equilibrium. In a CGE model all goods' prices are formulated relative to each other. This assures concentrating on the real value of goods while neglecting monetary issues (for example inflation) and it interconnects all markets with one another. The endogenous modelling of (relative) prices in a CGE model captures spill-over and feedback effects among economic actors. Electricity price changes, for example, spill over to electricity consumers who adjust their electricity demand depending on income, preferences or technology constraints. The adjusted demand decisions then influence the electricity sector, etc. Because of the circular flow of income, the adjustment processes spill over to other commodities and markets, including labour markets.

Production and welfare functions are formulated as constant elasticity of substitution (CES) functions. (For two production inputs, for example capital and labour, or two consumption goods, for example housing and transportation, the elasticity of substitution is the percentage change in one input associated with the percentage change in the other input such that the same output level is maintained; CES implies that this elasticity of substitution is constant at all levels of inputs.) These functions have specific mathematical properties (such as regularity and constant returns to scale, CRS) that ease the numerical analysis considerably, but are still flexible enough to allow for an appropriate representation of economic behaviour (Böhringer, Rutherford and Wiegard, 2003). The parameters of the CES functions are calibrated by a social accounting matrix (SAM) and the respective elasticities of substitution. A SAM is an expanded version of an I/O table that contains additional information on interrelations between all accounts (Rutherford and Paltsev, 1999). Elasticities of substitution describe the substitution possibilities of firms and households from an external shock, for example a change in national energy policy. In mathematical terms, elasticities of substitution refer to the curvature of the indifference curves (at equal welfare) or isoquants (at equal output).

Construction and decommissioning expenses are levelised over the power plants' lifetimes and reflected in the periodic capital demand of the firms. The annualisation of fixed capital costs is a result of a stock-to-flow conversion of the capital stock (see Springer, 1998). New power plant construction is reflected as an increase in capital demand. Any capital demand must be satisfied by the existing capital stock and new investments. The latter are constraint to household savings. This makes the financing of investment projects endogenous. Because of the circular flow of income, any additional activity spills over to nearly all other macroeconomic variables, like sectorial investment activities, capital prices (for example rental rates), wages, household savings, household consumption, etc. The influence of an investment project for national employment levels can be reported as *net* effects (including *induced* effects). Recently, NEWAGE has been applied to quantifying macroeconomic effects of different nuclear power phase-out scenarios in Germany (see IER, 2011; Beestermöller and Fahl, 2010; IER/ZEW, 2010; Küster, 2009; Küster, Ellersdorfer and Fahl, 2007).[1]

Both I/O and CGE models use the assumption of CRS. A production function is said to exhibit CRS if a proportional change in all inputs increases output by the same proportion. This implies, that, if all inputs are increased (decreased) by the same percent, output increases (decreases) by the same percent. Hence, average costs of the output are constant at each level of output. This is a simplifying assumption that disregards capacity limits in electricity generation, where average costs of output usually depend on the capacity factor of a specific power plant or power plant fleet: the capacity factor determines the share of capital costs per unit of output. The CRS assumption therefore implies *a constant capacity factor*. In the NEWAGE model, electricity generation technologies are differentiated by energy carrier and load segment (baseload, middle load and peak load). Gas-fired power plants can be operated in all three load segments, whereas nuclear power is only operated in baseload mode (Küster, Ellersdorfer and Fahl, 2007; IER, 2012). This differentiation relaxes the assumption of CRS and constant capacity factors in electricity generation.

A CGE model can be understood as a generalisation of an I/O model. If the substitution elasticities of the underlying CES functions are set to zero (leading to the classic I/O production function), supply and demand adjustments of the economic actors are constrained to fixed input ratios and fixed price relations. Exogenous shocks would then create similar results compared to an I/O modelling approach. The advantages of using a CGE over an I/O model depend on the policy or research issue. While I/O models are most appropriate for static, short-term, *ex-post* analyses of economic linkages, the main shortcomings of standard I/O models are fixed input ratios and constant prices that prevent the economy from adjusting input demands (price-induced substitution) after an external policy shock. Further, I/O models do not incorporate behavioural assumptions of firms' and households' supply and demand adjustments. CGE models, like NEWAGE or PACE (Böhringer, Rutherford and Wiegard, 2003), are suited for an *ex-ante* assessment of long-run effects of policy interventions, because they incorporate macroeconomic, price-induced substitution and income effects in all markets. This can be useful in comparing the macroeconomic performance of different energy technologies under different policy regimes, such as the early retirement of a nuclear fleet. The major drawbacks of using a CGE model can be seen in its challenging mathematical formulation, theoretical complexity, and numerical programming requirements, which might create a non-transparent "black box" (Böhringer, Rutherford and Wiegard, 2003). In consideration of these facts, the expert group decided to choose I/O models as the most appropriate modelling technique for modelling employment in nuclear generation. The shortcomings of the I/O modelling approach, however, should be kept in mind while interpreting the results.

1. A focus of the NEWAGE model is the technology-based representation of the electricity generating sector. The production of aggregate electricity is disaggregated into 18 electricity generation technologies distinguished by energy carrier and load segment. All generation technologies, including nuclear power, are modelled with CES production functions with capital, labour, and resource inputs. NEWAGE considers unemployment, wage rigidities, and different grades of labour qualifications (skilled and unskilled), hence labour markets do not necessarily clear: wages drive the substitution between skilled and unskilled labour. The circular flow of income makes it possible to report net employment effects of different policy scenarios.

Beyond the context of economic evaluation of an NPP programme, I/O models have been used even in a greater number of applications, to name just a few examples:

- economic impacts of oil and gas production, drilling (Penn and McCraw, 1996; McDonald et al., 2007; Guilhoto et al., 2007; Leung-Wai and Norman, 2007);
- economic impacts of coal production (Ivanova and Rolfe, 2011);
- economic impacts of renewable energy technology (Jensen et al., 2010; Timmons, Damery and Allen, 2007; Pollin, Heintz and Garrett-Peltier, 2010).

Other applications deal in particular with an economy-wide assessment of energy systems or climate change policies, whereas a nuclear technology represents only one among all energy options (see for example: Han, Yoob and Kwak, 2004; Allan et al., 2007; Marriot, 2007; Lindner, Legault and Guan, 2012).

1.3. Industrial classification systems

Different I/O tables have various definitions of industrial sectors. The OECD tables use the ISIC codes, available from the United Nations (see Annex A). Like many industrial classification systems, electricity generation is grouped with other similar services. For example, at the highest level of the ISIC (Revision 4), electricity generation is grouped with "gas, steam and air conditioning supply" in Section D (this can be considered the "public utility" sector). There is only one 2-digit level industry in Section D, Division 35, electricity, gas, steam and air conditioning. The 3-digit level (351) and 4-digit level (3510) is "Electric power generation, transmission and distribution," which includes i) operation of generation facilities that produce electric power, including thermal, nuclear, hydroelectric, gas turbine, diesel and renewable; ii) operation of transmission systems that convey the electricity from a generation facility to the distribution system; iii) operation of distribution systems that convey electric power received from a generation facility or the transmission system to the final consumer; iv) sale of electricity to the user; v) activities of electric power brokers that arrange sales of electricity; and vi) operation of electricity and transmission capacity exchanges for electric power.

Therefore in I/O tables based on ISIC, nuclear power generation is combined with all other forms of electricity generation, transmission and distribution. This implies that the relevant I/O coefficients describe the monetary amounts of all other industries that are consumed by the entire electricity sector, and if at the 2-digit level, the coefficient describes how much output of every other industry is consumed as intermediate inputs in the production and consumption of electricity, gas, steam and air conditioning. To analyse the flows between the nuclear power industry and all other industries, this document recommends:

(1) that the nuclear power sector be separated as a separate row and column;

(2) that the nuclear power sector consist only of NPPs, (it does not include supply chain industries;

(3) that the homogeneous output (electricity) of the nuclear power sector (other outputs, such as heat or medical radio-isotopes are not considered here) be sold as intermediate inputs either:

(3.1) to the electricity or utility sector that transmits and distributes electricity to the remaining sectors; see Section 3.1 on this approach to estimating nuclear sector labour requirements; or

(3.2) to all other sectors in proportion to the amount of electricity consumed annually by each sector, subtracting from the aggregated utility sector the value of electricity generated by the nuclear power sector, and add those amounts to appropriate output cells of the nuclear power sector as a proportion of the total electricity consumed by a particular industry or service; also, electricity consumed by the nuclear power sector is equal to the difference between the gross and net size of the plant times the capacity factor times the weighted, average annual wholesale price of electricity; see Section 3.2 on this approach to estimating nuclear sector labour requirements in Korea.

An alternative to the ISIC is the North American Industrial Classification System (NAICS), following the implementation of the North American Free Trade Agreement (NAFTA), see www.census.gov/eos/www/naics. These two systems require translation, see reference in Annex B. For example, nuclear power generation would be classified as NAICS 221113.

While the purpose of this document is to help member country experts determine the levels of inputs (particularly labour) flowing into the nuclear power sector, these inputs depend on the state of development of the nuclear power sector in a particular economy. This document recommends as a compromise between completeness and simplicity that the life of an NPP be divided into four periods: i) construction, ii) operation, iii) decommissioning, and iv) waste and spent nuclear fuel management. Direct employment follows the logic of the levelised cost methodology. Because an I/O model assumes static relationships between inputs and outputs, these relationships should be updated at least every five years. *I/O models should not be used for projections beyond the short term*.

During construction, although flows to other industries in an economy change each month and different types of labour with different levels of training change throughout the construction period, expenditures are discounted to the end of construction (assumed simultaneous with the start of operation and the output flow of electricity). These expenditures are spread uniformly over the construction period, assumed for simplicity to involve five years of site preparation and advanced procurement, and five years from the pouring of base-mat concrete to commercial operation, so expenditures (for example on labour, equal to hours times salaries or wages plus benefits) are discounted and divided by ten (years).

Further, even though during operation there are periods of refuelling and periods of refurbishment, expenditures on labour, maintenance supplies, equipment replacement, insurance, taxes, and capital are discounted to the start of operation and spread uniformly over the operating life of the NPP, assumed to be 50 years, again for simplicity.

In addition, after retirement of the NPP, there is a period of five years of decommissioning planning and preparation, and five years of active decontamination, dismantling and site restoration. Finally, there are 40 years of active waste management starting with the retirement of the plant. At the end of this period all remaining long-lived radioactive wastes are placed in geologic repositories, however, because repositories are so geologically site specific, they are not modelled here.

Therefore, the task of this document is to aid member country experts to create four vectors, $X^1_{\eta i}$, $X^2_{\eta i}$, $X^3_{\eta i}$, and $X^4_{\eta i}$, which describe the flows from the i^{th} sector of the economy into the nuclear power sector, η, during the four periods of the life of an NPP. For simplicity assume that economies of scale are exhausted with twin-unit plants, this implies units after the second unit at the same plant size increase labour and expenditures proportionally to those of the first two units. Again, for simplicity, assume that each unit is 1 000 MWe (net) and an NPP is 2 000 MWe (net). Scaling of the values of the input flows can be done for each set of dual-unit plants, for example, for an NPP of four units, input flows will be approximately twice that of an NPP of two units and input flows for a fleet of four 4-unit NPPs will be approximately four times the flows for a single four-unit NPP. This scaling is unlikely to be true for facilities in the nuclear fuel cycle sector, such as spent nuclear fuel management, discussed below.

Chapter 2. Methodology: Input flows to the nuclear power sector

The first step in the modelling process is to map the expenditure data from an NPP to the applicable codes used in the selected input/output (I/O) model. This involves converting expenditures, labour, profits and taxes into the applicable codes. For regional analysis, the total spending in each category and the percentage of that spending in each region are required.

2.1. Nuclear power plant construction (for example, years 0-9)

Nuclear power plant capital investment expenditures

Nuclear power plant construction is classified in the ISIC under Section: F – Construction, Division: 42 – Civil engineering, Group: 422 – Construction of utility projects, Class: 4220 – Construction of utility projects (North American Industrial Classification System, NAICS, 237130). However, these industry designations primarily refer to "engineering services," which represents only a small part of total construction cost: the total amount spent on construction and testing before any electricity or revenues are generated, as defined by the Generation IV International Forum's Economics Modeling Working Group (EMWG, 2007); see Annex C and Annex D. Total construction cost is equal to total overnight construction cost plus contingency and financing costs. To measure these consistently, a set of standard definitions of construction accounts, structures, equipment and personnel is presented in a Code of Accounts (COA) system. This is an industry-standard cost-accounting framework for allocating the direct and indirect costs of NPPs, as well as for comparisons of costs of these plants with fossil fuel plants. (In most COAs "indirect costs" refer to costs that cannot be attributed to a specific direct cost category; these are not the same as "indirect" costs in I/O models.) The cost estimates provided in the COA system detail expenditures on materials and services for virtually all aspects of NPP construction. As such, they can enter I/O models by assigning the appropriate industry codes in the I/O model used. See the discussion of the EMWG (2007) Code of Accounts in Annex C and the example of the GIF-COA estimates for a conventional NPP in Annex D.

Table 2.1 gives TVA (2005) percentages of direct cost for each system in the 20 Series and presents a stylised version of the direct cost breakdown for new NPPs. Equipment is installed into the balance of plant (BOP) (in some publications BOP can refer to all but the reactor; here, it refers to Series 21 costs), consisting of i) reactor building that would hold all reactor equipment; and ii) other structures that would hold all non-reactor equipment. Annex D provides a more detailed allocation of total direct costs, indirect costs, owners' costs, but does not detail financing and contingency costs (a contingency of 15% was distributed across all cost items).

Based on TVA (2005) and definitions of the Code of Accounts in EMWG (2007) in Annex D, Table 2.1 presents an allocation of NPP overnight construction costs to ISIC and NAICS industries at a high level. In Table 2.1, interest during construction would add an additional 25% for a total capital investment cost. This can be updated using the US Producer Price Index (see Federal Reserve Bank of St. Louis, 2015). Annex D shows a bottom-up breakdown for a generic Westinghouse 4-loop PWR-12 (circa 1987, also known as Generation II) from ORNL (2011). Compare this to the detailed breakdown of construction costs in Annex C that includes pre-construction costs, and where labour is allocated to the utility construction industry and land is allocated to the electric utility industry. When calculating *direct*, *indirect* and *induced* employment, the construction labour would be considered *direct* employment and the labour employed in producing the purchased equipment would be *indirect*. (Both *direct* and *indirect* employment and expenditures then create *induced* employment.)

Table 2.1. Decomposition of total construction investment costs (for an ABWR) (TCIC in EMWG, 2007)

System	TVA (2005)	ISIC	NAICS	
1: Structures (balance of plant)	20%	4220	23	Construction
2: Reactor	40%	2513	332	Manufacturing of steam generators
3: Turbine generator	25%	2811	333	Manufacturing of turbines and generators
4: Electrical (+ instrumentation and controls)	10%	2710	335	Manufacturing of electrical equipment
5: Cooling and misc.	5%	3320	333	Manufacturing of pumps, valves, etc.
Total direct costs	**100%**			
Capitalised indirect costs*	**+15%**	7110	54	Engineering services
Capitalised owners' costs	**+15%**	3510	22	Electric utilities
Contingency	**+20%**			Distributed across direct, indirect and owner's costs
Financing (e.g. interest during construction)	**+25%**	6492	522	Construction lending
Total capital investment cost	**175%**			**of total direct costs**

Source: Adapted from TVA (2005).

* Indirect in cost engineering references to items that cannot be attributed to a specific direct cost category, such as engineering services; in I/O modelling these are considered "direct" costs.

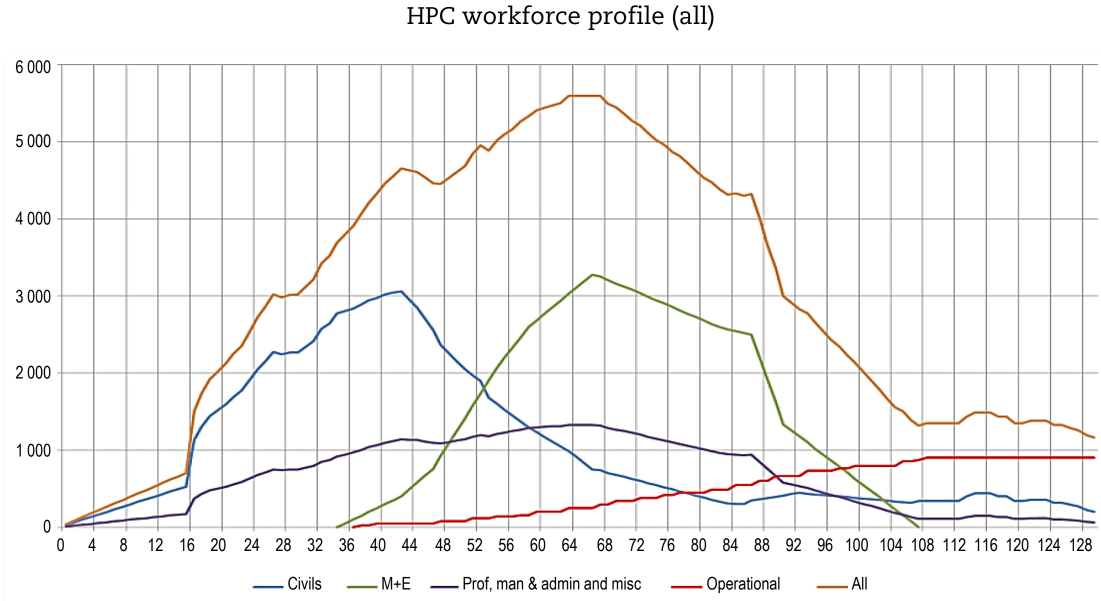
Nuclear power plant construction labour

The four Westinghouse AP1000 reactors ("Generation III") being built in the United States were estimated to require a total on-site construction workforce of 22 550 full-time *annual* equivalent (FTE) workers or 45 million hours, assuming 2 000 per year (SCG&E, 2012; Southern Company, 2012). The average number of *direct* jobs in any *year* over 10 years of construction is about 1 025 for a 1 000 MWe (net) unit, or 10 250 total employment per gigawatt (net), compared to 13 896 in Table 2.2 for 1 147 MWe. (See IAEA, 2012, for organisational charts of the construction workforce, in, for example, Figures 2 and 3.)

The construction workforce consists of two components: i) field craft labour and ii) field non-manual labour. Field craft labour is the largest component of the construction workforce, consisting of approximately 70% to 75% of the field work force makeup in conventional nuclear plant construction. The field craft labour force comprises civil, electrical, mechanical, piping and instrumentation personnel used during the installation and start-up of the units. The field non-manual labour makes up the balance of the construction workforce, approximately 25% to 30% when the design engineering is performed off-site. The non-manual labour force comprises of field management, field supervision, field engineers, quality assurance/quality control, environmental-safety and health, and administrative/clerical staff (SCG&E, 2012; Southern Company, 2012).

As another example, consider Figure 2.1 that breaks down the workforce requirements by construction of structures (civil), installation of equipment (mechanical and electrical, M+E), administration (professional, management, administration, and miscellaneous, operational and "all" (total).

Figure 2.1. FTE labour force requirements at Hinkley Point C (twin EPRs) by quarter



Source: EDF Energy (2011: 17). For an update, see www.bbc.com/news/uk-england-somerset-36894117.

The tables in Annex D describe construction expenditures on i) labour payrolls and ii) equipment plus materials to build a generic ("Generation II") 4-loop PWR, PWR-12 (1 147 MWe) similar to TVA's Watts Bar 1 & 2 (1 123 and 1 165 MWe). Table 2.2 translates these expenditures into the number of annual full-time equivalent jobs, about 12.1/MWe, and the number of jobs created in the supply chain (*first-order indirect* employment), about 9.2/MWe. The ((*first-order indirect*)/*direct*) multiplier, 0.761. This can be compared with the ((*total indirect*)/*direct*) multiplier for construction in Korea of 1.04 (Table 3.2) and for the entire nuclear power sector in France of 0.912 (Section 3.3). Therefore, second-order through the Nth-order *indirect* employment, those jobs created by first-order supply chain providers could increase total labour-years generated by a 1 000 MWe (net) NPP construction to 26 600 using the French *indirect* multiplier or 28 300 using the Korean *indirect* multiplier, compared to the 24 473 found here (for the *direct* plus *first-order indirect*). Of course, this does not include *induced* employment (employment generated in the macroeconomy from employing *direct* and *indirect* labour), which must be calculated with a macroeconomics model, such as an input/output model, as described in Chapter 1; see examples in Chapter 3.

Table 2.2. PWR-12 (1 147 MWe) direct and first-order indirect labour in construction
(not including local and national public sector jobs)

General NAICS industries	NAICS CODE	NPP labour payroll*	NPP other spend*	Industry revenues to jobs multiplier**	Sector annual wages (USD)	Direct labour	First order indirect labour+	Total direct & indirect labour
Heavy and other civil engineering construction	237	45 188	208 598	0.375%	56 915	794	782	1 576
Speciality trade contractors	238	290 469	205 413	0.601%	44 856	6 476	1 235	7 711
Primary metal manufacturing	331	18 679	40 431	0.146%	59 203	316	59	374
Fab. metal product manufacturing	332	97 203	491 036	0.408%	48 758	1 994	2 006	3 999
Machinery manufacturing	333	127 332	645 959	0.262%	56 743	2 244	1 695	3 939
Computer and electronic product manufacturing	334	53 562	97 944	0.273%	73 431	729	268	997
Electrical equipment component manufacturing	335	70 080	62 205	0.273%	52 252	1 341	170	1 511
Furniture and related product manufacturing	337	111	1 124	0.512%	37 822	3	6	9
Transportation and warehousing	48-49	0	13 292	0.589%	42 699	0	78	78
Finance and insurance	52	0	149 261	0.166%	86 668	0	248	248
Professional, scientific and technical services	541	0	727 253	0.554%	70 871	0	4 030	4 030
Labour		853 302			61 405	13 896	10 577	24 473
Labour per MWe						12.1	9.2	21.3
Multiplier: (first order indirect)/direct							0.761	

* In thousands of USD. ** divided by 1 000. + Equal to "industry revenues to jobs multiplier" times "NPP other spend".
Source: US Census Bureau (2016).

2.2. Nuclear power plant operation (for example, years 10-60)

Employment during nuclear generation

For most US companies, labour expenditures are the primary driver of economic impacts at the local and state level. To model the impact of labour expenditures, both salaries and benefits to the employees are included in the labour cost. While there are different methods for estimating employment at NPPs, given that there is a recommendation to leave transmission and distribution employment to the public utility sector, this document recommends following the bi-annual survey work of the Nuclear Energy Institute (NEI). Information on staff are collected in job categories, including engineering, materials and services, operations, support services, training and management. In particular, in 2013, the US commercial nuclear industry employed 62 170 *direct* jobs at 104 units (an average of 598 per unit), where jobs at fuel cycle facilities, vendors, and regulatory agencies are considered *indirect* (see Bradish, 2014). However, this varies from plant to plant; each nuclear *unit* employs 400 to 700 *direct* jobs. Table 2.3 shows the average, minimum and maximum number of employees that work at US NPPs. The data is provided based on how many reactors operate at a plant. Note: The average US NPP employee earns about USD 95 000 annually, *including employee benefits*. The salary and benefits costs are used in an I/O model to derive *indirect* and *induced* effects.

Table 2.3. US NPP employment during operation

1-unit plants	Employees	2-unit plants	Employees	3-unit plants	Employees
Average	700	Average	960	Average	1 640
Min	460	Minimum	640	Minimum	1 130
Max	1 040	Maximum	1 520	Maximum	2 260

Source: Nuclear Energy Institute.

Operation and maintenance expenditures during nuclear generation

The modelling process involves taking expenditure data provided by an NPP and assigning it to codes such as NAICS, ISIC, or others, and aggregating it to the appropriate level in the selected I/O model. These models typically use one year of data (or lifetime levelised data) that includes operation and maintenance, capital (structures and equipment, also known as "capex") purchases, and fuel purchases. The locations of the companies where expenditures are made allow the modeller to group the expenditures into regions. Each larger area grouping (national or regional, for example states in the United States) should be inclusive of the small area grouping (regional or sub-regional, for example counties in the states of the United States). For example, state data should include everything in the local area. Another important component for modelling impacts is tax data. The primary data of interest is property tax, but all relevant taxes should be included, for example, if possible, payroll taxes. In addition to non-labour expenditures, nuclear fuel costs must be included. Nuclear fuel costs are considered to be in the category of inorganic chemical manufacturing. Table 2.4 shows the average expenditures of a 1 000 MWe (net) NPP by Impact Analysis for Planning (IMPLAN) code and in the county, state (county plus state) and national (county plus state plus national) areas (for more on IMPLAN, see Section 3.2).

Fuel expenditures during nuclear generation

The light water reactor, LWR, nuclear fuel cycle can be broken into the "front end" before insertion of fuel into the reactor and the "back end" after removing fuel from the reactor. The "front end" involves all steps leading to the delivery of nuclear fuel to the reactor: i) uranium mining and milling, ii) conversion, iii) uranium enrichment, and iv) reconversion and fuel fabrication. The "back end" involves all steps after the used fuel is removed from the reactor. For a discussion of used fuel recycling, see NEA (2013). Front end fuel annual totals and costs per MWh can be calculated as in Table 2.5. For uranium, uranium conversion and uranium enrichment prices, see www.uxc.com. For a discussion of the international market structure of the nuclear fuel cycle, see NEA (2008).

Uranium mining and milling for uranium producing countries

Since the creation of a commercial market in the late 1960s, uranium exploration and production have been a function of uranium market prices (most uranium is traded through long-term contracts, but these contract prices are not publicly known; what is known are the spot market prices). Uranium is primarily extracted through in situ solution mining, underground mining and open-pit mining. Uranium ore is crushed and leached with acids to produce a uranium oxide powder, U_3O_8, known as "yellowcake". Expenditures on uranium can be included in ISIC Section: B – Mining and quarrying, Division: 07 – Mining of metal ores, Group: 072 – Mining of non-ferrous metal ores, Class: 0721 – Mining of uranium and thorium ores, or in NAICS 212291.

Table 2.4. Largest annual operating expenditures for an average US nuclear plant

(thousands of USD_{2013})

IMPLAN descriptors	IMPLAN codes	NAICS codes	County	State	National
Total (of which 32% in labour)					**215 000**
Labour	Labour	Labour*	30 700	64 500	68 900
Indirect taxes	Taxes	Taxes	6 900	8 500	20 300
Other basic inorganic chemical manufacturing	**125**	**325 180**	**0**	**200**	**18 300**
Architectural and engineering services	369	541 330	0	7 600	15 100
Other non-metallic mineral mining	**27**	**212 399**	**0**	**0**	**12 000**
Other federal government enterprises	429	926 130	0	0	14 000
Other maintenance and repair construction	40	811 310	1 200	6 100	8 800
Support activities for other mining	**30**	**213 115**	**0**	**0**	**7 000**
Misc. professional and technical services	380	541 300	100	1 500	5 300
Misc. electrical equipment manufacturing	275	335 999	100	1 200	4 300
Other state and local government enterprises	432	921 130	600	2 800	3 600
Investigation and security services	387	561 612	0	0	3 400
Scientific research and development services	376	541 712	0	100	2 700
Environmental and other consulting services	375	541 620	0	1 200	2 700
Electric power and transformer manufacturing	266	335 311	0	700	2 000
Waste management and remediation services	390	562 211	100	800	1 900
Fuel = IMPLAN CODES =	**27+30+125**	**325 180**	**0**	**200**	**37 300**

Source: Nuclear Energy Institute.

* There is no code in the NAICS for permanent NPP employees, unlike contracted labour during operation, for example, for security.

Table 2.5. Fuel sector expenditures per year in USD_{2013}

Levelised fuel cost parameters	Advanced light water reactor
Size (gross MWe, net = 1 000 MWe)	1 050
Natural uranium, tU	185.4
Cost of uranium, USD thousands/year	16 690
Cost of conversion, USD thousands/year	1 850
Cost of SWU, USD thousands/year	13 280
Enriched uranium, tU	19.723
Cost of fuel fabrication, USD thousands/year	5 920
Fuel cost, USD thousands/year	**37 740**

Source: Adapted from Rothwell (2016: 158).

Table 2.6 presents employment in existing uranium production centres from NEA/IAEA (2014), where all NEA/IAEA estimated data and all countries missing data or with less than 500 employees have been deleted. With approximately 185 tU per 1 000 MWe (net), there are approximately 170 full-time jobs created in the uranium mining sector. With 384 GW of total net installed nuclear capacity in the world there are approximately 65 000 employees in the global uranium mining sector, which corresponds to the values listed in NEA/IAEA (2014: Table 1.23).

Table 2.6. Employment related to uranium production

Country	2010			2011			2012		
	Person-years	tU	Person-years/tU	Person-years	tU	Person-years/tU	Person-years	tU	Person-years/tU
Australia	4 813	5 900	0.82	4 888	5 967	0.82	5 574	7 009	0.80
Canada	2 399	9 775	0.25	2 060	9 145	0.23	2 109	8 998	0.23
China	7 560	1 350	5.60	7 650	1 400	5.46	7 660	1 450	5.28
Kazakhstan	8 828	17 803	0.50	8 550	19 450	0.44	9 760	21 240	0.46
Russia	8 989	3 563	2.52	9 028	2 993	3.02	9 526	2 862	3.33
Ukraine	4 310	837	5.15	4 470	873	5.12	4 490	1 012	4.44
United States	948	1 626	0.58	1 089	1 535	0.71	1 017	1 595	0.64
Total or average	**37 847**	**40 854**	**0.93**	**37 735**	**41 363**	**0.91**	**40 136**	**44 166**	**0.91**

Source: NEA/IAEA (2014: Table 1.23).

Uranium conversion, enrichment and fuel fabrication for fuel fabricating countries

The remainder of the "front end" of the nuclear fuel cycle can be classified under ISIC as Section: C – Manufacturing, Division: 20 – Manufacture of chemicals and chemical products, Group: 201 – Manufacture of basic chemicals, fertilisers and nitrogen compounds, plastics and synthetic rubber in primary forms, Class: 2011 – Manufacture of basic chemicals; or as NAICS 325180 (in NAICS 2012 or 325188 in NAICS 2007). In the light water reactor fuel cycle, natural uranium is converted to uranium hexafluoride, UF_6. In the conversion process, uranium oxide, U_3O_8 is dissolved in nitric acid, yielding uranyl nitrate. This is treated with ammonia and reduced with hydrogen to yield uranium dioxide, which is converted with a fluoric acid and fluorine to UF_6. Uranium (UF_6) enrichment is now being done commercially using centrifuge technology. In centrifuge plants, the uranium gas is spun with the lighter U-235 separating from the heavier U-238. (Note that U-234 is also concentrated during the enrichment process.) Nuclear fuel is fabricated by reconverting the enriched UF_6 to a metallic oxide, the oxide is formed into pellets, and the pellets are assembled into fuel rods that are inserted into the reactors of NPPs (see Rothwell, 2010). Because fuel reloads are fabricated in batches with demanding specifications, the operating capacity is lower than one might expect, because a fuel line must be thoroughly cleaned after each batch is manufactured. Thus, there always appears to be overcapacity in the market because the capacity factor of fuel fabricators is necessarily less than 100%.

Following the same logic as with uranium mining, in conversion, enrichment, and fuel fabrication (see discussion of labour in Rothwell, 2009 and 2010), there are approximately 100 *indirect* employees ("*first-order indirect*") per year in each nuclear fuel sector per 1 000 MWe (net) of nuclear capacity.

2.3. Nuclear power plant decommissioning (for example, years 61-70)

Following PNNL (2012: vi), "Reported decommissioning costs were USD 323.8 million for Trojan (3 411 MWth and 1 155 MWe), USD 512.4 million for Rancho Seco (2 772 MWth and 917 MWe), USD 575.2 million for Maine Yankee (2 630 MWth and 900 MWe), and USD 918.5 million for Haddam Neck (1 825 MWth and 603 MWe)." These were single unit plants. The average cost was approximately USD 600 million per unit. Assuming that two-thirds of the cost of decommissioning is spent on labour (including project management and engineering services, based on member country surveys reported in NEA, 2016), this would yield about USD 400 million in labour expenditures. Assume that decommissioning, including planning through site restoration, takes ten years from the date of retirement, or USD 40 million per year. If the average decommissioning labour is paid USD 80 000 per year for wages/salary and benefits (www.indeed.com/q-Nuclear-Decommissioning-jobs.html), this would imply that decommissioning a nuclear power unit would employ about 500 people per year for 10 years. (This is likely to be a first-of-a-kind estimate; employment is likely to decline with more industry experience.)

Decommissioning can be allocated to ISIC Class: 3900 – Remediation activities and other waste management services and Class: 3822 – Treatment and disposal of hazardous waste. NPP decommissioning and environmental remediation work, such as the removal of underground steel tanks for hazardous materials are classified in NAICS industry 562910 – Remediation Services.

2.4. Spent nuclear fuel and waste management (for example, years 61-100)

Following Rothwell (2015), assume that spent nuclear fuel (SNF) is managed *for the foreseeable, discounted future* at independent spent fuel storage installation (ISFSI) facilities. If 40 000 MTHM of SNF is moved from one site to another every 40 years, the discounted cost of providing a trust fund for these facilities is approximately USD 0.85/MWh (similar to the USD 1/MWh that was collected for the Nuclear Waste Trust Fund to finance the Yucca Mountain Geologic Repository until 2014). Such a facility was licensed by the US Nuclear Regulatory Commission (US NRC); see US NRC (2001). Job descriptions were posted by the Private Fuel Services Facility. From these job descriptions an organisational chart was developed. It assumes a *permanent* staff of approximately 80 employees, see Annex E. The cost of transferring casks of SNF to the facility was assumed to be done by a contractor to move the SNF into the facility during its first ten years and out of the facility during its last ten years. The cost of labour was included in the cost of casks, therefore there was more labour than 80 employees in the first and last 10 years of the facility, but the was not enough information in the public domain to estimate the number of employees that would be hired by the transportation contractor. See NAICS 237990, including nuclear waste disposal site construction; 332420, including nuclear waste casks (and canisters), heavy gauge metal, manufacturing.

2.5. Direct employment generated by a twin-unit nuclear power plant

To summarise the results of Chapter 2, *direct* employment during site preparation and construction of a single 1 000 MWe (net) advanced light water unit about 12 000 *direct* labour-years during construction from Table 2.2. For 50 years of operation, annually there are approximately 600 administrative, operation and maintenance, and permanently contracted staff, or about *direct* 30 000 labour-years during operation. For 10 years during decommissioning, there are approximately 500 employees annually, or about *direct* 5 000 labour-years. Finally, for 40 years, there are about 80 employees managing nuclear waste, or about *direct* 3 000 labour-years. Hence, a total of about 50 000 *direct* labour-years per gigawatt, or about 100 million labour hours, assuming 2 000 hours per labour-year. If the unit is operating at a 90% capacity factor, it produces about 400 million MW-hours over 50 years, or about 4 MWh per *direct* labour-hour. This does not include labour in the supply chain.

Direct expenditures on equipment from the supply chain generate approximately the same number of *indirect* employment, or about 50 000 *indirect* labour-years. *Direct* and *indirect* expenditures generate approximately the same number of *induced* employment, or about 100 000 labour-years (see Chapter 3). *Total* employment is about 200 000 labour-years, or about 400 million labour-hours per gigawatt (assuming 2 000 hours per employee per year).

Chapter 3. Implementation: Estimated nuclear sector employment

3.1. Measuring nuclear power sector employment in the United States

The Nuclear Energy Institute (NEI) uses two models to analyse economic and expenditure data provided by the NPPs to develop estimates of their economic impacts: i) The Regional Economic Models Incorporated (REMI) Policy Insight Plus, and ii) The MIG Incorporated Impact Analysis for Planning (IMPLAN). The economic impacts of an NPP consist of *direct* and secondary impacts. The main metrics NEI uses to analyse these impacts are as follows:

- **Output:** The *direct* output is the value of power produced by NPP facilities. The secondary (*indirect* and *induced*) output is the result of how the *direct* output alters subsequent outputs among industries and how those employed at the facilities influence the demand for goods and services.
- **Labour income and employment:** The *direct* labour income is the employees' earnings at the NPP facilities. The secondary labour income is the employees' earnings in the other industries because of expenditures by NPP operators. The *direct* employment is the number of jobs at the NPP. Secondary employment is the number of jobs in the other industries supplying goods and services to the NPP.
- **Gross regional product:** Gross regional product is the value of output produced by employees with the NPP, for example sales minus intermediate goods. In the REMI model, electricity is the final good from an NPP in a particular region, be it local, state/provincial/departmental, or national. Intermediate goods are the components purchased to make that electricity.

Economic impact analysis: Regional Economic Models, Inc.

REMI is a modelling firm providing services related to economic impacts and policy analysis. It provides software, support services, and issue-based expertise and consulting in almost every region in the United States, and in other countries in North America, Latin America, Europe, the Middle East, Africa and Asia. The REMI model has two main purposes: forecasting and analysis of policy alternatives. All models have a "baseline" forecast of the future of a regional economy at the local level. Using policy variables in REMI provides scenarios based on different situations, making it a useful tool for conveying the social and economic impacts from a policy. The model translates various considerations into understandable concepts like gross domestic product and jobs. REMI relies on data from public sources, including the Bureau of Economic Analysis, Bureau of Labor Statistics, Energy Information Administration and the Census Bureau. Forecasts for future macroeconomic conditions in REMI come from a combination of resources, including the Research Seminar in Quantitative Economics at the University of Michigan and the Bureau of Labor Statistics. These sources serve as the main framework for the model needed to perform simulations. See www.remi.com.

Economic impact analysis: Impact Analysis for Planning (IMPLAN)

Impact Analysis for Planning (IMPLAN) has been widely used by government and private sector entities. It was originally developed by the US Department of Agriculture's Forest Service in co-operation with the Federal Emergency Management Agency and the

US Department of the Interior's Bureau of Land Management to assist in land and resource management planning. IMPLAN has been used since 1979 and is supported by the Minnesota IMPLAN Group, Inc., now known as MIG Inc. See www.implan.com.

The IMPLAN system consists of two components: software and database. The software performs the necessary calculations, using the study area data. It also provides an interface for the user to change the region's economic description, create impact scenarios and introduce changes in a locality. The methodology and software are described in a user's guide provided by MIG. The IMPLAN software was designed to serve the following functions: data retrieval, data reduction, model solution, and impact analyses. The IMPLAN database consists of two major parts: i) national technology matrices, and ii) estimates of regional data for institutional demand and transfers, value added, industry output and employment for each county in the United States, as well as state and national totals.

The model's data and account structure closely follow the accounting conventions used in I/O studies of the US economy by the Department of Commerce's Bureau of Economic Analysis. The comprehensive and detailed data coverage of the entire United States by county, and the ability to incorporate user-supplied data at each stage of the model-building process, provides a high degree of flexibility in terms of geographic coverage and model specification.

In applying the IMPLAN model to NPPs, three basic types of data are required: expenditures, employee compensation and tax payment data for a specific year. The NPP's expenditures are mapped to IMPLAN's 536 sector codes by identifying the spending at each geographic level and assigning them an industrial classification code within the IMPLAN sector codes. The expenditures and compensation data are then augmented by an estimate of revenues from electricity sales from an NPP into the *wholesale* market in a specific year. This augmentation was necessary because purchase orders and compensation do not reflect all the economic value of an NPP, while total output (approximated by total revenues) better reflects the full economic impacts of NPPs. The estimated revenues are generally above the expenditure data provided by an NPP, indicating a nuclear generation profit margin that was incorporated into IMPLAN as profits associated with the operation of the plant. These data then are incorporated into the IMPLAN model that combines the specifics of the local economy with data on economic activity of the NPP, providing estimates of an NPP's total impacts. IMPLAN then developed the economic and fiscal impact estimates that were reported in Bradish (2014). The IMPLAN model was used by Solan et al. (2010) to estimate the economic impacts of manufacturing and deploying small modular reactors (SMRs) in the United States.

3.2. Measuring nuclear power sector employment in Korea

Employment in a sector of an economy is affected by economic activity in the sector, and by associated sectors. The economic activity (for example output) in the nuclear power sector can be translated into employment by multiplying by the "labour coefficient", which is the ratio of labour to output. This section uses an I/O model to calculate employment of the nuclear power sector in Korea (see IAEA, 2009a).

Economic outputs from nuclear power plants in Korea

The inputs and outputs of the nuclear power sector in NPP construction and operation were calculated for 2009. (Values were inflated to KRW_{2013} [Won] with the OECD inflator of 1.14 and converted to USD_{2013} with the OECD currency converter of KRW 858 = USD 1, or KRW_{2009} 1 000 equals USD_{2013} 1.33) The number of sectors in the Korean national I/O table was reduced from 403 to 38. Table 3.1 lists these 38 sectors. (For currency conversion, see http://stats.oecd.org/Index.aspx?DataSetCode=SNA_Table4).

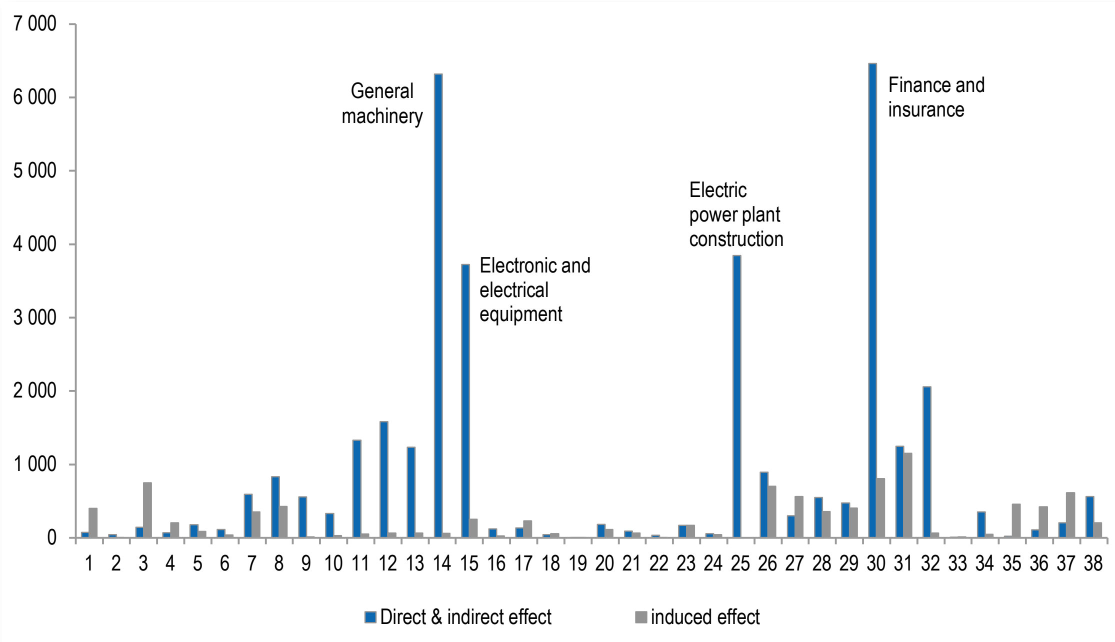
In 2009, eight nuclear power units were under construction. Total expenditures on domestic products from the construction of a nuclear power unit in 2009 was estimated to be KRW 1.7 trillion, which flowed to several sectors including (9) inorganic basic chemical products, (14) general machinery and equipment, (15) electronic and electrical equipment, (25) electric power plant construction, (30) finance and insurance, and (32) business services. The primary results are shown in Figure 3.1, which shows the sectorial linkages in NPP construction. In 2009, 20 units of nuclear power were under operation. NPP operation required intermediate inputs of KRW 4.1 trillion from other sectors. The requirements of intermediate inputs brought about the linkage effects. Figure 3.2 shows these linkage effects. Inorganic basic chemical products and business service sectors were greatly affected by the operation of NPPs.

Table 3.1. Thirty-eight sectors in the Korean nuclear power sector and national economy

No.	Sector name	No.	Sector name
1	Agriculture, forestry and fisheries	20	Thermal power generation
2	Mining and quarrying	**21**	**Nuclear power generation**
3	Food, beverage and tobacco	22	Other generation
4	Textile and apparel	23	Gas and water supply
5	Wood and paper products	24	Construction (except sector 25)
6	Printing and reproduction of recorded media	**25**	**Electric power plant construction**
7	Petroleum and coal products	26	Wholesale and retail trade
8	Chemicals, drugs and medicines	27	Accommodation and food services
9	**Inorganic basic chemical products**	28	Transportation
10	Non-metallic mineral products	29	Communications and broadcasting
11	Basic metal products (except sector 9)	**30**	**Finance and insurance**
12	Primary metal products	31	Real estate agencies and rental
13	Fabricated metal products	**32**	**Business services**
14	**General machinery and equipment**	33	Public administration and defence
15	**Electronic and electrical equipment**	34	Research and development
16	Precision instruments	35	Education
17	Transportation equipment	36	Health services and social welfare
18	Furniture and other manufactured products	37	Other services
19	Hydro power generation	38	Dummy sectors

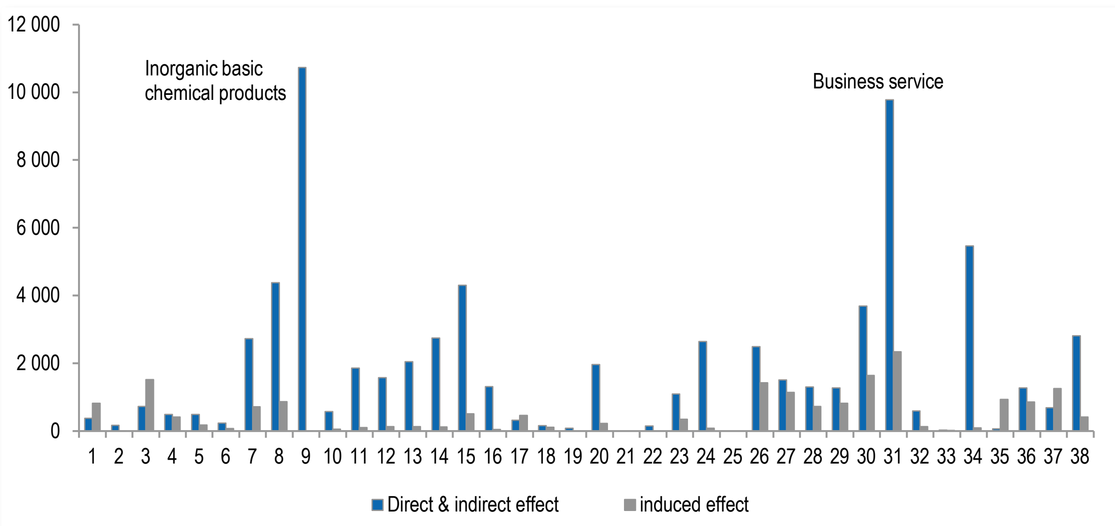
Source: Lee (2014).

Figure 3.1. Sectorial backward linkages in NPP construction (KRW 100 million, 2009)



Source: Lee (2014).

Figure 3.2. Sectorial backward linkages in NPP operation (KRW 100 million, 2009)



Source: Lee (2014).

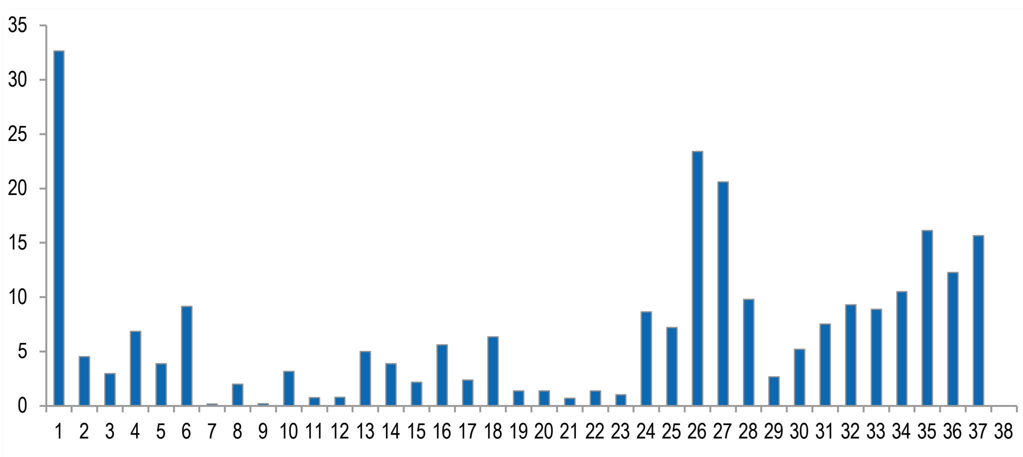
Labour employment associated with the nuclear power sector

Because the number of employees working for NPPs is not available from national I/O tables, this number was obtained through a survey of the NPPs in operation. In 2009, there were 6 711 *direct* employees. With a total installed NPP capacity of 17 716 MW, *direct* labour per GW was about 380 employees. Because the nuclear power sector in the I/O model includes transmission and distribution (T&D) services associated with nuclear power generation, the surveyed number of employees was revised. Economic output of T&D was estimated to be 21.7% for each power sector (Sectors 19, 20 and 21). Hence, the number of employees in the nuclear power sector was revised to include a proportional number of T&D employees at 8 164 people (8 164 = 1.217 x 6 711). (This is one of the options discussed in Section 1.2; another option is to sell all electric power to an electric utility sector, for example, Sector 35 in the ISIC, after subtracting nuclear power industry activity from Sector 35 and creating a separate nuclear power sector.)

The output (as measured by billions of won) from the nuclear power industry was transformed into the number of employees through labour coefficients, as shown in Figure 3.3. The number of full-time equivalent jobs directly created by the nuclear industry was estimated to be around 29 400 persons in 2009, which is divided between i) 9 000 for the construction of four nuclear power units and ii) 20 400 for the operation of 20 units. See Table 3.2. *Indirect* employment (created through linkages) is about 36 700 equal to 9 400 attributable to the construction of a nuclear power unit and 27 300 attributable to the operation of NPPs (Figures 3.4 and 3.5).

Jobs induced by the nuclear power industry arise through the circular flow of income in the national economy, see Section 1.1. The number of jobs created through the induced effects was estimated to be around 27 400 including 9 000 attributable to the NPP construction supply chain and 18 400 attributable to the NPP operations. The (*indirect/direct*) multiplier was 1.25, yielding 36 700 *indirect* employees. The ([*direct* + *indirect*]/*induced*) multiplier was 0.41, yielding 27 400 *induced* employees. Taking into account these values, the total employment associated with the nuclear industry as a whole was about 93 500 persons, which was 0.5% of Korean employment in 2009.

Figure 3.3. Labour coefficients (employee/billion won)



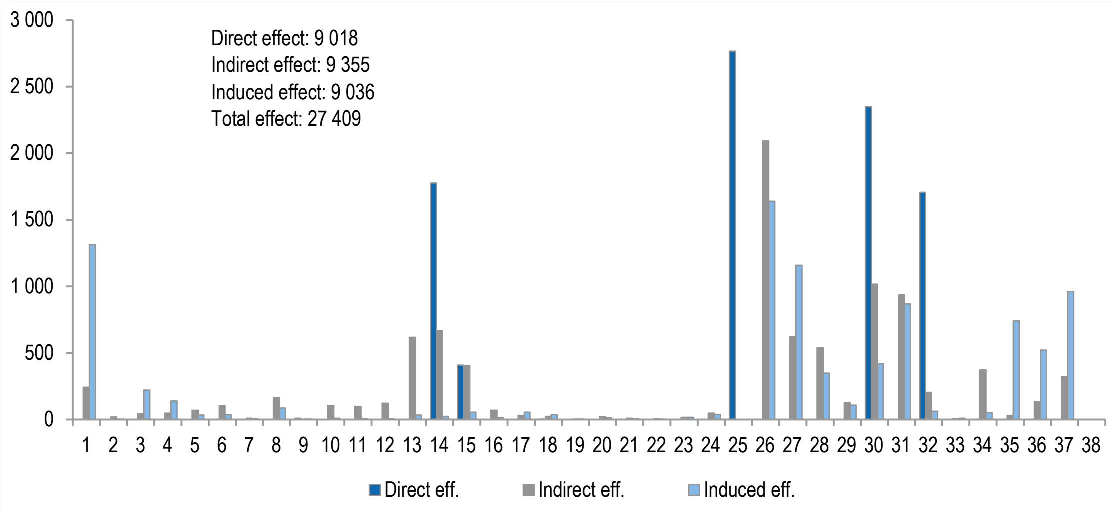
Source: Lee (2014).

Table 3.2. Korean direct, indirect and induced employment from the nuclear power sector

	Direct employment	Indirect employment	Induced employment	Total employment
Construction	9 000	9 400	9 000	27 400
Operation	20 400	27 300	18 400	66 100
Total	**29 400**	**36 700**	**27 400**	**93 500**
Multipliers		1.25 x direct	0.41 x (direct + indirect)	

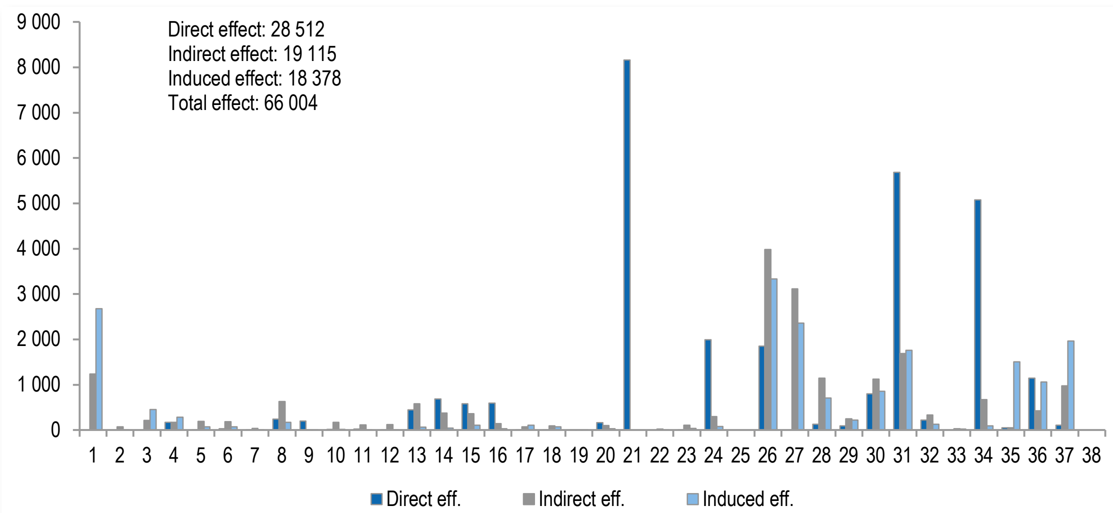
Source: Lee (2014).

Figure 3.4. Korean employment from NPP construction in 2009



Source: Lee (2014).

Figure 3.5. Korean employment from NPP operation



Source: Lee (2014).

3.3. Measuring nuclear power sector employment in France

In May 2011, PriceWaterhouseCoopers (PWC) estimated the *direct*, *indirect* and *induced* employment in the nuclear sector in France. The methodology of that study was explained in Lubek (2014, confidential). The original PWC study estimated the number of *direct* employees in the nuclear power sector in France as 125 000, representing approximately 4% of the industrial employment in France. This total was estimated as the sum of i) 23 000 in the front end of the fuel cycle, ii) 27 500 in the construction sector, iii) 47 000 in operation and maintenance, iv) 20 500 in the back end of the fuel cycle, and v) 7 000 directly employed by the French state. A censes of these employees was taken by identifying 454 firms supplying goods and services to EDF and AREVA. Each firm's revenues associated with the nuclear sector were divided by total revenues (this was done for 398 firms and estimated for 56 firms); this percentage was applied to the total number of employees in each firm and aggregated to *direct* 125 000 employees; see PWC (2011: 16). In 2009 there were 58 units in operation and two under construction (one in France and one in Finland). *Indirect* and *induced* employment was estimated by using multipliers calculated (in February 2011) by the National Institute of Statistics and Economic Studies (INSEE) using an I/O model. The (*indirect/direct*) multiplier was 0.912, yielding 114 000 *indirect* employees. The (*direct/induced*) multiplier was 1.368, yielding 171 000 *induced* employees. The total number of employees generated by the nuclear sector was estimated to be 410 000. This value was quoted in many studies, including European Nuclear Energy Forum (2012).

While cited here, this report does not follow the same definitions recommended by the current document. For example, following the NEI estimate of 62 170 *direct* jobs at 104 units with 66 697 MWe with an average of 598 per unit or 0.932 employees per MWe and the French industry has approximately 47 000 equivalent *direct* jobs at 58 units with 63 130 MWe, or 810 per unit, or 0.744 per MWe. Following Figure 2.1, there is a peak in the construction of twin EPRs at Hinkley Point C of 5 500 or for two twin sites (in France and Finland) a peak of about 11 000 jobs, which is less that the estimate of 27 500 in the construction sector in the PWC (2011) study. Therefore, it is likely that there is some double counting in PWC (2011) in the calculation of *indirect* jobs in the French nuclear sector (likely by including *indirect* labour in the supply chains in *direct* labour).

Chapter 4. Conclusions: Summary of recommendations

Below is a summary of recommendations explicitly or implicitly derived from the body of the report and appendices for measuring employment generated by the nuclear power sector in specific countries:

- When attempting to estimate the employment impacts of existing or anticipated nuclear power plants (in the construction, operation, decommissioning and waste management sectors), identify the most transparent input/output model of the country and adapt the model by creating a separate nuclear power sector, as described in this report. One should be aware of potential limitations of tools and methods used in modelling. Consider to what extent, for example, the impacts of stable electricity prices are included and evaluated. The results should be interpreted in the context of model features and assumptions. Whenever possible, estimate nuclear industry impacts at both national and regional (local) levels.
- *Direct* employment in the operation of commercial nuclear power plants consists of those employees working at nuclear power plants, including permanent subcontractors, such as security personnel and full-time equivalent outage personnel. *Indirect* employment in the "nuclear power sector" includes full-time equivalent personnel in the nuclear supply chain (*first-order indirect* employees) and industries supplying products and services to this supply chain (*Nth-order indirect* employees). *Induced* employment is composed of all employment in the relevant economy generated by *direct* and *indirect* expenditures.
- While *direct* employees can be determined through surveys of existing nuclear power plants, estimates of (total) *indirect* and *induced* employees require the specification of a macroeconomic model. Further, for policy analysis, total gross employment should be compared to the total gross employment of the "next best" alternative for generating electricity. The difference yields the total net employment of investing in nuclear power. The "next best" alternative varies and will usually be determined through the application of a multi-attribute analysis taking into account economics, energy security issues, and employment and environmental impacts.
- When attempting to estimate the employment generated by the nuclear power sector, one should pay particular attention to the consistency of the use of data for the modelling exercise. Generally, modelling requires using data from different sources. Potential sources of inconsistency between I/O tables and nuclear programme data should be eliminated, if possible; for example, by using only annual data. Depending on data availability, uniform or actual distributions of costs can be used. A uniform distribution provides an estimate of the average impact over time; an actual distribution allows an assessment of differences in economic impacts over time. The model should be tested by varying key parameters to determine the sensitivity of the results with respect to changes in assumed values. At the end of the exercise, modelling participants should suggest additional techniques and data for future modelling efforts.
- Consistency should be verified across assumptions, for example, the consistency between the financing structure and the level of local content. External financing from the vendor or the vendor's government will most likely be restricted to financing imports from the vendor; the local content will more likely be financed with funds from local sources. It is also probable that the greater the anticipated local content, the lower the external financing available.

Annex A. UN International Standard Industrial Classification (ISIC, Revision 4)

(http://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=27)

"One-digit" level:

- A – Agriculture, forestry and fishing
- B – Mining and quarrying
- C – Manufacturing
- D – Electricity, gas, steam and air conditioning supply
- E – Water supply; sewerage, waste management, and remediation activities
- F – Construction
- G – Wholesale and retail trade; repair of motor vehicles and motorcycles
- H – Transportation and storage
- I – Accommodation and food service activities
- J – Information and communication
- K – Financial and insurance activities
- L – Real estate activities
- M – Professional, scientific and technical activities
- N – Administrative and support service activities
- O – Public administration and defence; compulsory social security
- P – Education
- Q – Human health and social work activities
- R – Arts, entertainment and recreation
- S – Other service activities
- T – Activities of households as employers and household production for own use
- U – Activities of extraterritorial organisations and bodies

"Two-digit" level:

- A – Agriculture, forestry and fishing
  - 01 – Crop and animal production, hunting and related service activities
  - 02 – Forestry and logging
  - 03 – Fishing and aquaculture

- B – Mining and quarrying
  - 05 – Mining of coal and lignite
  - 06 – Extraction of crude petroleum and natural gas
  - 07 – Mining of metal ores
  - 08 – Other mining and quarrying
  - 09 – Mining support services activities
- C – Manufacturing
  - 10 – Manufacture of food products
  - 11 – Manufacture of beverages
  - 12 – Manufacture of tobacco products
  - 13 – Manufacture of textiles
  - 14 – Manufacture of wearing apparel
  - 15 – Manufacture of leather and related products
  - 16 – Manufacture of wood and of products of wood and cork, except furniture;
  - 17 – Manufacture of paper and paper products
  - 18 – Printing and reproduction of recorded media
  - 19 – Manufacture of coke and refined petroleum products
  - 20 – Manufacture of chemicals and chemical products
  - 21 – Manufacture of basic pharmaceutical products and pharmaceutical preparations
  - 22 – Manufacture of rubber and plastic products
  - 23 – Manufacture of other non-metallic mineral products
  - 24 – Manufacture of basic metals
  - 25 – Manufacture of fabricated metal products, except machinery and equipment
  - 26 – Manufacture of computer, electronic and optical products
  - 27 – Manufacture of electrical equipment
  - 28 – Manufacture of machinery and equipment (not elsewhere classified)
  - 29 – Manufacture of motor vehicles, trailers and semi-trailers
  - 30 – Manufacture of other transport equipment
  - 31 – Manufacture of furniture
  - 32 – Other manufacturing
  - 33 – Repair and installation of machinery and equipment
- D – Electricity, gas, steam and air conditioning supply
  - 35 – Electricity, gas, steam and air conditioning supply
- E – Water supply; sewerage, waste management, and remediation activities
  - 36 – Water collection, treatment and supply

  - 37 – Sewerage
  - 38 – Waste collection, treatment and disposal activities; materials recovery
  - 39 – Remediation activities and other waste management services
- F – Construction
  - 41 – Construction of buildings
  - 42 – Civil engineering
  - 43 – Specialised construction activities
- G – Wholesale and retail trade; repair of motor vehicles and motorcycles
  - 45 – Wholesale and retail trade and repair of motor vehicles and motorcycles
  - 46 – Wholesale trade, except of motor vehicles and motorcycles
  - 47 – Retail trade, except of motor vehicles and motorcycles
- H – Transportation and storage
  - 49 – Land transport and transport via pipelines
  - 50 – Water transport
  - 51 – Air transport
  - 52 – Warehousing and support activities for transportation
  - 53 – Postal and courier activities
- I – Accommodation and food service activities
  - 55 – Accommodation
  - 56 – Food and beverage service activities
- J – Information and communication
  - 58 – Publishing activities
  - 59 – Motion picture, video and television programme production, sound recording and music publishing activities
  - 60 – Programming and broadcasting activities
  - 61 – Telecommunications
  - 62 – Computer programming, consultancy and related activities
  - 63 – Information service activities
- K – Financial and insurance activities
  - 64 – Financial service activities, except insurance and pension funding
  - 65 – Insurance, reinsurance and pension funding, except compulsory social security
  - 66 – Activities auxiliary to financial service and insurance activities
- L – Real estate activities
  - 68 – Real estate activities
- M – Professional, scientific and technical activities
  - 69 – Legal and accounting activities

  - 70 – Activities of head offices; management consultancy activities
  - 71 – Architectural and engineering activities; technical testing and analysis
  - 72 – Scientific research and development
  - 73 – Advertising and market research
  - 74 – Other professional, scientific and technical activities
  - 75 – Veterinary activities
- N – Administrative and support service activities
  - 77 – Rental and leasing activities
  - 78 – Employment activities
  - 79 – Travel agency, tour operator, reservation service and related activities
  - 80 – Security and investigation activities
  - 81 – Services to buildings and landscape activities
  - 82 – Office administrative, office support and other business support activities
- O – Public administration and defence; compulsory social security
  - 84 – Public administration and defence; compulsory social security
- P – Education
  - 85 – Education
- Q – Human health and social work activities
  - 86 – Human health activities
  - 87 – Residential care activities
  - 88 – Social work activities without accommodation
- R – Arts, entertainment and recreation
  - 90 – Creative, arts and entertainment activities
  - 91 – Libraries, archives, museums and other cultural activities
  - 92 – Gambling and betting activities
  - 93 – Sports activities and amusement and recreation activities
- S – Other service activities
  - 94 – Activities of membership organisations
  - 95 – Repair of computers and personal and household goods
  - 96 – Other personal service activities
- T – Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
  - 97 – Activities of households as employers of domestic personnel
  - 98 – Undifferentiated goods- and services-producing activities of private households for own use
- U – Activities of extraterritorial organisations and bodies
  - 99 – Activities of extraterritorial organisations and bodies

Annex B. Translating industrial classification systems

To convert the International Standard Industrial Classification (ISIC) codes to the North American Industrial Classification System (NAICS) codes, see "Correspondence between NAICS 2012 and ISIC Rev.4", https://unstats.un.org/unsd/classifications.

To convert the NAICS codes to Impact Analysis for Planning (IMPLAN) proprietary codes, contact MIG, Inc., at www.implan.com.

To convert the NAICS codes to the Regional Economic Models, Inc. (REMI) codes, see "REMI Industries for v9 Models".

For a discussion comparing REMI and IMPLAN, see www.ilw.com/seminars/JohnNeill Citation.pdf.

Annex C. Generation IV International Forum (GIF) Code of Accounts

The Generation IV International Forum (GIF) Code of Accounts (COA) from Appendix G of the GIF/EMWG (2007) provides a system for categorising costs for construction and operation of all nuclear facilities. The following is an extract (pp. 139-144) from GIF/EMWG. This GIF-COA is the basis of cost estimation in a spreadsheet model, G4ECONS (GIF/EMWG, 2008). An example of the construction cost for a nuclear power plant in this GIF-COA is given in Annex D. Note in this annex, the term "indirect" refers to costs that cannot be assigned specifically to a cost category; this is a different use of the word as in I/O modelling where "indirect" refers to costs incurred off-site, such as in the manufacturing of equipment, which is sold for a price to the nuclear plant builder.

The investment costs for a complete nuclear energy system, or its parts, include the costs of engineering, construction, commissioning and testing before commercial operation. The base costs include costs associated with equipment, structures, installation, and materials (these are direct costs), as well as costs associated with field indirect, design services, construction supervision and project management/construction management (PM/CM) services (these are indirect costs). In addition to the base costs, there are supplementary costs (such as initial core and spare part costs), financial costs (such as interest during construction), owner's costs (including the owner's services costs), and contingency. The total capital investment cost is the cost of building the plant and bringing it to commercial operation.

The GIF-COA is a numeric system designed to provide cost information for any component of a project, from design, layout, and procurement of equipment, to the final installation. At the two-digit level, it can be applied to either top-down or bottom-up cost estimates, and the subsystem category names should be applicable regardless of the nuclear system or technology described. Commonality of account descriptions between reactor energy systems and fuel processing and reprocessing systems is less at the three-digit level. At the three- and four-digit levels, a bottom-up estimate is usually required. Although the GIF-COA is primarily a system of cost accounts, as a project matures, it can be used for other purposes, such as filing, drawing and document control and numbering and coding of equipment.

The GIF-COA is structured as follows:

10:	Capitalised pre-construction costs	(CPC)
+20:	Capitalised direct construction costs	(CDC)
=	Direct construction costs	(DCC)
+31-34:	Capitalised field indirect costs	(FIC)
=	Total field costs	(TFC)
+35-39:	Capitalised field management costs	(FMC)
=	Base construction cost	(BCC)
+40:	Capitalised owner costs	(COC)
+50:	Capitalised supplementary costs	(CSC)
=	Overnight construction cost	(OCC)
+60:	Capitalised financial costs	(CFC)
=	Total capital investment cost	(TCIC)

The GIF-COA structure includes prefixes and suffixes to the basic code to separate and summarise costs at various levels. The structure and details are described in the following sections: Section 1, structure; Section 2, direct costs; Section 3, indirect costs; Section 4, annualised costs; and Section 5, non-electric plant codes. The full GIF-COA structure consists of components to identify and segregate costs by i) unit, ii) plant, iii) system/facility, and iv) commodity. (Because only electricity producing NPPs are considered in this document, only the last two identifier components are discussed here.) The third component is the system/facility identifier consisting of two digits (derived from COAs in ORNL 1988, and IAEA 2000) representing the major systems of the plant.

The first digit groups costs by type:

- 10 – Capitalised pre-construction costs (CPC)
- 20 – Capitalised direct costs (CDC)
- 30 – Capitalised indirect services costs (CIC)
- 40 – Capitalised owner's costs (COC)
- 50 – Capitalised supplementary costs (CSC)
- 60 – Capitalised financial costs (CFC)
- 70 – Annualised operation and maintenance cost (AOC)
- 80 – Annualised fuel cost (ASC)
- 90 – Annualised financial cost (AFC)

The second digit identifies costs summarised by the first digit:

- **10 – Capitalised pre-construction costs (CPC)**
- 11 – Land and land rights
- 12 – Site permits
- 13 – Plant licensing
- 14 – Plant permits
- 15 – Plant studies
- 16 – Plant reports
- 17 – Other pre-construction costs
- 19 – Contingency on pre-construction costs
- **20 – Capitalised direct costs (CDC)**
- 21 – Structures and improvements
- 22 – Reactor equipment
- 23 – Turbine generator equipment
- 24 – Electrical equipment
- 25 – Heat rejection system
- 26 – Miscellaneous equipment
- 27 – Special materials
- 28 – Simulator
- 29 – Contingency on direct costs
- Accounts 10 + 20 = direct costs (DCC)

- **30 – Capitalised indirect services cost (CIC)**
- 31-34 Field indirect services costs (FIC)
- 31 – Field indirect costs
- 32 – Construction supervision
- 33 – Commissioning and start-up costs
- 34 – Demonstration test Run
- Accounts 10-34 = total field cost (TFC)
- **35-39 Field management services cost (FMC)**
- 35 – Design services off-site
- 36 – PM/CM services off-site
- 37 – Design services on-site
- 38 – PM/CM services on-site
- 39 – Contingency on indirect services cost
- Accounts 10 + 20 + 30 = base construction cost (BCC)
- **40 – Capitalised owner's cost (COC)**
- 41 – Staff recruitment and training
- 42 – Staff housing
- 43 – Staff salary-related costs
- 44 – Other owner's costs
- 49 – Contingency on owner's costs
- **50 – Capitalised supplementary costs (CSC)**
- 51 – Shipping and transportation costs
- 52 – Spare parts
- 53 – Taxes
- 54 – Insurance
- 55 – Initial fuel core load
- 58 – Decommissioning costs
- 59 – Contingency on supplementary costs
- Accounts 10 + 20 +30 + 40 + 50 = overnight construction cost (OCC)
- **60 – Capitalised financial costs (CFC)**
- 61 – Escalation
- 62 – Fees
- 63 – Interest during construction
- 69 – Contingency on financial costs
- Accounts 10 + 20 + 30 + 40 + 50 + 60 = total capital investment cost (TCIC)

- **70 – Annualised operation and maintenance cost (AOC)**
- 71 – Operation and maintenance staff
- 72 – Management staff
- 73 – Salary-related costs
- 74 – Operating chemicals and lubricants
- 75 – Spare parts
- 76 – Utilities, supplies and consumables
- 77 – Capital plant upgrades
- 78 – Taxes and insurance
- 79 – Contingency on annualised operation and maintenance costs
- **80 – Annualised fuel cost (ASC)**
- 81 – Refuelling operations
- 84 – Nuclear fuel
- 86 – Fuel reprocessing charges
- 87 – Special nuclear materials
- 89 – Contingency on annualised fuel costs
- **90 – Annualised financial costs (AFC)**
- 91 – Escalation
- 92 – Fees
- 93 – Cost of money
- 99 – Contingency on annualised financial costs

The third and fourth digits provide the lowest level of GIF code for comparisons among plants and development of reference plant costs by top-down techniques. Examples for the third digit coding for the electric power plant are discussed below. The fourth component of the full GIF-COA structure is a commodity identifier consisting of numeric digits, following a decimal point separator, located after the system/facility codes. Detailed, bottom-up estimates would be performed by i) quantifying the commodities to the individual-size level, ii) applying unit hour and unit material cost rates to develop the detail commodity cost, and iii) summarising to the third digit of the GIF code. (Commodity detail codes provide further separation for structural component, size or detailed type of commodity.) Detailed commodity accounts consist of the following categories and commodities:

- **1 – Concrete category:** (11) temporary formwork, (12) permanent formwork, (13) rebar, (14) embedded metals, (15) structural concrete, (16) fill concrete, (17) precast concrete, and (18) concrete structural modules.
- **2 – Structural category:** (21) structural steel, (22) miscellaneous steel, (23) liners, (24) fabricated commodities, (25) architectural, (26) earthwork, (27) piles, and (28) site improvements.
- **3 – Nuclear steam supply system category**: (31) reactor vessel, (32) reactor internals, (33) control rod drive components, (34) install internals, (35) install components, and (36) installation support activities.

- **4 – Mechanical equipment category:** (41) turbine generator equipment, (42) condenser, (43) rotating equipment, (44) heat exchangers, (45) tanks and vessels, (46) water treatment, (47) radioactive waste, (48) miscellaneous equipment, and (49) heating, ventilation, and air conditioning (HVAC) system components.
- **5 – Piping category:** (51) large shop-fabricated pipe, (54) special pipe, (55) small pipe, (56) vendor pipe, (58) valves, and (59) hangers and piping miscellaneous operations.
- **6 – Instrumentation category:** (61) control room equipment, (62) local control panels, (64) field mounted instruments, (65) instrument supports, (66) instrumentation tubing, (63) packaged control systems, (67) control and relief valves, and (68) calibration testing.
- **7 – Electrical equipment category:** (71) switchgear, (72) transformers, (73) bus duct, (74) DC equipment, (75) motor control centres, (76) other electrical equipment, (77) miscellaneous electrical equipment, and (78) switchyard equipment.
- **8 – Electrical bulks category:** (81) cable tray, (82) scheduled conduit, (83) other conduit, (84) scheduled wire and cable, (85) scheduled connections, and (86) other wire and cable.
- **9 – Specialty materials and equipment category:** plant-specific materials and equipment unique to other plants such as fuel fabrication, fuel reprocessing, hydrogen generation or desalination.

Using these codes, “1A212.1” refers to the cost of concrete for “Reactor Building Civil Structures” for the first reactor at a site. “1A212” refers to the cost of “Reactor Building Civil Structures” for the first reactor. “1A21” refers to the cost of all “Structures and improvements” for the first reactor. “1A2” refers to plant equipment for the first reactor. lA refers to all costs for the first reactor.

In the GIF-COA system structure, the 20 series is reserved for the direct costs of construction, for on-site labour, materials and equipment. The IAEA account system (IAEA, 2000) does not include labour in the 20 series of accounts, but included labour-hours in an indirect account. For the GIF-COA, labour is included in the direct costs to obtain greater understanding and integrity of subsystem costs across countries. The direct labour component includes the labour costs of “hands-on” craft (up to supervisor) employees. The category does not include *indirect* employees (non-manual labour) such as superintendents, field engineers, architects and engineers, reactor-vendor home office staff or construction services staff. These employees are included in the “Support Services” Accounts 30. Subcontract cost and labour should be included in the 20 series if they are for the direct scope of work. Craft labour providing common support of construction such as temporary lighting, warehousing and clean-up is included in Account 31, Field Indirect Costs.

At the two-digit level (GIF-COA 20), this GIF format should fit most nuclear energy system technologies and be useable for top-down estimates. The three-digit categories below (beneath each two-digit header) indicate where the more detailed cost items should be grouped. The three-digit definitions are as generic as possible, although most are based on the pressurised water reactor (PWR) COA dictionary in the original Energy Economic Database (EEDB) documents (ORNL, 1988). Engineering judgement can be used to assign non-PWR systems, such as circulating helium in a gas-cooled reactor, to GIF-COA accounts with functions similar to those in the PWR (for example Account 25, Heat Rejection System). Annex I of the IAEA document (IAEA, 2000) gives a “dictionary” of accounts at the three-digit level (nearly 30 pages long) and differs somewhat from the United States (ORNL, 1988) practice in the abbreviated three-digit definitions. At the two-digit level, all 20 accounts match the modified IAEA account system.

Annex D. Nuclear power plant construction cost allocation to the North American Industrial Classification System (NAICS) and to International Standard Industrial Classification (ISIC) industries

An implementation of the Generation IV International Forum (GIF)/Economics Modeling Working Group (EMWG) Code of Accounts (COA), referenced in Section 2.1 above, can be found in ORNL (2011) as applied to a generic Westinghouse PWR-12 with 1 147 MWe. The following tables use the GIF-COA to organise the *direct* and *indirect* (those not attributable to a direct cost category) construction costs for the PWR-12. In the ORNL (2011) report, these costs are then modified to estimate the cost of an advanced high-temperature reactor (AHTR), fluoride-salt-cooled high-temperature reactor (FHR), to incorporate size and design differences between the PWR12 and the AHTR. As noted in the ORNL (2011) report, the cost estimates presented below are based on PWR-12 construction costs in the late 1980s, updated to 2011 USD, and do not explicitly incorporate the history of increased costs experienced by the nuclear power industry since then. As a result, the costs indicated in the following figures are likely to be conservative. They do, however, represent one of the few, recent publicly available costs estimates for conventionally sized NPPs and are presented here for purposes of illustrating the use of the GIF-COA framework in estimating the economic impacts of NPP construction and operation. To do so, it is important to note that the cost estimates from new nuclear plant development constitute expenditures that can be entered into an input/output (I/O) model. In the tables below, each three-digit GIF-COA lists several types of expenditures that can be summed to yield the three-digit GIF-COA total expenditure (Table D.1, note: the names of some components were changed from ORNL, 2011, so when alphabetised, relevant systems would be listed together). Once these expenditures are estimated, each can be assigned an industry code (NAICS) for the appropriate I/O model used (Table D.2) and summed (Tables E.3 and E.4). The GIF-COA framework can be modified to reflect different reactor size or design. For example, this method was used to calculate cost and employment for small modular reactors in Black and Peterson (2014).

Table D.1. PWR-12 cost breakdown using the GIF/EMWG COA

(in USD_{2011} thousands)

COA	General description	Component	Cost
20	Capitalised direct costs		2 170 984
21	Structures and improvements		481 786
22	Reactor plant equipment		727 316
23	Turbine plant equipment		537 068
24	Electric plant equipment		195 175
25	Heat rejection system		117 554
26	Miscellaneous plant equipment		112 085
30	Capitalised indirect costs (not in COA 20)		1 322 537
	Base construction costs		3 493 513
40	Capitalised owner's cost (assumed)		300 000
50	Contingency (10%)		379 000
	Overnight construction cost		4 173 000
	Overnight construction cost/kWe	Size of plant: 1 147 MWe	3 638

Table D.1. PWR-12 labour and other costs breakdown using the GIF/EMWG COA *(cont'd)*

(in USD_{2011} thousands)

COA	General description	Component	Labour	Other
21	Structures and improvements	Total cost	272 432	209 354
211	Site preparation/yard work	Total	34 810	25 172
		Earthwork plus excavation work	1 822	881
		Roads, walks and parking areas	1 761	1 951
		Fencing and gates	251	267
		Sanitary sewer facilities	2 241	1 061
		Yard drainage storm sewers	1 081	2 383
		Roadway and yard lighting	962	776
		Settling basins	204	372
		Railroads	3 653	3 391
		Structure associated open cut	11 600	4 013
		Structure associated fill/backfill	11 236	10 078
212	Reactor building	Total	85 504	70 102
		Substructure concrete	6 385	6 083
		Containment shell	14 861	8 344
		Containment dome	6 011	3 479
		Interior concrete	24 960	13 692
		Removable plugs	438	178
		Structural and misc. steel	1 744	2 949
		Containment liner	19 404	29 914
		Painting	6 622	1 883
		Plumbing and drains	626	320
		Heating, ventilation and air conditioning (HVAC)	40	188
		HVAC (safety-related)	2 302	1 824
		Lighting and service power	2 040	1 031
		Elevator	70	218
213	Turbine generator building	Total	26 814	28 751
		Substructure concrete	8 238	4 293
		Superstructure	14 237	21 667
		Plumbing and drains	2 362	707
		HVAC	1 043	1 456
		Lighting and service power	874	412
		Elevator	58	217
214	Security building	Total	2 262	1 006
		Substructure concrete	134	79
		Superstructure	1 427	593
		Building services	701	335

Table D.1. PWR-12 labour and other costs breakdown using the GIF/EMWG COA *(cont'd)*

(in USD_{2011} thousands)

COA	General description	Component	Labour	Other
215	Reactor services building	Total	25 248	19 086
		Substructure concrete	936	795
		Superstructure	18 142	9 140
		Plumbing and drains	1 019	289
		HVAC	3 910	7 209
		HVAC (special)	258	948
		Lighting and service power	874	361
		Elevator	110	344
216	Radioactive waste building	Total	21 657	12 825
		Substructure concrete	1 953	1 496
		Superstructure	16 546	8 792
		Plumbing and drains	836	192
		HVAC	1 627	1 738
		Lighting and service power	583	258
		Elevator	111	349
217	Fuel service building	Total	10 812	12 898
		Substructure concrete	2 964	6 832
		Superstructure	6 443	3 156
		Plumbing and drains	249	150
		HVAC	853	465
		HVAC (special)	99	2 193
		Lighting and service power	204	103
218	Other buildings	Total	65 324	39 514
		Earthwork plus excavation work	758	439
		Substructure concrete	5 781	3 703
		Superstructure	45 031	25 443
		Elevator	29	94
		Plumbing and drains	3 480	1 314
		HVAC and HVAC (special)	7 239	7 123
		Lighting and service power	2 700	1 186
		Building services	304	212

Table D.1. PWR-12 labour and other costs breakdown using the GIF/EMWG COA *(cont'd)*

(in USD_{2011} thousands)

COA	General description	Component	Labour	Other
22	Reactor plant equipment	Total cost	117 593	609 723
221	Reactor equipment	Total	9 033	188 374
		Reactor supports (field cost)	1 220	2 074
		Reactor vessel structure (NSSS allocation)	0	68 867
		Reactor vessel structure (Field costs)	5 389	539
		Reactor lower internals (NSSS allocation)	0	25 825
		Reactor lower internals (Field cost)	794	79
		Reactor upper internals (NSSS allocation)	0	25 825
		Reactor upper internals (Field cost)	511	51
		Transport to site	0	13 292
		Control rods (NSSS allocation)	0	25 825
		Control rod drives (NSSS allocation)	0	25 825
		Control rod drives (field cost)	970	97
		Control rod drive missile shield (field cost)	111	11
		Control rod drive mechanism seismic supports (field cost)	39	64
222	Main heat transport system	Total	15 282	137 599
		Pumps, main coolant (NSSS allocation)	0	38 737
		Fluid circulation drive (Field cost)	3 684	3 553
		Piping, reactor coolant (NSSS allocation)	0	19 369
		Piping, reactor coolant (Field cost)	9 586	4 644
		Steam generators (NSSS allocation)	0	51 650
		Steam generator equipment (field cost)	1 774	241
		Pressurizer (NSSS allocation)	0	12 912
		Pressurising system (field cost)	237	36
		Pressurizer relief tank (NSSS allocation)	0	6 456
223	Safety systems	Total	13 154	81 208
		Pumps and drives, residual heat removal (NSSS)	0	12 912
		Heat exchanger, residual heat removal (NSSS)	0	12 912
		Heat exchanger, residual heat removal (field cost)	2 954	2 782
		Pumps and drives, safety injection system (NSSS)	0	12 912
		Pumps and drives, safety injection system (Field costs)	4 791	3 955
		Accumulator tank (NSSS allocation)	0	6 456
		Boron injection tank (NSSS allocation)	0	19 368
		Containment spray system	4 933	7 790
		Combustible gas control system	476	2 118

NSSS = Nuclear steam supply system.

Table D.1. PWR-12 labour and other costs breakdown using the GIF/EMWG COA *(cont'd)*

(in USD_{2011} thousands)

COA	General description	Component	Labour	Other
224	Radioactive waste system	Total	9 631	40 631
	Liquid waste stream	Waste train, liquid equipment	5 050	7 602
		Waste train, liquid, miscellaneous	478	4 396
		Waste train, liquid, detergent	55	1 205
		Waste train, liquid, chemical	6	23
		Steam generator blowdown, liquid waste	1 859	2 437
		Waste train, regenerated chemical liquids	563	3 188
		Radwaste equipment, miscellaneous	17	62
		Waste, instrumentation and controls	81	300
	Gas waste stream	Radwaste, gaseous (tritium) waste system	418	3 246
	Solid waste stream	Radwaste, solid, active dry volume reduction	41	436
		Waste, solid volume reduction system	1 063	17 737
225	Fuel handling systems	Total	2 059	27 063
		Fuel handling tools and racks (NSSS allocation)	0	21 521
		Fuel handling tools and equipment	928	2 463
		Fuel handling service platforms	73	253
		Fuel storage, cleaning and inspection equipment	1 058	2 826
226	Other reactor plant equipment	Total	39 682	72 462
		Reactor inert gas system	1 131	1 845
		Reactor makeup water system	1 317	2 265
		Reactor coolant treatment system	0	19 369
		Reactor chemical and volume control system	11 968	9 348
		Boron recycle system	3 717	9 308
		Reactor fluid leak detection system	40	375
		Reactor service water system	13 047	13 802
		Reactor primary component cooling water	7 694	11 948
		Reactor maintenance equipment (NSSS and field cost)	164	3 263
		Reactor sampling equipment	603	939

NSSS = Nuclear steam supply system.

Table D.1. PWR-12 labour and other costs breakdown using the GIF/EMWG COA *(cont'd)*

(in USD_{2011} thousands)

COA	General description	Component	Labour	Other
227	Reactor I&C	Total	18 497	54 756
		NSSS control board	867	2 506
		Heating, ventilation and air conditioning panels	133	207
		Radwaste panels	520	863
		Logic panels	520	827
		Instrument racks	405	1 078
		Alarm system	145	577
		Process computer	829	6 980
		Radiological monitoring	578	2 313
		Neutron monitoring	809	2 643
		Instrumentation for accident monitoring	87	319
		Reactor diagnostic system	289	1 048
		Containment atmosphere monitoring	289	486
		Containment leak monitor	145	250
		Failed fuel detection	133	226
		Reactor power control	578	2 024
		Reactor protection system	723	2 431
		Engineered safety feature actuation system	463	1 422
		Standard NSSS valve package	0	21 521
		Reactor plant instrumentation and control tubing	8 094	1 271
		TMI instrumentation	2 891	5 764
228	Reactor plant misc. items	Total	10 255	7 630
		Field painting	1 191	387
		Qualification of welders	6 079	911
		Pipe insulation	1 553	2 510
		Equipment insulation	299	919
		NSSS Insulation	1 135	2 903

I&C= Instrumentation and controls, NSSS = Nuclear steam supply system, TMI = post-Three Mile Island requirements.

Table D.1. PWR-12 labour and other costs breakdown using the GIF/EMWG COA *(cont'd)*

(in USD_{2011} thousands)

COA	General description	Component	Labour	Other
23	Turbine plant equipment	Total cost	100 711	436 358
231	Turbine generator(s)	Total	18 317	303 246
		Turbine generator	0	294 887
		Turbine generator, other	10 455	1 045
		Turbine generator, associated piping	334	55
		Turbine generator pedestal	3 966	1 740
		Turbine generator reheater/moisture separator drain system and supports	2 354	3 814
		Turbine generator lubricating oil system	414	903
		Turbine generator hydrogen storage system	482	486
		Turbine generator CO_2 storage system	312	316
232		There is no 232 in the GIF COA		
233	Condensing systems	Total	19 342	50 214
		Condenser equipment	4 651	27 105
		Condensate system	13 473	15 440
		Condenser gas removal system	868	1 789
		Turbine bypass system	0	579
		Condensate polishing	350	5 301
234	Feed heating system	Total	17 113	39 500
		Feed water heaters	1 438	10 275
		Feed water system	11 250	22 694
		Feed water steam extraction system	1 928	2 200
		Feed water heater vent and drain system	2 497	4 331
235	Other turbine plant equipment	Total	23 859	29 717
		Turbine main vapour piping system	15 848	16 676
		Turbine auxiliaries	40	24
		Turbine closed cooling water system	4 812	6 972
		Turbine demineralised water makeup system	2 344	4 901
		Turbine chemical treatment system	66	173
		Turbine neutralisation system	749	971
236	Turbine-Gen. I&C	Total	11 020	5 430
		Turbine process I&C equipment	2 636	4 126
		Turbine plant instrumentation and control tubing	8 383	1 304
237	Turbine plant misc. items	Total	11 060	8 250
		Field painting	2 516	665
		Qualification of welders	3 648	546
		Turbine plant insulation	4 896	7 039

Table D.1. PWR-12 labour and other costs breakdown using the GIF/EMWG COA *(cont'd)*

(in USD_{2011} thousands)

COA	General description	Component	Labour	Other
24	Electric plant equipment	Total cost	83 451	111 723
241	Switchgear	Total	1 449	27 222
	Generator equipment	Generator load break switch	73	3 091
		Generator neutral grounding equipment	81	16
		Transformer: generator current and potential	46	64
	Station service	Switchgear: 13.8 kV (non-class 1E)	184	7 881
		Switchgear: 4.16 kV (non-class 1E)	115	4 031
		Switchgear: 4.16 kV (class 1E)	184	7 977
		Diesel generator sequence logic panels	75	621
		Switchgear: 480 V motor control (non-class 1E)	345	1 877
		Switchgear: 480 V motor control (class 1E)	345	1 664
242	Station service equipment	Total	3 856	44 536
		Transformers: start-up	605	5 346
		Switchgear: load centre (non-class 1E)	656	3 725
		Switchgear: load centre (class 1E)	368	2 359
		Transformers: load centre (non-class 1E)	49	1 017
		Transformers: load centre (class 1E)	25	607
		Transformers: miscellaneous	75	71
		Switchgear: batteries (non-class 1E)	74	249
		Switchgear: batteries (class 1E)	148	298
		Switchgear: charger (non-class 1E)	43	133
		Switchgear: charger (class 1E)	72	215
		Diesel generator systems emergency	1 321	29 198
		Diesel generator systems emergency TMI	288	991
		Switchgear: inverters (non-class 1E)	6	207
		Switchgear: inverters (class 1E)	124	118
243	Switchboards	Total	847	4 071
		Generator/auxiliary power system control panel	288	962
		Generator protective relay panel	219	724
		Switchgear: technical and on-site system control panels	86	1 634
		Switchgear: AC distribution (non-class 1E)	18	34
		Switchgear: AC distribution (class 1E)	30	72
		Switchgear: DC distribution (non-class 1E)	20	99
		Switchgear: DC distribution (class 1E)	81	320
		Switchgear: misc. buttons panels and fuses	105	225

Table D.1. PWR-12 labour and other costs breakdown using the GIF/EMWG COA *(cont'd)*

(in USD_{2011} thousands)

COA	General description	Component	Labour	Other
244	Protective service equipment	Total	5 982	4 245
		Protection: general station grounding system	4 353	1 636
		Protection: lightning	178	176
		Protection: cathodic	868	824
		Protection: heat tracing and freeze	583	1 609
245	Electrical raceway systems	Total	43 156	10 368
		Conduit: underground ducts (non-class 1E)	1 665	692
		Conduit: underground ducts (class 1E)	5 740	2 347
		Conduit: cable tray	7 480	3 094
		Conduit: miscellaneous	28 271	4 236
246	Power and control cables and wiring	Total	28 161	21 281
		Wiring and cables: generator circuits wiring	1 317	2 252
		Wiring and cables: station service power	3 519	2 969
		Wiring and cables: control cable	11 839	7 904
		Wiring and cables: instrument wire	10 651	6 393
		Wiring and cables: containment penetrations	835	1 762
25	Heat rejection system	Total cost	36 672	80 882
251	Heat rejection structures	Total	6 437	3 961
		Cooling: makeup water intake structure	1 537	912
		Cooling: circulating water pump house structure	3 183	1 336
		Cooling: circulating water pump house services	201	302
		Cooling: makeup water pre-treat. building	1 238	1 172
		Cooling: makeup water pre-treat. building services	279	241
252	Heat rejection equipment	Total	30 235	76 921
		Cooling: water intake equipment	230	883
		Cooling: circulating water system	11 700	21 778
		Cooling towers	17 792	51 287
		Cooling tower basins	99	98
		Cooling tower makeup/blowdown system	414	2 875

Table D.1. PWR-12 labour and other costs breakdown using the GIF/EMWG COA *(cont'd)*

(in USD_{2011} thousands)

COA	General description	Component	Labour	Other
26	Miscellaneous equipment	Total cost	54 414	57 671
261	Transportation and lift equipment	Total	2 039	12 347
		Cranes: overhead in turbine building	350	3 089
		Cranes in heater bay	146	1 236
		Cranes in reactor containment building	993	6 207
		Cranes: misc. with hoists and monorails	467	780
		Cranes in diesel building	82	1 034
262	Air, water, plant fuel oil and steam services	Total	37 373	31 568
		Misc. system: compressed air	3 206	1 549
		Containment bldg. instrument air system	6 139	2 847
		Service water system	4 668	5 093
		Fire protection system	17 654	14 528
		Misc. system: potable water system	1 150	1 391
		Boiler, auxiliary system	1 657	2 973
		Boiler, auxiliary feed water system	54	166
		Fuel oil system, auxiliary	30	31
		Aerator and makeup system, auxiliary	59	155
		Chemical feed system, auxiliary	27	52
		Condensate and steam return, auxiliary	2 304	2 154
		Boiler blowdown, auxiliary	9	41
		Steam system complete I&C, auxiliary	202	351
		Fuel oil system, plant	214	237
263	Communications equipment	Total	9 296	6 101
		Communication: telephone system	262	158
		Communication: public address and intercom	1 166	479
		Fire detection system communications	2 623	1 339
		Security system communications	5 245	4 125
264	Furnishings and fixtures	Total	1 206	5 360
		Safety equipment	16	34
		Chemical laboratory shop	422	2 610
		Furnishings and office equipment	9	316
		Furnishings: change room equipment	51	366
		Environmental monitoring equipment	657	1 591
		Furnishings: dining facilities	51	442
265	Wastewater treatment equipment	Wastewater treatment equipment	4 500	2 295

Table D.1. PWR-12 labour and other costs breakdown using the GIF/EMWG COA *(cont'd)*

(in USD_{2011} thousands)

COA	General description	Component	Labour	Other
30	Capitalised indirect services	Total cost	239 437	1 083 101
31	Design of plant at home office	Design of plant at home office, total	0	482 090
32	Management at home office	Management at home office, including quality assurance, total	0	28 490
33	Design services in field	Design services in field, assumed to be	0	0
34	Construction management	Total	5 321	14 626
		Construction management cost	0	14 626
		Construction site labour costs	5 321	0
35	Field construction supervision	Total	16 282	175 006
		Construction management cost	0	175 006
		Construction site labour costs	16 282	0
36	Field indirect costs	Total	217 834	355 848
		Construction: buildings, temp.: labour	63 725	0
		Construction: buildings, temp.: materials	0	10 226
		Construction: buildings, temp. facilities: labour	133 846	0
		Construction buildings, temp. facilities: materials	0	36 958
		Construction equip., major: labour	17 664	0
		Construction equip., major: materials	0	69 175
		Construction equip., small tools: labour costs	571	0
		Construction equip., small tools: materials	0	15 293
		Construction: expendable materials	0	19 327
		Construction safety equip. inspection labour	571	0
		Construction safety equip.: materials	0	823
		Construction permits, insurance and local taxes	0	27 156
		Construction field office labour expenses	1 457	0
		Construction field office materials expenses	0	27 629
		Construction payroll insurance and taxes	0	149 261
37	Plant commissioning	Plant commissioning, total	0	27 041

Table D.2. Translating PWR-12 GIF/EMWG COA cost breakdown into NAICS codes

COA	Component	NAICS Industry	CODE
223	Accumulator tank (NSSS allocation)	Metal tank (heavy gauge) manufacturing	332420
262	Aerator and makeup system, auxiliary	Metal tank (heavy gauge) manufacturing	332420
227	Alarm system	Measuring and controlling device manufacturing	334519
262	Boiler blowdown, auxiliary	Power boiler and heat exchanger manufacturing	332410
262	Boiler, auxiliary feed water system	Power boiler and heat exchanger manufacturing	332410
262	Boiler, auxiliary system	Power boiler and heat exchanger manufacturing	332410
223	Boron injection system (NSSS allocation)	Power boiler and heat exchanger manufacturing	332410
226	Boron recycle system	Power boiler and heat exchanger manufacturing	332410
210	Building services	Power and related structures construction	237130
262	Chemical feed system, auxiliary	Metal tank (heavy gauge) manufacturing	332420
264	Chemical laboratory shop	Instruments and related products manufacturing	334513
223	Combustible gas control system	Instruments and related products manufacturing	334513
263	Communication: public address and intercom	Electrical and other wiring installation contractors	238210
263	Communication: telephone system	Electrical and other wiring installation contractors	238210
212	Concrete, interior	Concrete, poured structure contractors	238110
262	Condensate and steam return, auxiliary	Power boiler and heat exchanger manufacturing	332410
233	Condensate polishing	Power boiler and heat exchanger manufacturing	332410
233	Condensate system	Power boiler and heat exchanger manufacturing	332410
233	Condenser equip	Power boiler and heat exchanger manufacturing	332410
233	Condenser gas removal system	Power boiler and heat exchanger manufacturing	332410
245	Conduit: cable tray	Noncurrent-carrying wiring device manufacturing	335932
245	Conduit: miscellaneous	Noncurrent-carrying wiring device manufacturing	335932
245	Conduit: underground ducts (class 1E)	Noncurrent-carrying wiring device manufacturing	335932
245	Conduit: underground ducts (non-class 1E)	Noncurrent-carrying wiring device manufacturing	335932
360	Construction buildings, temp. facilities: materials	Labour, contracted	561320
360	Construction equip, major: labour	Labour, contracted	561320
360	Construction equip, major: materials	Power and related structures construction	237130
360	Construction equip, small tools: labour costs	Labour, contracted	561320
360	Construction equip, small tools: materials	Power and related structures construction	237130
360	Construction field office labour expenses	Labour, contracted	561320
360	Construction field office materials expenses	Power and related structures construction	237130
300	Construction management cost	Engineering services	541330
360	Construction payroll insurance and taxes	Insurance funds, other	525190
360	Construction permits, insurance and local taxes	Public finance activities (local)	921130
360	Construction safety equip: inspection	Labour, contracted	561320
360	Construction safety equip: materials	Power and related structures construction	237130
300	Construction site labour costs	Labour, contracted	561320
360	Construction: buildings, temporary facilities: labour	Labour, contracted	561320
360	Construction: buildings, temporary: labour	Labour, contracted	561320
360	Construction: buildings, temporary: materials	Power and related structures construction	237130
360	Construction: expendable materials	Power and related structures construction	237130

Table D.2. Translating PWR-12 GIF/EMWG COA cost breakdown into NAICS codes *(cont'd)*

COA	Component	NAICS Industry	CODE
227	Containment atmosphere monitoring	Measuring and controlling device manufacturing	334519
262	Containment building instrument air system	Measuring and controlling device manufacturing	334519
212	Containment dome	Power and related structures construction	237130
212	Containment liner	Structural steel, fabricated, manufacturing	332312
212	Containment shell	Structural steel and precast concrete contractors	238120
223	Containment spray system	Industrial heating and cooling equipment manufacturing	333415
221	Control rod drive mechanism seismic supports (field cost)	Power boiler and heat exchanger manufacturing	332410
221	Control rod drive missile shield (field cost)	Power boiler and heat exchanger manufacturing	332410
221	Control rod drives (field cost)	Power boiler and heat exchanger manufacturing	332410
221	Control rod drives (NSSS allocation)	Power boiler and heat exchanger manufacturing	332410
221	Control rods (NSSS allocation)	Power boiler and heat exchanger manufacturing	332410
252	Cooling tower basins	Industrial heating and cooling equipment manufacturing	333415
252	Cooling tower makeup/blowdown system	Industrial heating and cooling equipment manufacturing	333415
252	Cooling towers	Industrial heating and cooling equipment manufacturing	333415
251	Cooling: circulating water pump house services	Pump and pumping equipment manufacturing	333911
251	Cooling: circulating water pump house structure	Power and related structures construction	237130
252	Cooling: circulating water system	Pump and pumping equipment manufacturing	333911
251	Cooling: makeup water intake structure	Pump and pumping equipment manufacturing	333911
251	Cooling: makeup water pre-treatment building	Pump and pumping equipment manufacturing	333911
251	Cooling: makeup water pre-treatment building services	Pump and pumping equipment manufacturing	333911
252	Cooling: water intake equip	Pump and pumping equipment manufacturing	333911
261	Cranes in diesel building	Crane, hoist and overhead travelling system manufacturing	333923
261	Cranes in heater bay	Crane, hoist and overhead travelling system manufacturing	333923
261	Cranes in reactor containment building	Crane, hoist and overhead travelling system manufacturing	333923
261	Cranes: misc. with hoists and monorails	Crane, hoist and overhead travelling system manufacturing	333923
261	Cranes: overhead in turbine building	Crane, hoist and overhead travelling system manufacturing	333923
310	Design of plant at home office, total	Engineering services	541330
330	Design services in field, total	Engineering services	541330
241	Diesel generator sequence logic panels	Instruments and related products manufacturing	334513
242	Diesel generator systems, emergency	Turbine and turbine generator set manufacturing	333611
242	Diesel generator systems, emergency TMI	Turbine and turbine generator set manufacturing	333611
210	Earthwork plus excavation work	Site preparation contractors	238910
210	Elevator	Elevator and moving stairway manufacturing	333921
227	Engineered safety feature actuation system	Measuring and controlling device manufacturing	334519
264	Environmental monitoring equipment	Instruments and related products manufacturing	334513
228	Equipment insulation	Building equipment contractors, other	238290
227	Failed fuel detection	Measuring and controlling device manufacturing	334519
234	Feed water heater vent and drain system	Pipe, iron and steel pipe and tube manufacturing	331210
234	Feed water heaters	Water treatment equipment manufacturing	333318
234	Feed water steam extraction system	Water treatment equipment manufacturing	333318
234	Feed water system	Pump and pumping equipment manufacturing	333911

Table D.2. Translating PWR-12 GIF/EMWG COA cost breakdown into NAICS codes *(cont'd)*

COA	Component	NAICS Industry	CODE
211	Fencing and gates	Chain link fencing and fence gates	332618
263	Fire detection system, communications	Electrical and other wiring installation contractors	238210
262	Fire protection system	Fire detection and alarm systems manufacturing	334290
222	Fluid circulation drive (field cost)	Plumbing and HVAC contractors	238220
262	Fuel oil system, auxiliary	Metal tank (heavy gauge) manufacturing	332420
262	Fuel oil system, plant	Metal tank (heavy gauge) manufacturing	332420
225	Fuel storage, cleaning and inspection equipment	Measuring and controlling device manufacturing	334519
264	Furnishings and office equipment	Office furniture manufacturing	337214
264	Furnishings: change room equipment	Office furniture manufacturing	337214
264	Furnishings: dining facilities	Office furniture manufacturing	337214
241	Generator load break switch	Switchgear and switchboard apparatus manufacturing	335313
241	Generator neutral grounding equipment	Switchgear and switchboard apparatus manufacturing	335313
243	Generator protective relay panel	Switchgear and switchboard apparatus manufacturing	335313
243	Generator/auxiliary power system control panel	Switchgear and switchboard apparatus manufacturing	335313
223	Heat exchanger, residual heat removal (field cost)	Power and related structures construction	237130
223	Heat exchanger, residual heat removal (NSSS)	Power boiler and heat exchanger manufacturing	332410
210	HVAC	Plumbing and HVAC contractors	238220
212	HVAC (safety-related)	Plumbing and HVAC contractors	238220
210	HVAC (special)	Plumbing and HVAC contractors	238220
227	HVAC panels	Measuring and controlling device manufacturing	334519
227	Instrument racks	Measuring and controlling device manufacturing	334519
227	Instrumentation for accident monitoring	Measuring and controlling device manufacturing	334519
210	Lighting and service power	Electrical and other wiring installation contractors	238210
227	Logic panels	Measuring and controlling device manufacturing	334519
320	Management at home office, Including QA	Engineering services	541330
262	Misc. system: compressed air	Air compressors manufacturing	333912
262	Misc. system: potable water system	Water treatment equipment manufacturing	333318
227	Neutron monitoring	Measuring and controlling device manufacturing	334519
227	NSSS control board	Measuring and controlling device manufacturing	334519
228	NSSS Insulation	Building equipment contractors, other	238290
200	Painting, field	Painting engineered structures	238320
228	Pipe insulation	Building equipment contractors, other	238290
222	Piping, reactor coolant (field cost)	Power and related structures construction	237130
222	Piping, reactor coolant (NSSS allocation)	Pipe, iron and steel pipe and tube manufacturing	331210
370	Plant commissioning	Scientific and Technical Consulting Services	541690
210	Plumbing and drains	Metal products, all other misc. fabricated manufacturing	332999
222	Pressurising system (field cost)	Power and related structures construction	237130
222	Pressurizer (NSSS allocation)	Power boiler and heat exchanger manufacturing	332410
222	Pressurizer relief tank (NSSS allocation)	Metal tank (heavy gauge) manufacturing	332420
227	Process computer	Measuring and controlling device manufacturing	334519

Table D.2. Translating PWR-12 GIF/EMWG COA cost breakdown into NAICS codes *(cont'd)*

COA	Component	NAICS Industry	CODE
244	Protection: cathodic	Electrical equipment and components, all other, manufacturing	335999
244	Protection: general station grounding system	Electrical equipment and components, all other, manufacturing	335999
244	Protection: heat tracing and freeze	Electrical equipment and components, all other, manufacturing	335999
244	Protection: lightning	Electrical equipment and components, all other, manufacturing	335999
223	Pumps and drives, residual heat removal (NSSS)	Pump and pumping equipment manufacturing	333911
223	Pumps and drives, safety injection system (field cost)	Pump and pumping equipment manufacturing	333911
223	Pumps and drives, safety injection system (NSSS)	Pump and pumping equipment manufacturing	333911
200	Qualification of welders	Welding, on-site, contractors	238190
227	Radiological monitoring	Measuring and controlling device manufacturing	334519
224	Radwaste equipment, miscellaneous	Other industrial machinery manufacturing	333249
227	Radwaste panels	Measuring and controlling device manufacturing	334519
224	Radwaste, gaseous (tritium) waste system	Other industrial machinery manufacturing	333249
224	Radwaste, solid, active dry volume reduction	Other industrial machinery manufacturing	333249
211	Railroads (hardware)	Heavy and other civil engineering construction	237990
226	Reactor chemical and volume control system	Instruments and related products manufacturing	334513
226	Reactor coolant treatment system	Water treatment equipment manufacturing	333318
227	Reactor diagnostic system	Measuring and controlling device manufacturing	334519
226	Reactor fluid leak detection system	Instruments and related products manufacturing	334513
226	Reactor inert gas system	Instruments and related products manufacturing	334513
221	Reactor lower internals (field cost)	Power and related structures construction	237130
221	Reactor lower internals (NSSS allocation)	Power boiler and heat exchanger manufacturing	332410
226	Reactor maintenance equip (NSSS and field cost)	Power boiler and heat exchanger manufacturing	332410
226	Reactor makeup water system	Pump and pumping equipment manufacturing	333911
227	Reactor plant I&C tubing	Noncurrent-carrying wiring device manufacturing	335932
227	Reactor power control	Measuring and controlling device manufacturing	334519
226	Reactor primary component cooling water	Pump and pumping equipment manufacturing	333911
227	Reactor protection system	Measuring and controlling device manufacturing	334519
226	Reactor sampling equipment	Instruments and related products manufacturing	334513
226	Reactor service water system	Pump and pumping equipment manufacturing	333911
221	Reactor supports (field cost)	Power and related structures construction	237130
221	Reactor upper internals (field cost)	Power and related structures construction	237130
221	Reactor upper internals (NSSS allocation)	Power boiler and heat exchanger manufacturing	332410
221	Reactor vessel structure (field cost)	Power and related structures construction	237130
221	Reactor vessel structure (NSSS allocation)	Power boiler and heat exchanger manufacturing	332410
212	Removable plugs	Metal products, all other misc. fabricated manufacturing	332999
211	Roads, walks and parking areas	Highway, street and bridge construction	237310
211	Roadway and yard lighting	Electrical and other wiring installation contractors	238210
264	Safety equipment	Instruments and related products manufacturing	334513
211	Sanitary sewer facilities	Water and sewer line and related structures construction	237110
263	Security system, communications	Electrical and other wiring installation contractors	238210

Table D.2. Translating PWR-12 GIF/EMWG COA cost breakdown into NAICS codes *(cont'd)*

COA	Component	NAICS Industry	CODE
262	Service water system	Water treatment equipment manufacturing	333318
211	Settling basins	Power and related structures construction	237130
227	Standard NSSS valve package	Valve, industrial manufacturing	332911
224	Steam generator blowdown, liquid waste	Power boiler and heat exchanger manufacturing	332410
222	Steam generator equipment (field cost)	Power and related structures construction	237130
222	Steam generators (NSSS allocation)	Power boiler and heat exchanger manufacturing	332410
262	Steam system complete I&C, auxiliary	Instruments and related products manufacturing	334513
212	Structural and miscellaneous steel	Structural steel, fabricated, manufacturing	332312
211	Structure associated fill/backfill	Site preparation contractors	238910
211	Structure associated open cut	Site preparation contractors	238910
241	Switchgear: 13.8 kV (non-class 1E)	Switchgear and switchboard apparatus manufacturing	335313
241	Switchgear: 4.16 kV (class 1E)	Switchgear and switchboard apparatus manufacturing	335313
241	Switchgear: 4.16 kV (non-class 1E)	Switchgear and switchboard apparatus manufacturing	335313
241	Switchgear: 480 V motor control (class 1E)	Switchgear and switchboard apparatus manufacturing	335313
241	Switchgear: 480 V motor control (non-class 1E)	Switchgear and switchboard apparatus manufacturing	335313
243	Switchgear: AC distribution (class 1E)	Switchgear and switchboard apparatus manufacturing	335313
243	Switchgear: AC distribution (non-class 1E)	Switchgear and switchboard apparatus manufacturing	335313
242	Switchgear: batteries (class 1E)	Switchgear and switchboard apparatus manufacturing	335313
242	Switchgear: batteries (non-class 1E)	Switchgear and switchboard apparatus manufacturing	335313
242	Switchgear: charger (class 1E)	Switchgear and switchboard apparatus manufacturing	335313
242	Switchgear: charger (non-class 1E)	Switchgear and switchboard apparatus manufacturing	335313
243	Switchgear: DC distribution (class 1E)	Switchgear and switchboard apparatus manufacturing	335313
243	Switchgear: DC distribution (non-class 1E)	Switchgear and switchboard apparatus manufacturing	335313
242	Switchgear: inverters (class 1E)	Switchgear and switchboard apparatus manufacturing	335313
242	Switchgear: inverters (non-class 1E)	Switchgear and switchboard apparatus manufacturing	335313
242	Switchgear: load centre (class 1E)	Switchgear and switchboard apparatus manufacturing	335313
242	Switchgear: load centre (non-class 1E)	Switchgear and switchboard apparatus manufacturing	335313
243	Switchgear: misc. buttons, panels and fuses	Switchgear and switchboard apparatus manufacturing	335313
243	Switchgear: technical and on-site system control panels	Switchgear and switchboard apparatus manufacturing	335313
227	TMI instrumentation	Measuring and controlling device manufacturing	334519
241	Transformer: generator current and potential	Transformers, power and specialty, manufacturing	335311
242	Transformers: load centre (class 1E)	Transformers, power and specialty, manufacturing	335311
242	Transformers: load centre (non-class 1E)	Transformers, power and specialty, manufacturing	335311
242	Transformers: miscellaneous	Transformers, power and specialty, manufacturing	335311
242	Transformers: station service and start-up	Transformers, power and specialty, manufacturing	335311
221	Transport to site	Railroad line-haul	482111
235	Turbine auxiliaries	Turbine and turbine generator set manufacturing	333611
233	Turbine bypass system	Turbine and turbine generator set manufacturing	333611
235	Turbine chemical treatment system	Water treatment equipment manufacturing	333318
235	Turbine closed cooling water system	Water treatment equipment manufacturing	333318
235	Turbine demineralised water makeup system	Water treatment equipment manufacturing	333318

Table D.2. Translating PWR-12 GIF/EMWG COA cost breakdown into NAICS codes *(cont'd)*

COA	Component	NAICS Industry	CODE
231	Turbine generator	Turbine and turbine generator set manufacturing	333611
231	Turbine generator CO_2 storage system	Turbine and turbine generator set manufacturing	333611
231	Turbine generator hydrogen storage system	Turbine and turbine generator set manufacturing	333611
231	Turbine generator lubricating oil system	Turbine and turbine generator set manufacturing	333611
231	Turbine generator pedestal	Turbine and turbine generator set manufacturing	333611
231	Turbine generator reheater/moisture separator drain system and supports	Turbine and turbine generator set manufacturing	333611
231	Turbine generator, associated piping	Pipe, iron and steel pipe and tube manufacturing	331210
231	Turbine generator, other costs	Turbine and turbine generator set manufacturing	333611
235	Turbine main vapour piping system	Pipe, iron and steel pipe and tube manufacturing	331210
235	Turbine neutralisation system	Water treatment equipment manufacturing	333318
236	Turbine plant I&C tubing	Noncurrent-carrying wiring device manufacturing	335932
237	Turbine plant insulation	Building equipment contractors, other	238290
224	Waste train, liquid, chemical	Other industrial machinery manufacturing	333249
224	Waste train, liquid, chemical	Other industrial machinery manufacturing	333249
224	Waste train, liquid, detergent	Other industrial machinery manufacturing	333249
224	Waste train, liquid, detergent	Other industrial machinery manufacturing	333249
224	Waste train, liquid, miscellaneous	Other industrial machinery manufacturing	333249
224	Waste train, liquid, miscellaneous	Other industrial machinery manufacturing	333249
224	Waste train, regenerated chemical liquids	Other industrial machinery manufacturing	333249
224	Waste train, regenerated chemical liquids	Other industrial machinery manufacturing	333249
224	Waste, I&C	Instruments and related products manufacturing	334513
224	Waste, solid volume reduction system	Other industrial machinery manufacturing	333249
265	Wastewater treatment equipment	Water treatment equipment manufacturing	333318
246	Wiring and cables: containment penetrations	Electrical and other wiring installation contractors	238210
246	Wiring and cables: control cable	Electrical and other wiring installation contractors	238210
246	Wiring and cables: generator circuits wiring	Electrical and other wiring installation contractors	238210
246	Wiring and cables: instrument wire	Electrical and other wiring installation contractors	238210
246	Wiring and cables: station service power wiring	Electrical and other wiring installation contractors	238210
211	Yard drainage storm sewers	Water and sewer line and related structures construction	237110

Table D.3. PWR-12 cost breakdown into NAICS industries

(in USD_{2011} thousands)

NAICS Industry	NAICS CODE	Labour	Other	Total	ISIC* CODE
Water and sewer line and related structures construction	237 110	3 322	3 444	6 766	45 20
Power and related structures construction	237 130	36 452	199 812	236 264	45 20
Highway, street and bridge construction	237 310	1 761	1 951	3 712	45 20
Heavy and other civil engineering construction	237 990	3 653	3 391	7 044	45 10
Concrete, poured structure contractors	238 110	51 351	36 973	88 324	45 20
Structural steel and precast concrete contractors	238 120	122 698	80 614	203 312	45 20
Welding, on-site, contractors	238 190	9 727	1 457	11 184	45 20
Electrical and other wiring installation contractors	238 210	45 694	31 508	77 202	45 30
Plumbing and HVAC contractors	238 220	17 371	23 144	40 515	45 20
Building equipment contractors, other	238 290	7 883	13 371	21 254	45 30
Painting of engineered structures	238 320	10 329	2 935	13 264	45 40
Site preparation contractors	238 910	25 416	15 411	40 827	45 20
Pipe, iron and steel pipe and tube manufacturing	331 210	18 679	40 431	59 110	27 10
Structural steel, fabricated, manufacturing	332 312	21 148	32 863	54 011	28 11
Power boiler and heat exchanger manufacturing	332 410	29 106	360 507	389 613	28 13
Metal tank (heavy gauge) manufacturing	332 420	330	13 387	13 717	28 12
Chain link fencing and fence gates	332 618	251	267	518	28 99
Metal products, all other misc. fabricated manufacturing	332 999	9 010	3 150	12 160	25 99
Other industrial machinery manufacturing	333 249	7 691	37 895	45 586	25 99
Water treatment equipment manufacturing	333 318	21 655	53 640	75 295	25 99
Heating and cooling industrial equipment manufacturing	333 415	23 238	62 050	85 288	29 19
Turbine and turbine generator set manufacturing	333 611	19 632	333 983	353 615	31 10
Pump and pumping equipment manufacturing	333 911	48 493	140 558	189 051	29 12
Air Compressors manufacturing	333 912	3 206	1 549	4 755	29 12
Material Handling Equipment manufacturing	333 920	928	2 463	3 391	25 99
Elevator and moving stairway manufacturing	333 921	378	1 222	1 600	29 15
Crane, hoist, etc. overhead travelling system manufacturing	333 923	2 111	12 599	14 710	29 15
Fire detection and alarm systems manufacturing	334 290	17 654	14 528	32 182	31 90
Instruments and related products manufacturing	334 513	18 307	24 258	42 565	33 13
Measuring and controlling device manufacturing	334 519	17 601	59 158	76 759	33 12
Transformers, power and specialty, manufacturing	335 311	800	7 105	7 905	31 10
Switchgear and switchboard apparatus manufacturing	335 313	3 665	37 911	41 576	31 20
Current-carrying wiring device manufacturing	335 931	178	176	354	31 20
Noncurrent-carrying wiring device manufacturing	335 932	59 633	12 944	72 577	31 90
Electrical equipment and components, all other, manufacturing	335 999	5 804	4 069	9 873	32 10
Office furniture manufacturing	337 214	111	1 124	1 235	36 10
Railroad line-haul	482 111	0	13 292	13 292	60 10
Insurance funds, other	525 190	0	149 261	149 261	65 12
Engineering services	541 330	0	700 212	700 212	74 21
Scientific and technical consulting services	541 690	0	27 041	27 041	74 21
Labour, contracted	561 320	239 437	0	239 437	74 29
Public finance activities (local)	921 130	0	27 156	27 156	75 11
Total		904 703	2 588 810	3 493 513	

* Note that the ISIC is far less granular than the NAICS, so translation is imprecise.

Table D.4. PWR-12 cost breakdown into high-level NAICS industries

(in USD_{2011} millions)

General NAICS Industries	NAICS CODE	Cost	Cost/kWe	%
Heavy and civil engineering construction	237	209	182	5.0%
Specialty trade contractors	238	205	179	4.9%
Construction*	23	414	361	9.9%
Fabricated metal product manufacturing	331-332	451	393	10.8%
Machinery manufacturing	333	646	563	15.5%
Computer and electronic product manufacturing	334	98	85	2.3%
Electrical equipment, appliance and component manufacturing	335+337	63	55	1.5%
Manufacturing	33	1 258	1 097	30.1%
Trade and Transportation	48-49	13	12	0.3%
Finance and insurance	52	149	130	3.6%
Professional, scientific and technical services	54	727	634	17.4%
Labour services	56	905	789	21.7%
Services	50	1 781	1 553	42.7%
Public Administration (local)	92	27	24	0.7%
Total Direct and Indirect (indirect costs are those not allocated to a specific construction cost category)		3 494	3 046	83.7%
Owners' costs (site licence)	22	300	262	7.2%
Contingency (10% for a mature design)		379	331	9.1%
Overnight construction cost+		4 173	3 638	100.0%
Interest During Construction with a 6 year lead time (ORNL, 2011, p. 82) and a real cost of capital of 5% (ORNL, 2011, p. 84) following Rothwell (2016, p. 87)	522 292 (ISIC 6592)	907	791	21.7%
Total capital investment cost, TCIC+, GIF EMWG (2007, p. 27)		5 080	4 429	121.7%

* Includes equipment and construction materials cost, all labour has been separated into "labour services".

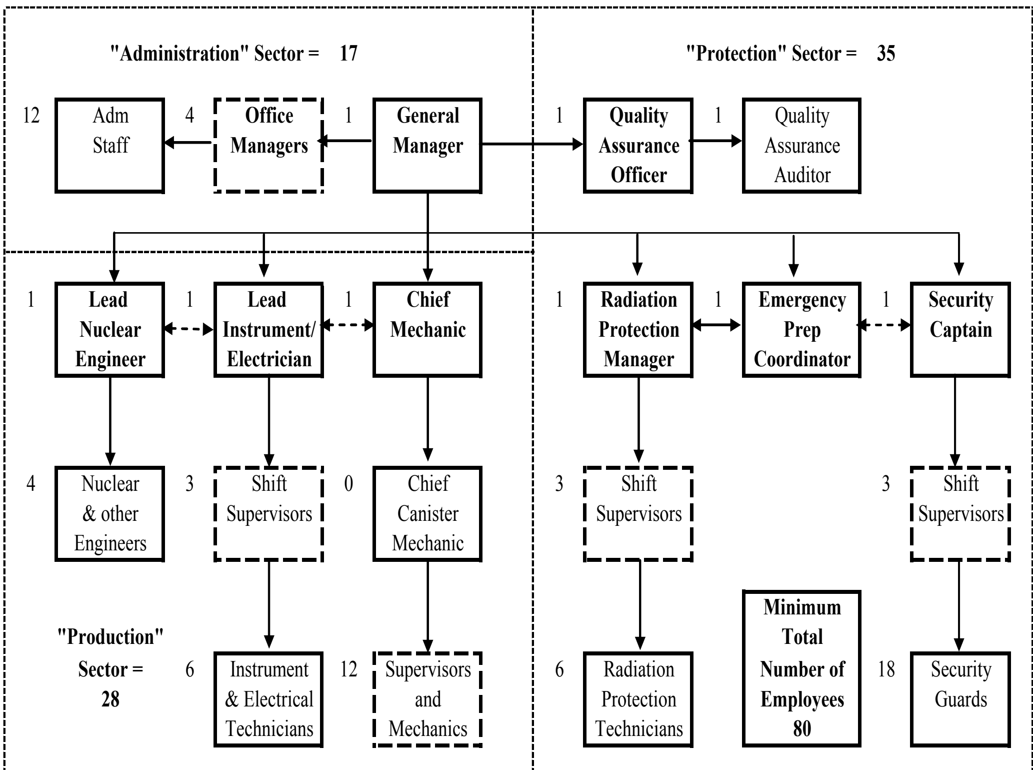
+ Does not include nuclear or diesel fuels.

The cost estimate of this generic Westinghouse (4-loop) PWR-12 with 1 147 MW can be compared to TVA's Watts Bar 1 (1 123 MWe net) or to Watts Bar 2 (1 165 MWe net). Recently, Watts Bar 2 was completed at a reported cost of USD 4 700 million (World Nuclear News, 2016). This cost was approved by the TVA Board of Directors to be entered into TVA's rate base. Common costs with Watts Bar 1 entered TVA's rate base in 1996 with the completion of Watts Bar 1. Therefore, as a function of how one allocates and escalates earlier costs, there are several cost estimates for Watts Bar 2. Given that the purpose of the present exercise has been to determine the allocation of total expenditures to labour and to professional services, users should adjust these results to the anticipated total costs of the nuclear plants that they are assessing. Expenditures on labour and professional services represent 39% of total expenditures (however, not all expenditures on professional services are spent on professional labour; some is spent on office space and equipment, etc.).

Annex E. Independent spent fuel storage installation: organisational chart

An independent spent fuel storage installation (ISFSI) is a facility that is designed and constructed for the interim storage of spent nuclear fuel. These facilities are licensed separately from an NPP and are considered independent even though they might be located on the site of a US Nuclear Regulatory Commission (US NRC)-licensed facility.[1]

Figure E.1. Implicit organisational chart for a centralised spent nuclear fuel storage facility



This annex presents a hypothetical organisational chart and job descriptions of an ISFSI facility (see Rothwell, 2015). They have been sorted by whether they would typically work in 1) the Administration Building, 2) the Security and Health Physics Building, 3) the Operations and Maintenance Building, or 4) the Canister Transfer Building. Salaries, wages, and benefits for employees working in the Canister Transfer building are accounted for in the cask handling charge. Thus, labour and materials (equipment replacement) are assumed to be about USD 13 million per year for each year of operation based on PSFS (1997: 1-6) whether there are any casks on-site. The minimum number of employees is about 80. Job descriptions are from a PSFS website, no longer in existence.

1. See www.nrc.gov/waste/spent-fuel-storage/faqs.html#16.

1. Administration Building

1.1.1. General Manager (GM and Chief Operating Officer)

- Reports to the Board of managers and keeps them advised of facility performance.
- Responsible for managing the facility to ensure the safe and efficient operation and maintenance of the facility; scheduling and procurement necessary of equipment and materials; and developing plans and procedures for facility administration, operation and maintenance.
- Serves as chairperson of both the facility Safety Review Committee and the Operating Review Committee. As such, this person is responsible for assessment of site operations to assure safety.
- Exercises direct control over all facility activities including staffing; document control and storage; training and certification; security facility modifications; procedures for operation and maintenance; equipment inspections, administration and the licensing interface with the US NRC.
- Also responsible for liaison between the facility and local governments for emergency planning and preparedness.

1.1.2. Administrative Staff (reports to General Manager)

- This group includes the administrative assistant, transportation specialist, secretary, public relations coordinator, and financial/purchasing specialist. These positions perform management and clerical services for the facility.

1.2.1. Quality Assurance Officer (reports to General Manager)

- Reports to the GM, but has direct access to the Board of Managers on all quality assurance issues to ensure independence and effectiveness of quality assurance programmes.
- Responsible for assuring that a Quality Assurance (QA) programme that complies with federal regulations is established and executed, including procedures for monitoring, inspection, audits to ensure safety, and compliance with procedures, standards and regulations.

1.2.2. Quality Assurance Auditor (reports to Quality Assurance Officer)

- Reports to the Lead Quality Assurance Technician.
- Responsible for assisting with the administration of the QA programme.

1.3.1. Lead Nuclear Engineer (reports to General Manager)

- This position is the staff technical expert on nuclear engineering and nuclear physics with responsibility for fuel accountability and management.
- Evaluates the performance of facility systems that affect nuclear safety, including criticality safety, fission product confinement, decay heat removal from the spent fuel canisters, and shielding of canisters.
- Reviews all procedural changes and modifications affecting nuclear safety and makes recommendations to the GM. Review facility operating data to identify trends that could potentially affect nuclear safety and performs detailed investigations of abnormalities or unusual occurrences related to spent fuel shipping, canister transfer operations and canister storage.

1.3.2. Nuclear (and Other) Engineers (report to Lead Nuclear Engineer)

- Responsible for compliance with all licences.

1.4.1. Emergency Preparedness Coordinator (reports to General Manager)

- Responsible for ensuring the facility is maintained in a state of readiness for effective emergency response in accordance with the Emergency Plan.
- This position also co-ordinates drills and exercises in which individuals demonstrate the ability to performed assigned emergency response functions.
- This position is also responsible for overall training at the facility, including orientation training; training on operating and maintenance procedures; and radiological training.
- *Must be a qualified radiation protection technician, capable of providing backup support to radiation protections and radiological monitoring functions as needed.*

2. Health Physics and Security Building

2.1.1. Radiation Protection Manager (reports to General Manager)

- Responsible for radiation safety at the facility, including planning and direction of the facility radiation protection programmes and procedures; operating of the health physics laboratory; the technical and functional supervision of the radiation protection technicians; and for the packaging, storage and shipment of solid radioactive waste.
- Responsibilities include routine and special radiation monitoring to ensure that packaging, storage and shipment of SNF complies with applicable regulations; maintaining and monitoring all radiation protection related records for trends that may affect facility operation.
- Authority to order cessation of hazardous work involving radiological materials until the GM is appraised and appropriate precautions are taken.
- Authority to direct emergency procedures to protect employees or the public.

2.1.2. Radiation Protection Technicians (report to Radiation Protection Manager)

- Responsible for monitoring of radiation and environmental conditions and for performing chemical and radiochemical analyses.
- Develop and recommend control or protective measures and check for compliance with procedures.
- Perform periodic and special radiation surveys of facility areas and equipment to define existing or potential hazards, and investigate and report on instances of abnormal contamination or radiation exposure.
- Package and store any solid low-level radioactive waste following regulations.

2.2.1. Security Captain (reports to General Manager)

- Responsible for establishing and maintaining physical security in accordance with the security plan approved by the US NRC. Manages, directs and supervises the security force, and is responsible for training these personnel.

- Responsible for the overall performance of the security force and ensuring that members of the force meet the general criteria for security personnel. This includes screening and interviewing applicants; administering pre-employment tests, background investigations and hiring.
- This position monitors completion of all tasks associated with security alarm systems, communication systems, closed-circuit television systems, and entry control systems; inspects and evaluates security facilities and ensures proper maintenance and functioning.
- This position oversees the involvement of security personnel in implementing the emergency plan and procedures, monitoring storage cask temperatures and reporting alarm conditions to the designated managers.

2.2.2. Security Guards (report to Security Captain)

- Individuals whose security tasks and job duties are directly associated with the effective implementation of the facility physical security and contingency plans must meet physical and mental qualifications required by US NRC regulations, and must be re-qualified at least annually.

3. Operation and Maintenance Building

3.1.1. Chief Mechanic/Operator (reports to General Manager)

- Responsible for proper maintenance and operation of all facility mechanical equipment needed to transport, transfer and store spent fuel canisters, including the shipping, transfer and storage casks, shipping cask trailers and rail cars, and the cranes that handle the equipment.
- Responsible for executing a preventative and predictive maintenance programme.
- Directs the maintenance crew, reviews maintenance records to ensure proper procedures are followed; schedules routine and non-routine maintenance; co-ordinates with all group leaders and engineers, including co-ordination with the Radiation Protection Manager to ensure that radiation doses to mechanics are as low as reasonably achievable.
- *Will be licensed to operate train locomotive and will become certified as a storage facility operator and a certified welder.*

3.2.1. Lead Instrument Technician and Electrician (reports to GM)

- Responsible for proper testing and maintenance of facility instrumentation and electric equipment; and for directing the activities of the instrument and electrical technicians.
- Responsible for ensuring proper procedures are followed; scheduling of non-routine maintenance; executing preventative and routine instrumentation testing and maintenance; and assuring that maintenance logs and records are kept and reviewed.

3.2.2. Instrument and Electrical Technicians (report to Lead Instrument Technician and Electrician)

- Responsible for the repair, testing, maintenance, and approved modification of facility instrumentation and controls, motors, lighting and switchgear.

- Conducts test programmes, prepares check lists and maintains records of activities; maintains adequate spare parts and ensures that electronic, pneumatic and electrical test equipment is functioning properly.

4. Canister Transfer Building

4.1. Canister Transfer Mechanic (reports to Chief Mechanic/Operator)

- Responsible for performing facility operation and maintenance associated with the transport, transfer and storage of spent fuel canisters.
- Responsible for ensuring that operation, maintenance and radiation protection procedures are followed; for maintaining the equipment and maintenance records.

Must become certified facility operator and welder, and licensed locomotive engineer.

Annex F. References

Allan, G. *et al.* (2007), "Impact of alternative electricity generation technologies on the Scottish economy: An illustrative input-output analysis", *Journal of Power and Energy*, Vol. 221 (2), pp. 243-254.

Anindita, R. (2007), "Estimating the economic impact of nuclear power and desalination plant construction in Indonesia", presented at the International Conference on Policy Modeling EcoMod2007, Sao Paulo, Brazil, 11-13 July 2007, http://ecomod.net/sites/default/files/document-conference/ecomod2007/278.pdf.

Applied Economics (2010), "Economic Impacts of Palo Verde Nuclear Generating Station on Arizona", Applied Economics, http://large.stanford.edu/courses/2016/ph241/chandler2/docs/ae-2010.pdf.

Aydin, L. (2011), "Towards a Low Carbon Economy in Turkish Energy Policy: Nuclear and Renewable vs. Fossil Fuelled Plants in Power Generation", Kırıkkale University, http://dergipark.gov.tr/download/article-file/181039.

Beestermöller, R. and U. Fahl (2010), "On the interaction between electricity generation technology formation and climate policy targets – a hybrid CGE modelling approach", presentation at the Modelling Technology and Climate Change Workshop, Kiel Institute for the World Economy (IfW), University of Kiel, 14-15 October 2010.

Biesl, M., I. Ellerdorfer and U. Fahl (2006), "The Contribution of Nuclear Energy to a Sustainable Energy System: Volume 3 in the CASCADE MINTS Project", Energy Research Centre of the Netherlands, https://iea-etsap.org/Applications/CASCADE-MINTS-nuclear-c05085.pdf.

Black, G. (2012), "Estimating the economic impacts of small modular reactors", presented at Platt's 3rd Annual Small Modular Reactors Conference, Arlington, VA, 21 May 2012.

Black, G. and S. Peterson, (2014), "SMR cost assessment for input-output modelling", presented at NEA Group of Experts Workshop on Modelling Employment in the Nuclear Power Sector, Issy-les-Moulineaux, France, 13-14 February, www.oecd-nea.org/ndd/workshops/modenps/presentations/docs/7-black-peterson.pdf.

Böhringer, C., T. Rutherford and W. Wiegard (2003), "Computable general equilibrium analysis: Opening a black box", *ZEW Discussion Paper No. 03*-56, Mannheim.

Böhringer, C., M. Wickart and A. Mueller (2003), "Economic impacts of a premature nuclear phase-out in Switzerland", *Swiss Journal of Economics and Statistics*, Vol. 139 (IV), pp. 461-505.

Bosetti, V. et al. (2006), "WITCH – A World Induced Technical Change Hybrid Model", *University Ca' Foscari of Venice*, Economic Research Paper No. 46/06, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=948382.

Bradish, D. (2014), "Modeling employment in the U.S. nuclear power sector", presented at the NEA Group of Experts Workshop on Modelling Employment in the Nuclear Power Sector, Issy-les-Moulineaux, France, 13-14 February.

Bretschger, L., R. Ramer and L. Zhang (2012), "Economic Effects of a Nuclear Phase-Out Policy: A CGE Analysis", Center of Economic Research at ETH Zurich Economics, Working Paper Series No.12/167.

Cameron, L. and B.C.C. van der Zwaan (2015), "Employment factors for wind and solar energy technologies: A literature review", *Renewable and Sustainable Energy Reviews*, Vol. 45, pp. 160-172.

Dominion Energy, Inc., Bechtel Power Corporation, TLG, Inc. and MPR Associates (2004), "Study of Construction Technologies and Schedules, O&M Staffing and Cost, Decommissioning Costs and Funding Requirements for Advanced Reactor Designs", Volume 1, http://pbadupws.nrc.gov/docs/ML1018/ML101820632.pdf.

EDF Energy (2011), "Hinkley Point C – Development Consent Order Application: Environmental Statement Annex 6", Doc. Ref 4.18.

ERA (2014), "Chapter 11 Social and Economic Considerations", *Draft Environmental Impact Statement*, ERA, www.energyres.com.au/operations/reserves-resources/ranger-3-deeps /draft-environmental-impact-statement.

European Nuclear Economic Forum (2012), "Socio-economic Benefits of the Nuclear Industry in the EU to 2050", European Commission, Energy Directorate, Working Group on Nuclear Energy Opportunities, Sub-Working Group on Competitiveness, EC.

Federal Reserve Bank of St. Louis (2015), Producer Price Index: All Commodities (web page), http://research.stlouisfed.org/fred2/series/PPIACO.

FPL (2007), "Testimony before the Florida Public Service Commission regarding Florida Power & Light Company's Petition to Determine Need for Turkey Point Nuclear Units 6 & 7 Power Plant".

Galinis, A. and M.J. van Leewen (2000), "A CGE model for Lithuania: The future of nuclear energy", *Journal of Policy Modeling*, Vol. 22(6), pp. 691-718, www.sciencedirect.com/ science/article/pii/S0161893898000283.

GIF/EMWG (2008), "Generation IV Excel-based Cost Calculation of Nuclear Systems, version 4.2", www.gen-4.org/gif/jcms/c_42161/g4econs.

GIF/EMWG (2007), *Cost Estimating Guidelines for Generation IV Nuclear Energy Systems*, GIF/EMWG/2007/004, www.gen-4.org/gif/jcms/c_40408/cost-estimating-guidelines-for-generation-iv-nuclear-energy-systems.

Guilhoto, J. et al. (2007), "The oil and gas sector in the Brazilian economy", paper presented at the 16th International Input-Output Conference, Istanbul, Turkey, 2-6 July.

Han, S-Y, S-H Yoob and S-J Kwak (2004), "The role of the four electric power sectors in the Korean national economy: An input-output analysis", *Energy Policy,* Vol. 32, pp. 1531-1543.

IAEA (2015), *Milestones in the Development of a National Infrastructure for Nuclear Power*, IAEA Nuclear Energy Series, No NG-G-3.1 (Rev.1), Vienna.

IAEA (2012), *Project Management in Nuclear Power Plant Construction: Guidelines and Experience*, IAEA, Vienna, www-pub.iaea.org/books/IAEABooks/8759/Project-Management-in-Nuclear-Power-Plant-Construction-Guidelines-and-Experience.

IAEA (2009a), *Nuclear Technology and Economic Development in the Republic of Korea*, IAEA, Vienna, www.iaea.org/sites/default/files/rok0809.pdf.

IAEA (2009b), *IAEA Tools and Methodologies for Energy System Planning and Nuclear Energy System Assessments*, IAEA, Vienna, www.iaea.org/sites/default/files/INPROPESS-brochure.pdf.

IAEA (2000), *Economic Evaluation of Bids for Nuclear Power Plants: 1999 Edition*, Technical Reports Series No. 396, IAEA, Vienna.

IEA/NEA (2015), *Projected Costs of Generating Electricity, 2015 edition,* OECD, Paris.

IER (2012), "NEWAGE – General Model Description", Institute of Energy Economics and the Rational Use of Energy (IER), University of Stuttgart, Germany, www.ier.uni-stuttgart.de/forschung/modelle/NEWAGE/index_en.html.

IER (2011), "Effects of changing operational lives of German nuclear power plants – scenario analysis until 2035" (in German), Institute of Energy Economics and the Rational Use of Energy (IER), University of Stuttgart, Working Paper No. 10.

IER/ZEW (2010), "The Development of the Energy Markets Until 2030 – Energy Outlook 2009", a study for the German Federal Ministry for Economic Affairs and Technology (BMWi).

INL (2004), *US Job Creation Due to Nuclear Power Resurgence in the United States*, Idaho National Laboratory.

INSEE (2013) "Les sites nucléaires du Tricastin et de Marcoule : un impact important sur plus de 200 communes", INSEE.

IPPR (2012), *Benefits from Infrastructure Investment: A Case Study in Nuclear Energy*, IPPR, London.

Itakura, K. (2011), "Calibrating the mix of electric power generation types", in Kimura, F. and X. Shi (eds.), *Deepen Understanding and Move Forward: Energy Market Integration in East Asia*, ERIA Research Project Report 2010-25, Jakarta, ERIA, pp. 298-310.

Ivanova, G. and J. Rolfe (2011), "Using input-output analysis to estimate the impact of a coal industry expansion on regional and local economies", *Impact Assessment and Project Appraisal*, Vol. 29(4), pp. 277-288.

Jensen, K. et al. (2010), "Projected Economic Impacts of Green Jobs Development in the Appalachian Region", http://beag.ag.utk.edu/pub/GreenJobsImpactARC2.pdf.

Kobayashi, T., K. Ochiai and Y. Tachi (2011), "Structural Change in Industry to Ease Downside of Power Shortage – Avert Current Account Deficit by Shifting Resources to Machinery Industry", www.jcer.or.jp/eng/research/pdf/pe(kobayashi20111020)e.pdf.

Konovalchuk, V. (2006), "A Computable General Equilibrium Analysis of the Economic Effects of the Chernobyl Nuclear Disaster", College of Agricultural Sciences, Pennsylvania State University.

Kratena, K. (2015), "An Extended Input-Output Model for Impact Assessment of Nuclear Power Plants", co-ordinated research project: "Assessing the National and Regional Economic and Social Effects of Nuclear Programmes", IAEA, Vienna.

Küster, R. (2009), "Climate Protection, Macro-economy and Employment – Analysis of the German and European Climate Policy Strategies using a CGE Model" (in German), Dissertation, Mensch und Buch Verlag, Berlin.

Küster, R., I. Ellersdorfer and U. Fahl (2007), "A CGE-Analysis of Energy Policies Considering Labor Market Imperfections and Technology Specifications", Fondazione Eni Enrico Mattei (FEEM).

Lee, M.K. et al. (2009), "Contribution of nuclear power to the national economic development in Korea", *Nuclear Engineering and Technology*, Vol. 41(4).

Lee, M.K. (2014), "Korean experiences in applying I/O analysis to economy wide effects from nuclear power", presented at the IAEA/NEA Group of Experts Workshop on Modelling Employment in the Nuclear Power Sector, Vienna, Austria, 21-22 October.

Lesser, J.A. (2011), *The Economic Benefits of Exelon Nuclear's Limerick Generating Station*, Continental Economics, Inc.

Leung-Wai, J. and D. Norman (2007), "Economic Impact of the Oil and Gas Sector on the Taranaki Region and New Zealand", Business and Economic Research Limited, www.taranaki.info/admin/data/business/eia_o_g_sector___sept_2007.pdf.

Lindner, S., J. Legault and D. Guan (2012), "Disaggregating the electricity sector of China's input out table: Application to environmental-economic life cycle analysis", *Economic Systems Research*, Vol. 25(3).

Lubek, J. (2014), "Jobs in the nuclear industry in France in 2009: Recipe and laboratory assistant view," presented at the NEA Group of Experts Workshop on Modelling Employment in the Nuclear Power Sector, Issy-les-Moulineaux, France, 13-14 February, www.oecd-nea.org/ndd/workshops/modenps/presentations/#presentations.

Magné, B., J. Chateau and R. Dellink (2014), "Global implications of joint fossil fuel subsidy reform and nuclear phase-out: Ann economic analysis", *Climatic Change*, Vol. 123 (3/4), p. 677.

Marriot, J. (2007), "An Electricity-focused Economic Input-output Model: Life-cycle Assessment and Policy Implications of Future Electricity Generation Scenarios", http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.116.6014&rep=rep1&type=pdf.

Mayeda, P. and K. Riener (2013), "Economic Benefits of Diablo Canyon Power Plant", www.pge.com/includes/docs/pdfs/shared/edusafety/systemworks/dcpp/PGE_Economi c_Impact_Report_Final.pdf.

McDonald, L.A. et al. (2007), "Oil and Gas Economic Impact Analysis", Colorado Energy Research Institute, Colorado School of Mines.

Molloy, B. (2014), "Nuclear workforce requirements", presented at the Consultancy Meeting on Modelling Employment in the Nuclear Power Sector, IAEA, Vienna, Austria, 21-22 October 2014.

Miller, R. and P. Blair (2009), *Input-Output Analysis: Foundations and Extensions*, Cambridge University Press.

Miller, S., D. Wei and A. Rose (2010), "The Macroeconomic Impact of the Michigan Climate Action Council Climate Action Plan on the State's Economy", www.michigan.gov/ documents/dnre/dnre-Climate-action-ECON-Impacts_340497_7.pdf.

Mukaida, K. et al. (2013), "The effect assessment for fast reactor fuel cycle deployment-improvement of the assessment method", *Energy Procedia,* Vol. 39, pp. 43-51, www.sciencedirect.com/science/article/pii/S1876610213012769.

NEA (2016), *The Cost of Decommissioning Nuclear Power Plants*, OECD, Paris, www.oecd-nea.org/ndd/pubs/2016/7201-costs-decom-npp.pdf.

NEA (2013), *The Economics of the Back End of the Nuclear Fuel Cycle*, OECD, Paris, www.oecd-nea.org/ndd/pubs/2013/7061-ebenfc.pdf.

NEA (2012a), *Nuclear Education and Training: from Concern to Capability*, OECD, Paris, www.oecd-nea.org/ndd/reports/2012/nuclear-edu-training-ex.pdf.

NEA (2012b), *Nuclear Power in Competitive Electricity Markets*, OECD, Paris, www.oecd-nea.org/ndd/reports/2000/nea2569-dereg-2.pdf.

NEA (2008), *Market Competition in the Nuclear Industry*, OECD, Paris, www.oecd-ilibrary.org/content/book/9789264054073-en.\

NEA/IAEA (2016), *Uranium 2016: Resources, Production and Demand,* OECD, Paris, www.oecd-nea.org/ndd/pubs/2016/7301-uranium-2016.pdf.

NEA/IAEA (2014), *Uranium 2014: Resources, Production and Demand,* OECD, Paris, www.oecd-nea.org/ndd/pubs/2014/7209-uranium-2014.pdf.

NEI (2014a), "Economic Impact of NextEra Energy's Duane Arnold Energy Center", NEI, www.nexteraenergyresources.com/pdf_redesign/DAEC_Economic_Study.pdf.

NEI (2014b), "Nuclear Energy's Economic Benefits – Current and Future", NEI.

NEI (2013), "Economic Impact of NextEra Energy's Seabrook Station", NEI, Washington. www.nexteraenergyresources.com/pdf_redesign/nei_seabrook.pdf.

NEI (2006a), "Economic Benefits of PPL Susquehanna Nuclear Power Plant: An Economic Impact", NEI.

NEI (2006b), "Economic Benefits of Salem and Hope Creek Nuclear Generating Stations: An Economic Impact", NEI.

NEI (2004a), "Economic Benefits of the Duke Power-Operated Nuclear Power Plants: An Economic Impact", NEI.

NEI (2004b), "Economic Benefits of Palo Verde Nuclear Generation Station", NEI.

NEI (2003), "Economic Benefits of Millstone Power Station: An Economic Impact", NEI.

NIA (2010), "Regional and National Economic Benefits from the UK's Nuclear Decommissioning Programme", NIA.

Okuno S., Y. Fujii and R. Komiyama (2012), "Development of a Bottom-up Based CGE Model and Evaluation of Energy Policy", Department of Nuclear Engineering and Management, Graduate School of Engineering, University of Tokyo, http://eneken.ieej.or.jp/3rd_IAEE_Asia/pdf/paper/014p.pdf.

ORNL (2011), "Advanced High Temperature Reactor Systems and Economic Analysis", ORNL/TM-2011/364, prepared by Oak Ridge National Laboratory under the direction of UT-Battelle, Oak Ridge, http://info.ornl.gov/sites/publications/files/Pub32466.pdf.

ORNL (1988), *Technical Reference Book for the Energy Economic Data Base Program EEDB-IX (1987)*, DOE/NE-0092, prepared by United Engineers and Constructors, Inc., Philadelphia, PA, under the direction of ORNL, Oak Ridge.

Oxford Economics (2013), "The Economic Benefit of Improving the UK's Nuclear Supply Chain Capabilities", Oxford Economics.

Oxford Economics (2008), "Economic, Employment and Environmental Benefits of Renewed U.S. Investment in Nuclear Energy", Oxford Economics, www.oxford economics.com/publication/open/222534.

Paltsev, S. et al. (2005), "The MIT Emissions Prediction and Policy Analysis (EPPA) Model: Version 4", Joint Program on the Science and Policy of Global Change, Report No. 125, https://globalchange.mit.edu/publication/14578.

Penn, D.A. and J. McCraw (1996), "The Impact of Oil and Gas Production and Drilling on the Oklahoma Economy for Commission on Marginally Producing Oil and Gas Wells", Center for Economic and Management Research, College of Business Administration, University of Oklahoma, http://origins.ou.edu/reports/impact/impact_1996.pdf.

PFS (1997), "Application for a License to Construct and Operate a Spent Fuel Storage Facility", Docket No. 72-22, US Nuclear Regulatory Commission.

PNNL (2011), "Assessment of the Adequacy of the 10 CFR 50.75(c) Minimum Decommissioning Fund Formula", PNNL, Richland, http://pbadupws.nrc.gov/docs/ML1306/ML13063A190.pdf.

Pollin, R., J. Heintz and H. Garrett-Peltier (2010), "Clean Energy Investments for the U.S. Economy: Researching the Effects on Employment Opportunities and Economic Growth", a Discussion Paper for 3/22/10 Conference, Surdna Foundation, www.peri.umass.edu/fileadmin/pdf/conference_papers/Surdna/Pollin-Heintz-Garrett-Peltier_paper_for_Surdna_Conf---3-16-10.pdf.

PWC (2011), "Le poids socio-économiques de l'électronucléaire en France", http://ehron.jrc.ec.europa.eu/sites/ehron/files/documents/public/le_poids_socioeconomique_de_l_electronucleaire_en_france.pdf.

PWC (2012), "Cartographie de l'emploi dans le secteur nucléaire en Belgique", https://ehron.jrc.ec.europa.eu/sites/ehron/files/documents/public/belgique_-_rapport_final_emploi_dans_le_secteur_nucleaire.pdf.

Rothwell, G.S. (2016), *Economics of Nuclear Power*, Routledge, London.

Rothwell, G.S. (2015), "Scale economies in a series of generic interim SNF storage facilities", *Proceedings of the International Congress on Advances in Nuclear Power Plants*, ICAPP 2015, Nice, France, 3-5 May 2015.

Rothwell, G.S. (2010), "International nuclear fuel fabrication supply: Are fabrication services assured?" *Energy Economics*, Vol. 32, pp. 538-544.

Rothwell, G.S. (2009), "Market power in uranium enrichment", *Science & Global Security*, Vol. 17 (2-3), pp. 132-154.

Rutherford, T.F. and S. Paltsev (1999), "From an Input-Output Table to a General Equilibrium Model: Assessing the Excess Burden of Indirect Taxes in Russia", working paper, University of Colorado.

SCE&G (2012), "South Carolina Electric & Gas: COL Application Part 3 – Environmental Report", http://pbadupws.nrc.gov/docs/ML1019/ML101930223.pdf.

Shoven, J.B. and J. Whalley (1984), "Applied general equilibrium models of taxation and international trade: An introduction and survey", *Journal of Economic Literature*, Vol. 22, pp. 1007-1051.

Shoven, J.B. and J. Whalley (1992), *Applying General Equilibrium*, Cambridge University Press.

Solan, D. et al. (2010), *Economic and Employment Impacts of Small Modular Nuclear Reactors*, the Energy Policy Institute, Boise State University, http://papers.ssrn.com/sol3/papers.cfm?abstract_id=2269337.

Southern Company (2012), "Vogtle Electric Generating Plant, Units 3 & 4 COL Application", http://pbadupws.nrc.gov/docs/ML0927/ML092740400.pdf.

Springer, K. (1998), "Climate Policy and Trade: Modeling Dynamics in a multi-regional Framework", working paper, Kiel Institute for the World Economy (IfW).

Timilsina, G. et al. (2008), *The Canadian Nuclear Industry: Contributions to the Canadian Economy,* Canadian Energy Research Institute, Ontario, http://teachnuclear.ca/wp-content/uploads/2013/05/CNAEconomicReport08.pdf.

Timmons, D. et al. (2007), "Energy from Forest Biomass: Potential Economic Impacts in Massachusetts", www.mass.gov/eea/docs/doer/renewables/biomass/bio-eco-impact-biomass.pdf.

TVA (2005), "ABWR Cost/Schedule/COL Project at TVA's Bellefonte Site", US Department of Energy, contract DE–AI07–04ID14620, TVA.

UKERC (2014), *Low Carbon Jobs: The Evidence for Net Job Creation from Policy Support for Energy Efficiency and Renewable Energy*, UKERC, London, www.ukerc.ac.uk/publications/low-carbon-jobs-the-evidence-for-net-job-creation-from-policy-support-for-energy-efficiency-and-renewable-energy.html.

United Nations Statistical Division (2014), *International Standard Industrial Classification of All Economic Activities: Revision.4,* United Nations, New York.

US Census Bureau (2016), Economic Census: Industry Snapshots (web page), www.census.gov/econ/snapshots/index.php.

US NRC (2013), GE Laser Enrichment Facility Licensing (web page), www.nrc.gov/materials/fuel-cycle-fac/laser.html (12 August 2013).

US NRC (2001), "Final Environmental Impact Statement for the Construction and Operation of an Independent Spent Fuel Storage Installation on the Reservation of the Skull Valley Band of Goshute Indians and the Related Transportation Facility in Tooele County, Utah", NUREG-1714, US Nuclear Regulatory Commission, Office of Nuclear Material Safety and Safeguards, Washington, DC.

World Nuclear News (2016), "Watts Bar 2 final completion cost approved", World Nuclear Association, London, www.world-nuclear-news.org/NN-Watts-Bar-2-final-completion-cost-approved-0402167.html.

WorleyParsons (2011), "White Paper on Nuclear Energy in Jordan: Final Report", a study prepared for Jordan Atomic Energy Commission, www.jaec.gov.jo/CMS/UploadedFiles/c18cbcac-92e9-481b-a781-498ca0bf7e9c.pdf.

Yamano, N. and N. Ahmad (2006), "The OECD Input-Output Database Edition 2006", STI Working Paper 2006/8, Statistical Analysis of Science, Technology and Industry, OECD, www.oecd.org/sti/37585924.pdf.

Yamazaki, M. and S. Takedo (2013), "An assessment of a nuclear power shutdown in Japan using the computable general equilibrium model", *Journal of Integrated Disaster Risk Management*, Vol. 3(1).

Yoo, S-H and T-H Yoo (2009), "The role of the nuclear power generation in the Korean national economy: An input-output analysis", *Progress in Nuclear Energy,* Vol. 51(1), pp. 86-92, www.sciencedirect.com/science/article/pii/S014919700700234X.

NEA PUBLICATIONS AND INFORMATION

The full **catalogue of publications** is available online at www.oecd-nea.org/pub.

In addition to basic information on the Agency and its work programme, the NEA website offers free downloads of hundreds of technical and policy-oriented reports. The professional journal of the Agency, **NEA News** – featuring articles on the latest nuclear energy issues – is available online at www.oecd-nea.org/nea-news.

An **NEA monthly electronic bulletin** is also distributed free of charge to subscribers, providing updates of new results, events and publications. Sign up at www.oecd-nea.org/bulletin.

Visit us on **Facebook** at www.facebook.com/OECDNuclearEnergyAgency or follow us on **Twitter** @OECD_NEA.

OECD/NEA PUBLISHING, 2 rue André-Pascal, 75775 PARIS CEDEX 16

Measuring Employment Generated by the Nuclear Power Sector

The nuclear energy sector employs a considerable workforce around the world, and with nuclear power projected to grow in countries with increasing electricity demand, corresponding jobs in the nuclear power sector will also grow. Using the most available macroeconomic model to determine total employment – the "input/output" model – the Nuclear Energy Agency and International Atomic Energy Agency collaborated to measure direct, indirect and induced employment from the nuclear power sector in a national economy. The results indicate that direct employment during site preparation and construction of a single unit 1 000 megawatt-electric advanced light water reactor at any point in time for 10 years is approximately 1 200 professional and construction staff, or about 12 000 labour years. For 50 years of operation, approximately 600 administrative, operation and maintenance, and permanently contracted staff are employed annually, or about 30 000 labour years. For up to 10 years of decommissioning, about 500 people are employed annually, or around 5 000 labour years. Finally, over an approximate period of 40 years, close to 80 employees are managing nuclear waste, totalling around 3 000 labour years. A total of about 50 000 direct labour-years per gigawatt. Direct expenditures on these employees and equipment generate approximately the same number of indirect employment, or about 50 000 labour years; and direct and indirect expenditures generate about the same number of induced employment, or 100 000 labour years. Total employment in the nuclear power sector of a given national economy is therefore roughly 200 000 labour years over the life cycle of a gigawatt of nuclear generating capacity.

Nuclear Energy Agency (NEA)
46, quai Alphonse Le Gallo
92100 Boulogne-Billancourt, France
Tel.: +33 (0)1 45 24 10 15
nea@oecd-nea.org **www.oecd-nea.org**

NEA No. 7204