

# Nuclear Power, The Energy Balance

by Jan Willem Storm van Leeuwen and Philip Smith

## References

- Andriess, C.D., *Comment on prospects for nuclear power, Energy technologies to reduce CO<sub>2</sub> emissions*, OECD/IEA, Paris, 1994.
- atw-5 2003 anonymous Kernenergie: Weltreport 2002 – Auswertung atw 48. Jg 2003, Heft 5 - Mai, pp.339-345.
- Becker, E.W., W. Bier, P. Bley, W. Ehrfeld, K. Schubert and D. Seidel, *Development and Technical Implementation of Separation Nozzle Process for the Enrichment of uranium-235*, KfK 3310, Kernforschungszentrum Karlsruhe, März 1982.
- Bell, J.T., 'Alternatives to high level waste vitrification: the need for common sense', *Nuclear Technology*, vol 130, April 2000, pp 89-98.
- Bitkolov N Z 'Greenhouse gas emission from NPP energy generation', Part of: *Assessment of greenhouse gas emissions from the full energy chain for nuclear power and other sources*, Working material, International Atomic Energy Agency, Vienna, Austria, 26-28 September 1995.
- Blok, K. and C.A. Hendriks, *Elektriciteitsproductietechnieken voor de komende twintig jaar. Vergelijking van Milieu-effecten*, (in Dutch) Rapport W-90006, Vakgroep Natuurwetenschap en Samenleving, University of Utrecht, November 1989.
- Bodlund, B., email dated 17 December 2001, 16:11 from <birgit.bodlund@vattenfall.com> to <storm@ceedata.nl>, subject, SV:nuclear power LCA.
- BP Amoco 1999-2005, *Statistical Review of World Energy*, June 1999-2005, [www.bp.com/centres/energy/](http://www.bp.com/centres/energy/)
- Brin A, 'Uranium from seawater: a review of recent papers', First IIASA Conference on Energy Resources, IIASA, Laxenburg, Austria, May 1975, CP-76-4.
- Bullard, C.W., P.S. Penner & D.A. Pilati, 'Net energy analysis', Handbook for combining process and input/output analysis, *Resources and Energy*, vol. 1, 1978, pp.267-313.
- Burk, M., *Gold, silver, uranium from seas and oceans. The emerging technology*, Los Angeles: Ardor Publishing, 1989.
- Burnham, J.B. et al., *Assessment of uranium and thorium resources in the United States and the effect of policy alternatives*, PN-238-658, Battelle Pacific Northwest Laboratories, Richland, Washington: December 1984.

- Chapman, P.F., 'Energy Analysis of Nuclear Power Stations', *Energy Policy*, December 1975, pp 285-298.
- Charpak, G., and R.L. Garwin, *Feux follets et champignons nucléaires*, Paris: Odile Jacob, 1997.
- Constanza, R. & R.A. Herendeen, 'Embodied energy and economic value in the United States economy, 1963, 1967 and 1972. *Resources and Energy*, vol.6, June 1984, pp. 129-163.
- Crossley, P.S., 'Centrifuges Help Match Supply and Demand', *Nuclear Engineering International*, October 1980, pp 45-48.
- Diaz N J, Regulating - for the people, *atw* 46. Jg. (2001) Heft 6 - Juni, pp. 407-410.
- Dilemma Study, *Study of the contribution of nuclear power to the reduction of carbon-dioxide emissions from electricity generation*, Commission of the European Communities, Directorate-General XVII, Report prepared by ERM Energy, London, UK, July 1999.
- Dodd, D.H. and J.F.A. van Hienen, Report ECN-C-96-046, Netherlands Energy Research Foundation ECN, Petten, June 1996.
- DOE/EIA, *Nuclear power generation and fuel cycle report 1997*, DOE/EIA-0436(97), Energy Information Administration, September 1997.
- DOE-NERAC 2001, *A roadmap to deploy new nuclear power plants in the United States by 2010*, Volume I, Summary Report, US Department of Energy (DOE), Office of Nuclear Energy Science and Technology, and Nuclear Energy Research Advisory Committee (NERAC). Subcommittee on Generation IV technology planning, October 31, 2001  
<http://nuclear.gov/nerac/ntdroadmapvolumel.pdf>
- Dunkerley, J. 'Trends in energy use in industrial societies.' An overview, Research paper R-19, *Resources for the Future Inc.*, Washington DC, 1980; Baltimore: Johns Hopkins 1980
- Dwarshuis D., 'Wat kernen kosten, Studentenrapport nr. 61, IVEM, Groningen, augustus 1992 (in Dutch).
- Dworschak, H., 'Characteristics, origin, production, applications', in F. Mannone (ed.), *Safety in Tritium Handling Technology*, EUR 15144 ECSC, EEC, EAEC, Brussels/Luxembourg, 1993, Dordrecht: Kluwer, 1993.
- Eaton, R.R., R.L. Fox and K.J. Touryan, 'Isotope Enrichment by Aerodynamic Means: a Review and some Theoretical Considerations, *Journal of Energy*, Vol. 1, no, 4 July-Aug 1977, pp.229-236.
- ERDA-76-1, *A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future*, Volume 1, The Plan, pp 111-116, Appendix B: Net energy analysis of nuclear power production. Washington DC: Energy Research and Development Administration, 1976.
- Europe Energy Scenario, *Energy in Europe, European Energy to 2020, a scenario approach*, European Commission, Directorate General for Energy, DG XVII,(ISBN 92-827-5226-7) Brussels, Spring 1996.
- Europe Energy, *Energy in Europe, Economic Foundation for Energy Policy*, European Commission, Directorate-General for Energy, Brussels, December 1999.
- Franklin et al., *Total energy analysis of nuclear and fossil fueled power plants*, ORNL-MIT-138, Oak Ridge National Laboratories and Massachusetts Institute of Technology, 23 November 1971.
- GJO-100, *Statistical data of the Uranium Industry*, Department of Energy, Grand Junction Office, Colorado, U.S.A., 1980.

- Huwlyer, S., L. Rybach & M. Taube, *Extraction of uranium and thorium and other metals from granite*, EIR-289, Technical Communications 123, Eidgenössische Technische Hochschule, Zürich, September 1975 (translated by Los Alamos Scientific Laboratory, LA-TR-77-42, 1977).
- IAEA-203, *Handling of Tritium-bearing wastes*, Technical Report Series No 203, International Atomic Energy Agency (IAEA), Vienna, 1981.
- IAEA-293, *Factors relevant to the recycling or reuse of components arising from the decommissioning and refurbishment of nuclear facilities*, Technical Report Series No 293, International Atomic Energy Agency (IAEA), Vienna, 1988
- IAEA-345, *Concepts for the conditioning of spent nuclear fuel for final disposal*, Technical Report Series No 345, International Atomic Energy Agency (IAEA), Vienna, 1992
- IAEA-349, 'Report on radioactive waste disposal', Technical Report Series No 349, International Atomic Energy Agency (IAEA), Vienna, 1993.
- IAEA-355, 'Containers for packaging of solid low and intermediate level radioactive wastes', Technical Report Series No 355, International Atomic Energy Agency (IAEA), Vienna, 1993.
- IAEA TecDoc-753 1994, *Net energy analysis of different electricity generation systems*, IAEA, Vienna, Austria, 1994.
- IAEA-377, 'Minimization of radioactive waste from nuclear power plants and the back end of the nuclear fuel cycle', Technical Report Series No 377, International Atomic Energy Agency (IAEA), Vienna, 1995.
- IAEA-389, 'Radiological characterization of shut down nuclear reactors for decommissioning purposes', Technical Report Series No 389, International Atomic Energy Agency (IAEA), Vienna, 1998.
- IAEA W.M., *Assessment of greenhouse gas emissions from the full energy chain for nuclear power and other sources*, Working material, International Atomic Energy Agency, Vienna, Austria, 26-28 September 1995.
- IFIAS, International Federation of Institutes for Advanced Study. Energy analysis workshop on methodology and convention. Guldsmedshyttan, Sweden, August 1974. Stockholm: IFIAS 1974.
- IFIAS, International Federation of Institutes for Advanced Study. Workshop on energy analysis and economics. Lidengo, Sweden, June 1975. Stockholm: IFIAS 1975.
- INFCE1, 1980, '*Fuel and Heavy Water Availability*', Report of the INFCE Working Group 1, IAEA, Vienna, 1980, STI/PUB/534.
- INFCE2, 1980, '*Enrichment Availability*', Report of the INFCE Working Group 2, IAEA, Vienna, 1980, STI/PUB/534.
- James, H.E. & H.A. Simonson, 'Ore-processing technology and the uranium supply outlook,' in *Uranium, supply and demand*, Proceedings Third International Symposium by the Uranium Institute, London, July 12-14, 1978, pp. 107-181.
- Jan, R. von and H. Krug, *Brennelemente für den weltweiten Einsatz*, (in German) ATW 40 Heft 3, März, pp 164-166, Jg 1995.
- Junker W.H., 'Das Stilllegungsprogramm der UKAEA', (in German) ATW 40 Heft 4, April, pp 236-238, Jg 1995.

- Kistemaker, J., *Energie-analyse van de totale kernenergiecyclus gebaseerd op licht-water reactoren*, Stichting voor Fundamentele Onderzoek der Materie (FOM), summer 1975 (in Dutch).
- Kistemaker, J., Aanvulling op: *Energie-analyse van de totale kernenergiecyclus gebaseerd op licht-water reactoren*, LSEO 818, juli 1976 (in Dutch).
- Knip, K., and Westerwoudt, Th., 'Opbergen van kernafval in Nederland onbetaalbaar. De rekenfouten van Greenpeace', (in Dutch) *NRC Handelsblad*, 28 maart 1997.
- Knox, R., 'Load Factors to end June 2001,' *Nuclear Engineering International*, November 2001, pp.40-44.
- Kolb, G., F. Niehaus, St. Rath-Nagel & A. Voss, *Der Energieaufwand für Bau und Betrieb von Kernkraftwerken*, Bericht Jul-1230. Jülich: Kernforschungsanlage Jülich GmbH, August 1975.
- Komorowski, K. & S. Meuresch, *Stillegung und Rückbau kerntechnischer Anlagen*, (in German) *ATW* 40, Heft 4, April, pp 231-235, Jg 1995.
- Konings, R.J.M. & D.H. Dodd, et al. *Nader onderzoek naar de verwerking van gebruikte splijtstof uit Nederlandse kerncentrales*, (in Dutch) NRG, Petten, 24 maart 1999.
- Koske, P. H., 'Extraction of uranium from seawater', paper in: 'Uranium and nuclear energy', Proceedings of Fourth International Symposium held by The Uranium Institute London, September 10-12, 1979.
- Lako, P. 'Greenhouse gas emissions from nuclear power plant construction, Part of: Assessment of greenhouse gas emissions from the full energy chain for nuclear power and other sources', Working material, International Atomic Energy Agency, Vienna, Austria, 26-28 September 1995.
- Liebholz, W.M., 'Grüne Wiese', (in German), *ATW* 40, Heft 8/9 August/September, pp 517, Jg 1995.
- MacDonald C, Rock to reactors: uranium exploration and the market, World Nuclear Association Annual Symposium 2001, [www.world-nuclear.org/sym/2001/macdonald.htm](http://www.world-nuclear.org/sym/2001/macdonald.htm)
- MacDonald C, Uranium: sustainable resource or limit to growth?, World Nuclear Association Annual Symposium 2003, [www.world-nuclear.org/sym/2003/macdonald.htm](http://www.world-nuclear.org/sym/2003/macdonald.htm)
- Mishra U C, 'Greenhouse gas contributions of PHWR fuel cycle and coal-based power plants in India', Part of: *Assessment of greenhouse gas emissions from the full energy chain for nuclear power and other sources*, Working material, International Atomic Energy Agency, Vienna, Austria, 26-28 September 1995.
- MIT, Interdisciplinary Study, "The Future of Nuclear Power," <http://www.mit.edu/afs/athena/org/n/nuclearpower/pdf/>, 2003.
- Mooz, W.E., *Cost analysis for LWR power plants*, Energy, vol.6 (1981), p.197-225.
- Mortimer, N.D., 'The Energy Analysis of Burner Reactor Power Systems,' Ph.D. dissertation, Milton-Keynes Open University, 1977.
- Mortimer, N.D., 'Energy analysis of renewable energy sources', Energy Policy, May 1991.
- Mortimer, N.D., 'Nuclear power and carbon dioxide, the fallacy of the nuclear industry's new propaganda', *The Ecologist*, Vol.21, No. 3, May/June 1991.
- Mortimer N D, Nuclear power and global warming', *Energy Policy*, January/February 1991, pp 76-78.

- Mudd G M, *Acid in-situ leach uranium mining: 2 - Soviet Block and Asia*, paper for: Tailings and Mine Waste '00, Fort Collins, CO, USA, January 23-26 2000, proceedings AA Balkema, Rotterdam, pp.527-536.
- Mutschler, P.H., J.J. Hill, & B.B. Williams, *Uranium from the Chatanooga shale, Some problems involved in development*, PB-251-986, Pittsburg, U.S.A.: Bureau of Mines 1976
- Nachrichten, *ATW* 42, Heft 7 Juli, p 496 Jg 1997.
- NEA, (Nuclear Energy Agency), *'Radiological significance and management of Tritium, Carbon-14, Krypton-85 and Iodine-129 arising from the nuclear fuel cycle'*, Report by an NEA Group of Experts, OECD, Paris, France, 1980.
- NEA, (Nuclear Energy Agency), *The NEA Co-operative Programme on Decommissioning. The First 10 years*, OECD, Paris, France, 1996.
- Nobukawa, H. M. Kitamura, S.A.M. Swylem, K. Ishibashi, *Development of a floating-type system for uranium extraction from seawater using sea current and wave power*, Proceedings of the Fourth (1994) International Offshore and Polar Engineering Conference, Osaka, Japan, April 10-15, 1994.
- NRC, (National Research Council), *Nuclear Wastes. Technologies for separations and transmutation*, Washington DC: National Academy Press, 1996.
- Oregon Office of Energy Research and Planning, *Energy Study: Interim Report 26, Salem, Oregon, U.S.A. July 1974*.
- Orita Y, 'Preliminary assessment on nuclear fuel cycle and energy consumption', Part of: *Assessment of greenhouse gas emissions from the full energy chain for nuclear power and other sources*, Working material, International Atomic Energy Agency, Vienna, Austria, 26-28 September 1995.
- ORNL 1974, Harrington, F.E. R. Salmon, W.E. Unger, K.B. Brown, C.F. Coleman & D.J. Crouse, 'Cost commentary on a proposed method for recovery of uranium from seawater' Oak Ridge National Laboratory, November 1974, ORNL-TM-4757.
- Paleit, J.A., *Der langfristige Welt-Trennarbeitsmarkt*, (in German), *ATW* 42, Heft, 4-April, pp. 233-236, Jg 1997.
- Papp, R., *Technische und geologische Barrieren bei der Endlagerung*, (in German) *ATW* 43, Heft 4, April, pp. 252-255, Jg 1998a.
- Papp, R., *Untersuchung unterscheidlicher Endlagerwirts-gesteine*, (in German), *ATW* 43, Heft 4, April, pp. 249-251. Jg 1998b.
- Parageau, M. and M.Scheider, *The Dutch plutonium dead end*, Commissioned by Greenpeace-Netherlands, WISE Paris, October 1997.
- Pease, R.S., former Director of Fusion research, UK Atomic Energy Authority, private communication, 47th Pugwash conference, Lillehammer 1997.
- Perrin, F., Head of French Atomic Energy Authority (1951-1971), private communication, 27th Pugwash conference, Munich, 1977.
- Proops, J., *The (non)-economics of the nuclear fuel cycle: an historical and discourse analysis*, *Ecological Economics*, vol. 39 2001, pp.13-19.
- RAND 1979, E.W. Merow, S.W. Chapel & C. Worthing, *A review of cost estimation in new technologies*, RAND-2481-DOE, Santa Monica, CA.: RAND Corporation, July 1979.

- RAND 1981, E.W. Merow, K.E. Philips & C.W. Myers, *Underestimating cost growth and performance shortfalls in pioneer process plants*, RAND/R-2569-DOE, Santa Monica, CA.: RAND Corporation, September 1981.
- Reister, D.B., *The energy embodied in goods*, ORAU/IEA(M)-77-6. Institute for Energy Analysis, Oak Ridge Associated Universities, February 1977.
- Roberts, F., *The convention conventions*, Energy Policy, December 1975, pp.345-347.
- Roberts, P.C., *Energy and value*, Energy Policy, September 1982, pp.171-180.
- Roddis, L.H. & J.H. Ward, *Operating experience with central-station light-water reactors in the U.S.A*, A/Conf49/P/036, 4th International Conference on peaceful uses of atomic energy, 1971, New York/Wien:UN/IAEA.
- Rombough, C.T. & B.V. Koen, *Total energy investment in nuclear power plants*, Nuclear Technology, Vol.26 May 1975, pp.5-11.
- Ross, A.H. & L.G. Guglielmin, *Milling Technology of uranium ores*, Nuclear Applications, vol.5 nr.11, November 1968. pp.311-318.
- Rotty, R.M., A.M. Perry & D.B. Reister, *Net energy from nuclear power*, ORAU-IEA-75-3, Institute for Energy Analysis, Oak Ridge Associated Universities, November 1975.
- Saito K, 'Japanese research plant for uranium from seawater', *Nuclear Engineering International*, June 1980, pp.32-33.
- Saraev, O.M., from IAEA-TECDOC-1180, *Operating experience with Beloyarsk fast reactor BN600 NPP, Technical committee meeting on unusual occurrences during LMFR operation, Vienna, (Austria) 9-13 Nov. 1998, pp. 101-115.*
- Scheidt, S. vom, *Kohärenz zwischen Brennstoff-Auslegung und -Fertigung*, ATW 40, Heft 3, März, pp. 167-169, Jg 1995.
- Schreuder, A., *Opslag van afval kost 1-2 miljard gulden*, (in Dutch) NRC Handelsblad, 22 februari 2000.
- Schwald, P., et al. *Demontage und Beseitigung von Niederaichbach*, (in German), ATW 40, Heft 4, April, pp. 242-246, Jg 1995.
- Simonson, H.A., Boydell, D.W. & H.E. James, *The impact of new technology on the economics of uranium production of low-grade ores*, in 'Uranium and nuclear energy', Proceedings Fifth International Symposium by the Uranium Institute, London, July 2-4, 1978, pp.92-180.
- SRI, *Manpower, materials, equipment and utilities required to operate and maintain energy facilities*, PB 255 438, Menlo Park, CA: Stanford Research Institute (SRI), March 1975.
- Stam, B., *Hoog-radioactief afval vanaf 2001 opgeslagen in high-tech bunker*, (in Dutch) Technisch Weekblad, 7 augustus 1996.
- Storm van Leeuwen, J.W., *Energie-analyse van en PWR kerncentrale*, (in Dutch) Rapport voor de Stuurgroep Brede Maatschappelijke Discussie Energiebeleid te Den Haag, Chaam, 14 september 1982.
- Storm van Leeuwen, J.W., *Atomstrom - ein Energiedarlehen?*, (in German), Gruppe Ökologie, Hannover/Braunschweiger Arbeitskreis gegen Atomenergie, Hannover/Braunschweig, Mai 1984.
- Storm van Leeuwen, J.W., *Nuclear Uncertainties. Energy Loans for fission power*, Energy Policy, pp. 253-266, June 1985.

- Thierfeldt, S., *Freigabebegrenzwerte für Reststoffe*, (in German) ATW 40 Heft 4, April, pp. 257-260 Jg 1995.
- Tyner Sr, G., R.Constanza & R.G. Fowler, 'Net energy yield of nuclear power', *Energy*, vol.13, no.1, 1988, pp.73-81.
- Uchiyama Y, 'Life cycle analysis of electricity generation and supply systems: net energy analysis and greenhouse gas emissions', Part of: *Assessment of greenhouse gas emissions from the full energy chain for nuclear power and other sources*, Working material, International Atomic Energy Agency, Vienna, Austria, 26-28 September 1995.
- UIC-34 2005, *Geology of uranium deposits*, Nuclear Issues Briefing Paper #34, Uranium Information Center, Melbourne, Australia, November 2001, [www.uic.com.au/nip34.htm](http://www.uic.com.au/nip34.htm)
- UIC-57 2001, *Energy Analysis of Power Systems*, UIC Nuclear Issues Briefing Paper #57, Uranium Information Centre, <http://www.uic.com.au/nip57.htm>, September 2001.
- Uitert, G.C. van, *Indirect CO2 emissions from nuclear power plants, Part of: Assessment of greenhouse gas emissions from the full energy chain for nuclear power and other sources*, Working material, International Atomic Energy Agency, Vienna, Austria, 26-28 September 1995.
- Uranium, 'Resources, Production and Demand', OECD Nuclear Energy Agency & International Atomic Energy Agency 1997.
- WEC 2004, Ailleret F et al., *Comparison of energy systems using life cycle assessment*. A special report of the World Energy Council, World Energy Council WEC, London, July 2004, ISBN 0 946121 16 8.
- Wijers, G.J., Minister van Economische Zaken, *Nut en noodzaak, Notitie over opwerken van radioactief materiaal*. (in Dutch) Bijlage van brief aan de Voorzitter van de Tweede Kamer der Staten Generaal 25 juni 1997.
- Wikdahl C E, *Uranium – a sustainable energy source*, The Analysis Group, Fact Series, December 2004, annual volume 8, [www.analysis.se](http://www.analysis.se)
- Wilkie, T., 'Tricastin Points the Road to Energy Independence', *Nuclear Engineering International*, October 1980, pp 41-45.
- WNA 2001 Website of the World Nuclear Association, <http://www.world-nuclear.org>
- WNA-11 2005, *Energy analysis of power systems*, Info Paper #11, World Nuclear Association, 2005 <http://www.world-nuclear.org/info/inf11.htm>
- WNA-11 2005, *Critique of April 2001 paper by Storm van Leeuwen and Smith: 'Is nuclear power sustainable?'* supplement to: *Energy analysis of power systems*, Info Paper #11, World Nuclear Association, 2003 <http://www.world-nuclear.org/info/inf11.htm>
- WNA-75 2004, *Supply of Uranium*, Appendix: The sustainability of mineral resources, World Nuclear Association, August 2004. Based on OECD, NEA & IAEA, Uranium 2003, per 0101003.
- WNA-info 2003 *Nuclear Power Reactors*, WNA info, April 2003 World Nuclear Association [www.world-nuclear.org/info/info.htm](http://www.world-nuclear.org/info/info.htm)
- WNA-mining 2005, *Uranium mining in Australia and Canada*, World Nuclear Association, June 2001, [www.world-nuclear.org/education/mining.htm](http://www.world-nuclear.org/education/mining.htm)