ANENT Reference Curricula for Master Degree in Nuclear Engineering (Draft #1 = version 19 Feb 2006)	**Reference Curricula = C1 + C2 + S1 (or S2, S3)** Subjects of C1 should be selected to take ~1/4 of Total Number of Credits; Subjects of C2 should be selected to take ~1/4 of TNC; Subjects of S1 (or S2, S3) should be selected to take ~ 1/2 of TNC.

Block of Subjects	Subject No	Subject Title	Credits	Master Programme in Nuclear Engineering			Subject Content by *V.S.Raghunathan,* B.J.Chung, and P.V.Duan ♣ – It would be very desirable to have a subject content as more detailed as possible in order to make the Reference Curricula more practical.
				Nuclear Power Engineering	Nuclear Non-Power Engineering	Fusion Engineering	
Common ≡ C1 ~ 1/4 of total credits	1.	Advanced Mathematics for Nuclear Engineering					*Would include all the topics necessary for Reactor physics, shielding and include statistical methods.* Overview of arithmetic errors in computations. Desirable features of an algorithm with respect to speed, accuracy, computer memory, stability etc. Linear systems solutions by direct methods, iterative methods and acceleration techniques. Linear systems: matrix inverse, ill conditioned matrices, sparse matrices. Linear systems: Eigen values. Non -Linear systems: Newton-Rapson & Successive Approximation methods. Data Approximation: curve fitting, Lagrange & Hermite interpolations, Least Square & Chebyshev fittings. Numerical Integration: Newton Cotes quadratures, Gauss quadratures. Solution of Ordinary Differential equations: Methods of Euler, Adams, RK, Predictor-Corrector, Stability of solutions, solutions of Stiff Equations.
	2.	Advanced Numerical Analysis					Finite Difference Approximation in 1-D and 2-D. Solution of steady and unsteady heat conduction equations. Modern Iterative Techniques Conjugate Gradient Method, Krylov Subspace Method, Preconditioning. Finite Element Method, Energy Theorem and integral equations, Weighted Residual Approximations, Point and sub domain collocations, Galerkin Method, Variational Principles, Lagranges multipliers. Interpolation Function, Lagranges interpolation, B-spline, Bezier curves. Response Surface Method 2K+1, factorial design, 3k factorial design. Monte Carlo Method. Artificial Intelligence and Genetic Algorithm. Artificial Neural Network. Gram-Schmidtt Orthogonalization. Transformation of matrix. Probability Distribution: continuous and discrete random variables, commonly used probability distributions, Extreme value distributions.

	3.	Advanced Computer Applications					
	4.	Engineering Physics					*Atomic Spectroscopy, Lasers, particle motion and accelerators.* Review of atomic physics: Spectroscopy, UV-visible, infrared spectroscopy, atomic absorption, fluorescence, ICPS measurements Laser Physics & Technology: Basic Physics- Energy Levels in atom and molecules, thermal equilibrium, thermal Boltzmaim distribution, spontaneous and stimulated emission, Einstein's A & B coefficient, population inversion, gain coefficient, homogenous broadening. Methods of obtaining population inversion- Optical excitation, electric discharge excitation, electron injection in semiconductors, thermal excitation, chemical excitation. Laser beams and resonators- Spherical mirror resonator. Modes of resonator, resonant frequencies, Gaussian beam propagation. Physics of Lasing- Threshhold condition, optimum reflectively of mirror, spectral hole burning, laser power, Q-switching, mode-locking. Some examples of laser- Optical pumping: Nd: YAG laser, Ti Sapphire Laser; Electrical discharge pumping: C02 laser, Electron Injection Laser: Semiconductor Laser. Laser Applications- Introduction Physics: Laser Induced Fluorescence for measurement of impurities. Laser Isotopes Separation. Industry: Metrology - Laser interferometer, Laser Micrometer; Material processing, cutting and welding, cladding, stereo-lithography. Introduction to Accelerators: Particle motion under electric and magnetic fields. Electron guns, Ion sources, D C Accelerator, Magnets for Accelerators and their Effects:- Dipoles, Quadrupoles, Sextupoles, Kicker and Septum, Power Supplies for such magnets RF Accelerators - Phase Stability: (a) Linear Accelerators, Electron Linac, Proton Linac- RFQ, DTL (b) Cyclic Accelerators, Cyclotron, Electron Synchrotron, Proton Synchrotron RF Systems for Accelerators: RF Cavities-EM Modes, Shunt impedance, Q Factor. RF Sources & Systems- RF Tubes, Klystrons, Magnetrons, RF System requirement for different Accelerators. Some Applications of Accelerators- ADSS-Synchrotron Radiation, Industrial Applications, Nuclear and particle physics applications. **Reference:** 1. Concepts of Modern Physics, Arthur Beiser (1994) 2. Introduction to Optical Electronics, Amnon Yariv (1977) 3. Principles of Cyclic Particle Accelerators, J.J.Livinghood, (D.Van Nostrand Company. Inc, 1961) 4. Principles of RF Linear Accelerators , T.P.Wangler, (John Wiley & Sons Inc. 1998) 5. Particle Accelerators and their Uses, Part I and Part II, Scharf.

Introductory ≡ C2 ~ 1/4 of total credits	5.	Introduction to Nuclear Engineering (Core)					This course is designed to cover the basic engineering principles underlying the nuclear power plant design and operation. Major subjects are : various types of nuclear energy utilizations(nuclear fission/fusion for electricity generation, nuclear ship propulsion, nuclear rocket, nuclear battery, etc.), introduction to nuclear power reactors, nuclear fuel cycles and radioactive waste disposal, nuclear fuel cycles, fundamentals of nuclear reactor theory, heat transfer of nuclear reactors
	6.	Radiation Detection and Measurements (Core)					This course will give fundamental physics about the interaction of quantum particles with matter. The topics of the course include various interactions of quantum particles such as electron, ion, neutron, and photon with matters and measurement of the quantum particles.
	7.	Radiation Safety and Shielding					This course is designed to provide knowledge concerning radiation shielding. Major items covered in the course is transport theory, buildup factors, Monte Carlo method, radiation biology.
	8.	Power Plant Instrumentation					This course is designed to provide high level undergraduate and graduate students in nuclear and quantum engineering with the basic electric and electronic knowledge such as electronic circuit, power electrics, power transmission and introductory instrumentation and control by theoretic analysis and experiments.
	9.	Nuclear Safety					This course deals with the safety objectives, the safety features, the safety analysis methods and the diagnostic techniques for a nuclear power plant. The probabilistic safety assessment is emphasized, which it includes the deterministic analysis for transient state and design basis accident, and the system reliability, the severe accident generation rate and phenomena. It also deals with TMI accident, Chernobyl accident and other severe reactor accidents as practical examples.
	10.	Nuclear and Reactor Physics					*Would cover from basics of atomic physics to all aspects of reactor physics. Introduce Reactor concepts.* Course discusses the history and the basic theory of quantum mechanics, atomic and nuclear physics as an introduction to nuclear engineering and radiological science. It covers the relativity, waves and particles, atomic and nuclear models, many-electron atom, molecules and solid state, radiation and radioactivity, radiation interactions with matter, and the introduction to applications of radiation to industrial and nuclear medicine etc. This course is designed to cover the nuclear reactor analysis and design, introduction of diffusion theory, approximation of diffusion theory, solution of few-group and multi-group neutron diffusion equation, calculation of energy distribution of fast and thermal neutrons, and homogenization to heterogeneous reactors.
	11.	Health Physics					This course covers topics of radiation biology, exposure, dose, health effects, and legal requirements for radiation biology.

	12.	Nuclear Heat Transfer					Major subjects included are : Fundamentals of heat transfer mechanisms and fluid mechanics, Energy and core flow distribution, heat transfer by conduction and convection of incompressible single and two-phase fluid flow in reactors, Applications of single and two-phase flow in core thermal design and safety analysis of nuclear reactors, Current research topics of the nuclear thermal-hydraulics concerned with safe and effective heat removal from the reactor core for power production.
	13.	Nuclear Power Plants Engineering					This course covers fundamental knowledge regarding nuclear power plant design, operation, and managements. This course may also cover the contents of the FSAR (Final Safety Analysis Report). *All aspects specific to thermal and fast reactors.*
	14.	Materials Science in Nuclear Engineering					*Structural Materials properties and behaviour including Corrosion and testing.* Mechanical properties of materials and their evaluations as per ASTM or equivalent standards, tension test, hardness test, creep, fatigue (low and High cycle) and Impact toughness measurement.. Non destructive Examination Techniques: LPT, Magnetic particles, UT, Eddy current, Neutron, Gamma ray, X-ray Radiography, etc. for welds. Corrosion: Basic principles, types of corrosion and their mechanism, chemical corrosion, cathodic protection of pipelines and vessels,; bio-fouling; prevention by monolithic coatings, standards, evaluation of corrosion, test methods, NACE/ASTM/IS standards. Metallurgy of steels: Classification of carbon steel, low alloy, carbon molybdenum, ferritic, austenitic and martensitic stainless steel. Selection and application of advanced alloys. Nuclear Materials: Fabrication, properties and application of Zircaloy, Zr-Nb alloys, Metallic fuels, ceramic fuels (oxide, mixed oxide, mixed carbide) their properties and applications. Advanced Polymeric materials and Composites: Physical and Chemical Properties, corrosion, mechanical properties; equipment design with polymeric materials; fabrication principles; standards for design, fabrication and testing. **Reference:** 1. “Introduction to Materials Science for Engineers” - James Shackelford 2. “Physical Metallurgy Principles & Practice” - V.Raghavan 3. “Introduction to Solids” - L.V.Azaroff 4. “Structure and Properties of Materials” - Wulff Series, Wiley Eastern, New Delhi 5. “Materials in Nuclear Application” - C.K.Gupta 6. “Nuclear Chemical Engineering” - Benedict and Pigford

Specialty 1 ≡ S1 ~ 1/2 of total credits	15.	Neutron Transport Theory		X			This course is designed to cover the particle transport solution theory, numerical algorithms, and computational methods for continuous, one-group, multigroup neutron and radiation transport phenomena. Major subjects are: singular eigenfunction expansion, Green's function, spherical harmonics, discrete ordinates, integral transport, even-parity transport, method of characteristics, Boltzmann-Fokker-Planck transport methods for neutrons transport phenomena, applied to the design of various nuclear reactors, radiation shielding facilities.
	16.	Reactor Kinetics		X			This course is designed to cover the dynamics of nuclear systems. Major subjects are: delayed neutrons and inhour equations, response to constant, step, and time-dependent reactivities, mechanisms of feedbacks - linear and nonlinear feedback models, transfer functions, linear and nonlinear stability criteria, Lyapunov method, and limit cycles and nonlinear oscillations.
	17.	Advanced Nuclear Heat Transfer		X			This course is meant to cover advanced topics of the nuclear thermal-hydraulic design and analysis of the core of a nuclear reactor along with the related current reactor thermal-hydraulic research topics. Major subjects included are : reactor thermal hydraulic design problems, transient analysis of a single and multiple heated channels, thermal analysis of the spent fuel storage canister, analysis of hypothetical severe reactor accidents, source term uncertainty analysis, hypothetical core disruptive accident of an LMFBR, and current research topics of the nuclear thermal-hydraulics.
	18.	Nuclear Reactor Numerical Analysis		X			This course deals with specific topics related neutron physics. Major items covered in this course is advanced numerical analysis methods, approximation methods, and computer code approach related to neutronics study.
	19.	Nuclear Fuel Cycle and Non-Proliferation		X			This course deals with topics related to nuclear fuel cycles. Major topics covered are : basic understanding of nuclear fuel cycle, various types of nuclear fuel cycles, related issues and options raised with emphasis on non-proliferation aspects
	20.	Power Reactor Design (System Engineering)		X			This course covers nuclear power plant design. Major items covered in the course is neutronics, nuclear thermal hydraulics, and heat cycles.
	21.	Advanced Nuclear Safety		X			This course is an extension of nuclear safety subject. It deals with the advanced topics of nuclear safety regarding deepened knowledge of nuclear regulation, probabilistic approaches, more detailed accident scenario, and recent trend of nuclear safety

	22.	Probabilistic Safety Analysis		X			This course deals with the methodologies and applications of PRA, and computer codes. Among the methodologies, there are probabilistic analysis and accident result analysis. The former includes data processing, fault tree, human error, common mode error and uncertainty analysis. The latter includes containment vessel state, core exposure and melting, pressure vessel melting penetration, core-concrete reaction, atmosphere source terms, radioactive nuclide dissipation and public result. This also includes various applications as the decision-making.
	23.	Strategy and Infrastructure for Nuclear Power		X			Course deals with the evaluation of the modern nuclear energy policy program and the development of analysis methodology for solving various related issues. Also the cost-benefit, risk-benefit, Del-Phi, and the socio-political factor analysis will be discussed in order to be used as the input of the decision making for the new nuclear policy. This course also covers some nuclear economics and regulatory aspects.
	24.	NPP Control and Instrumentation		X			
	25.	Nuclear Regulation		X			
	26.	Nuclear Material Engineering		X			Nuclear materials are introduced with an emphasis on structural integrity on the basis of materials science. Major subjects included are : Effects of microstructure and dislocation substructure on mechanical properties, deformation and fatigue properties in various temperatures and environments. Fracture mechanical analysis of crack propagation, stress corrosion cracking, irradiation effects, the ageing and integrity concerns on the structural materials of key components and recent developments of nuclear materials are included in view of theory and applications.
S2 ~1/2 of total credits	27.	Radiation Protection and Shielding			X		
	28.	Application of Radioisotope and Radiation Sources			X		
	29.	Non-Destructive Testing			X		
	30.	Nuclear Imaging			X		This course deals with the analysis and design methods of various radiation imaging devices used in medical diagnostics and non-destructive tests. It also covers the 2-dimensional x-ray radiography and advanced gamma-ray imagers together with emission and transmission tomographies and laminography, which can be extended into 3-dimensional imaging techniques.

	31.	Radioactive Waste Management			X		This course is designed to provide the students about the technology of the general management of the radioactive waste generated during the operation of nuclear power plant and nuclear fuel cycle facility including the treatment and disposal of the wastes. Major subjects included are : the sources of the gaseous, liquid and solid radioactive waste, and process and treatment facilities, solidification and volume reduction technology, packaging and transportation, storage methods of the wastes and spent nuclear fuel, design, safety and construction of the waste repositories, migration of the radionuclide at the subsurface, environmental monitoring and protection, repository safety assesment, decontamination and decommissioning, and the management of spent nuclear fuel will be covered.
	32.	Advanced Health Physics			X		In this course, the concepts and definitions about radiation dosimetry are introduced and the biological effects on cells and human body organs are discussed including cellular concepts, major organ systems, transuranics, nuclear war, radiotherapy and cancer in experimental animal and human exposure groups. Also the external and internal dose calculation models and the principles of radiation dosimetric instrumentations will be discussed together with the domestic and international regulations for the radiation protection. The principle and methodologies of radiation theraphutic technologies are discussed.
	33.	Applied Radiation Measurements			X		This course introduces the generation, amplification, transfer and measurement of the electronic signal from various radiation detectors based on the physics theory of the electronics signal and noise. Also it deals with the design methods of radiation counting, spectroscopy, timing and imaging system.
S3 ~1/2 of total credits	34.	Advanced Laser Application Engineering				X	
	35.	Advanced Quantum Engineering				X	
	36.	Plasma Diagnostics				X	
	37.	Plasma Processing Analysis				X	
	38.	Advanced Plasma Engineering				X	
	39.	Nuclear Spectroscopy				X	
	40.	Thermonuclear Fusion Engineering				X	