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Electron-Ion Collider Plan

Electron-Ion Collider Global Requirements

March 30, 2023

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01	7/7/2021	Timothy Michalski, Todd Satogata, and Walter Wittmer	Initial Version
02	3/30/2023	Elke Aschenauer, Chris Cullen, Christoph Montag, Dirul Nassar, Tom Nehring, Jason Remien, Ram Srinivasan, and Lori Stiegler	2.2.1 added "electron-proton", 2.2.2 replaced "hadron" with "proton"; added last paragraph, 2.3.3 added "-ion"; "hiding" replaced "sticking", 5. Added "Environmental" to title,5.8 added first paragraph; updated rules on fire protection, 6.1 significant additions to table. Changed document title from "EIC Level 1 Requirements" to "EIC Global Requirements"., 8. added last paragraph defining reliability

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LIST OF ACRONYMS

ACGIH	American Conference of Governmental Industrial Hygienists
AGS	Alternating Gradient Synchrotron
ALARA	As Low As Reasonably Achievable
ALD	Associate Laboratory Director
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASME	American Society of Mechanical Engineers
BNL	Brookhaven National Laboratory
BPVC	Boiler and Pressure Vessel Code
BSA	Brookhaven Science Associates
C-AD	Collider Accelerator Department
CDR	Conceptual Design Report
CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CEQ	Council of Environmental Quality
CFR	Code of Federal Regulations
CGA	Compressed Gas Association
DEAR	Department of Energy Acquisition Guide
DOE	Department of Energy
EIC	Electron-Ion Collider
EICUG	Electron-Ion Collider User Group
E_{cm}	Center of Mass Energy
EO	Executive Order
EPA	United States Environmental Protection Agency
FAR	Federal Acquisition Regulation
GeV	Giga electron Volt
IBC	International Building Code
ICC	International Code Council
IR	Interaction Region
ISO	International Organization for Standardization
kHz	kilo Hertz
L_{avg}	Value of the Luminosity Averaged Over the Time of Subsequent Hadron Fills
LHC	Large Hadron Collider
L_{peak}	Peak Value of Luminosity

MTBF	Mean Time Between Failure
MTTR	Mean Time to Recovery
NAS	National Academy of Sciences
NEPA	National Environmental Policy Act
NFPA	National Fire Protection Association
NRTL	Nationally Recognized Testing Laboratory
NSAC	Nuclear Science Advisory Committee
NSF	National Science Foundation
NSPS	New Source Performance Standards
NYCRR	New York Codes, Rules, and Regulations
NYS	New York State
ODH	Oxygen Deficiency Hazard
OPM	Operating Procedure Manual
OSHA	Occupational Safety and Health Administration
pC	pico Coulomb
QCD	Quantum Chromodynamics
RCRA	Resource Conservation and Recovery Act
RF	Radio Frequency
RHIC	Relativistic Heavy Ion Collider
SBMS	Subject Based Management System
SC	Department of Energy Office of Science
SPDES	State Pollutant Discharge Elimination System
SSPP	Strategic Sustainability Performance Plan
US	United States
WBS	Work Break Down Structure

Electron-Ion Collider Global Requirements

1. PHYSICS REQUIREMENTS

The EIC will address some of the most fundamental questions currently confronting nuclear science regarding the manner in which the basic particles of nature, interacting via the strong interaction described by quantum chromodynamics (QCD), give rise to the observed properties of visible matter in our universe. The goal is to explore in detail the dynamic substructure of quarks and antiquarks bound together by force-carrying gluons -- complex systems internal to the protons and neutrons of atomic nuclei -- with significantly greater precision and resolving power than heretofore possible, utilizing a next-generation facility for polarized electron-proton and electron-ion collisions.

The detailed measurements and corresponding requirements for a world-class experimental program with an electron-ion collider are presented in a comprehensive "White Paper" [9.1] resulting from an international scientific effort spanning more than a decade of study. The construction of a new facility to meet these requirements and carry out this program was endorsed in the 2015 US DOE/NSF Long Range Plan for Nuclear Science [9.2]. Such a facility, and the corresponding scientific program, were subsequently endorsed by the Science Council of the National Academies of Science [9.3]. The EIC project is now launched to provide this facility.

An EIC can uniquely address three profound questions about nucleons—neutrons and protons—and how they are assembled to form the nuclei of atoms:

- How does the mass of the nucleon arise?
- How does the spin of the nucleon arise?
- What are the emergent properties of dense systems of gluons?

The program of measurements to achieve these goals calls for extremely bright, high intensity beams of electrons colliding with similarly bright, intense beams of protons and atomic nuclei (ions) over a wide range of collision energies, with a high degree of spin polarization for the electrons and protons as well as for some light ions. In addition, key elements of the program call for an unprecedented degree of integration between accelerator and detector components.

A detailed description of the EIC collider and experimental equipment is given in the Conceptual Design Report (CDR) [9.4]. The major design requirements for the facility are as follows:

- Center-of-mass energy range from ~29 to 140 GeV.
- Ion beams from deuterons to the heaviest stable nuclei (e.g. gold, lead, uranium)
- Luminosity up to 10^{34} $cm^{-2}s^{-1}$ for electron-proton collisions
- Highly polarized (~70%) electron, proton, and light-ion beams
- An interaction region and integrated detector capable of nearly 100% kinematic coverage
- The capability of incorporating a second such interaction region as needed.

The scientific program for the EIC foresees large data samples over a range of operating conditions that will take many years to fully acquire and, if history is a guide, will lead to new insights requiring further investigation. The accelerator and detectors must be equipped, and staffed, for reliable 24/7 operation over ~8 months per year for a period of decades. A rigorous maintenance regime and the implementation of programmatic upgrades over the lifetime of the facility will be required for scientific success.

The Electron-Ion Collider (EIC) including its colliding beam detector will be built to carry out the physics program defined in the 2015 Long Range Plan for Nuclear Physics [9.2] submitted by Nuclear Science Advisory Committee, (NSAC), the 2015 Community White Paper on the Electron-Ion Collider, "Electron-Ion Collider, the Next QCD Frontier" [9.1] which has been reviewed and endorsed by the National Academy of Science as described in the Assessment of the US-Based Electron-Ion Collider Science of 2018 [9.3].

2. COLLIDER PERFORMANCE

2.1. Overview

To meet the physics requirements, the EIC must perform at very high levels of the performance parameters and provide favorable geometry and conditions for a distributed detector system:

- Luminosity
- Spin polarization of both hadron and electron beams
- Center of mass energy
- Range of ion species
- Sufficient aperture and space for forward detector systems
- Acceptable background conditions due to the presence of beam in the interaction region
- Possibility of implementing a 2nd detector and interaction region.

Furthermore, the interaction region must be designed not only to allow for the high luminosity beam parameters but also to allow for complements to the central detector with auxiliar forward detector systems such as a spectrometer next to the central detector, near-hadron-beam detectors (roman pots, off-momentum detectors, forward neutron calorimeter) the low-Q^2 electron taggers and luminosity monitor. The layout of the interaction region shall take into account the aperture requirements for these detector systems. The Compton polarimeter and a pC polarimeter for the electron and hadron beam, respectively needs also to be integrated between the respective spin rotators.

2.2. Operational Requirements for the Experimental Program

2.2.1. Luminosity

- The EIC is designed to achieve peak electron-proton luminosities between $10^{33}cm^{-2}s$-1 and 10^{34} $cm^{-2}s^{-1}$. Comment: With strong hadron cooling ($L_{peak} = L_{avg}$), 10^{33} $cm^{-2}s^{-1}$ yields an integrated luminosity of 1.5 fb^{-1} per month.
- The peak electron-proton luminosity of the EIC shall reach values between one and ten times 10^{33} cm^{-2} s^{-1} in the range 29 to 140 GeV of center of mass energies, $L_{peak}= (1\text{-}10) \cdot 10^{33}\ cm^{-2}\ s^{-1}$ for 29 GeV< E_{cm}<140 GeV.
- The design shall aim to maximize the range of center of mass energies where the peak electron-proton luminosity reaches values close to $L_{peak}=10^{34}\ cm^{-2}\ s^{-1}$.
- The luminosity averaged between two subsequent injections of hadron beams L_{avg} aims to be close to 90% of the peak luminosity.
- The collider shall be designed such that these luminosity goals can be achieved within the first five years of operations.

Comment: Most of the key physics topics discussed in the EIC White Paper [9.1] are achievable with an integrated luminosity of 10 fb^{-1}, corresponding to about one year of operation. Notable exceptions are the studies of the spatial distributions of quarks and gluons in the proton with polarized beams; such measurements require an integrated luminosity of up to 100 fb^{-1}calling for the highest luminosity. Judicious choice of beam species, energies, and spin orientation shall allow multiple measurements simultaneously per operating period.

2.2.2. Center of Mass Energies

To ensure a wide kinematic reach and a large coverage of phase space, the EIC requires a variable center-of-mass energy, in the range of ~29 to 140 GeV for electron-proton collisions. The highest energies are needed to provide sufficient kinematic reach into the gluon-dominated regime. Energies at the low end of the range allow the most accurate determination of properties related to the valence quarks in the nucleon. Some measurements require data over a range of collision energies.

The EIC must therefore cover a large range of center of mass energy. The collider shall be designed for center of mass energies in the range of

29 GeV to 140 GeV (electrons and protons).

The corresponding requirements for maximum proton beam energy is 275 GeV and for maximum electron energy is 18 GeV.

The corresponding requirements for minimum proton beam energy is 41 GeV and for minimum electron energy is 5 GeV.

The center of mass energy range for Electron-Ion collisions shall be (in case of electron gold collisions, a representative case)

29 GeV to 89 GeV (collisions of electrons with gold ions).

The corresponding Au ion energies are 110 GeV/nucleon and 41 GeV per nucleon, respectively.

The hadron ring of the collider must be built such that electrons and protons in the range of 100 GeV and 275 GeV have the same revolution time. For low energy hadron operation, the hadron accelerator lattice must include an option of a bypass so that the pathlength for protons with an energy of 41 GeV or a relativistic beta of 0.9997383 has the same revolution time as the electron beam.

The electron storage ring must be designed such that the revolution frequency of the electron beam equals the revolution frequency of a 133 GeV proton beam in the hadron storage ring. For low energy hadron operations, the hadron storage ring lattice must include an option of a bypass such that the path length for protons with an energy of 41 GeV - or any ion species with a relativistic beta of 0.9997383 - results in the same revolution time as the electron beam in the electron storage ring.

2.2.3. Beam Polarization

EIC physics involves two types of asymmetries: (i) double-spin asymmetries, requiring both electron and hadron beams to be polarized, and (ii) single-spin asymmetries, requiring only the electron or hadron beam to be polarized. The statistical uncertainties for spin asymmetries are strongly affected by the degree of polarization. For double-spin asymmetries the dependence is $1/(P_e P_h \sqrt{N})$ and for single-spin asymmetries it is $1/(P\sqrt{N})$. High beam polarizations, ≥70%, are mandatory to reduce the statistical uncertainties.

Electron- and proton beams as well as light ion beams such as He-3 need to be spin polarized accordingly in collisions with a polarization degree of 70% on average (over time).

High levels of polarizations of beam beams must be achieved and maintained during collision operation. The accelerator chain and the injection systems for electron must be able to provide beams with sufficiently high polarization at a sufficiently high injection frequency to maintain high electron average polarization levels in presence of unavoidable polarization loss with increasing storage time.

The polarization direction in collisions needs to be adjustable in the longitudinal direction and the transverse direction with respect to the hadron beam direction and the longitudinal direction for the electron beam.

The polarimeters are required to be able to measure the beam polarization on a bunch-by bunch level.

2.2.4. Ion Species

Ion beams of heavy nuclei (gold, lead, or uranium) combined with the highest collision energy will provide access to the highest gluon densities and to an understanding of how color charged particles propagate through nuclear matter. Light ions are essential to study the A-dependence of non-linear effects in QCD and for precision studies of short-range nuclear correlations.

The EIC collider shall include the capacity to produce ion beams of a large range in *A* from protons to uranium. While most of this capacity already exists in present RHIC and will be available for the EIC, polarized He3 beams are being provided for RHIC operation soon. The capacity of polarized deuteron beams is not yet available, and the components associated with deuterons not part of the EIC budget. However, the EIC injector complex must be configured such that this capability can be added with a minimum of additional hardware (such as a polarized deuteron source and deuteron polarimetry).

2.3. Accelerator Detector Interface Requirements

2.3.1. Machine Detector Interface

The EIC shall be built to support the full EIC physics program. In addition to the collider performance requirements, this implies additional design features that support the large acceptance requirement of the central colliding beam detectors as well as acceptance of auxiliary detectors, that favor good background conditions, and that provide the possibility to measure the parameters of the colliding bunches in a bunch-by-bunch fashion. These requirements will be detailed in the requirement document for the interaction region with the scope captured under 6.06 and 6.12 in the project work break down (WBS) structure.

2.3.2. Detector Acceptance

The current level of planning for the EIC experimental program is driven to a large extent by a year-long study initiated in 2019 by the EIC Users Group (EICUG, www.eicug.org), a scientific organization of ~1300 members representing 256 institutions located in 34 countries. The purpose of the study was to provide an organized, in-depth consideration of the EIC physics measurements and scientific equipment, including extensive simulations to quantify the technical requirements for detector components. The results of this study are compiled in a 900-page EICUG Yellow Report [9.5].

The EIC physics program imposes a range of requirements on the design of a general-purpose detector, i.e. a detector array in a single interaction region (IR) capable of addressing the full suite of physics measurements described in the White Paper [9.1] and National Academy of Sciences (NAS) report [9.3]. Such a detector must accommodate the full range of produced particle kinematics for center-of-mass collisions energies that span the range from ~20 GeV to 140 GeV.

The various physics processes encompass inclusive measurements, for which the scattered electron alone must be precisely measured, including a range of angles within a few milliradians of the beam; semi-inclusive measurements, which require detection of at least one hadron in coincidence with the scattered electron; and exclusive processes, which require the detection of all particles in the reaction with high precision. Sections 2.3 and 2.5 of the CDR [9.4] discuss in detail how the requirements on the accelerator, the interaction region, and the experimental equipment flow down from the EIC science. A conceptual Reference Detector design, based on results of EICUG Yellow Report study, is presented in section 8.3 of the CDR.

Figure 1 shows the kinematic distribution of the scattered electron and hadrons for the required acceptance of a general-purpose detector. As illustrated here, the detector must be "hermetic", with an acceptance that includes all angles, up to those of particles scattered within a few milliradians of the colliding beam directions. This requirement makes stringent demands on the layout of accelerator components comprising the IR.

In the EIC IR design, the main detector, comprising tracking, calorimetry, and particle identification for scattered particles with pseudorapidity in the range η = -4 to +4 must fit within a space -4.5 to +5 meters from the collision point. For scattered particles whose energy and momentum are very close to those of the circulating beams, far forward and backward detectors must be integrated with the accelerator components of the IR. How this is done in the current IR design is documented in detail in section 3.2.4 of the CDR [9.4].

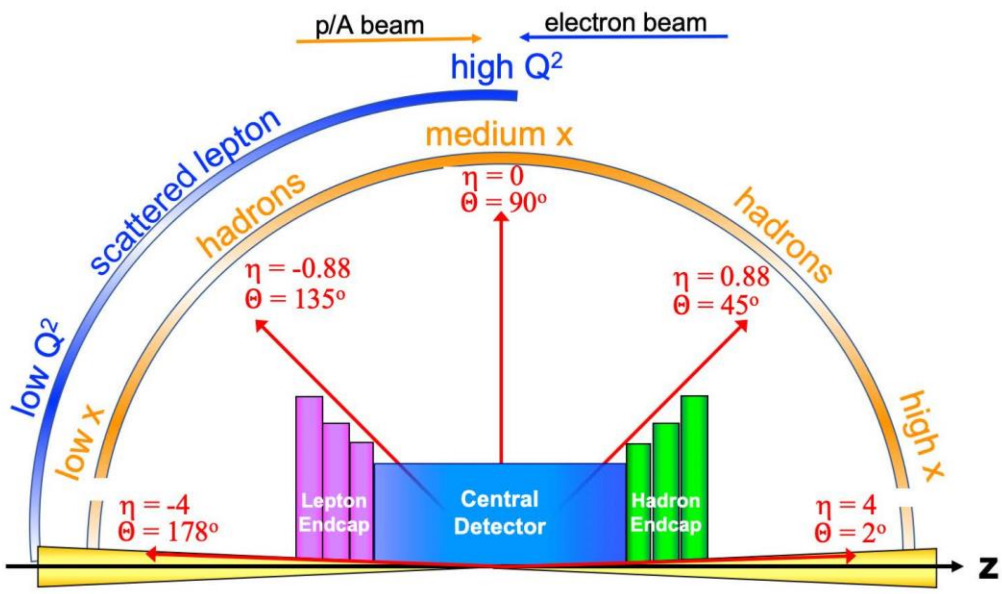

Figure 1 Schematic showing the distribution of the scattered electron and hadrons over the acceptance in polar angle (θ) and pseudorapidity (η).

In addition to the main detector, required experimental equipment includes:

- Very forward detectors to complete the hermetic coverage, such as Roman pots to detect scattered protons that remain inside the beam pipe, and large acceptance zero-degree calorimetry to effectively detect neutrons from the break-up of nuclei or neutrons from tagged deep inelastic scattering of electrons.

- Polarized beams require the implementation of electron, proton, and light-ion polarimetry. (See CDR section 8.6 [9.4]).

An EIC detector will have to cope with collision rates up to ~500 kHz at full luminosity. The strategy for detector read-out and data acquisition will need to be defined, taking into account the data rate of the experiment as well as the rapid developments in the field of digital electronics and computing power, suggesting a global approach to the readout and data acquisition on the one hand and software and computing on the other hand (See CDR section 8.5 [9.4]).

Chapter 8 of the CDR, and Volume 2 of the "Yellow Report", provide further details on the requirements for individual detector components and detailed discussion of the achievable precision for various observables.

2.3.3. Backgrounds

Because the cross sections for electron-ion scattering processes are small, backgrounds in the detector system must be kept to a very low level to extract the signals of interest, more so than is the case in hadron-hadron colliders such as RHIC or LHC. The central and far-forward detectors must be integrated into the accelerator and IR lattice, including the vacuum, controls, and beam protection systems, in such a way as to minimize backgrounds from scattered particles, such as beam-gas interactions from proton or ion beams and synchrotron radiation from the electron beam. For a detailed discussion, see CDR Section 8.3 [9.4].

The detectors must be well protected against background created by the beam. This implies that there must not be particle background from the electron and hadron beams hiding the interaction region vacuum walls. Unavoidable lost particles must be captured by a collimation system well away from the IR.

Particle loss due to scattering of beam particles with the rest-gas are unavoidable. Residual pressure levels must remain within limits defined by the background level which can be accepted by the detector.

2.3.4. Measure Bunch by Bunch Beam Parameters

Good Control of luminosity and polarization is essential for the EIC. The EIC measurements require that the instantaneous luminosity L be measurable to 1%. The precision of double spin asymmetries is dependent on the relative luminosity measurement R = (L++/--)/(L+-/-+), which shall be determined with an accuracy $<10^{-4}$.

The collider shall be constructed and operated such that important beam parameters can be measured for each electron and proton bunch, and each pair of bunches individually.

These bunch parameters are:

- Bunch polarization and polarization orientation in the interaction point.
- Luminosity per bunch crossing and relative luminosity for the spin different spin direction combinations (++, --, +- and -+)

This requirement may have implication on the maximum collision frequency.

3. SEAMLESS INTEGRATION INTO EXISTING HADRON ACCELERATOR COMPLEX

The EIC shall be designed such as to seamlessly integrate into the existing RHIC systems. This requirement implies:

- Duplication of existing functionality and infrastructure previously used for RHIC must be avoided. Either a new system will replace an existing, outdated system -or- the EIC shall adapt an existing system, possibly with an upgrade.
- RHIC components which are becoming part of the EIC shall remain unaltered wherever possible.
- The Electron-Ion collider rings shall use the existing RHIC tunnel and major changes of the present RHIC accelerator tunnel and the experimental halls must be avoided unless necessary.
- Present shielding measures of RHIC, in particular the RHIC berm must stay in place and its integrity as a radiation shielding measure must not be compromised.
- Existing RHIC buildings (service buildings) must be used wherever possible.
- New accelerator controls systems must be designed such as to interface to the existing or upgraded existing hadron accelerator control system without major additional efforts.
- The EIC hadron ring must be able to accept beam from the AGS via the AtE (former AtR) transfer line.

4. UPGRADABILITY

The EIC plans to include previsions to allow future upgrades that are (but are not limited to):

4.1. Upgrading to Two Interaction Regions and Two Colliding Beam Detectors

- The EIC must be planned such that a second interaction region and a second detector can be integrated in the collider with a minimum of cost and effort. It is important to maintain this possibility even if the decision to accommodate a second IR in the collider comes late, at a time collider construction is already underway or is already completed.
- This is achieved by designing the present beam trajectories in the possible area for the next IR around IP8 such that a second IR can be introduced without imposing a difference in circumference of electron ring and hadron ring.
- The design of the electron and hadron beam optics and their higher order correction must offer sufficient margin so that the accelerator performance is not compromised by the 2nd IR.
- Obsolete detector or equipment in the hall around IP8 shall be removed to avoid impeding the construction of a possible 2nd IR.

4.2. Deuterons

The facility must be upgradable to operation with colliding electron and polarized deuteron beams.

5. SAFETY AND ENVIRONMENTAL COMPLIANCE

5.1. General Remarks

The elements EIC collider complex must be designed and built to meet the norms and regulations to ensure safety, minimizing environmental impact and the requirements associated with good engineering practice to arrive at safely performing, enduring and maintainable equipment. These norms and regulations are found to be in the BNL Subject Based Management System (https://sbms.bnl.gov/) and the DOE 10CFR851Worker Safety and Health Program.

5.2. Electrical Systems

Electrical equipment purchased for the accelerator will be certified by a Nationally Recognized Testing Laboratory (NRTL) whenever possible. All equipment will adhere to the codes below.

NFPA 497	Classification of Flammable Liquids, Gases, or Vapors and of Hazardous (Classified) Locations for Electrical Installations in Chemical Process Areas
NFPA 70	National Electrical Code
NFPA 79	Electrical Standard for Industrial Machinery
NFPA 790	Standard for Competency of Third-Party Field Evaluation Bodies

5.3. Vacuum Systems

Will comply to guidelines set forth in the publication:

- "Vacuum Systems Consensus Guideline for Department of Energy Accelerator Laboratories", BNL-81715-2008-IR https://intranet.bnl.gov/esh/shsd/seg/refdoc/pressuresafety/vacuum_standard.doc

5.4. Cryogenic and Pressure Systems

Will be designed and built to meet:

- ASME BPVC Section VIII - Rules for Construction of Pressure Vessels, Division 1, Rules for Construction of Pressure Vessels and Division 2, Alternative
- ASME B31.3 Process Piping
- BNL-8715-2008-IR Vacuum Systems Consensus Guidelines for DOE Accelerator Laboratories
- Compressed Gas Association (CGA) Standard S-1.3, Pressure Relief Device Standards Part 3 – Stationary Storage Containers for Compressed Gases
- ISO 21013-3 Cryogenic vessels - Pressure-relief accessories for cryogenic service Part 3: Sizing capacity determination

This section refers to the regulations the completed collider complex must comply to. The rules and regulations for performing the work associated with creating the scope is not the subject of this document.

5.5. **EIC RF Systems**

Must comply to:

- ASME BPVC:
  - https://www.asme.org/codes-standards/find-codes-standards/bpvc-complete-code-boiler-pressure-vessel-code-complete-set
  - The operating EIC has to follow the review, inspection and maintenance requirements.
- RF Emissions Survey:
  - RF systems will be designed so that RF exposure to personnel will not exceed the thresholds set in ACGIH Threshold Limit Values – 2016.

5.6. **Other Non-Ionizing Radiation (Lasers, Magnetic Fields)**

Lasers and laser enclosures will be designed to comply with ANSI Z136.1, American National Standard for the Safe Use of Lasers.

Magnetic fields may be present in accelerator components and personnel exposure will not exceed the thresholds set in ACGIH Threshold Limit Values – 2016.

5.7. **Water Cooling Systems**

In the design of water-cooling systems, precaution need to be taken to avoid endangering the staff by dangerous bacterial infections. The suppression of unwanted effects such as algae in open water circuits must avoid aggressive chemicals.

The guideline for design of cooling water systems must obey the following requirements/codes (These are in the BNL SBMS also):

- Standards:
  - ANSI/ASHRAE Standard 188. Legionellosis: Risk Management for Building Water Systems. establishes minimum legionellosis risk management requirements for building water systems.

- State Requirements:
  - Protection Against Legionella. 10 NYCRR Part 4 – Protection Against Legionella: Subpart 4-1, Cooling Towers.

In addition, there are General Guidelines and best practices that need to be followed:

- ANSI/ASHRAE Guideline 12. Minimizing the Risk of Legionellosis Associated with Building Water Systems.

5.8. EIC Buildings and Fire Protection

New buildings and infrastructure shall follow sustainable design principles adhering to lab wide commitments towards supporting and achieving the targets in the DOE Strategic Sustainability Performance Plan (SSPP).

The new Buildings needed for the EIC will be constructed to meet the building and fire protection code that is outlined in the following:

The applicable building code is summarized in the compendium:
New York State Uniform Fire Prevention and Building Code (2020 Edition) (Division of Code Enforcement and Administration (ny.gov)). This compendium shall be used as the code of record for the acquisition, construction of new facilities, and in the significant modifications of existing facilities.

This is compliant with the DOE Order 420.lC "Facility Safety," construction of new facilities and significant modifications of existing facilities shall meet the applicable parts of the latest edition of the International Building Code (IBC, 2018 edition) and remains in compliance with DOE Orders and Standards directions in particular with DOE-STD-1066 section 2.2.4.

The amended and updated version of the NYS Code Books incorporates by reference the following publications:

- 2020 Building Code of New York State Chapters 2 to 35
- 2020 Existing Building Code of New York State, Chapters 2 to 16
- 2020 Fire Code of New York State, Chapters 2 to 67
- 2020 Fuel Gas Code of New York State, Chapters 2 to 6
- 2020 Mechanical Code of New York State, Chapters 2 to 15
- 2020 Plumbing Code of New York State, Chapters 2 to 15
- 2020 Property Maintenance Code of New York State, Chapters 2 to 8
- 2020 Residential Code of New York State, Chapters 2 to 44

These include the following rules on fire protection:

- 2020 Fire Code of New York State, Chapters 2 to 67
- 29 CFR 1910 Sub Part L Fire Protection
- ANSI Z 535.1 Safety Color Code
- DOE-STD-1066-2016 Fire Protection
- ICC A117.1-2009, Americas with Disability Act

5.9. Egress

- New construction in the collider complex must be constructed such as to avoid confined space in areas that must be entered by personnel for maintenance and repair. Shall that not be possible or lead to unreasonable conditions, the collider design must include mitigation of the corresponding hazard.
- The accelerator must provide safe egress conditions which implies:
  - Any work locations in the collider tunnel shall not be further away than 400 ft from the next tunnel exit when the tunnel has sprinkler protection.
  - The exit path from any work location in the collider tunnel to the next exit must be unobstructed by accelerator components and shall not require underpasses with less than 36 inches width and 36 inches height.
  - Markings are provided to denote and preserve access to the duck under.
  - In certain regions a ladder or stair is used to access a platform on top of the magnets for egress.
  - Emergency lighting and illuminated exit signs will be provided.

5.10. Radiation Safety

The radiation safety measures of the EIC shall be compliant with the DOE order 10 CFR 835, Energy/Occupational Radiation Protection and the more stringent requirements set forth in the BNL SBMS. All exposures shall be As Low as Reasonably Achievable.

The most important radiation protection requirements of the facility include (but are not limited to):

Radiation emitted by the EIC accelerator beams and due particle losses must be shielded such that dose limits outside the accelerator enclosures are below:

- 25 mrem annually for an inadvertently exposed person
- 5 mrem annually at the site boundary
- 20 mrem during a fault condition
- 0.5 mrem in 1 hour or 20 mrem in one week for continuously occupied areas

5.11. **Toxic Materials**

- Toxic materials must be avoided in the components of the EIC. At instances where non-toxic materials are not available personnel exposures will be below the thresholds set in ACGIH Threshold Limit Values – 2016, or OSHA 10 CFR 1910, whichever is lower.
- Hazard assessment in compliance with 10 CFR 851 will be completed for any use of Beryllium and exposures will be in accordance with the regulation.

5.12. **Oxygen Deficiency**

- Oxygen deficiency hazards must be avoided by providing oxygen monitoring, ventilation, adequate warning systems and corresponding training of operating and maintenance staff. Oxygen deficiency hazards are evaluated using the methodology in SBMS, Oxygen Deficiency Hazards (ODH), System Classification and Controls.

6. **ENVIRONMENTAL IMPACT**

6.1. **Compendium of Rules and Regulations**

In order to minimize the impact of the EIC on the environment, the facility must comply to the following compendium of rules and regulations:

10 CFR 1021	National Environmental Policy Act (NEPA)Implementing Procedures
10 CFR 1022	Compliance with Floodplain/Wetlands Environmental Review Requirements

16 USC 1531	Endangered Species Act (Title 16 - Conservation: Chapter 35- Endangered Species
16 USC 461-467	Historic Sites Act of 1935
16 USC 469	Archaeological and Historic Preservation Act
16 USC 470	National Historic Preservation Act
16 USC 470aa-470ll	Archaeological Resources Protection Act of 1979
16 USC 703-712	Migratory Bird Treaty Act
36 CFR 800	Protection of Historic Resources
40 CFR 82	Protection of Environment /Protection of Stratospheric Ozone
40 CFR 239 – 282	Resource Conservation and Recovery Act (RCRA)
42 USC 4321-4347	National Environmental Policy Act of 1969, et seq., as amended
6 NYCRR 193.3	Trees and Plants/Protected Native Plants
6 NYCRR 375	Environmental Remediation Programs
6 NYCRR 608	Article 15, Title 5 - Protection of Waters
6 NYCRR 662 & 663	Article 24 - Freshwater Wetlands
6 NYCRR 666	Article 15, Title 27 - Wild, Scenic, Recreational River Systems Act
8 NYCRR Part 101	New York State Environmental Quality Review Act
40 CFR 302.6	Notification Requirements under CERCLA and Title III of the Superfund Amendments and Reauthorization Act of 1986
49 CFR 172	Transportation/Hazardous Materials Regulations/ Hazardous Materials Table, Special Provisions, Hazardous Materials Communications, Emergency Response Information, and Training Requirements
6 NYCRR 360-364.9	Solid Wastes
6 NYCRR 370	Hazardous Waste Management System: General
6 NYCRR 371	Identification and Listing of Hazardous Wastes
6 NYCRR 374	Standards for the Management of Special Hazardous Wastes and Specific Types of Hazardous Waste Management Facilities
6 NYCRR 374-2	Standards for the Management of Used Oil, New York State Department of Environmental Conservation

10 NYCRR 5	New York State Department of Health, State Sanitary Code, Drinking Water Supplies
16 USC 668 a-d	The Bald and Golden Eagle Protection Act.
40 CFR 110.6	Discharge of Oil
40 CFR 112	Protection of Environment/Oil Pollution Prevention
40 CFR 122-131, 133	Code of Federal Regulations, National Pollutant Discharge Elimination System
40 CFR 141-143	National Primary and Secondary Drinking Water Standards
40 CFR 144 - 148	Underground Injection Control
40 CFR 1500-1508	November 1978, "Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act," Council on Environmental Quality, U.S. Code of Federal Regulations
40 CFR 262 & 264-265	Resource Conservation and Recovery Act/Standards Applicable to Generators of Hazardous Waste
40 CFR 279	Standards for the Management of Used Oil
40 CFR 300	Protection of the Environment/National Oil and Hazardous Substances Pollution Contingency Plan
40 CFR 60 - Subpart A	Standards of Performance for New Stationary Sources (NSPS)
40 CFR 60 Subpart IIII (as amended June 28, 2011)	Standards of Performance for Stationary Compression Ignition Internal Combustion Engine
40 CFR 61 - Subpart A	National Emissions Standards for Hazardous Air Pollutants (NESHAPs)-General Provisions
40 CFR 61 - Subpart H	National Emission Standards for Hazardous Air Pollutants (NESHAPs) - National Emission Standards for Emissions of Radionuclides Other Than Radon from Department of Energy Facilities
40 CFR 98	Mandatory Greenhouse Gas Reporting
48 FR 34263	USC 1996. July 1983, "CEQ Regulations for Implementing the Procedural Provisions of the National Environmental Policy Act," Council on Environmental Quality, Federal Register
50 CFR 17 Dept. of Interior, Fish and Wild Life Service [Fed. Reg. Vol.78 No.191, Oct 2, 2013]	Endanger and Threatened Wildlife and Plants; Listing the Northern Long-Eared Bat as an Endangered Species - Proposed Rule
6 NYCRR 200 - 234	New York State Department of Environmental Conservation/Prevention and Control of Air contamination and Air Pollution

6 NYCRR 595-599	New York State Department of Environmental Conservation, "Hazardous Substance Bulk Storage Regulations,"
6 NYCRR 611 and 613	New York State Department of Environmental Conservation, Storage and Handling of Petroleum/Petroleum Clean-up and Removal
6 NYCRR 750	State Pollutant Discharge Elimination System (SPDES) Permits
BSA Contract No. DE-SC0012704 - Clause I.134 (DEAR 970.5223-7)	Sustainable Acquisition Program (Oct 2010)(SC Alternate 1)(Sep 2018)
BSA Contract No. DE-SC0012704 - Clause I.52 — FAR 52.223-5	Pollution Prevention And Right-to-know Information (May 2011) (Alternate I)
BSA Contract No. DE-SC0012704 - Clause I.54 — FAR 52.223-9	Estimate Of Percentage Of Recovered Material Content For EPA Designated Items (May 2008)
BSA Contract No. DE-SC0012704 - Clause I.56 (FAR 52.223-11)	Ozone-Depleting Substances and High Global Warming Potential Hydrofluorocarbons (Jun 2016)
BSA Contract No. DE-SC0012704 - Clause I.62 — FAR 52.223-19	Compliance With Environmental Management Systems (May 2011)
BSA Contract No. DE-SC0012704 - Clause I.62A - FAR 52.223-20	Aerosols (Jun 2016)
BSA Contract No. DE-SC0012704 - Clause I.62B - FAR 52.223-21	Foams (Jun 2016)
EO 13693 was revoked by EO 13990, EO 14008, EO 14057, EO 14082	EO 13990: Climate Crisis; Efforts to Protect Public Health and Environment and Restore Science, January 20, 2021 EO 14008: Tackling the Climate Crisis at Home and Abroad, January 27, 2021 EO 14057: Catalyzing Clean Energy Industries and Jobs Through Federal Sustainability, December 8, 2021 EO 14082: Implementation of the Energy and Infrastructure Provisions of the Inflation Reduction Act of 2022, September 12, 2022
O 435.1 Chg 2 (AdminChg)	CRD - Radioactive Waste Management
O 436.1 (May 2, 2011)	Departmental Sustainability
O 458.1 Chg 4 (LtdChg)9-15-2020	Radiation Protection of the Public and the Environment
Suffolk County Sanitary Code - Article 12	Toxic and Hazardous Materials Storage and Handling Controls

Precautions shall be taken at locations with expected high beam loss, that activation of soil, ground water, and cooling water is kept ALARA, and that controls are implemented to minimize environmental impacts and exposure to personnel.

In addition, DOE buildings are subject to the requirements for efficiency and sustainability in DOE O 436.1, Departmental Sustainability.

6.2. Environmentally Sensitive Areas

Ecologically and environmentally sensitive areas such as the Peconic River that crosses the EIC facility must not be affected by EIC construction activities.

6.3. Contamination of Soil and Ground Water

Precautions shall be taken at locations with expected high beam loss, that activation of oil, ground water, and cooling water is kept within level defined by the document C-AD OPM 9.1.12.

6.4. Power Consumption

The inefficient use of electrical power shall be avoided by appropriate energy conscientious design.

7. TECHNICAL EFFICIENCY AND REDUNDANCY

7.1. Standardized Components

The facility shall be planned and designed preferably with standardized components that can be used in several hardware systems of the collider.

7.2. Re-useable Designs

Multipurpose components shall be used wherever they are not compromising performance, cost or schedule.

7.3. Use of Existing Technology

To minimize performance risks, commissioning and collider maturing periods and to reduce initial trouble shooting efforts, existing and proven technology shall be used wherever possible. Use of new technology must be motivated by substantial increase in performance, tolerances, service friendliness, maintainability, manufacturability, availability on the market, cost, and schedule and reasonable research and development effort.

8. OPERATIONAL EFFICIENCY AND RELIABILITY

The EIC collider design choices must consider high levels of operational efficiency and reliability to maximize the physics outcome. The efficiency has several components:

- Operating procedures which minimize the time between collision runs which includes the time for beam injection, collision adjustment and tuning.
- Consistently achieving good performance parameters near the anticipated design goals
- Minimizing unscheduled downtime by technically reliable accelerator hardware (thus large mean time between failure, MTBF) and short repair and replacement times (which implies short times between repairs, MTTR).

These aspects must be given a high weight in the design of the facility in addition to the goal of high peak performance parameters. There are other design consideration concerning operational efficiency:

- Switching center of mass energy shall not require changing or major moving accelerator components (rewiring maybe unavoidable but shall be designed such as to minimize tie and effort)

Maintain access for repair and maintenance without removing other components. All components need to be removeable/exchangeable without modifications to buildings and access to tunnels and service buildings.

Reliability is defined as time when beam is available as a fraction of scheduled time with beam. The difference between delivered and scheduled time is failure time. The EIC shall meet or exceeded a target of 80% reliability.

9. REFERENCES

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9.2 The 2015 Long Range Plan for Nuclear Science, Available at: https://www.osti.gov/biblio/1296778

9.3 An Assessment of U.S. Based Electron-Ion Collider Science, Available at: https://www.nap.edu/catalog/25171/an-assessment-of-us-based-electron-ion-collider-science

9.4 EIC Conceptual Design Report, January 2021, Available at: https://www.bnl.gov/ec/files/EIC_CDR_Final.pdf

9.5 EIC User Group Yellow Report, Science Requirements and Detector Concepts for the Electron-Ion Collider: EIC Yellow Report, https://arxiv.org/abs/2103.05419