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STUDIES OF REQUIREMENT FOR ITER DISRUPTION MITIGATION SYSTEMS

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Studies of Requirements for ITER Disruption Mitigation Systems

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ITER in-vessel components are designed to withstand the electromagnetic and thermal loading stress and erosion caused by disruptions. However, there are clear incentives in ITER to both avoid the occurrence of disruptions whenever possible and to reduce deleterious effects of such disruptions if they do occur. Disruption damage may limit the usable lifetime of the affected components, and time consuming reconditioning of plasma facing surfaces after disruptions will likely be required for subsequent discharges. Requirements for mitigation of disruption effects fall into three categories: (1) reduction of thermal loading on divertor and first-wall plasma facing component surfaces, and in particular avoiding material thermal limits (melting/ablation), (2) reduction of electromagnetic forces associated with halo currents, and (3) mitigation of runaway electron conversion in the current quench phase of the disruption. Methods and actions that accomplish these categories of mitigation have been tested and/or demonstrated with some degree of success and reactor relevancy in present tokamaks [1,2].

This paper will summarize recent work, conducted under the aegis of the US Burning Plasma Organization, related to establishing recommendations for requirements and design concepts for ITER systems. These recommendations have been developed in concert with the ITER Fusion Science and Technology Department. The initial focus of the joint work has been on establishing requirements for a massive gas injection (MGI) system sized to accomplish all three mitigation objectives. A preliminary set of specifications has been developed and the ITER IO has conducted a preliminary assessment of the operational impacts of MGI mitigation. The large quantity of neutral gas required to provide unequivocal collisional mitigation of runaway electron conversion is found to have a significant impact on the ITER torus vacuum pumping and exhaust processing systems. However the quantity of gas actually required may be less if appreciable intrinsic runaway losses occur. Alternatively, the gas quantity may be reduced by optimizing the plasma uptake of injected particles, possibly by use of solid pellet or liquid jet injection methods. Differences in the ability of the present ITER systems to rapidly exhaust hydrogenic and various noble gas species will affect the recovery of the vacuum systems after a disruption, and must be considered in making a selection of the optimal mitigation system concept and species. Finally, since mitigation of disruption effects may enter in reducing the likelihood of certain classes of off-normal event chains that have consequences for maintaining ITER in-vessel system integrity, the reliability and efficiency of the mitigation methods become important design considerations. These considerations motivate a better understanding of runaway losses and exploring a range of design concepts beyond presently-conceived “simple” MGI options.

Specifications for an ITER MGI System. Table 1 summarizes key specifications for a MGI disruption mitigation system sized to deliver sufficient in-plasma total electron content to suppress runaway avalanche. Both an empirical and self-consistent numerical 0-D model of the current quench thermal equilibrium are used to obtain the results. The design basis is injection of a low-Z noncondensable gas, either deuterium or helium, with neon being considered as a high-Z alternate. Core plasma uptake of 20% of the injected gas is assumed; this finite assimilation factor reflects results obtained in DIII-D MGI experiments [3]. The worst-case scenario is adopted for runaway electrons, in that no loss mechanisms are assumed during the current quench. Hence runaway suppression is assumed to be accomplished solely by increased collisionality.

Table 1. Parameters for an ITER MGI system (15-MA plasma, W_{th} = 350 MJ, $E \leq E_c$ mitigation per 0-D model)

Parameter or Requirement	Value	Comment or Basis
Gas	Helium	Encompasses requirements for $D_2 \rightarrow Ne$
Quantity, Pa-m^3	5x10^5	20% assimilation
Quantity, kg	0.93	20% assimilation
Duration, ms	10	Square-pulse FWHM
Rise, fall times, ms	≤3	≤1 ms desirable
Average flow, MPa-m^3/s	50	Sum from one or more units
Action time, ms	≤10	Determines "look-ahead" requirement for prediction; ≤3 ms desirable
Variability, %	1→100	To adapt to reduced current or reduced energy plasmas
Exit pressure (ρv^2), MPa	3-6	To facilitate direct penetration
Reliability	>0.99	Detailed study needed

Impacts of Injected Gas or Particles. The operational impacts of ~0.5 MPa-m^3 of deuterium or helium injected into the ITER torus vessel are significant: the after-injection torus pressure rises to ~100 Pa (10^{-3} bar), the thermal stability of the cryogenic torus and neutral beam pumping systems will likely be compromised, and, particularly for helium, the time to recover low-enough torus pressure to resume plasma operation will exceed several hours. In addition, the entire quantity of injected gas must be processed through the Tritium Exhaust Processing system: throughput capabilities of this system also presently set long recovery times. Use of neon allows a smaller quantity of injected gas (~10^5 Pa-m^3), reduces cryopump thermal loading and shortens recovery times. There are, however, indications from theoretical models and recent experiments that neon may not be as effective as helium or deuterium in avoiding runaway generation or suppressing avalanching. Hence the choice of an optimal gas species or mixture of species for ITER remains open.

Optimization, Runaway Physics, and Alternate Injection Concepts. Improvement of the present expectation for a low (~20%) assimilation factor for basic MGI would significantly reduce the amount and operational impacts (after-effects) of gas injection. A better quantification of runaway loss mechanisms during disruption mitigation on present devices, such as predictions for stochastic runaway losses [1,2], would lead to more realistic and less-restrictive estimates of particle-injection requirements. Alternately, liquid jet and/or solid pellet injection can, in principle, provide equivalent particle injection capability, with improved penetration, although in these cases assimilation may be limited by the plasma's ability to stop the pellets or liquids. In general, experimental tests of such methods in regimes applicable to collisional mitigation of runaway avalanching in ITER are presently lacking. The physics-basis and technology-basis trade-offs among the many options identified comprise a subject of on-going fusion science and technology research and development. The concluding content of this paper will attempt to identify implications for ITER application and the corresponding development/test requirements.

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[1] ITER Physics Basis, Nucl. Fusion **39**, 2137-2638 (1999).
[2] Progress in the ITER Physics Basis, Nucl. Fusion **47**, S1-S414 (2007).
[3] J.C. Wesley, *et al.*, "Fast Plasma Shutdowns Obtained With Massive Hydrogenic, Noble and Mixed-Gas Injection in DIII-D," this conference.