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North Korea's Artificial Intelligence Research: Trends and Potential Civilian and Military Applications

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January 2024

Appendix I. North Korea's Commercial Products Employing AI/ML.

Figure 1. Flyer for the Azalea 6/7 mobile phone. (Source: DPRK Today)

Figure 2. Flyer for the Yalu River Technology Development Company. (Source: DPRK Today)

Appendix II. Publication List of Ho Il Mun and So Chol.

Year	Authors	Title	Keywords
2000	Ho Il Mun, Ri Kyong Su	Calculation of Reactivity Change due to Coolant in PWR	reactivity, change effect, coolant, PWR
2000	Kang Sun Gil, Ho Il Mun	Thermodischarge-minimization under Restriction Condition of Xe Concentration	Xe concentration, thermodischarge-minimization
2004	Ho Il Mun, Jo In Hyong	Studies on Burn-up Property of MOX Fueled PWR Core Lattice	burn-up property, MOX-fueled PWR core lattice, conversion ratio, isotopic ratio of fissionable Pu(239Pu+241Pu)
2004	Ho Il Mun, Paek Yong Myong	Study on Some Reactivity Effects in Mox Fueled PWR Core Lattice	fuel/moderator temperature coefficients, void reactivity coefficient, MOX fueled core lattice, calculation code WIMS/D4
2004	Ho Il Mun, Kang Sun Gil, Ryu Kum Bong	Influence of Moderator-fuel Ratio on Reactor Physical Characteristics in MOX Fueled PWR Core Lattice	MOX fueled PWR core lattice, moderator-fuel ratio, reactor characteristics (infinite multiplication factor, neutron energy spectrum, conversion ratio)
2005	So Chol, Ho Il Mun	Solution of Integral Neutron Transport Equation in Square Fuel Assembly by Transmission Probability Method	calculation formula of neutron's escape and transmission probability, linear source approximation, simple p1 approximation
2005	Ho Il Mun, Paek Yong Myong, Kim Kyong Il	Influence of Fuel Enrichment and Moderator-fuel Ratio on Burn-up Property of PWR Core	level of enrichment, initial reactivity, discharged burn-up, conversion ratio, mass percent of heavier isotopes within Pu
2007	So Chol, Ho Il Mun	Integral Neutron Transport Calculation in Hexagonal Fuel Assembly by Transmission Probability Method	transmission probability, hexagonal geometry, fuel assembly
2007	So Chol, Ho Il Mun	Application of Transmission Probability Method in Physical Calculation of Square Fuel Assembly Based on Simple 4P1 Approximation	fuel assembly, transmission probability method
2007	So Chol, Ho Il Mun, Kim Kyong Il	Integral Neutron Transport Calculation in Square Fuel Assembly of LWR by Transmission Probability Method	transmission probability method, fuel assembly
2009	Ho Il Mun, So Chol, Ryu Kum Bong	Calculation of Resonance Region Group Constants of LWR Fuel Cell using WIMS69 Group Library	resonance integral, equivalence theorem, LWR
2011	Rim Chong Chon, Ho Il Mun	On the Neutron Multi-Group Diffusion Calculation by NGFM under Neumann Boundary Condition	NGFM, neutron multi-group diffusion equation
2011	Ri Chol Hak, Ho Il Mun	Solution of Neutron Multi-group Diffusion Equation by Quadratic NEM	NEM, neutron multi-group diffusion equation
2011	Ho Il Mun, So Chol, Ryu Kum Bong	Burnup Calculation of LWR Fuel Cell	LWR, burnup analysis, fuel assembly
2014	So Chol, Ho Il Mun, Ryu Kum Bong	3-Dimensional Core Burn-up Calculation of VVER-Type Pressured Water Reactor	VVER-type PWR, three-dimensional burn-up calculation
2014	Ho Il Mun, So Chol	Core Critical Diffusion Calculation Using Analytic Coarse Mesh Finite Difference Method (ACMFDM)	neutron diffusion, ACMFDM
2015	So Chol, Ho Il Mun	Three-Dimensional Neutron Two-Group Diffusion Calculation Using the Thermal Neutron Decoupling Method	NGFM, thermal neutron decoupling model
2016	Ho Il Mun, Ri Chol Hak, Kim Yong Hyok	Multicycle Physics Calculation for PWR of 750MWt	PWR, fuel assembly, equilibirum cycle
2016	Ho Il Mun, So Chol, Kim Kyong Il	Burn-up Calculation of LWR Core Loaded with UO2-ThO2 Fuel	thorium fuel reactor, burn-up calculation
2017	Ho Il Mun, Ri Chol Hak, So Chol	Optimization of PWR Fuel Loading Pattern by Simulated Annealing	

Figure 3. Table: Hyuk Kim. (Source: Journal of Kim Il Sung University)
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Appendix III. Visual information on 1,000 MWe PWR.

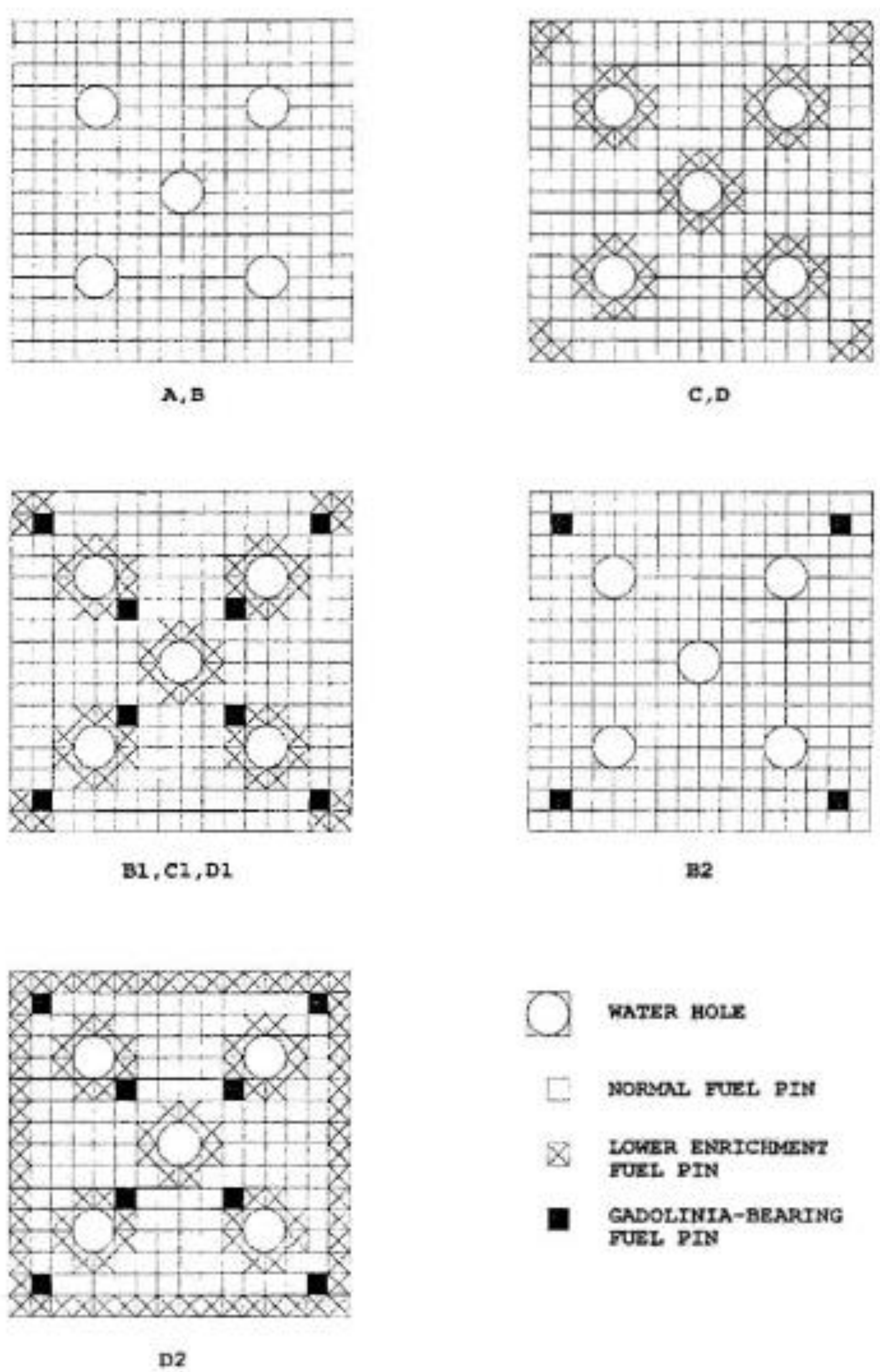

Figure 4. Configurations of fuel assemblies. (Source: Nuclear educational materials provided anonymously from a South Korean university)

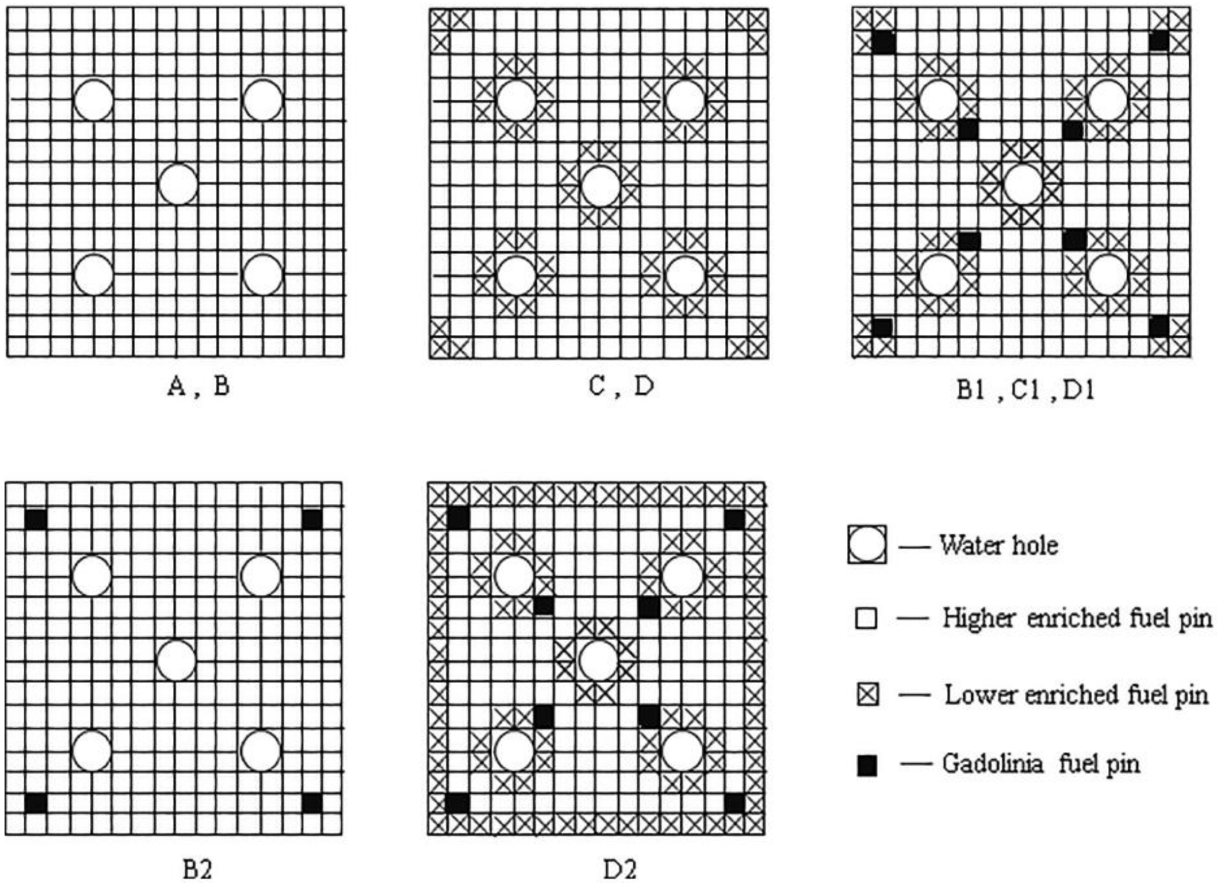

Fig. 2. Configurations of FAs.

Figure 5. Similar fuel assembly configurations as Figure 4, as seen in a North Korean study. (Source: Chol So, Il-Mun Ho, Jong-Suk Chae, Kwang-Hak Hong, "PWR core loading pattern optimization with adaptive genetic algorithm," **Annals of Nuclear Energy,** ***April 24, 2021, https://doi.org/10.1016/j.anucene.2021.108331)***

Design data for the 1000 MWe PWR.

Parameter	Value
Reactor core operating conditions	
Reactor nominal thermal power (MW)	2815
Pressurizer operating pressure (MPa)	15.82
Core active length (mm)	3800
Coolant inlet temperature (℃)	296
Flow area of the core (m^2)	4.165
Coolant flow rate (t/h)	5.346×10^3
Equivalent diameter of the core (m)	3.124
Number of fuel rods in core	41,772
Fuel rod	
Fuel pellet material	Enriched UO_2
Cladding material	Zircalloy-4
Fuel pellet diameter (mm)	8.26
Clad outer diameter (mm)	9.7
Clad inner diameter (mm)	8.43
Fuel rod pitch (mm)	12.85
Guide tube	
Tube material	Zircalloy-4
Outer diameter (mm)	24.934
Inner diameter (mm)	22.9

Figure 6. Specifications for the reactor design employed in the North Korean study. (Source: Ibid)

Appendix IV. Examples of AI/ML/RL Studies for Potential Military Applications.

Title	Keywords	Abstract	Country
전투유희에서 강화학습을 리용한 지능대행체의 결심채택방법 Unofficial translation: Reinforcement Learning-Based Decision-Making Methods for Intelligent Agents in Wargaming (or Combat Simulations)	지능대행체, 강화학습 Unofficial translation: Intelligent agent, Reinforcement learning		North Korea
DDPG-based Deep Reinforcement Learning for Loitering Munition Mobility Control: Algorithm Design and Visualization 10.1109/APWCS55727.2022.9906493	DDPG, Drone, Loitering munition, Reinforcement learning, Unity	Drone technology is estimated for its potential to be applied in many industries, including logistics, broadcasting, telecommunications, and warfare technology. In particular, in the field of modern warfare such as the current war in Ukraine, the use of drones has become an essential element. This paper includes a loitering munition to attack a single ground target in the scenario. A simulation environment for drone attack is built based on the 3D platform Unity, and learning is performed by applying DDPG, a reinforcement learning algorithm that can be used in continuous action space. Through the specific result, it is possible to achieve our purpose to attack target exactly.	South Korea
An experiment in tactical wargaming with platforms enabled by artificial intelligence 10.1177/15485129221097103	Army, Artificial intelligence, Autonomous, Machine learning, Remotely operated, Tactical, Vehicle, Wargame	In this report, researchers experimented with how postulated artificial intelligence/machine learning (AI/ML) capabilities could be incorporated into a wargame. We modified and augmented the rules and engagement statistics used in a commercial tabletop wargame to enable (1) remotely operated and fully autonomous combat vehicles and (2) vehicles with AI/ML-enabled situational awareness to show how the two types of vehicles would perform in company-level engagement between Blue (US) and Red (Russian) forces. The augmented rules and statistics we developed for this wargame were based in part on the US Army's evolving plans for developing and fielding robotic and AI/ML-enabled weapon and other systems. However, we also portrayed combat vehicles with the capability to autonomously detect, identify, and engage targets without human intervention, which the Army does not presently envision. The rules we developed sought to realistically portray the capabilities and limitations of AI/ML-enabled systems, including their vulnerability to selected enemy countermeasures, such as jamming. Future work could improve the realism of both the gameplay and representation of AI/ML-enabled systems, thereby providing useful information to the acquisition and operational communities in the US Department of Defense.	United States
Research on a Wargaming System for Deep Reinforcement Learning 10.1109/ICITBS55627.2022.00159	Deep reinforcement learning, War game	The automatic decision-making confrontation for wargames is faced with the related difficulties of large amount of information, incomplete information and high decision-making complexity. To overcome these problems, this paper sorts out the basic concepts and process framework of combat mission planning in wargames, and analyzes the application method of deep reinforcement learning in the intelligent game process based on wargaming system, and proposes the optimization scheme of deep reinforcement learning in wargaming system, which provides a new research idea for the intelligent development of wargaming. Experiments show that the intelligent wargaming system based on deep reinforcement learning has significant advantages over the traditional wargaming system in data processing, decision-making speed and strategies.	China

Figure 7. Table: Hyuk Kim. (Source: IEEE Xplore [https://ieeexplore.ieee.org] and SCOPUS)
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Appendix V. List of Jian Yao's Studies.

Year	Authors	Title
2019	Xiao, Wenhua (55545904200); Zhu, Xiaomin (57054311600); Bao, Weidong (35736807800); Liu, Ling (55628583368); Yao, Jian (55478504800)	Cooperative data sharing for mobile cloudlets under heterogeneous environments (DOI:10.1109/TNSM.2019.2907526)
2018	Zhang, Qi (56520586200); Yao, Jian (55478504800); Yin, Quanjun (23096547400); Zha, Yabing (8845252900)	Learning Behavior Trees for autonomous agents with hybrid constraints evolution (DOI:10.3390/app8071077)
2017	Lei, Yonglin (7201592058); Yao, Jian (55478504800); Zhu, Ning (55795111200); Zhu, Yifan (8855113900); Wang, Weiping (7501765704)	Weapon Effectiveness Simulation System (WESS) (DOI:10.16182/j.issn1004731x.joss.201706012)
2017	Zheng, Zhan (57195391374); Yao, Jian (55478504800); Yang, Feng (56408791400); Wang, Wenguang (55714176000)	Research on Weapon System Design for Risk Management Based on Object-Process Methodology (DOI:10.16182/j.issn1004731x.joss.201709017)
2017	Lei, Yonglin (7201592058); Zhu, Ning (55795111200); Yao, Jian (55478504800); Sarjoughian, Hessam (6701570994)*; Wang, Weiping (7501765704)	Model architecture-oriented combat system effectiveness simulation based on MDE (DOI:10.21629/JSEE.2017.05.09)
2017	Yao, Jian (55478504800); Wang, Weiping (7501765704); Li, Zhifei (55757763100); Lei, Yonglin (7201592058); Li, Qun (7405862038)	Tactics exploration framework based on genetic programming (DOI:10.2991/ijcis.2017.10.1.53)
2016	Yao, Jian (55478504800); Zhu, Ning (55795111200); Xu, Junqing (57193711648); Chen, Shuai (57190338585); Lei, Yonglin (7201592058)	A domain specific language for tactic representation in engagement level simulation
2016	Lei, Yong-Lin (7201592058); Zhu, Yi-Fan (8855113900); Tan, Yue-Jin (8271471300); Yang, Feng (56408791400); Yao, Jian (55478504800)	Model driven process modeling and simulation of complex man-machine systems (DOI:10.3969/j.issn.1001-506X.2016.01.34)
2016	Yao, Jian (55478504800); Huang, Qiwang (55361891500); Wang, Weiping (7501765704)	Adaptive human behavior modeling for air combat simulation (DOI:10.1109/DS-RT.2015.12)
2016	Lei, Yonglin (7201592058); Zhu, Ning (55795111200); Yao, Jian (55478504800); Zhu, Zhi (55721599100); Chen, Shuai (57190338585)	Architecture-oriented combat system effectiveness simulation modeling
2016	Huang, Qiwang (55361891500); Yao, Jian (55478504800); Li, Qun (7405862038); Zhu, Yifan (8855113900)	Cooperative searching strategy for multiple unmanned aerial vehicles based on modified probability map (DOI:10.1007/978-981-10-2666-9_27)
2016	Lei, Yonglin (7201592058); Zhu, Ning (55795111200); Yao, Jian (55478504800); Zhu, Zhi (55721599100); Sarjoughian, Hessam S. (6701570994)*	Model-architecture oriented combat system effectiveness simulation (DOI:10.1109/WSC.2015.7408464)
2015	Yao, Jian (55478504800); Huang, Qiwang (55361891500); Wang, Weiping (7501765704)	Adaptive CGFs Based on Grammatical Evolution (DOI:10.1155/2015/197306)
2015	Zhu, Ning (55795111200); Yao, Jian (55478504800); Lei, Yonglin (7201592058); Mei, Shan (15822615600); Zhu, Yifan (8855113900)	Generating domain-specific simulation environments from SMP2-based model frameworks for rapid development of simulation applications
2015	Yao, Jian (55478504800); Huang, Qiwang (55361891500); Wang, Weiping (7501765704)	Analyzing ballistic missile defense system effectiveness based on functional dependency network analysis (DOI:10.2174/1874110x01509010678)
2014	He, Lei (56438398500); Yao, Jian (55478504800); Lei, Yong Lin (7201592058)	Air-combat decision modeling method based on DSM (DOI:10.4028/www.scientific.net/AMM.536-537.416)

Figure 8. An asterisk denotes a scholar affiliated with a university in the United States. Table: Hyuk Kim. (Source: SCOPUS)
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