**High Energy Laser Weapons: Tomorrow's precise, stealth, speed-of-light weapon for improved force protection**

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**ABSTRACT (MAXIMUM 200 WORDS)**

HEL weapons are on the cusp of becoming a reality for use across the joint force. They will provide a precise and nearly undetectable direct fire capability with “zero time of flight” against conventional weapon systems and munitions. HEL weapons will significantly improve force protection of civilian and military infrastructure and populations against rockets, artillery, mortars, aircraft (manned and unmanned), water craft, vehicles, and missiles in the domains of air, land, sea, and space. Furthermore, offensive HEL weapons will improve speed and precision of fire support and strike capability, while also providing capacity for fires from nontraditional aircraft platforms. Since HEL weapons provide such significant advancement in defensive and offensive capability and capacity, they will be included in the arsenal of military assets to operate in tomorrow’s conflicts.
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Think for a moment about the current laser designation capability used to direct precision guided munitions (PGMs) to destroy an enemy target. Now, imagine replacing that laser designator with a high energy laser (HEL) weapon that emits enough thermal energy to directly render a target ineffective, without using a conventional munition. That HEL weapon will affect targets faster, with more precision, and with more stealth than a conventional munition or weapon system. Additionally, that HEL weapon could affect targets across the domains of air, ground, maritime, and space. Defensive HEL weapons could be used to counter indirect fire munitions (rockets, artillery, and mortars), aircraft, water vessels, vehicles, and even ballistic missiles. Offensive HEL weapons could be used for offensive air support and even strategic air strike missions. In future conflict, HEL weapons will be utilized across the joint force to dramatically improve force protection of military and civilian infrastructure and populations.

With this paper I intend to link ongoing research and development of laser technology to show the reader that HEL weapons will be a reality. In doing so, I will define what a HEL and a HEL weapon are, and briefly discuss some of the advantages of a HEL weapon over conventional weapons. Next, I will develop some concepts of employment for HEL defensive and offensive weapons as they apply to the tactical and strategic levels of warfare. Threaded within the concepts of employment, I will present several vignettes to illustrate possible HEL weapon applications accounting for the joint nature of tomorrow’s fight. By the end of this
paper, the reader will be familiar with the achievements of HEL research and development to date, and be able to envision future employment scenarios for HEL weapons.

**High Energy Laser Weapons**

First, it is important to understand what a HEL is. Current military HELs are generally defined as having laser power greater than 1 kilowatt. However, most HELs being developed and tested for military application have laser powers ranging from tens of kilowatts to 100 kilowatts for tactical level employment, and up to multi-megawatts in power for strategic class application. For comparison, a powerful laser pointer that emits less than one watt can cause permanent eye damage in less than one second, while average power outputs of 300 watts up to 1 kilowatt are commonly used for industrial laser cutting. In comparison, these examples are far below the laser power output measurements of military HELs currently being tested. This illustrates the remarkable potential impact for damage and harm by a HEL. Another common measurement to classify a HEL is the emission of a single pulse of energy exceeding 30 kilojoules. To qualify this measurement, just .2-.4 Joules/cm² over 10 nanoseconds can burn skin, and just 10 kilojoules/cm² in .2 seconds could result in damage to the structure of an aircraft or missile without armor. There are other qualifiers that can be used to classify different types of HELs, however the aforementioned power and energy parameters are two key measurements used to distinguish HELs from low energy lasers.

With these high power emissions and pulse energies, HELs will achieve extraordinary thermal effects on a target within seconds from initial engagement. Most likely, the optimal engagement time for achieved effects will be between two and four seconds. In some cases, HELs may only need to engage targets for less than a second to achieve desired effects. Even
with these short engagement times, HEls will induce an explosive reaction, perforate a critical surface, ignite a critical component, or disrupt the optics or control system of a threat. As listed, option one is to heat "the target inducing an explosive reaction of the high explosive" contained within. Targets containing high explosives heated beyond the auto-ignition point, or fuel heated greater than the flash point, will be swiftly destroyed. A different effect could be the perforation of a fragile aircraft wing, hull of a watercraft, or even the tire of a vehicle resulting in disruption or prevention of critical capabilities of a targeted threat. Next, the high, concentrated heat of a HEL could cause a surface or component to ignite, resulting in temporary distraction, at a minimum. Lastly, the thermal effects of a HEL could disrupt the optics and control systems by temporarily or permanently blocking a sensor from operating or even blinding an operator. Nonetheless, whether the thermal effects of a HEL on a target induce explosion, perforation, burning, or blinding, the effects will be measurable and swift.

Additionally, the speed of a HEL makes it superior to most conventional weapon systems and munitions. Lasers operate at the speed of light, resulting in an almost immediate impact from laser initiation to the target. With a "zero time of flight", a HEL may immediately affect the target following positive identification. This will reduce the time to engage a target by seconds or even minutes compared to most conventional subsonic and supersonic weapon systems and munitions. This nearly instantaneous ability to affect a target practically eliminates the time for an enemy to react. Furthermore, with a "zero time of flight," a HEL can ostensibly engage and affect many more targets in a given period than a conventional gun. Therefore, the innate speed of a HEL will potentially cause immediate effects on a target, reduce time for the target to respond, and allow more targets to be engaged in a given period of time.
Another remarkable advantage of a HEL is long-range precision. Lasers are intrinsically accurate, as has been proven by the use of lasers for medical surgery. Now magnify the energy output of that surgical laser in an operating room and place it on the battlefield. One can rapidly envision a new meaning of the phrase, “surgical strike”. However, surgically accurate fires against targets that may be moving (or perhaps maneuvering) on a vast battlefield demand precision aiming. To overcome these challenges, advanced systems, such as the high-resolution laser radar (LADAR) and Hi-power Phased Array Transceiver (HiPAT), are also being developed to improve accuracy in acquiring, identifying, and tracking targets at distant ranges. Furthermore, another new development, the Precision Aimpoint Maintenance using Continually Updated Templates (PAMCUT), can be used to translate from the identification of an adversary system to aim points that will direct a HEL weapon onto specific system vulnerabilities (i.e. fuel tanks, wings, optics, areas with less armor, etc). Marrying a surgically accurate HEL to ancillary advanced acquisition, identification, tracking, and aiming systems will create a very promising and effective HEL weapon system.

Lastly, the stealth of a HEL weapon will add a psychological impact when used on the battlefield. Most lasers operate in a spectrum that is not visible to the naked eye, and therefore lasers may not be immediately detected by an enemy receiving effects. In fact, there may be no recognition of laser effects on a target until there is no time left for the target to react for survival. Currently only a limited number of existing systems have the frequency and bandwidth detection capabilities to identify a HEL while in use. To lessen the effects of a laser weapon possible reaction maneuvers by an intended target could include: a change in speed, attitude, or altitude; a counter attack; or a movement to a concealed position. However, even when an enemy discerns the effects of a laser, he may not know the direction or distance of the source of
the effects, as there is no smoking gun, or combustion flash from the laser “shot". Therefore an adversary may not be capable of effectively conducting reactionary maneuvers. At least initially, even the sound and appearance of a HEL weapon, let alone a HEL “shot”, will not be recognizable by the enemy, making a stand-alone laser weapon system difficult to target.

“Mysterious weapons have a psychological effect,” wrote Montgomery Miegs in reference to the evolution of military innovation. A HEL weapon certainly could fall into this category of mysterious weapons, as an adversary may not know if a HEL weapon is being used until it is too late. An adversary may not even know if the weapon is even on the battlefield. The current limited ability to detect a HEL weapon system or the effects of a HEL weapon will result in tactical asymmetry on tomorrow’s battlefield.

Laser weapon employment

Since HEL weapons encapsulate into one system the enhancements of speed, precision, and stealth, their use for future military application is inevitable. HEL weapons will provide a marked advantage over existing conventional weapons, to include indirect fire munitions, aircraft, water vessels, vehicles, and even ballistic missiles. In 2008, the U.S. Army formally recognized the potential of HEL technology for future weapons by awarding a contract to Boeing for the High Energy Laser Technology Demonstrator (HEL TD). Their justification identified the following capability gaps that HEL weapons could fill:

1) Defeat In-Flight Projectiles such as rockets, artillery, mortars, anti-tank guided missiles, and man-portable surface-to-air missiles,
2) Ultra-Precision Strike with little to no collateral damage,
3) Disruption of Electro-Optical (EO) and Infra-Red (IR) sensors, and
4) Neutralizing mines and other ordnance from a stand-off distance.
In 2009, Lieutenant General George Flynn, U.S. Marine Corps Deputy Commandant for Combat Development and Integration, formally recognized that recent advancements in solid-state laser technology citing the “near zero time of flight, low shot cost, and ostensibly ‘deep-magazine’ capability to counter the primary low altitude unmanned aerial system (UAS) threat.”\textsuperscript{xiv} There is a vast list of employment scenarios for HEL weapons across the domains of air, sea, land, and space. The following vignettes and analysis of current research and development tests will illustrate the potential for HEL weapons on the battlefield.

Vignette Background: It is December, 2020. North Korea has taken military action to threaten South Korea. International disputes have escalated regarding island territories and the maritime border between North Korea and South Korea. North Korea has increased the size of its Navy fleets at Munch’on Naval Base, on the east coast north of Wonsan, and Namp’o Naval Base, on the west coast which serves as a waterway to P’yongyang. From these bases the North Korean Navy has deployed numerous torpedo craft (PT), missile craft (PTG), and patrol craft (PC) to guard the southeastern and southwestern coasts. Reports from merchant ships have shown these craft are frequenting waters between 10-30 miles off the coast. The North Korea Air Force has increased air patrols over coastal airspace to the south. The North Korea Army also appears to be mobilizing toward the south. North Korea seems to be posturing to conduct limited military operations under centralized control in order to provoke military action against them first, intending to deliver a strong and immediate counterattack.

Vignette #1: On 1 December, 2020, North Korea conducts an artillery attack on the island of Yeonpyeong with a mixture of 170 mm and 152 mm artillery rounds launched from mainland North Korea. While approximately 100 rounds were destined to impact on the island, only 50 actually impacted with no loss of life and no destruction to critical infrastructure due to
networked land and maritime laser defense systems. The U.S. Army had previously deployed land laser defense systems (LLDS) to protect the population center and economic port of Yeonpyeong from rocket and artillery attack. Additionally, U.S. Navy ships from the George Washington Battle Group had recently been upgraded with the maritime laser defense system (MLDS) for ship and area defense against rockets, missiles, and UAVs. On 1 December, the networked LLDS and MLDS engaged and forced detonation of all artillery rounds with trajectories destined for the port and city at Yeonpyeong.

Today, ground forces are already looking to apply HEL weapons to target rocket, artillery, and mortar (RAM) threats. Northrup Grumman’s Skyguard laser defense system has proven effective against RAM threats at a range of 5 kms. Skyguard, more recently known as the Tactical High Energy Laser (THEL), has the interest of the U.S. and Israeli Armies. Further advancement in laser technology has resulted in the Mobile THEL (MTHEL) as a point defense weapon that can be displaced to a base, key operational node, or population center to engage and destroy RAM threats for force protection. During testing the MTHEL engaged and destroyed 28 122 mm and 160 mm Katyusha rockets, multiple artillery shells and mortar rounds, and a salvo attack by mortars. Currently, at the size of a single container-sized semitrailer, the MTHEL can be deployed today to an expeditionary environment to protect military or civilian infrastructure or personnel. Additionally, Raytheon has developed a HEL weapon for short range air defense against RAM threats and aircraft. In June, 2006, Raytheon mounted a HEL on the turret of its Phalanx Close-in Weapon System (CIWS), which is already in use for ship and land based short-range air defense. Known originally as the Laser Area Defense System (LADS), the short range point defense HEL weapon included a 20 kW fiber laser and a bench-mounted beam director attached to the top of a Phalanx mount. During testing the LADS detonated a 60 mm mortar at a
range of 550 meters. The MTHEL and LADS are potential tactical HEL weapons capable of terminal defense of a local area against RAM threats.

HEL weapons will also be used for defense against enemy offensive aircraft. In December 2008, Boeing successfully tested a kilowatt-class laser weapon on its Avenger air-defense system that shot down an unmanned aerial vehicle (UAV). The acquisition, tracking, and aiming systems acquired and tracked three small UAVs, and then the HEL was used to shoot down one of the UAVs “from an operationally relevant range,” by burning a hole through the vehicle. Although this could be considered a minor success against a UAV, it is indicative of an expeditionary mobile tactical HEL anti-aircraft capability for protection of key infrastructure or even a halted tactical convoy.

Vignette #2: On 2 December, 2015, North Korea launched two Surface-to-Surface Missiles (SSM) at the U.S.S. Normandy (CG-60) from a missile craft (PTG) approximately 20 miles west of Namp’O Naval Base. U.S.S Vicksburg (CG-69) initiated its two MLDS for six seconds each to detonate both SSMs before they reached the U.S.S. Normandy. Simultaneously, the U.S.S. Normandy utilized its MLDS in manual mode to engage the North Korean PTG. The PTG was neutralized when the MLDS ignited its engine after laser weapon engagement for 20 seconds.

There is great potential for using HEL weapons for maritime defense. In June, 2010, Raytheon’s maritime variant of the HEL with a Phalanx mount, dubbed the Laser Weapon System (LaWS) by the U.S. Navy, detected, engaged, and downed a “threat representative” unmanned aerial vehicle (UAV) in a simulated combat encounter at sea. More recently, on 10 April, 2011, the U.S. Navy demonstrated the ability to use a HEL against watercraft by setting an
outboard engine of a small boat on fire from a distance of a few miles. An additional advantage of a maritime HEL is the logistically friendly “deep magazine” effect as compared to the traditional Phalanx that expends 3,000-4,500 20 mm rounds per minute. Furthermore, the high electrical power required for the LaWS is easily available aboard the ship. HEL weapons can provide point defense against surface and air threats both ashore and in a maritime environment.

Vignette #3: While conducting a Combat Air Patrol (CAP) mission in vicinity of the George Washington Battle Group in the Yellow Sea, one U.S. Navy F/A-18 Super Hornet was illuminated by a land-based Fan Song radar, presumably associated with an SA-2 launcher. In response, the F/A-18’s onboard airborne laser defense system (ALDS) immediately engaged the radar operating system, rendering it inoperable before the SA-2 was launched.

Offensive air support against ground targets will also be enhanced by HEL weapons. Different than ground forces, a pilot’s “bird’s eye” view of the battlefield is often less obstructed by terrain, although it can be severely diminished by vegetation. Nonetheless, pilots will make frequent use of direct fire HEL weapons for offensive air support. This is the concept for the U.S. Air Force Advanced Tactical Laser (ATL). Currently mounted on a C-130, although envisioned for other aircraft to include the V-22 Osprey, the ATL is designed as a close air support weapon using a Mega-Watt class HEL. In September 2009, the ATL penetrated an unoccupied stationary vehicle in eight seconds from an undisclosed altitude and distance. While this may seem negligible in effect, the high heat generated with precision accuracy from a moving aircraft reveals the reality of close air support with a HEL for limited high value target engagement.
Vignette #4: On 3 December, 2015, a section of U.S. Air Force F-16 Fighting Falcons was conducting CAP north of Seoul, South Korea, when they were engaged by four MiG-19 Farmers. The result was an immediate and short air-to-air engagement. All four MiG-19 Farmers were destroyed: One Farmer was destroyed by 20 mm cannon fire, another destroyed by an AIM-7 Sparrow, and two were destroyed by the ALDS. While the two F-16s each engaged a MiG-19 using conventional munitions, their respective onboard ALDS targeted and detonated the drop tanks of the remaining two enemy aircraft.

The ability of aircraft to conduct counter air warfare will be greatly enhanced by a HEL weapon. The HEL weapon could provide a counter air capability that operates distinctly from the primary mission of the aircraft and pilot. In other words, while a pilot is conducting his assigned aviation mission (for instance, offensive air support or aerial reconnaissance), a HEL weapon could automatically identify, acquire, target, and engage an enemy missile or aircraft. The counter air capability of HEL weapons will enhance the survivability of pilots, especially aboard aircraft not designed specifically for that purpose.

Onboard airborne HEL defense weapons could be used to protect more than just tactical fighter and attack aircraft. The Defense Advanced Research Projects Agency (DARPA) High-Energy Liquid Laser Area Defense System (Hellads) competition has the goal of creating a 150 kW laser weapon within a three cubic meter space and weighing no more than 5 kg/kW. The intent is to create an airborne HEL that is small enough to fit in a bomber, transport, or tanker aircraft without interrupting the main function of the aircraft. The milestones for the project include a ground test in 2011 to shoot down two SA-10 class surface-to-air missiles.
simultaneously and then an airborne test in 2012-13. These tests are encouraging the evolution of tactical defense HEL weapons beyond military application.

Vignette #5: On 4 December, 2015, North Korea launches a Scud-ER from a northern province. The Scud-ER appeared to be on a trajectory to impact in the vicinity of Pusan, South Korea, where coalition forces were conducting reception, staging, onward movement, and integration for potential follow-on land operations against North Korea. A U.S. Air Force strategic airborne laser defense system (SALDS) detected, engaged, and detonated the Scud-ER while it was still in North Korean airspace. What remained of the detonated Scud-ER fell to the surface within North Korea.

The strategic impact of a HEL against a ballistic missile still provides promise. Evolving from the Strategic Defense Initiative concept, the U.S. Air Force has continued research and development to use a laser weapon against ballistic missiles. Specifically, the AL-1A Airborne Laser (ABL) has been designed to attack ballistic missiles in the boost phase. The intent is to cause slight damage to the booster skin resulting in catastrophic failure and ultimate detonation. The concept of employment is to deploy the ABL to borders of a nation threatening ballistic missile attack and then to detect, track, and attack the missiles once they clear the cloud base. The debris would then fall back to the nation that launched the weapon, or some other safe environment. Once the system is more mature it could be used against short, intermediate, and intercontinental ballistic missiles, as well as high flying aircraft, and cruise missiles. In Feb, 2010, MDA announced that the ABL shot down a liquid-filled Scud-like target. However, in the most recent test in Oct, 2010, "preliminary indications are that the system acquired and tracked the plume (rocket exhaust) of the target, but never transitioned to active tracking.
Therefore, the HEL [shot] did not occur.\textsuperscript{xxvii} Even with these recent setbacks this initiative is likely to result in a strategic HEL weapon that will provide a defense against a ballistic missile.

**Challenges**

Obstacles that will have to be overcome before HEL weapons are commonplace are costs, counter-laser defense, and collateral damage. None of these obstacles are insurmountable. Additionally, these obstacles will likely remain even when HELs are operational.

A cost-benefit analysis is necessary to determine the right time to integrate HEL weapons into the DoD arsenal. In 2006, Northrop Grummon stated that their first Skyguard/THEL systems would cost $150 - $200 million due to nonrecurring developmental costs, but the cost would drop to $25-$30 million per system.\textsuperscript{xxviii} That price is very likely to be reduced even more through further research and development of the three components of laser action: laser medium, pumping stations, and resonant optical cavities.\textsuperscript{xxix} In contrast to the high price, even the cost of a few million dollars for each HEL weapon is minimal compared to the loss of a Navy ship, an aircraft, a key facility, or a grouping of military or civilian personnel. The monetary cost of HEL is high, although at some point the cost will be deemed worthwhile for force protection.

Time is also a cost when considering that global competitors are likely also developing HEL weapons. Russia is developing their Almaz-Antey HEL DE weapon (HEL DEW) air defense system which has already engaged a target drone. The expected concept of employment of this weapon is like the U.S. and Israeli THEL, although with enhanced capability to engage surface-to-air missiles and PGMs for point defense. Russia has also developed an airborne Almaz/Beriev A-60 HEL DEW "Testbed" capability.\textsuperscript{xxx} Additionally, in 2007 the DoD presented
evidence that the Chinese People’s Liberation Army (PLA) funded a well developed and advanced HEL program intending to attack low orbit satellites, cruise missiles, and PGMs, while also providing point defense.\textsuperscript{xxxi} Most recently, India released information regarding their testing of a laser ballistic missile defense system with capability of producing 25 kW pulses that can reportedly destroy a ballistic missile at a range of 7 km, as well as an air defense laser capable of engaging aircraft at a range of 10 km. India’s laser research has even resulted in a hand held laser sensor capable of identifying an impending laser threat.\textsuperscript{xxxi} While the Russian, Chinese, and Indian HEL weapon capabilities do not appear to be as robust as the U.S. initiatives, there is potential for a future HEL arms race. Therefore even time is a cost when it comes to developing HEL weapons for military employment.

The cost to effectively counter a HEL will also be high. It is just a matter of time for every innovation to be countered. A seemingly obvious counter to a laser weapon is to use material that has reflectivity that either dissipates or fully reflects the transfer of energy from a laser. In many cases these surface material innovations will just delay the thermal effects of a HEL by a matter of seconds. For the adversary, this counter will be costly financially and temporally as they will have to redesign and field modified materials on current equipment, or completely design new equipment.

Lastly, forethought is necessary to understand the possible collateral damage of a HEL weapon. At the strategic level, the U.S. Department of Defense is developing “decentralized predictive avoidance” measures to prevent unintended collateral damage of satellites on the trajectory of a stray laser. At the tactical level, HEL weapons could cause unintentional permanent and temporary personnel blinding. As reflectivity of material is further advanced it is
even possible that a "thermal ricochet" could result in collateral damage. While the precision of a HEL weapon will likely reduce collateral damage, there is more research that must be done to predict and regulate the collateral damage of a HEL.

**Conclusion**

HEL weapons are on the cusp of becoming a reality for use across the joint force. They will provide a precise and nearly undetectable direct fire capability with "zero time of flight" against conventional weapon systems and munitions. HEL weapons will significantly improve force protection of civilian and military infrastructure and populations against rockets, artillery, mortars, aircraft (manned and unmanned), water craft, vehicles, and missiles in the domains of air, land, sea, and space. Furthermore, offensive HEL weapons will improve speed and precision of fire support, counter air, and strike capability, while also providing capacity for fires from nontraditional aircraft platforms. Since HEL weapons provide such significant advancement in defensive and offensive capability and capacity, they will be included in the arsenal of military assets to operate in tomorrow’s conflicts.
Notes:

i Major Billy Short, Office of Naval Research, email correspondence to author, 9 December 2011.


iv For information regarding the additional varieties of HELs, to include advantages and disadvantages of each type, the reader may want to research “gas lasers,” “solid-state lasers,” and “fiber lasers.”


vi “It is prohibited to employ laser weapons specifically designed, as their sole combat function or as one of their combat functions, to cause permanent blindness to unenhanced vision, that is to the naked eye or to the eye with corrective eyesight devices. The High Contracting Parties shall not transfer such weapons to any State or non-State entity.” Convention on Prohibitions or Restrictions on the Use of Certain Conventional Weapons Which May Be Deemed to Be Excessively Injurious or to Have Indiscriminate Effects, Protocol IV on Blinding Laser Weapons, Article 1, negotiated and adopted on 13 October 1995.

vii Lasers operate at the speed of light (c), which depends on the medium. In a vacuum that is 3.0x10^8 m/s (by definition since the definition of a meter is also tied to the speed of light) and slightly slower in air (but still rounds to 3.0x10^8). The speed of light in a medium (v) is related to the index of refraction (n) where v = c/n and n = 1.0003 for air and 1.0000 for vacuum). R. P. Feynman, R. B. Leighton, & M. L. Sands. The Feynman lectures on physics. (Addison-Wesley Publishing Company, Reading, MA, 1963).


ix Anderberg, 96.


Kopp, 46.

Mr. Ashley G. Johnson, Office of Naval Research. “POM13-07: Ground Based Air Defense On-the-Move” (brief, 9 July 2010).


Kopp, 37-47.

Kopp, 53.


Kopp, 48.


During the Reagan era, innovative thinking elevated the idea of engaging aerial targets to a strategic level by targeting ballistic missiles. In 1980, the United States Navy produced the “first megawatt-class, continuous wave, chemical laser built in the free world,” called the Mid Infrared Advanced Chemical Laser (MIRACL). The MIRACL was part of the SEALITE Beam Director (SLBD) that was tested to support the Strategic Defense Initiative (SDI). Through 150 lasing tests, the SLBD showed capabilities of engaging subsonic and supersonic missiles. However, the SLBD weighs 28,000 pounds and the Department of Defense (DoD) investment for the MIRACL, SLBD, and the High Energy Laser Systems Test Facility (HELSTF) is now well over $800 million. “Mid-Infrared Advanced Chemical Laser (MIRACL),” Federation of American Scientists, Space Policy Project, Military Space Programs, updated March 21, 1998. [http://www.fas.org/spp/military/program/asat/miracl.htm](http://www.fas.org/spp/military/program/asat/miracl.htm)

Kopp, 14-36.


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