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Recommendations on Filtering of IPv4 Packets Containing IPv4 Options

Abstract

This document provides advice on the filtering of IPv4 packets based on the IPv4 options they contain. Additionally, it discusses the operational and interoperability implications of dropping packets based on the IP options they contain.

Status of This Memo

This memo documents an Internet Best Current Practice.

This document is a product of the Internet Engineering Task Force (IETF). It has been approved for publication by the Internet Engineering Steering Group (IESG). Further information on BCPs is available in Section 2 of RFC 5741.

Information about the current status of this document, any errata, and how to provide feedback on it may be obtained at http://www.rfc-editor.org/info/rfc7126.

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1. Introduction

This document discusses the filtering of IPv4 packets based on the IPv4 options they contain. Since various protocols may use IPv4 options to some extent, dropping packets based on the options they contain may have implications on the proper functioning of such protocols. Therefore, this document attempts to discuss the operational and interoperability implications of such dropping. Additionally, it outlines what a network operator might do in typical enterprise or Service Provider environments. This document also draws and is partly derived from [RFC6274], which also received review from the operational community.

We note that data seems to indicate that there is a current widespread practice of blocking IPv4 optioned packets. There are various plausible approaches to minimize the potential negative effects of IPv4 optioned packets while allowing some option semantics. One approach is to allow for specific options that are expected or needed, and have a default deny. A different approach is to deny unneeded options and have a default allow. Yet a third possible approach is to allow for end-to-end semantics by ignoring options and treating packets as un-optioned while in transit. Experiments and currently available data tend to support the first or third approaches as more realistic. Some results regarding the current state of affairs with respect to dropping packets containing IP options can be found in [MEDINA] and [FONSECA]. Additionally, [BREMIER-BARR] points out that the deployed Internet already has many routers that do not process IP options.

We also note that while this document provides advice on dropping packets on a "per IP option type", not all devices (routers, security gateways, and firewalls) may provide this capability with such granularity. Additionally, even in cases in which such functionality is provided, an operator might want to specify a dropping policy with a coarser granularity (rather than on a "per IP option type" granularity), as indicated above.

Finally, in scenarios in which processing of IP options by intermediate systems is not required, a widespread approach is to simply ignore IP options and process the corresponding packets as if they do not contain any IP options.

1.1. Terminology and Conventions Used in This Document

The terms "fast path", "slow path", and associated relative terms ("faster path" and "slower path") are loosely defined as in Section 2 of [RFC6398].

Because of the security-oriented nature of this document, we are deliberately including some historical citations. The goal is to explicitly retain and show history, as well as remove ambiguity and confusion.

The key words "MUST", "MUST NOT", "REQUIRED", "SHALL", "SHALL NOT", "SHOULD", "SHOULD NOT", "RECOMMENDED", "MAY", and "OPTIONAL" in this document are to be interpreted as described in [RFC2119].

1.2. Operational Focus

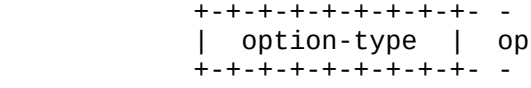
All of the recommendations in this document have been made in an effort to optimize for operational community consensus, as best the authors have been able to determine that. This has included not only accepting feedback from public lists, but also accepting off-list feedback from people at various network operators (e.g. Internet Service Providers, content providers, educational institutions, commercial firms).

2. IP Options

IP options allow for the extension of the Internet Protocol. As specified in [RFC0791], there are two cases for the format of an option:

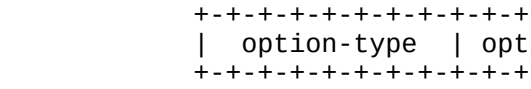
- Case 1: A single byte of option-type.
- Case 2: An option-type byte, an option-length byte, and the actual option-data bytes.

IP options of Case 1 have the following syntax:



The length of IP options of Case 1 is implicitly specified by the option-type byte.

IP options of Case 2 have the following syntax:



In this case, the option-length byte counts the option-type byte and the option-length byte, as well as the actual option-data bytes.

All current and future options, except "End of Option List" (Type = 0) and "No Operation" (Type = 1), are of Class 2.

The option-type has three fields:

- 1 bit: copied flag.
- 2 bits: option class.
- 5 bits: option number.

The copied flag indicates whether this option should be copied to all fragments in the event the packet carrying it needs to be fragmented:

- 0 = not copied.
- 1 = copied.

The values for the option class are:

- 0 = control.
- 1 = reserved for future use.
- 2 = debugging and measurement.
- 3 = reserved for future use.

This format allows for the creation of new options for the extension of the Internet Protocol (IP).

Finally, the option number identifies the syntax of the rest of the option.

The "IP OPTION NUMBERS" registry [IANA-IP] contains the list of the currently assigned IP option numbers.

3. General Security Implications of IP Options

3.1. Processing Requirements

Historically, most IP routers used a general-purpose CPU to process IP packets and forward them towards their destinations. This same CPU usually also processed network management traffic (e.g., SNMP), configuration commands (e.g., command line interface), and various routing protocols (e.g., RIP, OSPF, BGP, IS-IS) or other control protocols (e.g., RSVP, ICMP). In such architectures, it has been common for the general-purpose CPU also to perform any packet

filtering that has been enabled on the router (or router interface). An IP router built using this architecture often has a significant Distributed Denial-of-Service (DDoS) attack risk if the router control plane (e.g., CPU) is overwhelmed by a large number of IPv4 packets that contain IPv4 options.

From about 1995 onwards, a growing number of IP routers have incorporated silicon specialized for IP packet processing (i.e., Field-Programmable Gate Array (FPGA), Application-Specific Integrated Circuit (ASIC)), thereby separating the function of IP packet forwarding from the other functions of the router. Such router architectures tend to be more resilient to DDoS attacks that might be seen in the global public Internet. Depending upon various implementation and configuration details, routers with a silicon packet-forwarding engine can handle high volumes of IP packets containing IP options without any adverse impact on packet-forwarding rates or on the router's control plane (e.g., general-purpose CPU). Some implementations have a configuration knob simply to forward all IP packets containing IP options at wire-speed in silicon, as if the IP packet did not contain any IP options ("ignore options & forward"). Other implementations support wire-speed silicon-based packet filtering, thereby enabling packets containing certain IP options to be selectively dropped ("drop"), packets containing certain other IP options to have those IP options ignored ("ignore options & forward"), and other packets containing different IP options to have those options processed, either on a general-purpose CPU or using custom logic (e.g., FPGA, ASIC), while the packet is being forwarded ("process option & forward").

Broadly speaking, any IP packet that requires processing by an IP router's general-purpose CPU can be a DDoS risk to that router's general-purpose CPU (and thus to the router itself). However, at present, the particular architectural and engineering details of the specific IP router being considered are important to understand when evaluating the operational security risks associated with a particular IP packet type or IP option type.

Operators are urged to consider the capabilities of potential IP routers for IP option filtering and handling as they make deployment decisions in the future.

Additional considerations for protecting the control plane from packets containing IP options can be found in [RFC6192].

Finally, in addition to advice to operators, this document also provides advice to router, security gateway, and firewall implementers in terms of providing the capability to filter packets

with different granularities: both on a "per IP option type" granularity (to maximize flexibility) as well as more coarse filters (to minimize configuration complexity).

4. Advice on the Handling of Packets with Specific IP Options

The following subsections contain a description of each of the IP options that have so far been specified, a discussion of possible interoperability implications if packets containing such options are dropped, and specific advice on whether to drop packets containing these options in a typical enterprise or Service Provider environment.

4.1. End of Option List (Type = 0)

4.1.1. Uses

This option is used to indicate the "end of options" in those cases in which the end of options would not coincide with the end of the Internet Protocol header.

4.1.2. Option Specification

Specified in RFC 791 [RFC0791].

4.1.3. Threats

No specific security issues are known for this IPv4 option.

4.1.4. Operational and Interoperability Impact if Blocked

Packets containing any IP options are likely to include an End of Option List. Therefore, if packets containing this option are dropped, it is very likely that legitimate traffic is blocked.

4.1.5. Advice

Routers, security gateways, and firewalls SHOULD NOT drop packets because they contain this option.

4.2. No Operation (Type = 1)

4.2.1. Uses

The no-operation option is basically meant to allow the sending system to align subsequent options in, for example, 32-bit boundaries.

4.2.2. Option Specification

Specified in RFC 791 [RFC0791].

4.2.3. Threats

No specific security issues are known for this IPv4 option.

4.2.4. Operational and Interoperability Impact if Blocked

Packets containing any IP options are likely to include a No Operation option. Therefore, if packets containing this option are dropped, it is very likely that legitimate traffic is blocked.

4.2.5. Advice

Routers, security gateways, and firewalls SHOULD NOT drop packets because they contain this option.

4.3. Loose Source and Record Route (LSRR) (Type = 131)

RFC 791 states that this option should appear at most once in a given packet. Thus, if a packet contains more than one LSRR option, it should be dropped, and this event should be logged (e.g., a counter could be incremented to reflect the packet drop). Additionally, packets containing a combination of LSRR and SSRR options should be dropped, and this event should be logged (e.g., a counter could be incremented to reflect the packet drop).

4.3.1. Uses

This option lets the originating system specify a number of intermediate systems a packet must pass through to get to the destination host. Additionally, the route followed by the packet is recorded in the option. The receiving host (end-system) must use the reverse of the path contained in the received LSRR option.

The LSSR option can be of help in debugging some network problems. Some Internet Service Provider (ISP) peering agreements require support for this option in the routers within the peer of the ISP.

4.3.2. Option Specification

Specified in RFC 791 [RFC0791].

4.3.3. Threats

The LSRR option has well-known security implications [RFC6274]. Among other things, the option can be used to:

- Bypass firewall rules.
- Reach otherwise unreachable internet systems.
- Establish TCP connections in a stealthy way.
- Learn about the topology of a network.
- Perform bandwidth-exhaustion attacks.

Of these attack vectors, the one that has probably received least attention is the use of the LSRR option to perform bandwidth exhaustion attacks. The LSRR option can be used as an amplification method for performing bandwidth-exhaustion attacks, as an attacker could make a packet bounce multiple times between a number of systems by carefully crafting an LSRR option.

> This is the IPv4 version of the IPv6 amplification attack that was widely publicized in 2007 [Biondi2007]. The only difference is that the maximum length of the IPv4 header (and hence the LSRR option) limits the amplification factor when compared to the IPv6 counterpart.

Additionally, some implementations have been found to fail to include proper sanity checks on the LSRR option, thus leading to security issues. These specific issues are believed to be solved in all modern implementations.

> [Microsoft1999] is a security advisory about a vulnerability arising from improper validation of the Pointer field of the LSRR option.

Finally, we note that some systems were known for providing a system-wide toggle to enable support for this option for those scenarios in which this option is required. However, improper implementation of such a system-wide toggle caused those systems to support the LSRR option even when explicitly configured not to do so.

> [OpenBSD1998] is a security advisory about an improper implementation of such a system-wide toggle in 4.4BSD kernels. This issue was resolved in later versions of the corresponding operating system.

4.3.4. Operational and Interoperability Impact if Blocked

Network troubleshooting techniques that may employ the LSRR option (such as ping or traceroute with the appropriate arguments) would break when using the LSRR option. (Ping and traceroute without IPv4 options are not impacted.) Nevertheless, it should be noted that it is virtually impossible to use the LSRR option for troubleshooting, due to widespread dropping of packets that contain the option.

4.3.5. Advice

Routers, security gateways, and firewalls SHOULD implement an option-specific configuration knob to select whether packets with this option are dropped, packets with this IP option are forwarded as if they did not contain this IP option, or packets with this option are processed and forwarded as per [RFC0791]. The default setting for this knob SHOULD be "drop", and the default setting MUST be documented.

Please note that treating packets with LSRR as if they did not contain this option can result in such packets being sent to a different device than the initially intended destination. With appropriate ingress filtering, this should not open an attack vector into the infrastructure. Nonetheless, it could result in traffic that would never reach the initially intended destination. Dropping these packets prevents unnecessary network traffic and does not make end-to-end communication any worse.

4.4. Strict Source and Record Route (SSRR) (Type = 137)

4.4.1. Uses

This option allows the originating system to specify a number of intermediate systems a packet must pass through to get to the destination host. Additionally, the route followed by the packet is recorded in the option, and the destination host (end-system) must use the reverse of the path contained in the received SSRR option.

This option is similar to the Loose Source and Record Route (LSRR) option, with the only difference that in the case of SSRR, the route specified in the option is the exact route the packet must take (i.e., no other intervening routers are allowed to be in the route).

The SSRR option can be of help in debugging some network problems. Some ISP peering agreements require support for this option in the routers within the peer of the ISP.

4.4.2. Option Specification

Specified in RFC 791 [RFC0791].

4.4.3. Threats

The SSRR option has the same security implications as the LSRR option. Please refer to Section 4.3 for a discussion of such security implications.

4.4.4. Operational and Interoperability Impact if Blocked

Network troubleshooting techniques that may employ the SSRR option (such as ping or traceroute with the appropriate arguments) would break when using the SSRR option. (Ping and traceroute without IPv4 options are not impacted.) Nevertheless, it should be noted that it is virtually impossible to use the SSRR option for trouble-shooting, due to widespread dropping of packets that contain such option.

4.4.5. Advice

Routers, security gateways, and firewalls SHOULD implement an option-specific configuration knob to select whether packets with this option are dropped, packets with this IP option are forwarded as if they did not contain this IP option, or packets with this option are processed and forwarded as per [RFC0791]. The default setting for this knob SHOULD be "drop", and the default setting MUST be documented.

Please note that treating packets with SSRR as if they did not contain this option can result in such packets being sent to a different device that the initially intended destination. With appropriate ingress filtering this should not open an attack vector into the infrastructure. Nonetheless, it could result in traffic that would never reach the initially intended destination. Dropping these packets prevents unnecessary network traffic, and does not make end-to-end communication any worse.

4.5. Record Route (Type = 7)

4.5.1. Uses

This option provides a means to record the route that a given packet follows.

4.5.2. Option Specification

Specified in RFC 791 [RFC0791].

4.5.3. Threats

This option can be exploited to map the topology of a network. However, the limited space in the IP header limits the usefulness of this option for that purpose.

4.5.4. Operational and Interoperability Impact if Blocked

Network troubleshooting techniques that may employ the RR option (such as ping with the RR option) would break when using the RR option. (Ping without IPv4 options is not impacted.) Nevertheless, it should be noted that it is virtually impossible to use such techniques due to widespread dropping of packets that contain RR options.

4.5.5. Advice

Routers, security gateways, and firewalls SHOULD implement an option-specific configuration knob to select whether packets with this option are dropped, packets with this IP option are forwarded as if they did not contain this IP option, or packets with this option are processed and forwarded as per [RFC0791]. The default setting for this knob SHOULD be "drop", and the default setting MUST be documented.

4.6. Stream Identifier (Type = 136) (obsolete)

The Stream Identifier option originally provided a means for the 16-bit SATNET stream Identifier to be carried through networks that did not support the stream concept.

However, as stated by Section 3.2.1.8 of RFC 1122 [RFC1122] and Section 4.2.2.1 of RFC 1812 [RFC1812], this option is obsolete. Therefore, it must be ignored by the processing systems. See also [IANA-IP] and [RFC6814].

RFC 791 states that this option appears at most once in a given datagram. Therefore, if a packet contains more than one instance of this option, it should be dropped, and this event should be logged (e.g., a counter could be incremented to reflect the packet drop).

4.6.1. Uses

This option is obsolete. There is no current use for this option.

4.6.2. Option Specification

Specified in RFC 791 [RFC0791], and deprecated in RFC 1122 [RFC1122] and RFC 1812 [RFC1812]. This option has been formally obsoleted by [RFC6814].

4.6.3. Threats

No specific security issues are known for this IPv4 option.

4.6.4. Operational and Interoperability Impact if Blocked

None.

4.6.5. Advice

Routers, security gateways, and firewalls SHOULD drop IP packets containing a Stream Identifier option.

4.7. Internet Timestamp (Type = 68)

4.7.1. Uses

This option provides a means for recording the time at which each system (or a specified set of systems) processed this datagram, and it may optionally record the addresses of the systems providing the timestamps.

4.7.2. Option Specification

Specified by RFC 791 [RFC0791].

4.7.3. Threats

The timestamp option has a number of security implications [RFC6274]. Among them are:

- It allows an attacker to obtain the current time of the systems that process the packet, which the attacker may find useful in a number of scenarios.
- It may be used to map the network topology in a similar way to the IP Record Route option.
- It may be used to fingerprint the operating system in use by a system processing the datagram.

- It may be used to fingerprint physical devices by analyzing the clock skew.

[Kohno2005] describes a technique for fingerprinting devices by measuring the clock skew. It exploits, among other things, the timestamps that can be obtained by means of the ICMP timestamp request messages [RFC0791]. However, the same fingerprinting method could be implemented with the aid of the Internet Timestamp option.

4.7.4. Operational and Interoperability Impact if Blocked

Network troubleshooting techniques that may employ the Internet Timestamp option (such as ping with the Timestamp option) would break when using the Timestamp option. (Ping without IPv4 options is not impacted.) Nevertheless, it should be noted that it is virtually impossible to use such techniques due to widespread dropping of packets that contain Internet Timestamp options.

4.7.5. Advice

Routers, security gateways, and firewalls SHOULD drop IP packets containing an Internet Timestamp option.

4.8. Router Alert (Type = 148)

4.8.1. Uses

The Router Alert option has the semantic "routers should examine this packet more closely, if they participate in the functionality denoted by the Value of the option".

4.8.2. Option Specification

The Router Alert option is defined in RFC 2113 [RFC2113] and later updates to it have been clarified by RFC 5350 [RFC5350]. It contains a 16-bit Value governed by an IANA registry (see [RFC5350]).

4.8.3. Threats

The security implications of the Router Alert option have been discussed in detail in [RFC6398]. Basically, the Router Alert option might be exploited to perform a DoS attack by exhausting CPU resources at the processing routers.

4.8.4. Operational and Interoperability Impact if Blocked

Applications that employ the Router Alert option (such as RSVP [RFC2205]) would break.

4.8.5. Advice

This option SHOULD be allowed only in controlled environments, where the option can be used safely. [RFC6398] identifies some such environments. In unsafe environments, packets containing this option SHOULD be dropped.

A given router, security gateway, or firewall system has no way of knowing a priori whether this option is valid in its operational environment. Therefore, routers, security gateways, and firewalls SHOULD, by default, ignore the Router Alert option. Additionally, routers, security gateways, and firewalls SHOULD have a configuration setting that governs their reaction in the presence of packets containing the Router Alert option. This configuration setting SHOULD allow to honor and process the option, ignore the option, or drop packets containing this option.

4.9. Probe MTU (Type = 11) (obsolete)

4.9.1. Uses

This option originally provided a mechanism to discover the Path-MTU. It has been declared obsolete.

4.9.2. Option Specification

This option was originally defined in RFC 1063 [RFC1063] and was obsoleted with RFC 1191 [RFC1191]. This option is now obsolete, as RFC 1191 obsoletes RFC 1063 without using IP options.

4.9.3. Threats

This option is obsolete. This option could have been exploited to cause a host to set its Path MTU (PMTU) estimate to an inordinately low or an inordinately high value, thereby causing performance problems.

4.9.4. Operational and Interoperability Impact if Blocked

None

This option is NOT employed with the modern "Path MTU Discovery" (PMTUD) mechanism [RFC1191], which employs special ICMP messages (Type 3, Code 4) in combination with the IP DF bit. Packetization Layer PMTUD (PLPMTUD) [RFC4821] can perform PMTUD without the need for any special packets.

4.9.5. Advice

Routers, security gateways, and firewalls SHOULD drop IP packets that contain a Probe MTU option.

4.10. Reply MTU (Type = 12) (obsolete)

4.10.1. Uses

This option originally provided a mechanism to discover the Path-MTU. It is now obsolete.

4.10.2. Option Specification

This option was originally defined in RFC 1063 [RFC1063] and was obsoleted with RFC 1191 [RFC1191]. This option is now obsolete, as RFC 1191 obsoletes RFC 1063 without using IP options.

4.10.3. Threats

This option is obsolete. This option could have been exploited to cause a host to set its PMTU estimate to an inordinately low or an inordinately high value, thereby causing performance problems.

4.10.4. Operational and Interoperability Impact if Blocked

None

> This option is NOT employed with the modern "Path MTU Discovery" (PMTUD) mechanism [RFC1191], which employs special ICMP messages (Type 3, Code 4) in combination with the IP DF bit. PLPMTUD [RFC4821] can perform PMTUD without the need of any special packets.

4.10.5. Advice

Routers, security gateways, and firewalls SHOULD drop IP packets that contain a Reply MTU option.

4.11. Traceroute (Type = 82)

4.11.1. Uses

This option originally provided a mechanism to trace the path to a host.

4.11.2. Option Specification

This option was originally specified by RFC 1393 [RFC1393] as "experimental", and it was never widely deployed on the public Internet. This option has been formally obsoleted by [RFC6814].

4.11.3. Threats

This option is obsolete. Because this option required each router in the path both to provide special processing and to send an ICMP message, it could have been exploited to perform a DoS attack by exhausting CPU resources at the processing routers.

4.11.4. Operational and Interoperability Impact if Blocked

None

4.11.5. Advice

Routers, security gateways, and firewalls SHOULD drop IP packets that contain a Traceroute option.

4.12. DoD Basic Security Option (Type = 130)

4.12.1. Uses

This option [RFC1108] is used by Multi-Level Secure (MLS) end-systems and intermediate systems in specific environments to:

- transmit from source to destination in a network standard representation the common security labels required by computer security models [Landwehr81],
- validate the datagram as appropriate for transmission from the source and delivery to the destination, and,
- ensure that the route taken by the datagram is protected to the level required by all protection authorities indicated on the datagram.

The DoD Basic Security Option (BSO) was implemented in IRIX [IRIX2008] and is currently implemented in a number of operating systems (e.g., Security-Enhanced Linux [SELinux2008], Solaris [Solaris2008], and Cisco IOS [Cisco-IPSO]). It is also currently deployed in a number of high-security networks. These networks are typically either in physically secure locations, protected by military/governmental communications security equipment, or both.

Such networks are typically built using commercial off-the-shelf (COTS) IP routers and Ethernet switches, but they are not normally interconnected with the global public Internet. MLS systems are much more widely deployed now than they were at the time the then-IESG decided to remove IPSO (IP Security Options) from the IETF Standards Track. Since nearly all MLS systems also support IPSO BSO and IPSO ESO, this option is believed to have more deployment now than when the IESG removed this option from the IETF Standards Track. [RFC5570] describes a similar option recently defined for IPv6 and has much more detailed explanations of how sensitivity label options are used in real-world deployments.

4.12.2. Option Specification

It is specified by RFC 1108 [RFC1108], which obsoleted RFC 1038 [RFC1038] (which in turn obsoleted the Security Option defined in RFC 791 [RFC0791]).

> RFC 791 [RFC0791] defined the "Security Option" (Type = 130), which used the same option type as the DoD Basic Security option discussed in this section. Later, RFC 1038 [RFC1038] revised the IP security options, and in turn was obsoleted by RFC 1108 [RFC1108]. The "Security Option" specified in RFC 791 is considered obsolete by Section 3.2.1.8 of RFC 1122 [RFC1122] and Section 4.2.2.1 of RFC 1812 [RFC1812], and therefore the discussion in this section is focused on the DoD Basic Security option specified by RFC 1108 [RFC1108].

Section 4.2.2.1 of RFC 1812 states that routers "SHOULD implement [this option]".

> Some private IP networks consider IP router-based per-interface selective filtering of packets based on (a) the presence of an IPSO option (including BSO and ESO) and (b) the contents of that IPSO option to be important for operational security reasons. The recent IPv6 Common Architecture Label IPv6 Security Option (CALIPSO) specification discusses this in additional detail, albeit in an IPv6 context [RFC5570].
>
> Such private IP networks commonly are built using both commercial and open-source products -- for hosts, guards, firewalls, switches, routers, etc. Some commercial IP routers support this option, as do some IP routers that are built on top of MLS operating systems (e.g., on top of Trusted Solaris [Solaris2008] or Security-Enhanced Linux [SELinux2008]).

For example, many Cisco routers that run Cisco IOS include support for selectively filtering packets that contain the IP Security Options (IPSO) with per-interface granularity. This capability has been present in many Cisco routers since the early 1990s [Cisco-IPSO-Cmds]. Some government-sector products reportedly also support the IP Security Options (IPSO), for example, CANEWARE [RFC4949].

Support for the IPSO Basic Security Option also is included in the "IPsec Configuration Policy Information Model" [RFC3585] and in the "IPsec Security Policy Database Configuration MIB" [RFC4807]. Section 4.6.1 of the IP Security Domain of Interpretation [RFC2407] includes support for labeled IPsec security associations compatible with the IP Security Options. (Note: RFC 2407 was obsoleted by [RFC4306], which was obsoleted by [RFC5996].)

4.12.3. Threats

Presence of this option in a packet does not by itself create any specific new threat. Packets with this option ought not normally be seen on the global public Internet.

4.12.4. Operational and Interoperability Impact if Blocked

If packets with this option are blocked or if the option is stripped from the packet during transmission from source to destination, then the packet itself is likely to be dropped by the receiver because it is not properly labeled. In some cases, the receiver might receive the packet but associate an incorrect sensitivity label with the received data from the packet whose BSO was stripped by an intermediate router or firewall. Associating an incorrect sensitivity label can cause the received information either to be handled as more sensitive than it really is ("upgrading") or as less sensitive than it really is ("downgrading"), either of which is problematic.

4.12.5. Advice

A given IP router, security gateway, or firewall has no way to know a priori what environment it has been deployed into. Even closed IP deployments generally use exactly the same commercial routers, security gateways, and firewalls that are used in the public Internet.

Since operational problems result in environments where this option is needed if either the option is dropped or IP packets containing this option are dropped, but no harm results if the option is carried in environments where it is not needed, the default configuration SHOULD NOT (a) modify or remove this IP option or (b) drop an IP packet because the IP packet contains this option.

A given IP router, security gateway, or firewall MAY be configured to drop this option or to drop IP packets containing this option in an environment known to not use this option.

For auditing reasons, routers, security gateways, and firewalls SHOULD be capable of logging the numbers of packets containing the BSO on a per-interface basis. Also, routers, security gateways, and firewalls SHOULD be capable of dropping packets based on the BSO presence as well as the BSO values.

4.13. DoD Extended Security Option (Type = 133)

4.13.1. Uses

This option permits additional security labeling information, beyond that present in the Basic Security Option (Section 4.12), to be supplied in an IP datagram to meet the needs of registered authorities.

4.13.2. Option Specification

The DoD Extended Security Option (ESO) is specified by RFC 1108 [RFC1108].

Some private IP networks consider IP router-based per-interface selective filtering of packets based on (a) the presence of an IPSO option (including BSO and ESO) and (b) based on the contents of that IPSO option to be important for operational security reasons. The recent IPv6 CALIPSO option specification discusses this in additional detail, albeit in an IPv6 context [RFC5570].

Such private IP networks commonly are built using both commercial and open-source products -- for hosts, guards, firewalls, switches, routers, etc. Some commercial IP routers support this option, as do some IP routers that are built on top of MLS operating systems (e.g., on top of Trusted Solaris [Solaris2008] or Security-Enhanced Linux [SELinux2008]).

For example, many Cisco routers that run Cisco IOS include support for selectively filtering packets that contain the IP Security Options (IPSO) with per-interface granularity. This capability

has been present in many Cisco routers since the early 1990s [Cisco-IPSO-Cmds]. Some government sector products reportedly also support the IP Security Options (IPSO), for example, CANEWARE [RFC4949].

Support for the IPSO Extended Security Option also is included in the "IPsec Configuration Policy Information Model" [RFC3585] and in the "IPsec Security Policy Database Configuration MIB" [RFC4807]. Section 4.6.1 of the IP Security Domain of Interpretation [RFC2407] includes support for labeled IPsec security associations compatible with the IP Security Options.

4.13.3. Threats

Presence of this option in a packet does not by itself create any specific new threat. Packets with this option ought not normally be seen on the global public Internet.

4.13.4. Operational and Interoperability Impact if Blocked

If packets with this option are blocked or if the option is stripped from the packet during transmission from source to destination, then the packet itself is likely to be dropped by the receiver because it is not properly labeled. In some cases, the receiver might receive the packet but associate an incorrect sensitivity label with the received data from the packet whose ESO was stripped by an intermediate router or firewall. Associating an incorrect sensitivity label can cause the received information either to be handled as more sensitive than it really is ("upgrading") or as less sensitive than it really is ("downgrading"), either of which is problematic.

4.13.5. Advice

A given IP router, security gateway, or firewall has no way to know a priori what environment it has been deployed into. Even closed IP deployments generally use exactly the same commercial routers, security gateways, and firewalls that are used in the public Internet.

Since operational problems result in environments where this option is needed if either the option is dropped or IP packets containing this option are dropped, but no harm results if the option is carried in environments where it is not needed, the default configuration SHOULD NOT (a) modify or remove this IP option or (b) drop an IP packet because the IP packet contains this option.

A given IP router, security gateway, or firewall MAY be configured to drop this option or to drop IP packets containing this option in an environment known to not use this option.

For auditing reasons, routers, security gateways, and firewalls SHOULD be capable of logging the numbers of packets containing the ESO on a per-interface basis. Also, routers, security gateways, and firewalls SHOULD be capable of dropping packets based on the ESO presence as well as the ESO values.

4.14. Commercial IP Security Option (CIPSO) (Type = 134)

4.14.1. Uses

This option was proposed by the Trusted Systems Interoperability Group (TSIG), with the intent of meeting trusted networking requirements for the commercial trusted systems marketplace.

It was implemented in IRIX [IRIX2008] and is currently implemented in a number of operating systems (e.g., Security-Enhanced Linux [SELinux2008] and Solaris [Solaris2008]). It is also currently deployed in a number of high-security networks.

4.14.2. Option Specification

This option is specified in [CIPSO] and [FIPS1994]. There are zero known IP router implementations of CIPSO. Several MLS operating systems support CIPSO, generally the same MLS operating systems that support IPSO.

> The TSIG proposal was taken to the Commercial Internet Security Option (CIPSO) Working Group of the IETF [CIPSOWG1994], and an Internet-Draft was produced [CIPSO]. The Internet-Draft was never published as an RFC, but the proposal was later standardized by the U.S. National Institute of Standards and Technology (NIST) as "Federal Information Processing Standard Publication 188" [FIPS1994].

4.14.3. Threats

Presence of this option in a packet does not by itself create any specific new threat. Packets with this option ought not normally be seen on the global public Internet.

4.14.4. Operational and Interoperability Impact if Blocked

If packets with this option are blocked or if the option is stripped from the packet during transmission from source to destination, then the packet itself is likely to be dropped by the receiver because it is not properly labeled. In some cases, the receiver might receive the packet but associate an incorrect sensitivity label with the received data from the packet whose CIPSO was stripped by an intermediate router or firewall. Associating an incorrect sensitivity label can cause the received information either to be handled as more sensitive than it really is ("upgrading") or as less sensitive than it really is ("downgrading"), either of which is problematic.

4.14.5. Advice

Because of the design of this option, with variable syntax and variable length, it is not practical to support specialized filtering using the CIPSO information. No routers or firewalls are known to support this option. However, routers, security gateways, and firewalls SHOULD NOT by default modify or remove this option from IP packets and SHOULD NOT by default drop packets because they contain this option. For auditing reasons, routers, security gateways, and firewalls SHOULD be capable of logging the numbers of packets containing the CIPSO on a per-interface basis. Also, routers, security gateways, and firewalls SHOULD be capable of dropping packets based on the CIPSO presence.

4.15. VISA (Type = 142)

4.15.1. Uses

This options was part of an experiment at the University of Southern California (USC) and was never widely deployed.

4.15.2. Option Specification

The original option specification is not publicly available. This option has been formally obsoleted by [RFC6814].

4.15.3. Threats

Not possible to determine (other than the general security implications of IP options discussed in Section 3), since the corresponding specification is not publicly available.

4.15.4. Operational and Interoperability Impact if Blocked

None.

4.15.5. Advice

Routers, security gateways, and firewalls SHOULD drop IP packets that contain this option.

4.16. Extended Internet Protocol (Type = 145)

4.16.1. Uses

The EIP option was introduced by one of the proposals submitted during the IP Next Generation (IPng) efforts to address the problem of IPv4 address exhaustion.

4.16.2. Option Specification

Specified in [RFC1385]. This option has been formally obsoleted by [RFC6814].

4.16.3. Threats

This option is obsolete. This option was used (or was intended to be used) to signal that a packet superficially similar to an IPv4 packet actually contained a different protocol, opening up the possibility that an IPv4 node that simply ignored this option would process a received packet in a manner inconsistent with the intent of the sender. There are no known threats arising from this option, other than the general security implications of IP options discussed in Section 3.

4.16.4. Operational and Interoperability Impact if Blocked

None.

4.16.5. Advice

Routers, security gateways, and firewalls SHOULD drop packets that contain this option.

4.17. Address Extension (Type = 147)

4.17.1. Uses

The Address Extension option was introduced by one of the proposals submitted during the IPng efforts to address the problem of IPv4 address exhaustion.

4.17.2. Option Specification

Specified in [RFC1475]. This option has been formally obsoleted by [RFC6814].

4.17.3. Threats

There are no known threats arising from this option, other than the general security implications of IP options discussed in Section 3.

4.17.4. Operational and Interoperability Impact if Blocked

None.

4.17.5. Advice

Routers, security gateways, and firewalls SHOULD drop packets that contain this option.

4.18. Sender Directed Multi-Destination Delivery (Type = 149)

4.18.1. Uses

This option originally provided unreliable UDP delivery to a set of addresses included in the option.

4.18.2. Option Specification

This option is specified in RFC 1770 [RFC1770]. It has been formally obsoleted by [RFC6814].

4.18.3. Threats

This option could have been exploited for bandwidth-amplification in DoS attacks.

4.18.4. Operational and Interoperability Impact if Blocked

None.

4.18.5. Advice

Routers, security gateways, and firewalls SHOULD drop IP packets that contain a Sender Directed Multi-Destination Delivery option.

4.19. Dynamic Packet State (Type = 151)

4.19.1. Uses

The Dynamic Packet State option was used to specify the Dynamic Packet State (DPS) in the context of the differentiated services architecture.

4.19.2. Option Specification

The Dynamic Packet State option was specified in [DIFFSERV-DPS]. The aforementioned document was meant to be published as "Experimental", but never made it into an RFC. This option has been formally obsoleted by [RFC6814].

4.19.3. Threats

Possible threats include theft of service and denial of service. However, we note that this option has never been widely implemented or deployed.

4.19.4. Operational and Interoperability Impact if Blocked

None.

4.19.5. Advice

Routers, security gateways, and firewalls SHOULD drop packets that contain this option.

4.20. Upstream Multicast Pkt. (Type = 152)

4.20.1. Uses

This option was meant to solve the problem of doing upstream forwarding of multicast packets on a multi-access LAN.

4.20.2. Option Specification

This option was originally specified in [BIDIR-TREES]. It was never formally standardized in the RFC series and was never widely implemented and deployed. Its use was obsoleted by [RFC5015], which

employs a control-plane mechanism to solve the problem of doing upstream forwarding of multicast packets on a multi-access LAN. This option has been formally obsoleted by [RFC6814].

4.20.3. Threats

This option is obsolete. A router that ignored this option instead of processing it as specified in [BIDIR-TREES] could have forwarded multicast packets to an unintended destination.

4.20.4. Operational and Interoperability Impact if Blocked

None.

4.20.5. Advice

Routers, security gateways, and firewalls SHOULD drop packets that contain this option.

4.21. Quick-Start (Type = 25)

4.21.1. Uses

This IP Option is used in the specification of Quick-Start for TCP and IP, which is an experimental mechanism that allows transport protocols, in cooperation with routers, to determine an allowed sending rate at the start and, at times, in the middle of a data transfer (e.g., after an idle period) [RFC4782].

4.21.2. Option Specification

Specified in RFC 4782 [RFC4782], on the "Experimental" track.

4.21.3. Threats

Section 9.6 of [RFC4782] notes that Quick-Start is vulnerable to two kinds of attacks:

- attacks to increase the routers' processing and state load, and,
- attacks with bogus Quick-Start Requests to temporarily tie up available Quick-Start bandwidth, preventing routers from approving Quick-Start Requests from other connections.

4.21.4. Operational and Interoperability Impact if Blocked

The Quick-Start functionality would be disabled, and additional delays in TCP's connection establishment (for example) could be introduced. (Please see Section 4.7.2 of [RFC4782].) We note, however, that Quick-Start has been proposed as a mechanism that could be of use in controlled environments, and not as a mechanism that would be intended or appropriate for ubiquitous deployment in the global Internet [RFC4782].

4.21.5. Advice

A given router, security gateway, or firewall system has no way of knowing a priori whether this option is valid in its operational environment. Therefore, routers, security gateways, and firewalls SHOULD, by default, ignore the Quick-Start option. Additionally, routers, security gateways, and firewalls SHOULD have a configuration setting that governs their reaction in the presence of packets containing the Quick-Start option. This configuration setting SHOULD allow to honor and process the option, ignore the option, or drop packets containing this option. The default configuration is to ignore the Quick-Start option.

> We note that if routers in a given environment do not implement and enable the Quick-Start mechanism, only the general security implications of IP options (discussed in Section 3) would apply.

4.22. RFC3692-Style Experiment (Types = 30, 94, 158, and 222)

Section 2.5 of RFC 4727 [RFC4727] allocates an option number with all defined values of the "copy" and "class" fields for RFC3692-style experiments. This results in four distinct option type codes: 30, 94, 158, and 222.

4.22.1. Uses

It is only appropriate to use these values in explicitly configured experiments; they MUST NOT be shipped as defaults in implementations.

4.22.2. Option Specification

Specified in RFC 4727 [RFC4727] in the context of RFC3692-style experiments.

4.22.3. Threats

No specific security issues are known for this IPv4 option.

4.22.4. Operational and Interoperability Impact if Blocked

None.

4.22.5. Advice

Routers, security gateways, and firewalls SHOULD have configuration knobs for IP packets that contain RFC3692-style Experiment options to select between "ignore & forward" and "drop & log". Otherwise, no legitimate experiment using these options will be able to traverse any IP router.

Special care needs to be taken in the case of "drop & log". Devices SHOULD count the number of packets dropped, but the logging of drop events SHOULD be limited so as to not overburden device resources.

The aforementioned configuration knob SHOULD default to "drop & log".

4.23. Other IP Options

4.23.1. Specification

Unrecognized IP options are to be ignored. Section 3.2.1.8 of RFC 1122 [RFC1122] specifies this behavior as follows:

> The IP and transport layer MUST each interpret those IP options that they understand and silently ignore the others.

Additionally, Section 4.2.2.6 of RFC 1812 [RFC1812] specifies it as follows:

> A router MUST ignore IP options which it does not recognize.

This document adds that unrecognized IP options MAY also be logged.

Further, routers, security gateways, and firewalls MUST provide the ability to log drop events of IP packets containing unrecognized or obsolete options.

A number of additional options are listed in the "IP OPTION NUMBERS" IANA registry [IANA-IP] as of the time this document was last edited. Specifically:

Copy	Class	Number	Value	Name
0	0	10	10	ZSU - Experimental Measurement
1	2	13	205	FINN - Experimental Flow Control
0	0	15	15	ENCODE - ???
1	0	16	144	IMITD - IMI Traffic Descriptor
1	0	22	150	- Unassigned (Released 18 Oct. 2005)

The ENCODE option (type 15) has been formally obsoleted by [RFC6814].

4.23.2. Threats

The lack of open specifications for these options makes it impossible to evaluate their security implications.

4.23.3. Operational and Interoperability Impact if Blocked

The lack of open specifications for these options makes it impossible to evaluate the operational and interoperability impact if packets containing these options are blocked.

4.23.4. Advice

Routers, security gateways, and firewalls SHOULD have configuration knobs for IP packets containing these options (or other options not recognized) to select between "ignore & forward" and "drop & log".

Section 4.23.1 points out that [RFC1122] and [RFC1812] specify that unrecognized IP options MUST be ignored. However, the previous paragraph states that routers, security gateways, and firewalls SHOULD have a configuration option for dropping and logging IP packets containing unrecognized options. While it is acknowledged that this advice contradicts the previous RFCs' requirements, the advice in this document reflects current operational reality.

Special care needs to be taken in the case of "drop & log". Devices SHOULD count the number of packets dropped, but the logging of drop events SHOULD be limited so as to not overburden device resources.

5. Security Considerations

This document provides advice on the filtering of IP packets that contain IP options. Dropping such packets can help to mitigate the security issues that arise from use of different IP options. Many of the IPv4 options listed in this document are deprecated and cause no operational impact if dropped. However, dropping packets containing IPv4 options that are in use can cause real operational problems in deployed networks. Therefore, the practice of dropping all IPv4 packets containing one or more IPv4 options without careful consideration is not recommended.

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7. References

7.1. Normative References

[RFC0791] Postel, J., "Internet Protocol", STD 5, RFC 791, September 1981.

[RFC1122] Braden, R., "Requirements for Internet Hosts - Communication Layers", STD 3, RFC 1122, October 1989.

[RFC1191] Mogul, J. and S. Deering, "Path MTU discovery", RFC 1191, November 1990.

[RFC1812] Baker, F., "Requirements for IP Version 4 Routers", RFC 1812, June 1995.

[RFC2113] Katz, D., "IP Router Alert Option", RFC 2113, February 1997.

[RFC2119] Bradner, S., "Key words for use in RFCs to Indicate Requirement Levels", BCP 14, RFC 2119, March 1997.

[RFC4727] Fenner, B., "Experimental Values In IPv4, IPv6, ICMPv4, ICMPv6, UDP, and TCP Headers", RFC 4727, November 2006.

[RFC4821] Mathis, M. and J. Heffner, "Packetization Layer Path MTU Discovery", RFC 4821, March 2007.

[RFC5015] Handley, M., Kouvelas, I., Speakman, T., and L. Vicisano, "Bidirectional Protocol Independent Multicast (BIDIR-PIM)", RFC 5015, October 2007.

[RFC6398] Le Faucheur, F., "IP Router Alert Considerations and Usage", BCP 168, RFC 6398, October 2011.

[RFC6814] Pignataro, C. and F. Gont, "Formally Deprecating Some IPv4 Options", RFC 6814, November 2012.

7.2. Informative References

[BIDIR-TREES]
Estrin, D. and D. Farinacci, "Bi-Directional Shared Trees in PIM-SM", Work in Progress, May 1999.

[BREMIER-BARR]
Bremier-Barr, A. and H. Levy, "Spoofing prevention method", Proceedings of IEEE InfoCom 2005, Volume 1, pp. 536-547, March 2005.

[Biondi2007]
Biondi, P. and A. Ebalard, "IPv6 Routing Header Security", CanSecWest 2007 Security Conference, 2007, <http://www.secdev.org/conf/IPv6_RH_security-csw07.pdf>.

[CIPSOWG1994]
IETF CIPSO Working Group, "Commercial Internet Protocol Security Option (CIPSO) Charter", 1994, <http://www.ietf.org/proceedings/94jul/charters/cipso-charter.html>.

[CIPSO] IETF CIPSO Working Group, "COMMERCIAL IP SECURITY OPTION (CIPSO 2.2)", Work in Progress, 1992.

[CPNI2008] Gont, F., "Security Assessment of the Internet Protocol", 2008, <http://www.gont.com.ar/papers/InternetProtocol.pdf>.

[Cisco-IPSO-Cmds]
Cisco Systems, Inc., "IP Security Options Commands", Cisco IOS Security Command Reference, Release 12.2, <http://www.cisco.com/en/US/docs/ios/12_2/security/command/reference/srfipso.html>.

[Cisco-IPSO]
Cisco Systems, Inc., "Configuring IP Security Options", Cisco IOS Security Configuration Guide, Release 12.2, 2006, <http://www.cisco.com/en/US/docs/ios/12_2/security/configuration/guide/scfipso.html>.

[DIFFSERV-DPS]
Stoica, I., Zhang, H., Venkitaram, N., and J. Mysore, "Per Hop Behaviors Based on Dynamic Packet State", Work in Progress, October 2002.

[FIPS1994]
FIPS, "Standard Security Label for Information Transfer", Federal Information Processing Standards Publication, FIP PUBS 188, 1994, <http://csrc.nist.gov/publications/fips/fips188/fips188.pdf>.

[FONSECA] Fonseca, R., Porter, G., Katz, R., Shenker, S., and I. Stoica, "IP Options are not an option", EECS Department, University of California, Berkeley, December 2005, <http://www.eecs.berkeley.edu/Pubs/TechRpts/2005/EECS-2005-24.html>.

[IANA-IP] IANA, "IP OPTION NUMBERS", <http://www.iana.org/assignments/ip-parameters>.

[IRIX2008] IRIX, "IRIX 6.5 trusted_networking(7) manual page", 2008, <http://techpubs.sgi.com/library/tpl/cgi-bin/getdoc.cgi?coll=0650&db=man&fname=/usr/share/catman/a_man/cat7/trusted_networking.z>.

[Kohno2005]
Kohno, T., Broido, A., and kc. Claffy, "Remote Physical Device Fingerprinting", IEEE Transactions on Dependable and Secure Computing, Vol. 2, No. 2, 2005.

[Landwehr81]
Landwehr, C., "Formal Models for Computer Security", ACM Computing Surveys, Vol. 13, No. 3, Association for Computing Machinery, New York, NY, USA, September 1981.

[MEDINA] Medina, A., Allman, M., and S. Floyd, "Measuring Interactions Between Transport Protocols and Middleboxes", Proc. 4th ACM SIGCOMM/USENIX Conference on Internet Measurement, October 2004.

[Microsoft1999] Microsoft, "Microsoft Security Program: Microsoft Security Bulletin (MS99-038). Patch Available for "Spoofed Route Pointer" Vulnerability", September 1999, <http://www.microsoft.com/technet/security/bulletin/ms99-038.mspx>.

[OpenBSD1998] OpenBSD, "OpenBSD Security Advisory: IP Source Routing Problem", February 1998, <http://www.openbsd.org/advisories/sourceroute.txt>.

[RFC1038] St. Johns, M., "Draft revised IP security option", RFC 1038, January 1988.

[RFC1063] Mogul, J., Kent, C., Partridge, C., and K. McCloghrie, "IP MTU discovery options", RFC 1063, July 1988.

[RFC1108] Kent, S., "U.S. Department of Defense Security Options for the Internet Protocol", RFC 1108, November 1991.

[RFC1385] Wang, Z., "EIP: The Extended Internet Protocol", RFC 1385, November 1992.

[RFC1393] Malkin, G., "Traceroute Using an IP Option", RFC 1393, January 1993.

[RFC1475] Ullmann, R., "TP/IX: The Next Internet", RFC 1475, June 1993.

[RFC1770] Graff, C., "IPv4 Option for Sender Directed Multi-Destination Delivery", RFC 1770, March 1995.

[RFC2205] Braden, B., Zhang, L., Berson, S., Herzog, S., and S. Jamin, "Resource ReSerVation Protocol (RSVP) -- Version 1 Functional Specification", RFC 2205, September 1997.

[RFC2407] Piper, D., "The Internet IP Security Domain of Interpretation for ISAKMP", RFC 2407, November 1998.

[RFC3585] Jason, J., Rafalow, L., and E. Vyncke, "IPsec Configuration Policy Information Model", RFC 3585, August 2003.

[RFC4306] Kaufman, C., "Internet Key Exchange (IKEv2) Protocol", RFC 4306, December 2005.

[RFC4782] Floyd, S., Allman, M., Jain, A., and P. Sarolahti, "Quick-Start for TCP and IP", RFC 4782, January 2007.

[RFC4807] Baer, M., Charlet, R., Hardaker, W., Story, R., and C. Wang, "IPsec Security Policy Database Configuration MIB", RFC 4807, March 2007.

[RFC4949] Shirey, R., "Internet Security Glossary, Version 2", RFC 4949, August 2007.

[RFC5350] Manner, J. and A. McDonald, "IANA Considerations for the IPv4 and IPv6 Router Alert Options", RFC 5350, September 2008.

[RFC5570] StJohns, M., Atkinson, R., and G. Thomas, "Common Architecture Label IPv6 Security Option (CALIPSO)", RFC 5570, July 2009.

[RFC5996] Kaufman, C., Hoffman, P., Nir, Y., and P. Eronen, "Internet Key Exchange Protocol Version 2 (IKEv2)", RFC 5996, September 2010.

[RFC6192] Dugal, D., Pignataro, C., and R. Dunn, "Protecting the Router Control Plane", RFC 6192, March 2011.

[RFC6274] Gont, F., "Security Assessment of the Internet Protocol Version 4", RFC 6274, July 2011.

[SELinux2008] National Security Agency (United States), "Security-Enhanced Linux - NSA/CSS", January 2009, <http://www.nsa.gov/research/selinux/index.shtml>.

[Solaris2008] "Solaris Trusted Extensions: Labeled Security for Absolute Protection", 2008, <http://www.oracle.com/technetwork/server-storage/solaris10/overview/trusted-extensions-149944.pdf>.

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