



The Printer Working Group

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Working Draft

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PWG Safe G-Code Subset for 3D Printing v1.0

Status: Stable

Abstract: This Best Practice document defines a "safe" subset of G-code for use in 3D printing with IPP along with the capabilities and parameters needed to allow a client to generate G-code compatible with the printer.

This is a PWG Working Draft. For a definition of a "PWG Working Draft", see:

<https://ftp.pwg.org/pub/pwg/general/pwg-process30.pdf>

This white paper is available electronically at:

<https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20190318.docx>

<https://ftp.pwg.org/pub/ipp/wd/wd-pwgsafegcode10-20190318.pdf>

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25 Title: *PWG Safe G-Code Subset for 3D Printing v1.0*

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79 **1. Introduction**

80 G-Code [ISO6893-1] [RS274D] [RS274NGC] [REPRAP] is a commonly-used format for 3D
81 printing with so-called Fused Deposition Modeling (FDM) printers. Besides the commands
82 used to move the print head and/or platform and to extrude material, G-Code includes a
83 variety of device control (e.g., set extruder temperature) and hardware access (e.g., write
84 file to SD card) commands that pose serious safety and security concerns. To make matters
85 worse, such commands are often printer-specific or have printer-specific variations in syntax,
86 requiring the equivalent of printer driver software to produce G-Code suitable for a particular
87 model or firmware version. Finally, differences in filament and extruder nozzle diameters
88 mean that G-Code created for one print job may not work on the same printer due to changes
89 to the material or extruder.

90 The IPP 3D Printing Extensions v1.0 [PWG5100.21] define the model and semantics for
91 networked 3D printing, along with a required high-level 3D file format. However, the
92 processing requirements of such a format require either improved printer controllers with
93 greater memory, storage, and CPU capacity or the use of Cloud services to offload that
94 processing.

95 The IPP Shared Infrastructure Extensions (INFRA) [PWG5100.18] define the model and
96 semantics for Cloud printing, however it does not specify an intermediate format suitable for
97 3D printing.

98 This document defines a "safe" subset of G-Code that can be used for direct and Cloud
99 printing configurations, along with a description of the capabilities and parameters that will
100 be needed to generate suitable layers for printing to the target printer.

101 The goal of this document is to enable the use of IPP with existing entry-level FDM printers
102 that are not able to perform their own slicing and to enable generic Cloud and local
103 infrastructure services to provide slicing services to existing FDM printers. Support for other
104 kinds of 3D printers will likely require an intermediate format such as the 3MF Slice Extension
105 [3MF-SLICE].

106

107 **2. Terminology**

108 **2.1 Terms Used in This Document**

109 *Cloud*: the environment supporting services such as Cloud Computing.

110 *Cloud Computing*: "... a model for enabling ubiquitous, convenient, on demand network
111 access to a shared pool of configurable computing resources (e.g., networks, servers,
112 storage, applications, and services) that can be rapidly provisioned and released with
113 minimal management effort or service provider interaction." The NIST Definition of Cloud
114 Computing [NISTSP800-145].

115 *Fused Deposition Modeling*: A 3D printing process that extrudes a molten material to draw
116 layers, sometimes also called material extrusion.

117 **2.2 Acronyms and Organizations**

118 *IANA*: Internet Assigned Numbers Authority, <https://www.iana.org/>

119 *IETF*: Internet Engineering Task Force, <https://www.ietf.org/>

120 *ISO*: International Organization for Standardization, <https://www.iso.org/>

121 *PWG*: Printer Working Group, <https://www.pwg.org/>

122

123 **3. PWG Safe G-Code Subset**

124 This document defines a safe G-Code subset with the MIME Media Type
125 "application/vnd.pwg-safe-gcode". Safe G-Code files consist solely of the following
126 commands which represent the common subset of commands supported by most FDM
127 printers:

128 G0: Rapid Linear Move

129 G1: Controlled Linear Move

130 G4: Dwell

131 G21: Set Units to Millimeters

132 G28: Move to Origin (Home)

133 G90: Set Absolute Positioning

134 G91: Set Relative Positioning

135 G92: Set Position

136 M82: Set Absolute Extrusion

137 M83: Set Relative Extrusion

138 Tnnn: Set Tool

139 Most machine ("M") commands are not allowed since they directly control or access the
140 machine hardware. Temperature control and other machine settings are the responsibility
141 of the IPP Printer, which will likely use the IPP Job Template attribute values to send the
142 corresponding printer-specific G-code commands to a lower-level controller.

143 The line number command ("N") and checksum ("*") are similarly not allowed because they
144 are used for direct communications with the controller - IPP provides the necessary
145 infrastructure for reliable communication of the G-Code file to the IPP Printer.

146 Comments starting with the ";" character are allowed and continue to the end of the current
147 line.

148 For simplicity, safe G-Code always uses millimeters for the units (the default).

149 **3.1 G0 and G1: (Rapid/Controlled) Linear Move**

150 These commands move the current tool (extruder) and/or extrude material for printing.
151 Parameters for this command are:

152 Xnnn: Set X position in millimeters

153 Ynnn: Set Y position in millimeters

154 Znnn: Set Z position in millimeters

155 Ennn: Extrude the specified number of millimeters of material

156 Fnnn: Set the feed rate in millimeters/minute

157 Note: The "S" parameter is not allowed in safe G-Code.

158 **3.2 G4: Dwell**

159 This command pauses printing for a specifies amount of time. The "Pnnn" parameter
160 specifies the time interval in milliseconds.

161 **3.3 G21: Set Units to Millimeters**

162 This command explicitly specifies that coordinates are in millimeters (the default).

163 Note: This command is only provided for completeness - there is no support in safe G-Code
164 for any other units.

165 **3.4 G28: Move to Origin (Home)**

166 This command moves the current tool to the home position (end stops). The "X", "Y", and
167 "Z" parameters may optionally be specified to move the tool on the specified axes - if not
168 supplied the tool is moved on all axes.

169 **3.5 G90: Set Absolute Positioning**

170 This command specifies that all coordinates are relative to the origin of the machine.

171 **3.6 G91: Set Relative Positioning**

172 This command specifies that all coordinates are relative to the current position of the tool.

173 **3.7 G92: Set Position**

174 This command sets the current tool positions without moving or extruding material.
175 Parameters for this command are:

176 Xnnn: Set X position in millimeters

177 Ynnn: Set Y position in millimeters

178 Znnn: Set Z position in millimeters

179 Ennn: Set extrusion to the specified number of millimeters of material

180 All positions are set to 0 if no parameters are specified.

181 **3.8 M82: Set Absolute Extrusion**

182 This command specifies that the extrusion ("E") coordinates in move commands are
183 absolute.

184 **3.9 M83: Set Relative Extrusion**

185 This command specifies that the extrusion ("E") coordinates in move commands are relative.

186 **3.10 Tnnn: Set Tool**

187 This command sets the current tool (extruder) to use, starting at 0. Tool numbers correspond
188 to the index within the "materials-col" Job Template attribute.

189

190 4. Generating Safe G-Code

191 IPP Clients [STD92] and Infrastructure Printers [PWG5100.18] can generate safe G-Code
 192 using the values of Printer Description attributes reported by the IPP Printer or Proxy. Table
 193 1 shows the information that is needed to generate safe G-Code for a printer. The "materials-
 194 col" values are obtained from the "materials-col-database" and/or "materials-col-ready"
 195 Printer Description attributes which provide a list of all possible materials and those that are
 196 loaded in the Printer, respectively.

197 **Table 1 - Information Needed to Generate Safe G-Code**

Description	Current IPP Attribute
Accuracy limits/minimum layer height	print-accuracy-supported (collection)
Build platform dimensions	printer-volume-supported (collection)
Build platform shape	platform-shape (type2 keyword)
Extruder nozzle size/maximum layer height	See section 4.1
Filament diameter	materials-col.material-diameter (integer)
Retraction support	See section 4.1

198 4.1 Material Extrusion Parameters

199 IPP 3D v1.0 [PWG5100.21] does not define attributes or values for the extruder nozzle size,
 200 nor does it define a way to specify whether retraction is used. These can be added to the
 201 "materials-col" collection as:

202 "material-nozzle-diameter (integer(0:MAX))": Specifies the required extruder
 203 diameter in nanometers, with the value 0 indicating the nozzle diameter is less than
 204 1 nanometer.

205 "material-retraction (boolean)": Specifies whether retraction should be used with the
 206 material.

207 A corresponding "material-nozzle-diameter-supported (1setOf (integer(0:MAX) |
 208 rangeOfInteger(0:MAX)))" Printer Description attribute can provide the supported nozzle
 209 diameter values. The presence of 'material-retraction' in the "materials-col-supported"
 210 Printer Description attribute indicates that the Printer supports material retraction.

211 4.2 Support for Additional "Safe" G-Code Commands

212 In addition to the common subset of G-Code commands listed in the previous sections,
 213 newer FDM printers support additional "safe" commands such as mixing of extruded material
 214 ("M163", "M164", and "M165"), controlled arc ("G2" and "G3") and Bézier cubic spline ("G5").
 215 In order for a generic slicer to support these commands, a printer needs to advertise its
 216 support for them. The usual method employed for IPP is a PDL-specific capability attribute,
 217 such as "safe-gcode-supported (1setOf text(MAX))" with each value corresponding to a
 218 named command.

219 5. Printing Safe G-Code

220 Printers that support safe G-Code can largely pass the print file to the controller - typically
 221 all that is required is to add printer-specific commands to initialize the printer to set
 222 temperatures and other machine settings, send the print file, and then add printer-specific
 223 commands to return the printer to an idle state.

224 Status information returned by the printer can be used to set the values of the various IPP
 225 Printer Status attributes.

226 5.1 Adding Printer-Specific Machine Commands

227 IPP Job Template attributes provide the values for extruder and build platform temperatures,
 228 as well as the list of materials used in the print job. Table 2 lists the standard attributes a
 229 FDM printer can use to configure the machine prior to printing.

230 **Table 2 - IPP Job Template Attributes**

Description	IPP Attribute(s)	Typical G-Code
Build platform temperature	platform-temperature	M140/M190
Chamber humidity	printer-volume-humidity	M146
Chamber temperature	printer-volume-temperature	M141/M191
Extruder nozzle size	materials-col/material-nozzle-diameter	
Extruder temperature	materials-col/material-temperature	M104/M109
Filament color	materials-col/material-color	
Filament diameter	materials-col/material-diameter materials-col/material-diameter-tolerance	M200
Filament type	materials-col/material-type	
Flow rate	materials-col/material-rate materials-col/material-rate-units	M203
Job Name	job-name	M531
Print accuracy	print-accuracy	M201/M202/ M222/M223
Print quality/speed	print-quality	

231 When an IPP Client does not specify one or more of these attributes, the corresponding
 232 default attribute values are used - "materials-col-default", "platform-temperature-default",
 233 "print-accuracy-default", "print-quality-default", "printer-volume-humidity-default", and
 234 "printer-volume-temperature-default" for the attributes in Table 2.

235 5.2 Printer-Specific Attributes and Values

236 IPP allows implementors to add printer-specific attributes and values as defined in section 7
 237 of [STD92]. However, printers cannot depend on IPP Clients or Infrastructure Printers to
 238 support such attributes or values, particularly for generation of safe G-Code. Default values
 239 should be used as a backup when necessary.

240 **5.3 Canceling Jobs**

241 When a Job is canceled, Printers SHOULD stop sending G-Code commands as soon as
242 possible and then send printer-specific commands to the controller to return the printer to an
243 idle state.

244

245 6. IANA Considerations

246 6.1 Attribute Registrations

247 The attributes defined in this white paper will be published by IANA according to the
248 procedures in IPP/1.1 Model and Semantics [STD92] section 7.2 in the following file:

249 <https://www.iana.org/assignments/ipp-registrations>

250 The registry entries will contain the following information:

251	Job Template attributes:	Reference
252	-----	-----
253	materials-col (1setOf collection)	[PWG5100.21]
254	material-extruder-diameter (integer(0:MAX))	[SAFEPCODE]
255	material-retraction (boolean)	[SAFEPCODE]
256		
257	Printer Description attributes:	Reference
258	-----	-----
259	material-extruder-diameter-supported (1setOf (integer(0:MAX)	
260	rangeOfInteger(0:MAX))	[SAFEPCODE]
261	safe-gcode-supported (1setOf text(MAX))	[SAFEPCODE]

262 6.2 MIME Media Type Registration

263 The MIME media type defined in this white paper will be published by IANA according to the
264 procedures in the Media Type Specifications and Registration Procedures [BCP13] in the
265 following file:

266 <https://www.iana.org/assignments/media-types>

267 The registry will contain the following information:

268	Type name: application
269	
270	Subtype name: vnd.pwg-safe-gcode
271	
272	Required parameters: N/A
273	
274	Optional parameters: N/A
275	
276	Encoding considerations: US ASCII
277	
278	Security considerations: Safe G-code prohibits machine control commands,
279	however it is up to the consumer to verify that such commands are not part
280	of the print file.
281	
282	Interoperability considerations: While the format is interoperable, the
283	contents of each file are still specific to the combination of material
284	parameters and printer capabilities used for the G-code.
285	

286 Published specification: [this white paper]
287
288 Applications that use this media type: IPP 3D
289
290 Fragment identifier considerations: N/A
291
292 Additional information:
293
294 Deprecated alias names for this type: N/A
295 Magic number(s): N/A
296 File extension(s): pwggc
297 Macintosh file type code(s): N/A
298
299 Person & email address to contact for further information: Michael Sweet,
300 msweet@apple.com
301
302 Intended usage: COMMON
303
304 Restrictions on usage: N/A
305
306 Author/Change controller: The Printer Working Group, c/o The IEEE Industry
307 Standards and Technology Organization, 445 Hoes Lane, Piscataway, NJ
308 08854, USA
309
310 Provisional registration? (standards tree only): No

311 7. References

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340 8011, January 2017, <https://tools.ietf.org/html/std92>
- 341

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351 white paper:

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353 **9. Change History**

354 **9.1 March 18, 2019**

- 355 • PT1: Fix references in table 1.

356 **9.2 January 17, 2019**

- 357 • Added document version number to page headings.

358 **9.3 January 14, 2019**

- 359 • Updated status to stable
- 360 • Added version number to title
- 361 • Section 3.10: Tool number corresponds to the materials-col index.
- 362 • Section 5: Added subsection on canceling jobs.
- 363 • Section 7: Fixed reference link for STD92.

364 **9.4 July 4, 2018**

- 365 • Removed old comments.
- 366 • RFC 8011 is now STD 92.

367 **9.5 June 4, 2018**

- 368 • Status: Prototype
- 369 • Type: Best Practice
- 370 • Section 3: Reword M command prohibition.
- 371 • Changed registered extension to ".pwggc".
- 372 • Added RS274NGC reference.

373 **9.6 April 26, 2018**

- 374 • Made a PWG Best Practice working draft.
- 375 • Added reference to RepRapWiki for G-Code
- 376 • Added reference to ISO 6983-1 for current official G-Code specification
- 377 • Section 4: Mention materials-col-database and materials-col-ready
- 378 • Section 4.1: Retitle as "Material Extrusion Parameters"

379 9.7 April 16, 2018

- 380 • Status: Interim
- 381 • Introduction: Added discussion of nozzle and filament diameter influencing
- 382 portability of G-code, and why we want this.
- 383 • Added G21, M82, and M83 commands, and hooks for other printer-specific
- 384 commands (safe-gcode-supported)
- 385 • Updated T command (set tool) to use 0 as the first index.
- 386 • Added sections on generating and printing safe G-code
- 387 • Added IANA registration of new attributes and the MIME media type
- 388 • Added references to 3MF slicing and RFC 8011.

389 9.8 April 12, 2018

390 Initial revision.